

# **Comprehensive Study of Lake Zwai and Its Watershed for Sustainable Management**

**Brook Lemma, Editor  
Addis Ababa University  
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**Front cover image:** Lake Zwai and some of its islands seen from the eastern mountain Chilalo. Spectacular is the cloud cover loaded with drenching rainwater and the white patch on the opposite side is the gruesome Share Flower Farm that releases its effluents into the lake.



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## Preface

This conference on the Ecology and Sustainable Management of Lake Zwai was conducted back in 2018. For many technical reasons, it was not possible to publish the proceeding. The articles captured here were peer reviewed and couldn't come to light. One of the major obstacles was to find sponsoring agency.

The delay was not however completely a disaster in the direction of making the scientific data captured in here obsolete. The Editor continued to capture as many articles published since then on Lake Zwai and included them in this proceeding. There are even some data that are original to add academic value to the collection of the papers edited and published here.

The conference held back in 2017 and now the publications compiled in this proceeding are attempts to bring out the services this remarkable lake is providing to millions of local populations relying on it for multiple functions of livelihoods they lead. These people spread out from the peaks of the watersheds in the east all the way from the large regional city of Assela at about 2430 m above sea-level (asl), sitting at the foot of Mount Chilalo (elevation 4036 masl) (the rim of the Eastern Escarpment of the Ethiopian Rift valley) and Butajira city located at 2131 m asl found at the foot of Gurage or Zebidar Mountain (elevation 3,611 masl) in the West (the rim of the Western Escarpment of the Ethiopian Rift Valley) to the five islands of the lake (Debre Sina, Galila, Funduro, Tsedecha and Tulu Gudo) with resident communities and monasteries. Like any other tropical African population people of this watershed mainly thrive in rain fed and irrigated agriculture overstretching the riverine and lacustrine freshwater resources, compromising the soil and biodiversity resources. The blame does not solely rest on the people of the watershed but millions of others elsewhere in Ethiopia and around the World. It suffices to mention a few examples. The majority of the Ethiopian population residing in Central Ethiopia, including huge urban centers like Addis Ababa, Adama and many others, rely of the sweet pepper (*Capsicum annum*) produced in the Western watershed, wheat (*Triticum* spp.) and barley (*Hordeum vulgare*) produced in the eastern watershed, the fishes captured from the wild, and the



vegetables produced throughout the year that are served on the Ethiopian Airlines (EAL) for national and international travels. The influence of international flower consumers, especially European cities where EAL reaches is extremely huge as numerous flower farms that rely on the water supply of Lake Zwai and its feeder rivers in

All the above and many other production efforts that are underway in this watershed come with costs. These come in the form of deterioration of the quality and quantity of water, of soil, degradation of biodiversity which are all replaced by settlements, cultivated land and many other infrastructures, such as roads, that disrupt the patterns of groundwater flow to the lowest point in this wide watershed, namely, Lake Zwai. The vegetable, salt, flower and other exports have left consumers in Europe always wanting more exerting untold pressures on Lake Zwai and its watershed.

Another predisposing factor, among many, is the close proximity of this lake and its watershed to major population centers like Addis Ababa and Adama; and the accessibility of the same with all-weather tarmac roads. For instance, a fish landing made early in the morning is ready for lunch on the same day in Addis Ababa. The flowers cut in the evening in Zwai are available early morning the next day in European markets. These same so called predisposing factors have also encouraged researchers and community development agents to be active in data collection and engaging themselves in monitoring self-help community activities and job creations by public offices and non-governmental offices (NGOs).

Of course, the limited natural resources this watershed has cannot be stretched without reaching the flipping point where it breaks. Furthermore, this pressure does not come from direct humans actions alone (farming, fisheries, water abstraction, expanding settlements, etc.); but also the long-term human consequences of climate change and the ever increasing human population that requires space and resources by the day.

Professor Brook Lemma, Editor

## Chapter 1

### Assessment of the water quality of Lake Zwai and its impacts on humans and other living organisms

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#### Abstract

Excess pollutant inputs from agricultural activities and industrial effluents from around Lake Zwai watershed can pose serious threats on the lake ecosystem. This study was made to investigate the water quality of Lake Zwai and suggest possible management options for sustainable use of the same. Water and sediment samples were collected from nine representative sampling sites of the lake for the measurement of physicochemical parameters and nutrients in 2014 and 2015 in both dry and wet seasons. Nutrients and chlorophyll-*a* were determined by following the standard procedures outlined in APHA (1999) using UV/visible spectrophotometry. Concentrations of nutrients, electrical conductivity and total dissolved solids were recorded from samples collected from sites of effluents of the floriculture industry (Fb) and around the floriculture industries (Fa) at all seasons. Results of physicochemical analysis of the four data sets which explained more than 88.10 % and 90.97 % of the total variance in wet and dry seasons showed pollutant sources were mainly from sampling sites around the floriculture industry (Fb) during dry season

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and Meki (Mb) and Qatar (Kb) Rivers during wet season, respectively. CA grouped the nine sampling stations into three clusters of similar water quality features and hence the whole lake was categorized into low, moderate and high pollution status. The results of sediment depth profile analyses showed that the mean concentrations of SRP, TP, NO<sub>3</sub>-N, NO<sub>2</sub>-N and TN were 27.7, 6, 5.3, 8.5 and 1733 mg kg<sup>-1</sup> respectively in dry season, and 21.2, 73, 8.0, 28.4, 24.2 and 1750 mg kg<sup>-1</sup> respectively in wet season. The values for SRP, TP, NO<sub>3</sub>-N, NO<sub>2</sub>-N and TN distributions were higher at sediment top surface and decline with depth of the sediment profiles in most of the sampling sites and seasons. Qatar and Meki Rivers catchments were the major sources of external nutrient loads to the lake ecosystem. These nutrient loads for the lake clearly show the amount of nutrients that enters the lake exceed the exports, indicating that nutrients are being retained in the lake. According to Carlson and Vollenweider models Lake Zwai is under eutrophic condition. In order to stop further deterioration of lake water quality and to eventually restore the beneficial uses of the lake, management of pollutants mainly from fertilizers and pesticides in the lake watershed should be given urgent priority.

**Keywords:** Water quality, agrochemicals, external and internal nutrient loads, trophic state index, eutrophication, Lake Zwai

## Introduction

Most tropical African lakes are facing problems of pressure from rapid population growth residing in the watershed, which normally discharge pollutants into the lakes. This has led to the deterioration of the water quality in receiving lakes. Some lakes are getting eutrophic due to high nutrient loads whilst others are facing problems of siltation and toxic pollutant discharges, thereby reducing their economic and aesthetic values (Usanzineza *et al.*, 2015). The rapid urbanization and industrialization together with intensive farming practices are increasingly impacting the rift valley lakes of Ethiopia, particularly Lake Zwai (also known as Zwai or Zeway in the literature). Human activities like application of fertilizers and pesticides in the lake catchment mainly affect the lake water quality (Ayenew and Legesse, 2007; Spliethoff *et al.*, 2009; Desta *et al.*, 2016). Population increase and

rising living standards have also contributed to excessive water withdrawal while escalating the level of external nutrient load and eutrophication that have far exceeded the natural inputs (Herco *et al.*, 2007; Tadele, 2012). This has resulted in major changes in the biological structures and dynamics of the lake, often showing significant shift from clear water to turbid state. Consequently, pollution is becoming a major challenge to the preservation of Lake Zwai. Moreover, the uncontrolled overuse and misuse of fertilizers and pesticides for both the agricultural and industrial activities around the lake have been indicated as the most important potential threats to the degradation of lake water quality.

Therefore, there is a need to conduct an intensive research to fill these gaps and provide baseline data with regard to Lake Zwai water quality and its impact on human and other living organisms. More specifically this study attempts to assess the physico-chemical parameters of the lake water, spatio-temporal variations of nutrients in the lake, evaluate the lake internal and external nutrient loads and finally to use the data thus generated to determine the trophic status of the lake.

## Materials and methods

The study area Lake Zwai (also known in the literature as Zwai, Zwai or even Lake Batu) is a shallow freshwater lake found in the northern part of the Ethiopian Rift Valley at a location of 08°00'N and 38°47'E (Fig. 1). The woredas (a local word more like district) that share the lake are Adami Tullu, Jido Kombolcha, Dugda Bora, and Zwai Dugda (Turdu *et al.*, 1999). Table 1 describes the sampling sites in the study area.

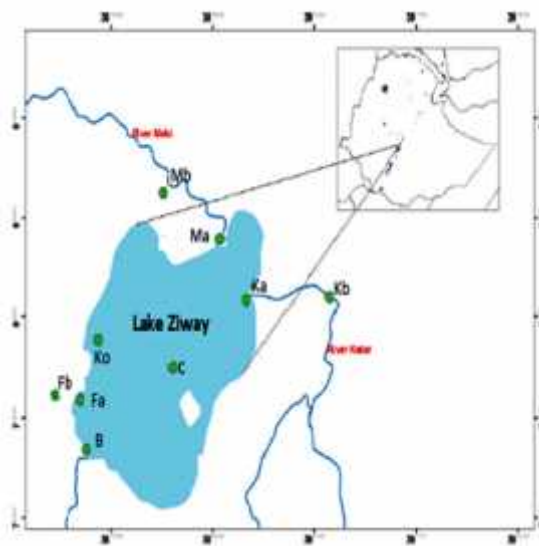


**Figure 1:** Lake Zwai and the sampling sites and its feeder rivers, Ethiopia – on the left is River maki, on the right River Qatar feeding the lake and on the south-east River Bulbula, fowing out to Lake Abijata

**Table 1:** List with codes of the sampling sites and their geographic locations

| Codes     | Sampling Sites                    | Longitude | Latitude |
|-----------|-----------------------------------|-----------|----------|
| <b>Fb</b> | Floriculture effluent             | 38.044020 | 7.547150 |
| <b>B</b>  | Bulbula River mouth               | 38.743261 | 7.899822 |
| <b>Fa</b> | Around Floriculture industries    | 38.740261 | 7.917644 |
| <b>C</b>  | Central part of the lake          | 38.841453 | 7.971989 |
| <b>Ka</b> | Qatar River mouth                 | 38.924100 | 8.031094 |
| <b>Ma</b> | Meki River mouth                  | 38.848733 | 8.051128 |
| <b>Mb</b> | Meki River at Meki Gage Station   | 38.835000 | 8.103000 |
| <b>Kb</b> | Qatar River at Abura Gage Station | 39.019033 | 8.032822 |
| <b>Ko</b> | Korekonch                         | 38.755692 | 7.995050 |

Sampling design and sample collection procedures: Nine representative sampling sites were purposefully selected (Table 1) based on the water cycle patterns of the lake; where the inflowing rivers (Meki and Qatar) enter the lake and the spillway river (Bulbula) takes the water out. The assumption would be the balance between

the external nutrient/pesticide loads added with the internal one may make their exit through River Bulbula with the difference remaining in the lake for some time (water residence time or period).

In 2014 and 2015 monthly water samples were collected with a Van Dorn water sampler from different depths of the entire water column at 1 m intervals and mixed in equal proportions to produce composite samples. The collected water samples were kept in acid-washed polyethylene plastic bottles rinsed thoroughly with glass-distilled water (US EPA, 2014). All water samples were stored in insulated dark ice boxes and taken on the same day to the laboratory and stored at 4°C for analysis on the next day.

*In-situ* physicochemical parameters, namely, lake-water temperature, pH, electrical conductivity (EC), total dissolved solid (TDS), and dissolved oxygen (DO) were measured using HACH MM150 model multimeter; Secchi depth (SD) was measured with a standard Secchi disk of 20 cm diameter with black-and-white quarters.

In the laboratory, NH<sub>4</sub>-N, NO<sub>3</sub>-N, NO<sub>2</sub>-N, total nitrate (TN), soluble reactive phosphorus (SRP), total phosphorus (TP), SiO<sub>2</sub>-Si, total alkalinity and Chlorophyll-*a* were measured using the methods described in Yang *et al.* (1998) and APHA (1999).

External nutrient loads were measured from sediment samples were collected from the designated sampling sites with depths ranging from one to three meters sediment core sampler that cut the sediment without mixing the layers. Nutrients in sediment samples were analyzed according to the standard procedures outlined in EPA (1993). The external nutrient load was then computed using the method described in Huai-en *et al.* (2003). And the trophic status of Lake Zwai was determined using methods described in Carlson (1977) and Kretzer and Brezonik (1981).

Data were analyzed using different procedures of statistical analyses, such as, analysis of variance (ANOVA) to test the differences between and within sampling sites at 95% confidence intervals using SPSS (version 20) software (Chicago, USA). Depth profiles of sediment nutrient distributions were analyzed using sigma

plot software (Sigma Stat 10.0) and PAST statistical software (version 1.93) was applied for the depth sediment profile analyses.

### Results and discussions

Spatial and temporal variations of physico-chemical water quality of Lake Zwai: The surface water temperature measured during day time between 9 and 15 hours in the study sites ranged from 19.0 to 28.0°C and 18.0 to 27.0°C in dry and wet seasons, respectively, where the highest values were measured at B and Ka while the lowest values were measured at C and Fb during dry and wet seasons, respectively (Table 2 and 3). The spatial and temporal variation of mean water temperature in Lake Zwai was not significant ( $p > 0.05$ ) during the study period.

The mean temperature of the lake water was 23.0°C in both seasons, which is similar to previously reported mean value of 22.4°C (Tilahun and Ahlgren, 2010); but lower than the value (26.1°C) reported by Tamire and Mengistou (2012). However, in the wet seasons, the mean temperature was lower than the previously reported data. Lake Zwai has narrow seasonal fluctuations in water temperature as the lake is a shallow tropical lake. The mean temperature of Lake Zwai was similar to Lakes Hawassa, Chamo, and Navaishia but slightly higher than Lake Hayq (Table 2).

**Table 2:** Means and ranges of the physicochemical parameters measured at the surface water of Lake Zwai in the dry seasons (Temp. for temperature in °C, DO for dissolved oxygen in mg L<sup>-1</sup>, pH for H<sup>+</sup> concentration, EC for electrical conductivity in µScm<sup>-1</sup>, TDS f for total dissolved solids in mg L<sup>-1</sup>; SD for secchi depth in cm; TA for total alkalinity in mg L<sup>-1</sup>; Turbidity in NTU)

|                | Site                   | Temp             | DO             | pH               | EC               | TDS              | TA             | Turbidity    |
|----------------|------------------------|------------------|----------------|------------------|------------------|------------------|----------------|--------------|
| B              | $\bar{x} \pm$ Std. Err | 24.75 $\pm$ 1.3  | 7.3 $\pm$ 1.8  | 8.3 $\pm$ 0. 31  | 385 $\pm$ 38     | 248 $\pm$ 24     | 314 $\pm$ 41   | 159 $\pm$ 9  |
|                | Range                  | 21-28            | 4.8-12.4       | 8-9              | 289-521          | 189-335          | 216-425        | 145-175      |
| C              | $\bar{x} \pm$ Std. Err | 21.2 $\pm$ 1.3   | 5.2 $\pm$ 1.1  | 8.1 $\pm$ 0.17   | 408 $\pm$ 43     | 268 $\pm$ 33.7   | 225 $\pm$ 22   | 180 $\pm$ 26 |
|                | Range                  | 18-25            | 4-8.4          | 8-9              | 337-558          | 215-393          | 184-300        | 151-233      |
| F <sub>a</sub> | $\bar{x} \pm$ Std. Err | 23.8 $\pm$ 0.99  | 6.8 $\pm$ 1.7  | 8.13 $\pm$ 0.23  | 639.73 $\pm$ 114 | 423.8 $\pm$ 83   | 320 $\pm$ 50   | 156 $\pm$ 44 |
|                | Range                  | 21-26            | 4.2-11.2       | 8-9              | 376-1028         | 249-720          | 200-425        | 88-239       |
| F <sub>b</sub> | $\bar{x} \pm$ Std. Err | 23.5 $\pm$ 1.4   | 6.2 $\pm$ 1.4  | 7.56 $\pm$ 0.11  | 1233.6 $\pm$ 107 | 789.6 $\pm$ 68.3 | 463 $\pm$ 71.7 | 17 $\pm$ 5   |
|                | Range                  | 19-27            | 2.6-9.3        | 7-8              | 1050-1650        | 672-1056         | 200-625        | 11-27        |
| K <sub>a</sub> | $\bar{x} \pm$ Std. Err | 21.3 $\pm$ 0.49  | 4.4 $\pm$ 1.5  | 8.1 $\pm$ 0.16   | 382.6 $\pm$ 39.4 | 237.8 $\pm$ 18.6 | 24 $\pm$ 29    | 141 $\pm$ 4  |
|                | Range                  | 20-23            | 2.5-9.2        | 7-8              | 307-543          | 196-307          | 156-325        | 135-147      |
| K <sub>b</sub> | $\bar{x} \pm$ Std. Err | 20.15 $\pm$ 0.23 | 5.5 $\pm$ 0.64 | 7.4 $\pm$ 0.08   | 170.7 $\pm$ 14.3 | 107.7 $\pm$ 9    | 187 $\pm$ 44   | 77 $\pm$ 6   |
|                | Range                  | 20-21            | 4.0-7.0        | 7-8              | 134-204          | 86-130           | 104-275        | 65-86        |
| K <sub>o</sub> | $\bar{x} \pm$ Std. Err | 24.2 $\pm$ 1.3   | 5.4 $\pm$ 1.3  | 7.4 $\pm$ 0.75   | 399 $\pm$ 14.4   | 254 $\pm$ 10.5   | 330 $\pm$ 38   | 172 $\pm$ 28 |
|                | Range                  | 21-28            | 2.4-9.0        | 7-9              | 362-435          | 219-278          | 200-425        | 157-210      |
| M <sub>a</sub> | $\bar{x} \pm$ Std. Err | 22.2 $\pm$ 0.7   | 4.4 $\pm$ 0.56 | 7.98 $\pm$ 0.164 | 404.13 $\pm$ 43  | 291.9 $\pm$ 37.7 | 227.6 $\pm$ 26 | 146 $\pm$ 6  |
|                | Range                  | 21-25            | 3.3-6.5        | 8-9              | 333-576          | 213-403          | 160-300        | 139-158      |
| M <sub>b</sub> | $\bar{x} \pm$ Std. Err | 22.9 $\pm$ 0.76  | 7.6 $\pm$ 1.6  | 7.95 $\pm$ 0.22  | 424 $\pm$ 625    | 267 $\pm$ 38     | 263 $\pm$ 48   | 59 $\pm$ 41  |
|                | Range                  | 20-24            | 3.8-10         | 7-9              | 203-584          | 130-365          | 100-375        | 6-139        |



The level of DO ranged from 2.42 to 12.4 mgL<sup>-1</sup> and 1.4 to 7.2 mgL<sup>-1</sup> in dry and wet seasons, respectively (Table 1.2 and 1.3). The lowest values in both seasons were at K<sub>o</sub> (2.4 mgL<sup>-1</sup>) in dry and K<sub>b</sub> (1.4 mgL<sup>-1</sup>) in the wet seasons whereas the highest values were at B (12.4 mgL<sup>-1</sup>) in dry and F<sub>b</sub> (7.2 mgL<sup>-1</sup>) in wet seasons, respectively. The low DO values at K<sub>o</sub> are attributed to human impacts that release complex soluble substances (e.g., car washing, bathing, animal watering), low macrophytes that release low amounts of DO into the water, which result in low partial pressure for O<sub>2</sub> to remain in solution. In the wet seasons, K<sub>b</sub> is completely muddy due to agricultural runoffs. High DO values in B can be attributed to the presence of macrophytes and phytoplankton with higher biomass and abundance than in other sites (see also Girum Tamire and Seyoum Mengistou, 2012). However, in the wet seasons the effluent from the floriculture right on the shoreline of Lake Zwai (F<sub>b</sub>) was relatively clear due to high dilution from rains. The overall mean DO concentration of this study was 5.00 mgL<sup>-1</sup> in lake water samples, which was much lower than the one reported by Roba (2008) as 8.72 mgL<sup>-1</sup>. Tadele (2012) reported DO concentration of 1.4 mg L<sup>-1</sup> around the floriculture effluent which is lower than the present study, presumed to be a measurement taken at times of high concentration of floriculture effluents. Table 1.3, shows a comparative analysis of DO against other similar lakes to Lake Zwai.

Lake Zwai is alkaline with pH values ranging from 7.0 to 9.0 and 6.5 to 9.7 in dry and wet seasons, respectively (Tables 2 and 3). The maximum pH was 9.7 at B during the dry season and the minimum was 6.5 at station M<sub>b</sub>. The overall mean pH value was 8.10, as with previous reports of 8.39 and 8.44 by Roba (2008) and Tamire and Mengistou (2012), respectively. This is also similar to the alkaline waters of Lakes Hawassa and Chamo with pHs of 8.66 and 8.84, respectively (Tilahun and Ahlgren 2010).

The electrical conductivity (EC) of the study sites ranged from 134 to 1650  $\mu\text{S cm}^{-1}$  in the dry season and 65 to 496  $\mu\text{S cm}^{-1}$  in the wet season. K<sub>b</sub> gave the lowest mean conductivity (134  $\mu\text{S cm}^{-1}$ ) in the dry periods and 65  $\mu\text{S cm}^{-1}$  in wet seasons while site F<sub>b</sub> recorded the highest mean values of 1650  $\mu\text{S cm}^{-1}$  in dry and K<sub>o</sub> mean values 496  $\mu\text{S cm}^{-1}$  in wet seasons, respectively (Table 1.2 and 1.3). In general, the overall mean measurement of EC (404.30  $\mu\text{S cm}^{-1}$ ) was comparable with previous reports of Zinabu

Gebre-Mariam *et al.* (2002); Girma Tilahun and Ahlgren (2010) and Tamire and Mengistou (2012) with mean EC values of 410, 478, 419  $\mu\text{Scm}^{-1}$ , respectively. When compared to other rift valley lakes, the EC values of Lake Zwai (404  $\mu\text{Scm}^{-1}$ ) was lower than Lakes Chamo (1910  $\mu\text{Scm}^{-1}$ ), Hawassa (846  $\mu\text{Scm}^{-1}$ ), Hayq (910  $\mu\text{Scm}^{-1}$ ), Abaya (623  $\mu\text{Scm}^{-1}$ ), Langano (1810  $\mu\text{S cm}^{-1}$ ), Bishoftu (1830  $\mu\text{Scm}^{-1}$ ), Abijata (15800  $\mu\text{Scm}^{-1}$ ), Shalla (19200  $\mu\text{Scm}^{-1}$ ), Chitu (28600  $\mu\text{Scm}^{-1}$ ) as reported by Tilahun and Ahlgren (2010); Fetahi (2010); Wood and Talling (1988) (Table 4.1.5), respectively but higher than at Lake Tana (115 -148  $\mu\text{Scm}^{-1}$ ) and Lake Naivasha (290) as reported by Wondie (2006) and Momanyi *et al.* (2012), respectively.

The differences in EC over seasons and across different stations were very significant. Higher conductivity values were measured at the floriculture sites ( $F_a$  and  $F_b$ ) as compared to other sampling sites, owing to the high contents of dissolved salts (e.g., agrochemicals) in the effluents (Ayenew, 2005; Tadele, 2012). There were significantly lower values of EC during the main rainy season which as a result of dilution by rainwaters. In the present study, the EC values of different sampling sites were borehole below the WHO guideline values prescribed for drinking water purpose (1500  $\mu\text{Scm}^{-1}$ ) (WHO, 1996). Moreover, Koshy and Nayar (2000) observed that the EC value of 250  $\mu\text{Scm}^{-1}$  in freshwater is conducive for aquatic life. ZwaiZwai

The TDS ranged from 119.77 to 746.80  $\text{mg L}^{-1}$  with the low values in dry at site  $K_b$  and the high values at site  $F_b$  while in the wet season it ranged from 129.5 to 547.76  $\text{mg L}^{-1}$  at sites  $M_b$  and  $F_b$ , respectively (Tables 2 and 3). The overall mean value of TDS in the lake was 263  $\text{mg L}^{-1}$ . The TDS at station  $F_b$  in general was relatively higher than other stations during the entire period of study. This is again due to the increased effect of effluent from the floriculture. Zwai

Total alkalinity (TA) represented by  $\text{CaCO}_3$  ranged from 100 to 625  $\text{mg L}^{-1}$  in the dry seasons and 60 to 472  $\text{mg L}^{-1}$  in the wet seasons (Tables 1.2 and 1.3).  $M_b$  showed the lowest mean TA (100  $\text{mg L}^{-1}$ ) in dry and 60  $\text{mg L}^{-1}$  in wet seasons while site  $F_b$  showed the highest mean values of 625  $\text{mg L}^{-1}$  in dry and 472  $\text{mg L}^{-1}$  in wet season, respectively. The fluctuations in TA across all the sites were significant at  $p < 0.05$ . TA has generally decreased in the wet seasons due to the dilution effect of the rains and

freshwater incoming in as runoff (Singh *et al.*, 2004; Ghafar *et al.*, 2014). Alkalinity concentrations more than  $60 \text{ mgL}^{-1}$  in lakes indicate richness in the nutrient status (Krishnan 2008).

Turbidity ranged from 88 to 239 NTU and 98 to 399 NTU in the dry and wet seasons, respectively (Tables 1.2 and 1.3). Dagne (2010) reported that turbidity of Lake Zwai varied between 49.4 and 299 NTU with mean values of 80.2 NTU. Tamire and Mengistou (2012) also reported that the turbidity of Lake Zwai ranged from 42 to 70 NTU and their range was narrower than in the present work. The turbidity of lake water is high in the rainy season. Higher turbidity during wet season is due to higher impact of silt loaded runoff. This observation is in agreement with other works in which turbidity is 3 to 4 times higher in the rainy seasons as compared to dry seasons due to siltation imported into lakes by rain and runoff erosions (Bhade *et al.*, 2001; Dagne, 2010). The mean turbidity value of the lake water was 161.6 NTU, where the highest possible turbidity is accepted to be at a maximum of 342 NTU.

The shallowest records of SD and the lowest DO were recorded during the time of high turbidity. According to WHO; the turbidity of drinking water should be less than 5 NTU. Therefore, the turbidity of Lake Zwai water is above the acceptable range. According to (US EPA, 2005) turbidity 100-500 NTU or higher is classified as very cloudy to muddy and some fish species may become stressed at prolonged exposures to such water. In the long term it is very likely that Lake Zwai is becoming more turbid as SD gets shallower.

**Table 3:** Means and ranges of the physico-chemical parameters at the surface water of Lake Zwai in the wet seasons (Temp. for temperature in <sup>0</sup>C, DO for dissolved oxygen in mgL<sup>-1</sup>; pH for H<sup>+</sup> concentration; EC for electrical conductivity in μScm<sup>-1</sup>; TDS for total dissolved solids in mgL<sup>-1</sup>; TA for total alkalinity, mgL<sup>-1</sup>; and Turbidity in NTU)

| Sites |                        | Temp.     | DO        | pH        | EC        | TDS        | TA       | Turbidity |
|-------|------------------------|-----------|-----------|-----------|-----------|------------|----------|-----------|
| B     | $\bar{x} \pm$ Std. Err | 22+0.47   | 4.72+0.35 | 8.59+0.09 | 274.5+9   | 175.7+58.2 | 207+6.3  | 191+40    |
|       | Range                  | 21.5-23   | 4.27-5.4  | 8.4 - 8.7 | 176 - 456 | 113-292    | 200-220  | 125-262   |
| C     | $\bar{x} \pm$ Std. Err | 21.2+0.25 | 4.75+28   | 8.57+0.09 | 218+44    | 147.8+37   | 168+6.11 | 138+24    |
|       | Range                  | 20.7-22   | 4.4-5.3   | 8.4-8.7   | 173-306   | 110-222    | 160-180  | 98-179    |
| Fa    | $\bar{x} \pm$ Std. Err | 22+0.56   | 4.4+0.25  | 8.78+0.54 | 353+89    | 226+56     | 172+14   | 112+5     |
|       | Range                  | 20.8-23   | 3.95-4.8  | 7.9-9.7   | 187-488   | 120-312    | 148- 196 | 103-124   |
| Fb    | $\bar{x} \pm$ Std. Err | 21+1.6    | 6.2+0.65  | 8.53+0.14 | 370+98    | 216+84     | 250+111  | 18+7      |
|       | Range                  | 18-24     | 4.9-7.2   | 8.3-8.7   | 175-478   | 49-306     | 120-472  | 10-32     |
| Ka    | $\bar{x} \pm$ Std. Err | 22+ 0.28  | 3.1+0.34  | 8.4+0.08  | 230+41.4  | 180+32     | 117-35   | 237+77    |
|       | Range                  | 20 – 27   | 2.4-3.5   | 8.3-8.5   | 183-312   | 117-221    | 80-188   | 129-385   |
| Kb    | $\bar{x} \pm$ Std. Err | 20+0.15   | 2.6+0.64  | 7.78+0.24 | 101+17.9  | 65+11.7    | 72.3+,33 | 381+230   |
|       | Range                  | 20-21     | 1.4-3.6   | 7.5-8.3   | 65-120    | 42-78.3    | 72-73    | 129-840   |
| Ko    | $\bar{x} \pm$ Std. Err | 22.5+0.86 | 4.8+0.28  | 8.67+0.10 | 381+101   | 234+61     | 175+14.6 | 115+105   |
|       | Range                  | 21-24     | 4.35-5.3  | 8.5-8.8   | 179-496   | 116-318    | 146-190  | 105-125   |
| Ma    | $\bar{x} \pm$ Std. Err | 23+0.11   | 3.9+0.12  | 8.6+0.01  | 273+49    | 153+21.3   | 130+24.9 | 280+82    |
|       | Range                  | 22-23     | 3.68-4.1  | 8.6-8.61  | 176-337   | 113-185    | 100-180  | 124-399   |
| Mb    | $\bar{x} \pm$ Std. Err | 20.4+0.7  | 4.8+0.75  | 7.44+0.53 | 120+3     | 77+1.9     | 100+20   | 266+247   |
|       | Range                  | 19.5-22   | 3.35-5.8  | 6.5-8.3   | 115-126   | 73.7-80.4  | 60-120.  | 0-360     |

The spatial and temporal variations of nutrients are summarized in Tables 1.4 and 1.5. The mean  $\text{NO}_3\text{-N}$  concentration ranged from 0.1 to  $5.26\text{mgL}^{-1}$  and 0.01 to  $0.86\text{mgL}^{-1}$  in dry and wet seasons, respectively (Tables 4 and 5). The highest mean  $\text{NO}_3\text{-N}$  was at  $F_b$  in the dry and at  $K_b$  in the wet seasons; while  $M_a$  has the lowest values in both seasons. The mean nitrate value found in this study ( $0.21\text{mgL}^{-1}$ ) was higher than those values 0.17, 0.003,  $0.06\text{mg L}^{-1}$  reported by Kebede *et al.* (1994), Tilahun and Ahlgren (2010), Tamire and Mengistou (2012) respectively. As compared to other tropical lakes, Tilahun and Ahlgren (2010) reported that the mean concentration of  $\text{NO}_3\text{-N}$  was about 0.0025 and  $0.003\text{mgL}^{-1}$  in Lakes Hawassa and Chamo, which are lower than in Lake Zwai (Table 1.5), respectively. Similarly, Fetahi (2010) reported that the average concentration of  $\text{NO}_3\text{-N}$  was  $0.042\text{mgL}^{-1}$  in Lake Hayq. That was lower than what is reported for Lake Zwai in this study (Table 5). The increasing trend in nitrate concentration is because of increasing external loads of nutrients from the catchment area. The nitrate concentration measured at the different sites during all the seasons did not significant ( $p > 0.05$ ) variations.

Some of the major public health concerns of nitrate in drinking water are methaemoglobinemia, stomach cancer and negative reproductive outcomes (Camargo and Alonso, 2006; Leo *et al.*, 2014). High nitrate concentrations have also been linked to lower productivity in livestock (Leo *et al.*, 2014) is that it is reduced to nitrites (USEPA, 2000; WHO, 1996) to cause methaemoglobinemia, stomach cancer and negative reproductive outcomes (Camargo and Alonso, 2006; Leo *et al.*, 2014) and low productivity in livestock (Leo *et al.*, 2014), particularly at sustained consumption of such waters (Camargo and Alonso, 2006). This is not uncommon in rural societies like around Lake Zwai where people directly drink the lake water.

Nitrite-nitrogen ( $\text{NO}_2\text{-N}$ ) ranged from 0.06 to  $2.89\text{mgL}^{-1}$  in the dry seasons and 0.20 to  $1.8\text{mgL}^{-1}$  in wet seasons (Tables 4 and 5). The lowest concentrations of  $\text{NO}_2\text{-N}$  were at  $M_a$  in both dry and wet seasons; whereas the highest concentration were at  $F_b$  and  $K_b$  in the dry and wet seasons, respectively (Tables 4 and 5). The mean  $\text{NO}_2\text{-N}$  value found in this study ( $0.5\text{mg L}^{-1}$ ) was higher than those values

0.06, 0.01 mgL<sup>-1</sup> reported by Beneberu and Mengistou (2005) and Tamire and Mengistou (2012) respectively. Relatively higher NO<sub>2</sub>-N concentrations were measured near effluent of the floriculture industry for reasons described above (Tadele, 2012). Comparatively, higher concentrations of NO<sub>2</sub>-N values were also measured in Lake Zwai than in some other Ethiopian lakes such as, Lake Hayq (0.01 mg L<sup>-1</sup>) as reported by Fetahi (2010). The mean concentration of NO<sub>2</sub>-N in this study is above the concentration limits of the EU guidelines for drinking water (0.1 mg NO<sub>2</sub>-N L<sup>-1</sup>) (EU, 1998). Consequently, such results are likely to cause environmental concerns due to NO<sub>2</sub>-N toxicity to aquatic biota (e.g. irreversibly binding hemoglobin in fishes) as borehole as to human health (Jensen, 2003)..

Concentration of NH<sub>4</sub>-N in Lake Zwai ranged from 0.17 to 0.29 mgL<sup>-1</sup> in dry and 0.08 to 0.15 mgL<sup>-1</sup> in the wet seasons with their lowest concentrations at Sites C and M<sub>a</sub> in the dry seasons and K<sub>o</sub> and M<sub>a</sub> in the wet seasons while the highest value were at F<sub>b</sub> in the dry and M<sub>b</sub> and K<sub>b</sub> in wet seasons, respectively (Tables 1.4 and 1.5). The mean concentration of NH<sub>4</sub>-N (0.12 mg L<sup>-1</sup>) in this study was similar with the reports by Tilahun and Ahlgren (2010) (0.11 mgL<sup>-1</sup>), and Tamire and Mengistou, 2012 (0.14) but higher than that of made reports by Kebede *et al.*, 1994 (0.036 mgL<sup>-1</sup>) indicating increasing trend.

The mean TN concentration ranged from 4.5 to 12.21 mgL<sup>-1</sup> in the dry and 4.98 to 12.0 mgL<sup>-1</sup> in the wet seasons. The highest concentrations were at K<sub>o</sub> and F<sub>b</sub> in dry and wet seasons, respectively; whereas the lowest concentrations were at B in both seasons (Tables 1.4 and 1.5). There was a seasonal trend of a slightly higher amount of TN during the wet season at most stations. The content of organic N in unpolluted surface waters can vary from 0.3 to 2 mgL<sup>-1</sup>. In eutrophic waters, organic N can reach 7 to 10 mgL<sup>-1</sup> and much higher values (> 20 mg N L<sup>-1</sup>) are found in polluted waters and wastewaters (APHA, 1999).

The mean values of soluble reactive phosphorus (SRP) ranged from 0.05 to 0.08 mgL<sup>-1</sup> and showed similar concentrations for lower values for most of the sampling sites and high values at F<sub>b</sub> in the dry seasons; while in the wet seasons, it ranged from 0.05 to 0.12 mgL<sup>-1</sup> (Tables 4 and 5). Most sites have also similar

concentrations in the wet seasons and only Site F<sub>b</sub> has the highest values. The overall mean SRP concentration was 0.06 mgL<sup>-1</sup>, which is higher than the previous reports of Kebede (1994), Gebre-Mariam (2002), Tilahun and Ahlgren (2010), and Tamire and Mengistou (2012). This is because in recent times Lake Zwai is exposed to strong anthropogenic impacts due to excessive use of agrochemicals and domestic wastes in which organic and inorganic pollutants are found in high concentrations. The mean SRP of Lake Zwai (0.06 mg L<sup>-1</sup>) showed lower concentrations than in Lakes Chitu (1.7 mg L<sup>-1</sup>), Shalla (0.76 mg L<sup>-1</sup>), Chamo (0.118 mg L<sup>-1</sup>), Tana (0.1 to 1.8 mg L<sup>-1</sup>), and Arenguade (0.7 to 2.12 mg L<sup>-1</sup>) as reported by Wood and Talling (1988), Tilahun and Ahlgren (2010), Wondie (2006), and Belachew (2010). The amounts in Lake Zwai are higher than in lakes of Hawassa (0.015 mgL<sup>-1</sup>), Hayq (0.002 mgL<sup>-1</sup>) and Navaisha (0.003 mgL<sup>-1</sup>) as reported by Tilahun and Ahlgren (2010), Fetahi (2010) and Momanyi *et al.* (2012), respectively (Table 6).

Total phosphorus (TP) concentrations ranged from 0.12 to 0.97 mgL<sup>-1</sup> and 0.23 to 1.02 mgL<sup>-1</sup> in the dry and wet seasons, respectively (Tables 3.1.3 and 3.1.4). Mean TP concentration was highest at M<sub>b</sub> in both seasons; whereas the lowest concentrations were at B and K<sub>o</sub> in the dry and K<sub>a</sub> in wet seasons. The overall mean TP value of the lake water was 0.311 mg L<sup>-1</sup>, which is greater than previous reports of Kebede *et al.*, (1994) and Tilahun and Ahlgren (2010). Tilahun and Ahlgren (2010) also reported that the concentrations of TP in Lakes Hawassa and Chamo were 0.034 and 0.182 mgL<sup>-1</sup>, respectively, which were lower than in Lake Zwai (Table 6). According to Jeppesen *et al.* (1997), SRP ranging from 0.05 to 0.1 mgL<sup>-1</sup> are considered to be thresholds for natural waters. SRP is considered to be critical limiting nutrient, and when it becomes in excess, it causes eutrophication of freshwater systems (Wetzel, 2001).

**Table 4:** Means and ranges of nutrient concentrations measured at the surface waters of Lae Zwai in the dry seasons (TP for total phosphorus inmgL<sup>-1</sup>; SRP for soluble reactive phosphorus in mgL<sup>-1</sup>; NO<sub>2</sub>-N for nitrite-nitrogen in mgL<sup>-1</sup>; NO<sub>3</sub>-N for nitrate-nitrogen in mgL<sup>-1</sup>; NH<sub>4</sub>-N for ammonia-nitrogen in mgL<sup>-1</sup>; TIN-N for total inorganic nitrogen in mgL<sup>-1</sup>; TN for total nitrogen in mgL<sup>-1</sup>; SiO<sub>2</sub>-Si for soluble silica inmgL<sup>-1</sup>).

| Sites     |                      | TP         | SRP       | NO <sub>2</sub> -N | NO <sub>3</sub> -N | NH <sub>4</sub> -N | TIN       | TN         | SiO <sub>2</sub> -Si |
|-----------|----------------------|------------|-----------|--------------------|--------------------|--------------------|-----------|------------|----------------------|
| <b>B</b>  | $\bar{x}$ ± Std. Err | 0.12±0.02  | 0.06±0.01 | 0.48±0.20          | 0.17±0.04          | 0.21±0.05          | 0.85±0.25 | 5.7±.25    | 46.2±6.2             |
|           | Range                | 0.06-0.15  | 0.04-0.08 | 0.188-1.3          | 0.06-0.25          | 0.1-0.35           | 0.34-1.8  | 4.9-6.4    | 32-68                |
| <b>C</b>  | $\bar{x}$ ± Std. Err | 0.14±0.02  | 0.05±0.01 | 0.29±0.05          | 0.26±0.17          | 0.17±0.03          | 0.72±0.22 | 9.1±0.65   | 46.8±2.4             |
|           | Range                | 0.1-0.185  | 0.03-0.07 | 0.18-0.41          | 0.01-0.91          | 0.09-0.26          | 0.29-1.5  | 7.34-11.20 | 39.5-54              |
| <b>Fa</b> | $\bar{x}$ ± Std. Err | 0.14±0.02  | 0.05±0.01 | 0.96±0.22          | 0.38±0.13          | 0.24±0.04          | 1.6±0.36  | 6.1±.6     | 46.8±4.9             |
|           | Range                | 0.105-0.23 | 0.03-0.1  | 0.6-1.8            | 0.1-0.75           | 0.15-0.35          | 0.9-2.9   | 4.5-8.3    | 35-60                |
| <b>Fb</b> | $\bar{x}$ ± Std. Err | 0.19±0.05  | 0.08±0.03 | 1.7±0.44           | 0.58±0.19          | 0.29±0.05          | 2.6±0.6   | 8.1±.56    | 91.39.8              |
|           | Range                | 0.05-0.32  | 0.04-0.16 | 0.72-2.89          | 0.08-0.97          | 0.15-0.42          | 1.0-4.2   | 6.5-9.8    | 56.9-114             |
| <b>Ka</b> | $\bar{x}$ ± Std. Err | 0.13±0.02  | 0.05±0.01 | 0.35±0.08          | 0.12±0.02          | 0.22±0.05          | 0.68±0.10 | 7.1±1.1    | 50.5±6.7             |
|           | Minimum              | 0.09-0.19  | 0.04-0.07 | 0.155-0.64         | 0.08-0.18          | 0.10-0.4           | 0.40-0.95 | 5.0-11     | 40.1-77              |
| <b>Kb</b> | $\bar{x}$ ± Std. Err | 0.17±0.03  | 0.05±0.01 | 0.34±0.03          | 0.22±0.05          | 0.34±0.03          | 0.89±0.08 | 9.2±1.3    | 68±7.8               |
|           | Range                | 0.08-0.24  | 0.04-0.09 | 0.24-0.42          | 0.07-0.35          | 0.24-0.42          | 0.76-1.2  | 7- 9       | 43-88.7              |
| <b>Ko</b> | $\bar{x}$ ± Std. Err | 0.12±0.02  | 0.05±0.01 | 0.32±0.09          | 0.10±0.03          | 0.2±0.04           | 0.62±0.14 | 9.7±.42    | 39± 3.4              |
|           | Range                | 0.07-0.19  | 0.04-0.07 | 0.05±0.188         | 0.01-0.18          | 0.09-0.3           | 0.3-1.2   | 8.5-11     | 30-47                |
| <b>Ma</b> | $\bar{x}$ ± Std. Err | 0.14±0.02  | 0.05±0.01 | 0.23±0.08          | 0.10±0.02          | 0.17±0.03          | 0.55±0.08 | 6.3±.49    | 49±3.8               |
|           | Range                | 0.09-0.2   | 0.04-0.06 | 0.1-0.53           | 0.04-0.14          | 0.114-0.3          | 0.35-0.8  | 4.8-7.6    | 38-62                |
| <b>Mb</b> | $\bar{x}$ ± Std. Err | 0.97±0.75  | 0.06±0.01 | 0.41±0.17          | 0.28±0.19          | 0.41±0.17          | 1.3±0.53  | 9.4±1.2    | 61.3±3.9             |
|           | Range                | 0.2-3.95   | 0.04-0.08 | 0.06-1.1           | 0.03-1.1           | 0.1-1.1            | 0.21-3.2  | 5.6-12.21  | 50.8-73              |



The seasonal variations of  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$ , TIN, TN, SRP, TP and  $\text{SiO}_2$  were at their highest records at Fb, Mb and Kb sites as compared to the other sites. The presence of  $\text{NH}_4\text{-N}$  is very likely to be an indication of domestic waste pollution; while the other nutrients are closely associated with agricultural effluents from horticulture and floriculture effluents, domestic wastes and surface runoff into the two rivers (Gebre-Mariam, 2002, Ayenew and Legesse, 2007; Tadele, 2012 and Tamire and Mengistou, 2014). This suggests that Lake Zwai is experiencing high influxes of phosphorus and nitrogen species from external loads.  $\text{NO}_2\text{-N}$  and SRP concentrations showed little variation among the sampling sites.

**Table 5:** Means and ranges of nutrient concentrations measured at the surface waters of Lake Zwai in the wet seasons (TP for total phosphorus in mg L<sup>-1</sup>; SRP for soluble reactive phosphorus in mg L<sup>-1</sup>; NO<sub>2</sub>-N for nitrite-nitrogen in mg L<sup>-1</sup>; NO<sub>3</sub>-N for nitrate-nitrogen in mg L<sup>-1</sup>; NH<sub>4</sub>-N for ammonia-nitrogen in mg L<sup>-1</sup>; TIN-N for total inorganic nitrogen in mg L<sup>-1</sup>; TN for total nitrogen in mg L<sup>-1</sup>; SiO<sub>2</sub>-Si for soluble silica in mg L<sup>-1</sup>) (TP for total phosphate)

| Sites     |                             | TP<br>(mg/L)      | SRP<br>(mg/L)    | NO <sub>2</sub> -N<br>(mg/L) | NO <sub>3</sub> -N<br>(mg/L) | NH <sub>4</sub> -N<br>(mg/L) | TIN<br>(mg/L)    | TN<br>(mg/L)    | SiO <sub>2</sub> -Si<br>(mg/L) |
|-----------|-----------------------------|-------------------|------------------|------------------------------|------------------------------|------------------------------|------------------|-----------------|--------------------------------|
| <b>B</b>  | $\bar{x} \pm$ Std.<br>Error | 0.347 $\pm$ 0.07  | 0.046 $\pm$ 0.01 | 0.47 $\pm$ 0.06              | 0.145 $\pm$ 0.03             | 0.108 $\pm$ 0.02             | 0.725 $\pm$ 0.08 | 5.13 $\pm$ 1.2  | 35.5 $\pm$ 11.6                |
|           | Range                       | 0.21-0.42         | 0.04-0.06        | 0.35-0.53                    | 0.08-0.20                    | 0.07-0.13                    | 0.57-0.86        | 2.8-7.0         | 12.37- 47.3                    |
| <b>C</b>  | $\bar{x} \pm$ Std.<br>Error | 0.382 $\pm$ 0.023 | 0.05 $\pm$ 0.01  | 0.33 $\pm$ 0.12              | 0.171 $\pm$ 0.12             | 0.09 $\pm$ 0.01              | 0.59 $\pm$ 0.24  | 6.02 $\pm$ 0.26 | 43.6 $\pm$ 72                  |
|           | Range                       | 0.34-0.41         | 0.03-0.08        | 0.21-0.57                    | 0.05-0.41                    | 0.08-0.10                    | 0.352-1.1        | 5.60-6.5        | 42.9-45.1                      |
| <b>Fa</b> | $\bar{x} \pm$ Std.<br>Error | 0.29 $\pm$ 0.12   | 0.05 $\pm$ 0.01  | 0.74 $\pm$ 0.22              | 0.26 $\pm$ 0.12              | 0.09 $\pm$ 0.03              | 1.1 $\pm$ 0.33   | 7.0 $\pm$ 0.81  | 36 $\pm$ 7.5                   |
|           | Range                       | 0.176-0.52        | 0.04-0.07        | 0.43-1.2                     | 0.03-0.39                    | 0.03-0.14                    | 0.48-1.62        | 5.6-8.4         | 22.2-47.7                      |
| <b>Fb</b> | $\bar{x} \pm$ Std.<br>Error | 0.416 $\pm$ 0.175 | 0.11 $\pm$ 0.04  | 0.89 $\pm$ 0.44              | 0.44 $\pm$ 0.19              | 0.09 $\pm$ 0.04              | 1.42 $\pm$ 0.62  | 6.66 $\pm$ 0.53 | 39.2 $\pm$ 26                  |
|           | Range                       | 0.17-0.75         | 0.04-0.16        | 0.34-1.8                     | 0.17-0.80                    | 0.02-0.15                    | 0.75-2.7         | 5.6-7.4         | 6.0 -90.5                      |
| <b>Ka</b> | $\bar{x} \pm$ Std.<br>Error | 0.23 $\pm$ 0.02   | 0.05 $\pm$ 0.01  | 0.84 $\pm$ 0.16              | 0.47 $\pm$ 0.04              | 0.09 $\pm$ 0.03              | 1.39 $\pm$ 1.18  | 7.6 $\pm$ 0.43  | 37.9 $\pm$ 4.68                |
|           | Range                       | 0.20-0.27         | 0.04-0.07        | 0.5 - 1.1                    | 0.4-0.54                     | 0.03-0.12                    | 1.1 $\pm$ 1.7    | 7-8.4           | 30.3 -46.45                    |
| <b>Kb</b> | $\bar{x} \pm$ Std.<br>Error | 0.732 $\pm$ 0.27  | 0.06 $\pm$ 0.01  | 1.2 $\pm$ 0.20               | 0.86 $\pm$ 0.22              | 0.15 $\pm$ 0.10              | 2.2 $\pm$ 5.0    | 8.1 $\pm$ 0.86  | 38.15 $\pm$ 17.10              |
|           | Range                       | 0.238-1.2         | 0.05-0.08        | 0.89-1.6                     | 0.52-1.3                     | 0.05-0.3                     | 1.5-3.1          | 7-9.8           | 11.24-70                       |
| <b>Ko</b> | $\bar{x} \pm$ Std.<br>Error | 0.268 $\pm$ 0.08  | 0.05 $\pm$ 0.01  | 0.42 $\pm$ 0.12              | 0.20 $\pm$ 0.04              | 0.08 $\pm$ 0.02              | 0.7 $\pm$ 0.12   | 10 $\pm$ 1.9    | 34.3 $\pm$ 11                  |
|           | Range                       | 0.12-0.376        | 0.04-0.07        | 0.2-0.6                      | 0.1-0.3                      | 0.05-0.1                     | 0.5-0.9          | 8.4-12.0        | 12.6-48.2                      |
| <b>Ma</b> | $\bar{x} \pm$ Std.<br>Error | 0.242 $\pm$ 0.04  | 0.06 $\pm$ 0.02  | 0.76 $\pm$ 0.06              | 0.23 $\pm$ 0.11              | 0.08 $\pm$ 0.02              | 1.06 $\pm$ 0.14  | 6.1 $\pm$ 5.5   | 42.62 $\pm$ 1.9                |
|           | Range                       | 0.19-0.33         | 0.04-0.082       | 0.664-0.86                   | 0.01-0.369                   | 0.03-0.11                    | 0.8-1.3          | 4.97-7          | 38.96-45.42                    |
| <b>Mb</b> | $\bar{x} \pm$ Std.<br>Err   | 1.0 $\pm$ 0.30    | 0.09 $\pm$ 0.02  | 1.02 $\pm$ 2                 | 0.50 $\pm$ 0.24              | 0.16 $\pm$ 0.06              | 1.66 $\pm$ 4.8   | 13.5 $\pm$ 4.5  | 39.1 $\pm$ 14.72               |
|           | Range                       | 0.47-1.5          | 0.06-0.12        | 0.7-1.42                     | 0.02-0.75                    | 0.05-0.23                    | 0.76-2.4         | 5.6-12.0        | 11.2-61.2                      |

The mean concentration of soluble reactive silica ( $\text{SiO}_2\text{-Si}$ ) ranged from 39.36 to 91.29 and 35.53 to 42.62  $\text{mgL}^{-1}$  with mean values of 55.4 and 38.5  $\text{mgL}^{-1}$  in the dry and wet seasons, respectively (Tables 4 and 5). The lowest amount of silica was recorded as 30.0 and 6.0  $\text{mgL}^{-1}$  and the highest amount was 114 and 90.7  $\text{mgL}^{-1}$  during the dry and wet seasons, respectively. In contrast, Gebre-Mariam (2002) reported that  $\text{SiO}_2\text{-Si}$  concentrations of Lake Zwai ranging from 13.4 to 31 and 14.7 to 37.5  $\text{mgL}^{-1}$  with mean values of 19.0 and 22.9  $\text{mgL}^{-1}$  in the dry and wet seasons, respectively. The mean  $\text{SiO}_2\text{-Si}$  concentration of both seasons showed significant variations ( $p < 0.05$ ) over the seasons and across the different sampling sites. The overall mean concentration of  $\text{SiO}_2\text{-Si}$  (40.68  $\text{mgL}^{-1}$ ) was higher than the previously reported values of Tilahun and Ahlgren (2010) and Gebre-Mariam (2002) which were 23.8 and 21  $\text{mg L}^{-1}$ , respectively. As compared to other tropical lakes, the mean  $\text{SiO}_2\text{-Si}$  (40.68  $\text{mgL}^{-1}$ ) in Lake Zwai was lower than Lakes Chitu (320  $\text{mgL}^{-1}$ ), Shala (112  $\text{mgL}^{-1}$ ), Abijata (128  $\text{mgL}^{-1}$ ) and higher than in lakes like Chamo (1.0  $\text{mgL}^{-1}$ ), Hayq (3.7  $\text{mgL}^{-1}$ ) and Arenguade (3.5 to 37  $\text{mgL}^{-1}$ ); but comparable with Lakes Hawassa (37.6  $\text{mgL}^{-1}$ ), Abaya (40  $\text{mgL}^{-1}$ ) Langano (48  $\text{mgL}^{-1}$ ) and Bishoftu (38  $\text{mgL}^{-1}$ ) (Table 6). Therefore, the amount of dissolved  $\text{SiO}_2\text{-Si}$  in Lake Zwai was very high similar to the high silica concentrations ( $> 10 \text{ mg SiO}_2\text{L}^{-1}$ ) commonly encountered in African lakes (Talling, 1992).

**Table 6:** Composition of the physico-chemical parametrs of Lake Zwai with other tropical lakes (mgL<sup>-1</sup> for nutrients and DO, μScm<sup>-1</sup> for EC and m for SD)

| Lakes     | Temp. (°C) | DO       | pH         | EC        | SRP          | TP        | NO <sub>3</sub> -N | SiO <sub>2</sub> -Si | SD         | Publications                 |
|-----------|------------|----------|------------|-----------|--------------|-----------|--------------------|----------------------|------------|------------------------------|
| Abaya     | -          | -        | 8.9        | 623       | 0.04         | -         | -                  | 40                   | -          | Wood and Talling, 1988       |
| Abijata   | -          | -        | 10.2       | 15800     | 0.05         | -         | -                  | 128                  | -          | Wood and Talling, 1988       |
| Arenguade | 20.2-24.5  | 0.4-13.1 | 9.62- 9.84 | -         | 0.70 - 2.12  | -         | 0 - 0.78           | 3.5 - 37             | 0.21- 0.37 | Belachew, 2010               |
| Bishoftu  | -          | -        | 9.2        | 1830      | 0.005 to 0.1 | -         | -                  | 38                   | -          | Wood and Talling, 1988       |
| Chamo     | 26.3       | 5 – 9    | 8.84       | 1910      | 0.118        | 0.182     | 0.033              | 1.0                  | 0.18       | Tilahun and Ahlgren, 2010    |
| Chitu     | -          | -        | 9.8        | 28600     | 1.7          | -         | -                  | 320                  | -          | Wood and Talling, 1988       |
| Hawassa   | 23.5       | 5 - 7    | 8.66       | 846       | 0.015        | 0.034     | 0.025              | 37.6                 | 0.85       | Tilahun and Ahlgren, 2010    |
| Hayq      | 18.2       | 1- 8.4   | 9          | 910       | 0.022        | 0.058     | 0.042              | 3.7                  | 2.7        | Fetahi, 2010                 |
| Langano   | -          | -        | 9.4        | 1810      | 0.09         | -         | -                  | 48                   | -          | Wood and Talling, 1988       |
| Navaishia | 22.4       | 5.89     | 8.51       | 290       | 0.003        | 0.03-0.41 | 0.012              | -                    | 0.1- 0.75  | Momanyi <i>et al.</i> , 2012 |
| Shala     | -          | -        | 9.9        | 19200     | 0.76         | -         | -                  | 112                  | -          | Wood and Talling, 1988       |
| Tana      | 20 -27     | 5.9 -7   | 7.3 - 8.5  | 115 - 148 | 0.1- 1.8     |           | 0.1-1              |                      | 0.51-1.82  | Wondie, 2006                 |
| Zwai      | 23         | 5        | 8.1        | 404.3     | 60           | 0.311     | 0.21               | 40.68                | 0.2        | Original data                |

### Multivariate analysis

**Principal component analysis (PCA):** Four components of PC analysis showed 88.10 % of the variance in the data set of the wet seasons, as the eigenvectors classified the 15 physico-chemical parameters into four groups. PC<sub>1</sub> (38.93 % of the total variance in the data set) has strong positive external loads on TP, NH<sub>4</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, TIN, pH and SD (Table 7) during the wet seasons. The second component (PC<sub>2</sub>) accounted for 24.02 % of the total variance measured, demonstrating strong positive external load for TN, EC, TDS and TA and the third component (PC<sub>3</sub>) demonstrated 16.76 % of the total variance and has strong positive external load for SiO<sub>2</sub>-Si, PO<sub>4</sub>-P, DO and temperature, while, the fourth component (PC<sub>4</sub>) accounts for only 8.39 % of the total variance in the season (Table 7).

As indicated in the PCA analysis, PC<sub>1</sub> has strong positive external load for NH<sub>4</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, PO<sub>4</sub>-P, TP, SiO<sub>2</sub>-Si, TIN, EC, TDS, TA and SD associated sampling Sites Mb and Kb during the wet seasons. The presence of nutrients in PC<sub>1</sub> demonstrated the intensive agricultural activities in the watershed of the lake that resulted in high nutrient inflows due to excess use of fertilizers and pesticides (Meshesha *et al.*, 2012, Desta *et al.*, 2016).

Nitrate nitrogen source is due to numerous sources, such as, geologic deposits, natural organic matter decomposition and agricultural runoff (Leo *et al.*, 2014). The second component (PC<sub>2</sub>) demonstrated strong positive external load of TN, EC, TDS and TA. The third components (PC<sub>3</sub>) demonstrated strong positive loadings for SiO<sub>2</sub>-Si and PO<sub>4</sub>-P. This factor indicates that PO<sub>4</sub>-P source is from domestic and agricultural wastes, detergents from industries whereas SiO<sub>2</sub>-Si is from bed rock materials and probably compounds silica containing from floriculture industry (Tadele, 2012), while the fourth component (PC<sub>4</sub>) had no strong external load in all the measured parameters.

**Table 7:** The factors of external nutrient load values and explained variances of water quality in two seasons (positive and negative strong correlations are marked bold)

| Parameters            | PC1          |               | PC 2          |              | PC3          |               | PC 4         |        |
|-----------------------|--------------|---------------|---------------|--------------|--------------|---------------|--------------|--------|
|                       | Dry          | wet           | Dry           | wet          | Dry          | wet           | Dry          | Wet    |
| TP                    | 0.065        | <b>0.918</b>  | <b>-0.692</b> | -0.180       | 0.483        | 0.213         | 0.100        | 0.225  |
| SRP                   | <b>0.930</b> | 0.148         | -0.157        | -0.179       | 0.132        | <b>0.850</b>  | -0.034       | 0.374  |
| NH <sub>4</sub> -N    | <b>0.907</b> | <b>0.853</b>  | -0.039        | -0.379       | 0.265        | 0.316         | -0.105       | 0.048  |
| NO <sub>2</sub> -N    | <b>0.966</b> | <b>0.879</b>  | 0.099         | 0.090        | -0.073       | -0.332        | -0.087       | -0.145 |
| NO <sub>3</sub> -N    | <b>0.963</b> | <b>0.897</b>  | -0.040        | -0.005       | -0.205       | 0.031         | 0.104        | -0.344 |
| TIN                   | <b>0.980</b> | <b>0.938</b>  | -0.010        | 0.027        | -0.171       | -0.136        | 0.060        | -0.235 |
| TN-N                  | -0.097       | 0.561         | -0.315        | <b>0.680</b> | 0.176        | -0.277        | <b>0.875</b> | 0.200  |
| SiO <sub>2</sub> -Si  | <b>0.791</b> | 0.109         | -0.52         | -0.096       | -0.286       | <b>-0.620</b> | -0.051       | 0.485  |
| Temp                  | 0.283        | -0.191        | <b>0.793</b>  | 0.192        | 0.431        | <b>0.632</b>  | -0.091       | -0.620 |
| DO                    | 0.349        | 0.078         | -0.423        | 0.551        | <b>0.757</b> | <b>0.644</b>  | -0.091       | 0.396  |
| PH                    | -0.373       | <b>-0.854</b> | <b>0.761</b>  | 0.129        | 0.489        | 0.004         | 0.078        | -0.165 |
| EC                    | <b>0.963</b> | -0.249        | 0.159         | <b>0.959</b> | -0.022       | -0.069        | 0.086        | 0.030  |
| TDS                   | <b>0.955</b> | -0.255        | 0.167         | <b>0.954</b> | -0.049       | -0.087        | 0.077        | 0.025  |
| SD                    | 0.035        | <b>0.611</b>  | <b>0.660</b>  | 0.580        | -0.335       | -0.214        | 0.317        | -0.164 |
| TA                    | <b>0.801</b> | 0.440         | 0.538         | <b>0.626</b> | 0.201        | 0.429         | 0.112        | 0.030  |
| Eigenvalues           | 7.970        | 5.840         | 3.051         | 3.603        | 1.663        | 2.515         | 0.961        | 1.258  |
| % variance            | 53.133       | 38.933        | 20.340        | 24.017       | 11.087       | 16.764        | 6.408        | 8.388  |
| % Cumulative variance | 53.133       | 38.933        | 73.473        | 62.95        | 84.560       | 79.714        | 90.968       | 88.102 |

The dry season PCA analysis showed that four principal components (PCs) represented about 90.97 % of the total variation in the entire dataset. The first PC accounted for 53.4 % of the total variations between sites and comprised of the following parameters: nutrients (NH<sub>4</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, TIN, PO<sub>4</sub>-P, SiO<sub>2</sub>-Si), TDS, EC, TA. The second PC accounted for 20.34 % of the total variance and had strong positive loading with temperature, pH, TP and SD as the associated

parameters. The third PC explained 11.09 % of the total variations between sites comprising only DO. Scree plot showed the eigenvalues sorted from large to small as a function of the principal components number after the fourth PC (Figs. 2 and 3).

In the dry seasons, the PCA performed by sites showed that four principal components (PCs) represented about 90.97 % of the total variation in the entire dataset. The first PC accounted nutrients ( $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$ , TIN,  $\text{PO}_4\text{-P}$ ,  $\text{SiO}_2\text{-Si}$ ), TDS, EC, TA associated with Sites Fa and Fb. The high values in these sites in the dry seasons were attributed to the point pollution of the floriculture industry.

The second PC had strong positive external load with temperature, pH, TP and SD and the associated parameters. TP demonstrated that intense agricultural activity had occurred at Sites Fa and B, causing pollution due to fertilizers and pesticides (see also Meshesha *et al.*, 2012). Singhet *al.* (2004) interpreted similar external loads as causes of eutrophication from domestic wastewater, industrial effluents and agricultural activities. The third PC explained the total variations between sites comprising only DO at Site Mb. The inverse relationship between temperature and DO is a natural process, because water can hold less DO with increasing temperature (Singh *et al.*, 2004). The fourth PC explained site variations with TN only. Liu *et al.* (2003) classified the factor of external load as “strong,” “moderate,” and “weak,” corresponding to absolute load values of  $>0.75$ , 0.75 to 0.50, and 0.50 to 0.30, respectively.

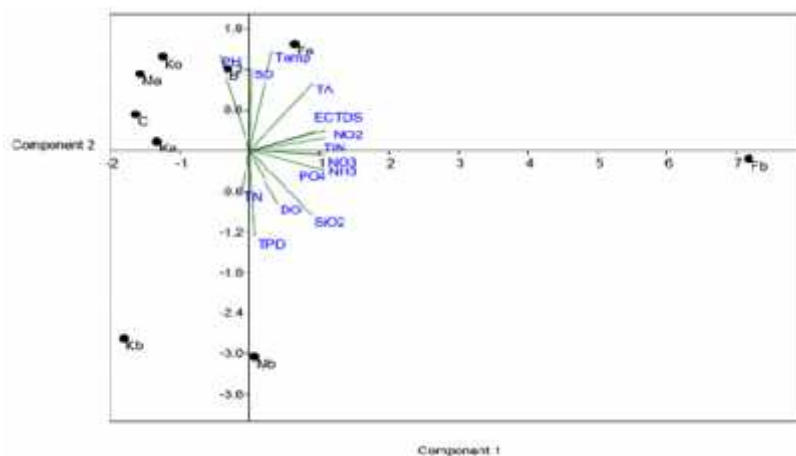


**Figure 2:** Results of the bi-plot of the correlation among various water quality parameters with respect to the studied sites using PCA in the dry seasons of 2014 and 2015

The bi-plot of PCs associated with nutrients ( $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{SiO}_2\text{-Si}$  and  $\text{PO}_4\text{-P}$ ), EC and TDS were characterized at Site  $F_b$  (Fig. 2), due to the floriculture effluents. Similarly, Tadele (2012) reported that floriculture industries are known for using excessive fertilizers and the effluents from the farms drain directly to the lake.  $F_a$  distinctiveness was attributed to temperature, SD and TA. The parameter influencing the distinction at Site B was mainly pH; while Site  $M_b$  was influenced by DO, TN and TP in the dry season (Fig. 2).

The bio-plot of PCs associated with nutrients ( $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{SiO}_2\text{-Si}$ , TIN, SRP and TP), which were the key parameters characterizing Sites  $M_b$  and  $K_b$  in the wet seasons (Fig. 3), suggesting the influence of agricultural activities in the catchment of the two rivers feeding the lake (Meki and Qatar Rivers) (Meshesha *et al.*, 2012; Desta *et al.*, 2016).  $F_a$  distinctiveness was attributed to temperature, TDS, EC and DO. The parameter influencing the distinction at Site



$K_o$  was mainly pH while Site  $F_b$  was influenced by DO, TN, TA and SD in the wet seasons. In the present study, higher EC and TDS values were found for sampling points near the floriculture area ( $F_b$  and  $F_a$ ) in both seasons. In an aquatic environment, EC is an important and a simple indicator to characterize the pollution status of surface waters, as a sudden increase in conductivity can indicate the presence of more dissolved ions, which may have impact on aquatic life and water quality (Camacho *et al.*, 2015).

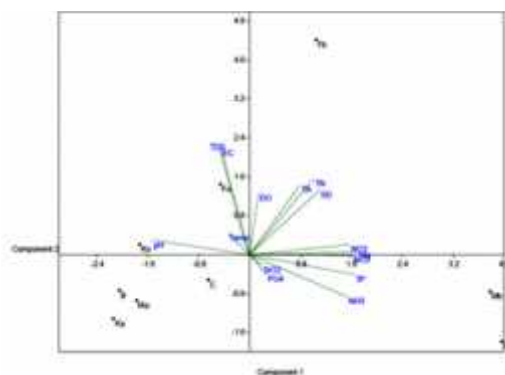


**Figure 3:** Results of the bi-plot of the correlation among various water quality parameters with respect to the studied sites using PCA in the wet seasons in 2014 and 2015

The results from temporal PCA/FA suggested that agrochemicals were potential pollution sources for both temporal clusters, although the influence of each was different. For the two temporal clusters, 90.97 % and 88.10 % of the variances in dry and wet seasons, respectively, were explained by the four main factors. The results of the present study indicated the existence of contamination of Lake Zwai with both inorganic and organic agrochemicals and other pollutant sources (Meshesha *et al.* 2012; Tadele 2012). Moreover, there is increasing concentrations of phosphate and nitrate, as borehole as silicates which all contributed to increases

in salinity in Lake Zwai since the 1980s (Ayenew and Legesse2007; Tilahun 2010; Tadele 2012).

**Cluster analysis (CA):** A dendrogram of sampling sites obtained by the Ward's Method is shown in Fig. 4. Nine sampling sites were divided into three groups. Cluster 1 corresponded to site F<sub>b</sub>, which is located in the western part of the lake. The sources of pollutants in this site are effluents of the floriculture industry. Cluster 2 included site K<sub>b</sub>, which is located in the eastern portion of the lake. The pollutants at K<sub>b</sub> were largely from agricultural and domestic sewage, particularly the dispersed and unsettled wastewaters from the local villages and agrochemicals from agricultural runoffs. Cluster 3 contained Sites F<sub>a</sub>, K<sub>o</sub> and B at the western part of the lake, C at central station; Site M<sub>b</sub> and M<sub>a</sub> in the north and K<sub>a</sub> in the east. The CA revealed different properties of each site with respect to physical and chemical variables. The three groups vary according to natural background features, and land use-land cover changes such as industrial impacts and anthropogenic sources of pollution such as agricultural and settlement impacts.

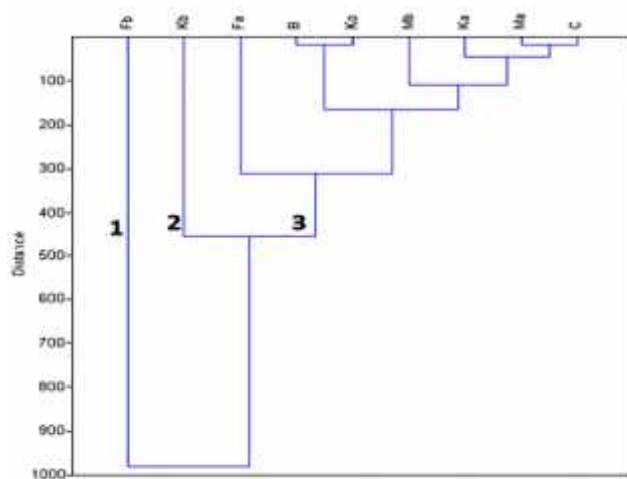


**Figure 4:** Dendrogram based agglomerative hierarchical clustering (Ward's Method) based on the PCA scores in the dry seasons

In the case of wet seasons, sampling sites classification was performed by the use of cluster analysis and generating a dendrogram, which grouped all nine sites of the basin into three statistically significant clusters (Fig. 5). Grouped stations under each cluster can be seen in Fig. 5. Based on the results of cluster analysis in the wet season, results can be explained as follows:

Sites mainly located at different parts of the lake were grouped under Cluster III (Sites C,  $M_a$ ,  $K_a$ ,  $K_o$ , B and  $F_a$ ), which were basically at the center of the lake and shore water. In addition, Site  $M_a$  and  $K_a$  located upstream of the lake, showed similar water quality characteristics of these sites. Impacts of urbanization (settlements) and industrialization level are relatively low at these sites. Cluster III showed relatively less pollution (LP), suggesting that anthropogenic sources of pollution are less in this cluster.

Cluster II comprises of the two stations that are in close proximity to the mouth of Meki River that drains part of the western highland and Qatar River that drains the eastern Arsi Mountains. These two rivers transported many agrochemicals, domestic wastes and industrial effluents from the cultivated lands in the western and the eastern highlands of the lake watershed and from the towns (e.g. Meki, Abuna, Butagira, etc.) and industries located in these towns and along the rivers.

Cluster I, containing Site F<sub>b</sub> only), is the effluent of the floriculture which directly entered into the lake with its load of nutrients, pesticides and other chemicals such as heavy metals. Cluster I corresponded to a relatively highly polluted (HP) site, because of the inclusion of floriculture that released untreated sewage at this site.

Therefore, the results indicate that the CA technique is useful in offering reliable classification of surface water in the selected region and make it possible to design a future spatial sampling strategy in an optimal way to reduce the number of sampling stations and associated costs of sampling. As a result, different measures can be taken to control water pollution in the zones with the additional application of PCA.

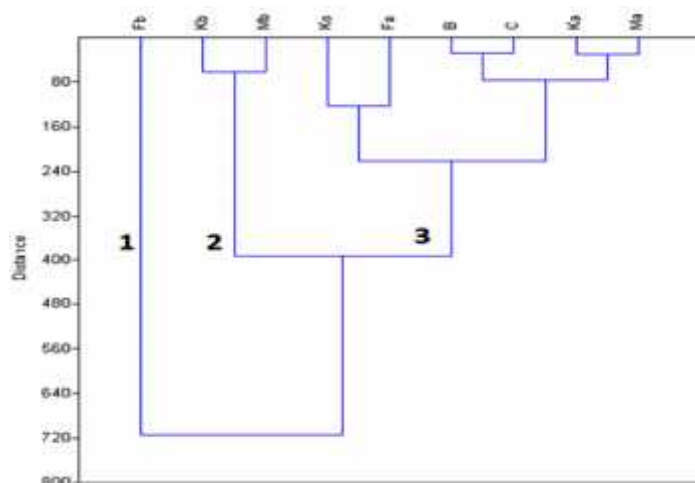


**Figure 5:** Dendrogram based agglomerative hierarchical clustering (Ward's Method) based on the PCA scores in the wet seasons

Other water quality studies that applied PCA and CA analysis found the techniques helpful in the interpretation of large datasets. Kazi *et al.*, (2009) used PCA and CA in the analysis of water quality at Manchar Lake in Pakistan and found the techniques useful in apportionment of pollution sources based on parameter association. Their findings agree with the present study particularly in the association of nutrients with catchment runoffs in the wet season and point sources during the dry seasons. Magyar *et al.* (2013) used PCA and CA in 33 sites for 13 physico-chemical and biological water quality parameters which helped them in identifying the underlying processes responsible for the heterogeneity in different parts of Lake Neusiedler in Hungary. Their study also showed that the river input region is significantly different. This study also agreed with Mohammad *et al.*, (2011), who used 16 water quality parameters where most parameters increased in the dry season due to evaporative effects leaving behind concentrating salts, whereas lower values were observed in the wet season as the lake water was diluted by rain water. Similarly, Sridhar *et al.*, (2014) also applied PCA and CA to

identify the factors influencing the water quality in different seasons in Hyderabad lakes, India. All these studies revealed that water pollution was more significant during the dry seasons (no additional injection of freshwater; but evaporation and concentration of salts) as compared to the rainy seasons (adding massive volumes of freshwater; but low evaporation rates due to cool weather and hence dilution of lake water).

**Analysis of internal nutrient load and its dynamics in Lake Zwai:** Soluble reactive phosphorus SRP distributions were analyzed from all sediment samples collected from the selected sites in both the dry and wet seasons with spatio-temporal depth profiles results (Fig. 6 (a) and (b)).

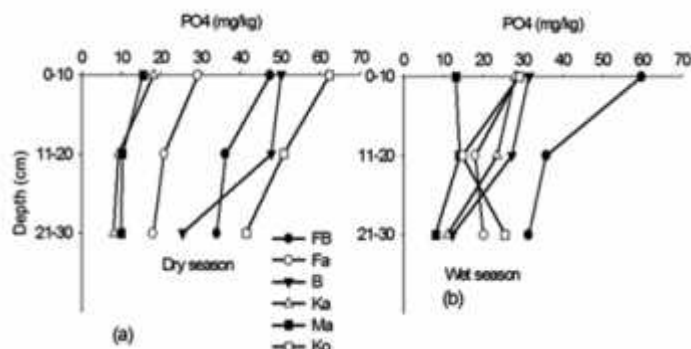


**Figure 6:** Vertical profiles of sediment SRP from six representative sites (a) in dry and (b) in wet seasons of 2014 and 2015.

SRP concentrations ranged from 8.15 to 56.0  $\text{mgkg}^{-1}$  and 8.01 to 28.0  $\text{mgkg}^{-1}$  in the dry and wet seasons, respectively. Higher SRP concentrations occurred in the upper layer and declined with depth in most sites of both seasons (Fig. 6a) and (b) (see also Sobczykński and Joniak, 2009 and Kangur *et al.*, 2013). The main reason for the declining of SRP along depths of the sediment might be the 'bound up' of SRP with other metal complexes and not being actively released to the overlying

water column. Similarly, Søndergaard *et al.*, (2003) agreed that phosphorus in the upper approximately 10 cm is considered to take part in the whole lake metabolism, but mobility of phosphorus from depths down to the bottom is decreasing.

The mean concentrations of SRP were  $27.7 \text{ mg kg}^{-1}$  and  $21.2 \text{ mg kg}^{-1}$  in the dry and wet seasons, respectively. The value of sediment SRP in Lake Zwai is in the same range of its value in other Ethiopian lakes like Lake Tana (ranged between 9.6 to  $52.2 \text{ mg kg}^{-1}$  with the overall mean value of  $21.8 \text{ mg kg}^{-1}$ ) reported by Kebede and Muhabaw, (2015). Similarly, Wang *et al.*, (2014) and North *et al.*, (2015) reported that released SRP in the sediment is available for algal growth and can further sustain the eutrophication processes. Therefore, this result indicated that the sediment might be an important internal source of SRP for Lake Zwai ecosystem in increasing eutrophication process.

In the case of temporal variations, the dry season SRP concentrations were slightly higher than the wet season, due to its internal load enhanced by warm temperature and biological activities in the lake ( $P < 0.05$ ). Similarly, Feuchtmayr *et al.*, (2009) reported that higher temperature increases the release of phosphorus from bottom sediments during warm dry seasons.

TP concentrations varied within the range of 16.2 to  $207 \text{ mg kg}^{-1}$  and 24 to  $192 \text{ mg kg}^{-1}$  with mean values of 62 and  $73 \text{ mg kg}^{-1}$  in the dry and wet seasons, respectively. The vertical distribution of sediment TP concentration was higher at the top sediment depth (0 - 10 cm) and lower in the middle (11-20 cm) in most sampling sites in the wet season but showing a decreasing trend down the depth profiles in the dry season (Fig. 7).

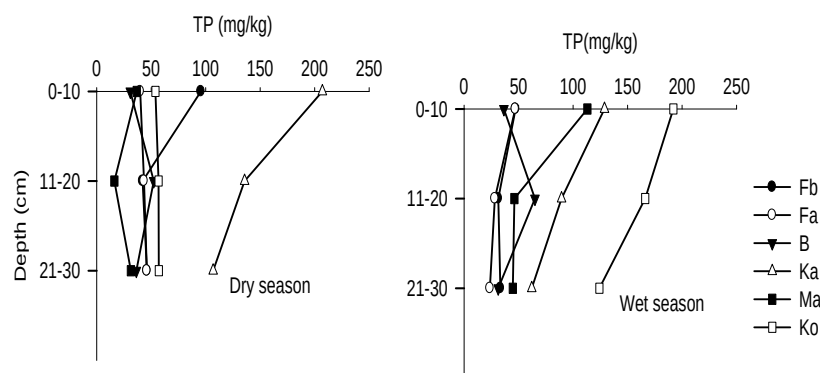


**Figure 7:** Vertical distributions of TP in sediments from six representative sites (left) in dry and (right) in wet seasons of 2014 and 2015

Similarly, Sobczyński and Joniak (2009) and Chang *et al.* (2010) reported the concentration of TP in sediment depth profiles of lakes decreased with depth. Similarly, (Kim *et al.*, 2004 and Trolle, 2009) suggested that the elevated TP concentrations in the uppermost sediment layers of the lake are due to higher localized external agrochemical load and biodegradation of organic matter.

$\text{NO}_3\text{-N}$  concentrations in depth profile ranged from 2.52 to 7.99  $\text{mgkg}^{-1}$  and 2.95 to 61.80  $\text{mgkg}^{-1}$  with mean values of 5.28 and 28.40  $\text{mgkg}^{-1}$  in the dry and wet seasons respectively. ANOVA (Kruskal-Wallis test) analyses showed that  $\text{NO}_3\text{-N}$  concentrations among sites were significantly different during the wet seasons ( $P < 0.05$ ) but not during the dry seasons ( $P > 0.05$ ). High  $\text{NO}_3\text{-N}$  concentrations were obtained during the wet season than the dry seasons, which is apparently associated with high inflows of water into the lake. Sites  $\text{K}_0$  and  $\text{F}_b$  have high  $\text{NO}_3\text{-N}$  concentrations in both seasons as compared to others (Fig. 8 and see also Tadele, 2012). This could be due to high animal and human interference (mainly fish marketing and animal grazing) in  $\text{K}_0$  and effluents of the floriculture in  $\text{F}_b$ .



The vertical distribution of  $\text{NO}_3\text{-N}$  concentrations in the lake sediment decreased by depth in most sampling sites in both seasons (Fig. 8). Similarly, Dasmot *et al.* (2013) reported that the  $\text{NO}_3\text{-N}$  concentration in the lake sediment were typically lower in the deeper depth (>10 cm) than the shallower depth (0-10 cm) in both seasons. The decreasing trends of  $\text{NO}_3\text{-N}$  with depth very likely to be the conversion of nitrate to nitrite and then to nitrogen gas through microbially mediated denitrification processes (Lehmann *et al.*, 2007).

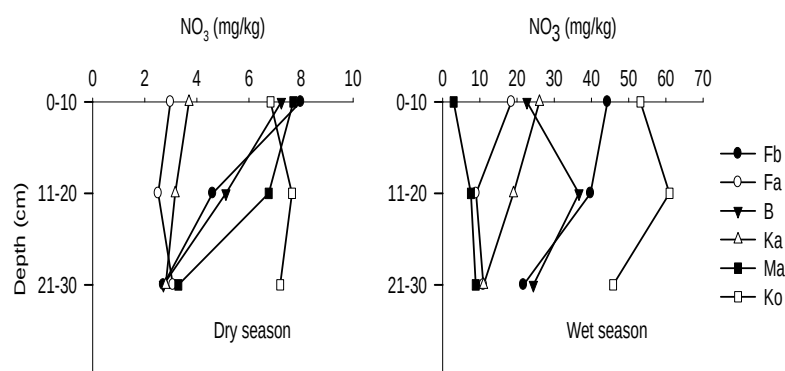


**Figure 8:** Vertical distribution of  $\text{NO}_3\text{-N}$  concentrations in sediment depths profiles of six sites (left) in dry and (right) in wet seasons of 2014 and 2015

Other studies also suggested that the population of nitrifying bacteria, free living nitrogen fixing bacteria and total bacterial population showed a slight decreasing trend with gradual increase in depth (Lehmann *et al.*, 2007). Moreover, Zhang *et al.* (2014) explained that  $\text{NO}_3\text{-N}$  diffusion from the water column to the sediment decreased severely with sediment depth due to the denitrification processes.

$\text{NO}_2\text{-N}$  concentrations ranged from 0.84 to 20.0  $\text{mgkg}^{-1}$  and 11.3 to 45.30  $\text{mgkg}^{-1}$  and the mean concentrations of  $\text{NO}_2\text{-N}$  were 8.51  $\text{mgkg}^{-1}$  and 24.20  $\text{mgkg}^{-1}$  in the

dry and wet seasons, respectively. In this study, there were strong seasonal variations at  $P < 0.05$  (Fig. 9).

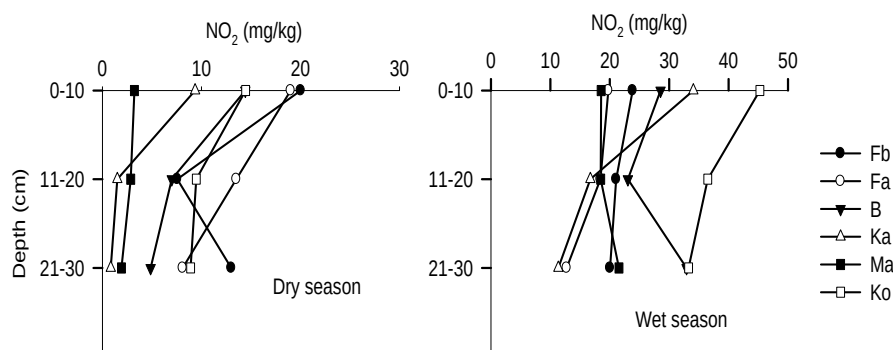


**Figure 9:** Vertical distribution of sediment  $\text{NO}_2\text{-N}$  from six representative sites (left) in dry and (right) in wet seasons of 2014 and 2015

Most sites had high  $\text{NO}_2\text{-N}$  concentrations at the top sediment layers and decreased with depth in both seasons (Fig. 9). Similar results were reported by Trolle (2009), Dasm *et al.* (2013) and Zhang *et al.* (2014) in their studies in other lakes.

In this study, spatial trends were also observed in  $\text{NO}_2\text{-N}$  concentrations in most of the sites. For instance, some cores samples in Ka showed that the bottom sediments were relatively low  $\text{NO}_2\text{-N}$  concentrations in sediment depth in both seasons (Fig. 9). However, profiles from Sites of F<sub>b</sub> and K<sub>o</sub> generally had high  $\text{NO}_2\text{-N}$  concentrations in the uppermost sediment layers during the dry and wet seasons, respectively. Wet season  $\text{NO}_2\text{-N}$  concentrations were higher than the dry seasons. The most probable reason might be related to excessive anthropogenic input from agricultural runoff, industrial effluents and domestic sewage in the surrounding lake catchments, as these factors are also reported by other studies on the same lake (Meshesha *et al.*, 2012, Desta *et al.*, 2016).

TN concentrations in the sediment depth profile ranged from 508 to 3200  $\text{mg kg}^{-1}$  and 443 to 3753  $\text{mg kg}^{-1}$ , with the overall means of 1511 and 1631  $\text{mg kg}^{-1}$  in the dry and wet seasons, respectively. Though TN concentration variations between seasons were not significant ( $p < 0.05$ ), the wet season values were slightly higher than the dry seasons in most sites. The probable reasons for increasing TN in wet seasons is similar to that for  $\text{NO}_2\text{-N}$  as mentioned above. The depth profiles of TN concentrations decreased with sediment depth in both seasons (Fig. 10). Similar results have been reported in different lakes Trolle (2009); Kim *et al.* (2004) and Kelderman *et al.* (2005). The high TN concentrations in the uppermost sediment layers of the lake might be due to aerobic condition at the sediment-water interface for decomposition and breakdown of binding molecules and the higher localized external loads (Kelderman *et al.*, 2005). Similarly, Jinglu *et al.* (2007) and Trolle (2009) explained that the increased top surface nutrient concentrations in the sediment could be due to the injection and accumulation of continued external loads from the urbanization, industrialization and agricultural intensifications in the lake catchment, which do not sink as fast as they come in.

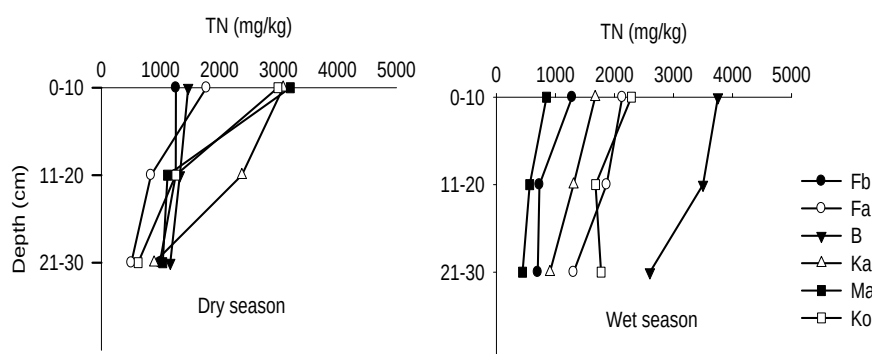


**Figure 10:** Vertical distribution of TN from six representative sites (left) in the dry and (right) in the wet seasons of 2014 and 2015

As can be seen from Fig.11, Ma ( $3200 \text{ mgkg}^{-1}$ ) and B ( $3753 \text{ mgkg}^{-1}$ ) have the highest concentrations of TN in the dry and wet seasons, respectively, at the top sediment layers. The highest values of TN in these sites are probably due to the differences in the origins of the sediments and related anthropogenic factors. According to EPA, (1994), the evaluation criteria of TN pollution in the sediment sampling sites of Ma in the dry seasons and B in wet seasons in Lake Zwai are serious concerns of pollution, and the rest sampling sites have reached mild pollution levels. Throughout the whole lake, sediment TN concentration shows Zwai very high levels of pollution, indicating that the endogenous or internal nutrient load is a serious factor to reckon with.

#### **External nutrient loads and determination of the trophic status of Lake Zwai:**

Water quality and quantity data are used to describe the recent loads of TP, SRP,  $\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$ ,  $\text{NH}_4\text{-N}$ , TIN, TN and  $\text{SiO}_2\text{-Si}$  into Lake Zwai over the study period. The results of the study are shown on spatial and seasonal bases in Tables 1.9 and 1.10.

SRP load ranged from values of  $0.0$  to  $33 \text{ Kgday}^{-1}$  and  $25$  to  $245 \text{ Kgday}^{-1}$  during the dry and wet seasons, respectively (Tables 1.8 and 1.9). Mean SRP loads were  $14.1$  and  $102 \text{ Kgday}^{-1}$  during the dry and wet seasons respectively. SRP loads were significantly different between rivers ( $p < 0.05$ ) in the dry seasons. SRP loads were significantly higher in Kb ( $p < 0.05$ ) during the dry seasons.

The external TP loads into Lake Zwai ranged between  $0$  to  $155 \text{ Kgday}^{-1}$  and  $96.77$  to  $4821 \text{ Kgday}^{-1}$  with mean TP values of  $54.4$  and  $1333 \text{ Kgday}^{-1}$  in the dry and wet seasons, respectively (Tables 1.8 and 1.9). The ANOVA (Kruskal-Wallis) results showed that TP values between sites were significantly different ( $P < 0.05$ ) during the dry but not significantly different ( $P > 0.05$ ) during the wet seasons.

The external  $\text{NO}_3\text{-N}$  load into Lake Zwai ranged between  $0$  to  $295 \text{ Kgday}^{-1}$  and  $45$  to  $5189 \text{ Kgday}^{-1}$  with mean values of  $63$  and  $1928 \text{ Kgday}^{-1}$  in the dry and wet

seasons, respectively.  $\text{NO}_3\text{-N}$  loads were significantly different between sampling sites ( $p < 0.05$ ), with  $K_b$  having significantly greater than  $M_b$  during the wet seasons (Tables 9 and 10).

$\text{NO}_2\text{-N}$  load ranged from a maximum of  $598 \text{ Kgday}^{-1}$  in March to none in April at Meki River because of the drying of the river at peak dry seasons and a maximum of  $6378 \text{ Kgday}^{-1}$  in August at Qatar and minimum of  $434 \text{ Kg day}^{-1}$  in May during the wet seasons in Meki River (Tables 9 and 10). The total mean  $\text{NO}_2\text{-N}$  loads were  $168 \text{ Kg day}^{-1}$  and  $1594 \text{ Kg day}^{-1}$  during the dry and wet seasons, respectively, and the mean  $\text{NO}_2\text{-N}$  loads were not significantly different between sites ( $p > 0.05$ ) in both seasons. The higher  $\text{NO}_2\text{-N}$  load during wet seasons was due to agricultural runoff from the catchment precipitation.

The  $\text{NH}_4\text{-N}$  load to Lake Zwai ranged between 5 to  $1098 \text{ Kgday}^{-1}$  and 0 to  $177 \text{ Kg day}^{-1}$  with mean values of 225 and  $49.2 \text{ Kgday}^{-1}$  in the wet and dry seasons, respectively (Tables 9 and 10). Through the mean  $\text{NH}_4\text{-N}$  loads were not significantly different between sites ( $p > 0.05$ ) in both seasons. The greatest external  $\text{NH}_4\text{-N}$  loads into Lake Zwai occurred in August at Qatar River ( $1098 \text{ kgday}^{-1}$ ) and the lowest loads occurred in June ( $5 \text{ kgday}^{-1}$ ) at Meki River during wet seasons, while in dry seasons the highest and the lowest  $\text{NH}_4\text{-N}$  load were in March ( $178 \text{ kgday}^{-1}$ ) and April none at Meki River again due to the drying of the river, respectively.

TIN loading into the study sites ranged from 0 to  $722 \text{ kgday}^{-1}$  and 584 to  $12634 \text{ kgday}^{-1}$  in dry and wet seasons, respectively, during the study periods (Tables 8 and 9). The highest load of TIN in wet seasons could be due to rainfall variability at the time (unexpected increase). The greatest external TIN loads to Lake Zwai occurred in August ( $12,634 \text{ kgday}^{-1}$ ) and the lowest loads occurred in May ( $584 \text{ kgday}^{-1}$ ) at Qatar River during the wet season while in the dry season the lowest and highest values were zero in April at Meki (dried out) and March ( $261.8 \text{ kgday}^{-1}$ )

<sup>1)</sup> at Qatar Rivers, respectively. However, the ANOVA (Kruskal-Wallis) results showed that TIN values between sites were significantly different ( $P < 0.05$ ) during the dry but not ( $P > 0.05$ ) during the wet seasons.

The TN loads ranged from 0 to 3347 kgday<sup>-1</sup> and 1,961 to 40,041 Kgday<sup>-1</sup> during the dry and the wet seasons, respectively (Tables 3.3.1 and 3.3.2). The TN load to Lake Zwai was an average of 1,029 Kgday<sup>-1</sup> and 11,084 Kg day<sup>-1</sup> in dry and wet seasons, respectively. The ANOVA (Kruskal-Wallis) results showed that TN values between sites were significantly different ( $P < 0.05$ ) in dry seasons but not in the wet seasons ( $p > 0.05$ ).

SiO<sub>2</sub>-Si loads into Lake Zwai ranged from 0 to 41,565 Kgday<sup>-1</sup> and 21,365 to 49,170 kgday<sup>-1</sup> during dry and wet seasons, respectively (Tables 1.8 and 1.9). The mean SiO<sub>2</sub>-Si loads were 12,677 and 36,979 kgday<sup>-1</sup> in dry and wet seasons, respectively. SiO<sub>2</sub>-Si loads were significantly different between sites ( $p < 0.05$ ) in both seasons. The SiO<sub>2</sub>-Si load is the highest in April at Qatar River and the lowest in the same month at Meki River during the dry seasons.

The seasonal variability in nutrients loads into Lake Zwai is mostly determined by variability in seasonal inflows of Qatar and Meki Rivers, as demonstrated by the relationship between seasonal inflows (influenced by rainfall patterns) of the two rivers and their corresponding seasonal nutrients concentrations. This indicated that nutrient loads are higher during rainfall periods due to increasing agricultural runoffs. Moreover, the external nutrients loads were maximum in the wet seasons and minimum in the dry seasons which are attributed to the seasonality of precipitation, land use patterns, and periods when fertilizers are applied on farmlands (Alan *et al.* 2007; May *et al.* 2012; Mihkel *et al.* 2013).

Higher nutrients loads in the wet seasons are attributed to the application of phosphorus and nitrogen fertilizers and pesticides in the catchments of Meki and

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Qatar Rivers during this season (See also Meshesha *et al.*, 2012 and Desta *et al.*, 2016).

**Table 8:** Mean, mean standard errors, minimum and maximum values of the external loading (kg day<sup>-1</sup>) in Qatar River (kb) and Meki River (Mb) in the dry seasons

| Site  | Statistics             | TP              | SRP            | NO <sub>3</sub> -N | NO <sub>2</sub> -N | NH4-N            | TIN              | TN                 | SiO <sub>2</sub> -Si |
|-------|------------------------|-----------------|----------------|--------------------|--------------------|------------------|------------------|--------------------|----------------------|
| Kb    | $\bar{x} \pm$ Std. Err | 86.4 $\pm$ 21.1 | 16.4 $\pm$ 4.3 | 60.1 $\pm$ 17.2    | 174.7 $\pm$ 74.1   | 53.6 $\pm$ 8.2   | 288.3 $\pm$ 88.3 | 1558.4 $\pm$ 383.8 | 19526 $\pm$ 4515     |
|       | Min                    | 37              | 8              | 36                 | 45                 | 42               | 148              | 733                | 12149                |
|       | Max                    | 154             | 33             | 144                | 536                | 94               | 722              | 3347               | 41565                |
| Mb    | $\bar{x} \pm$ Std. Err | 22.3 $\pm$ 8.8  | 11.9 $\pm$ 5.0 | 65.9 $\pm$ 47.4    | 161.9 $\pm$ 98.4   | 44.83 $\pm$ 27.2 | 87.17 $\pm$ 34.4 | 500.1 $\pm$ 114.1  | 5828 $\pm$ 1801      |
|       | Min                    | 0               | 0              | 0                  | 0                  | 0                | 0                | 0                  | 0                    |
|       | Max                    | 62              | 30             | 295                | 590                | 177              | 203              | 798                | 12399                |
| Total | $\bar{x} \pm$ Std. Err | 54.4 $\pm$ 14.6 | 14.1 $\pm$ 3.2 | 63.0 $\pm$ 24.0    | 168.3 $\pm$ 58.8   | 49.2 $\pm$ 13.6  | 187.7 $\pm$ 54.4 | 1029.3 $\pm$ 248.8 | 12677 $\pm$ 3104     |
|       | Min                    | 0               | 0              | 0                  | 0                  | 0                | 0                | 0                  | 0                    |
|       | Max                    | 154             | 33             | 295                | 590                | 177              | 722              | 3347               | 41565                |

**Table 9:** Mean, mean standard deviation error, minimum and maximum values of the external nutrient loads (kg day<sup>-1</sup>) in Kb and Mb in the wet seasons (NOTE: \*Correlation is significant at the 0.05level and \*\*Correlatio is significant at 0.01 level)

| Site         | Statistics               | TP              | SRP              | NO <sub>3</sub> -N  | NO <sub>2</sub> -N  | NH4-N             | TIN                | TN               | SiO <sub>2</sub> -Si |
|--------------|--------------------------|-----------------|------------------|---------------------|---------------------|-------------------|--------------------|------------------|----------------------|
| <b>Kb</b>    | $\bar{x} \pm$ Std. Error | 1528 $\pm$ 1121 | 110.8 $\pm$ 47.9 | 1510.5 $\pm$ 1220.7 | 2182.7 $\pm$ 1413.5 | 323.7 $\pm$ 258.1 | 4017 $\pm$ 2889    | 13974 $\pm$ 8832 | 44833 $\pm$ 2266     |
|              | Min                      | 97              | 28               | 45                  | 487                 | 43                | 584                | 2117             | 38453                |
|              | Max                      | 4821            | 245              | 5159                | 6378                | 1098              | 12634              | 40041            | 49170                |
| <b>Mb</b>    | $\bar{x} \pm$ Std. Error | 1138 $\pm$ 626  | 92.83 $\pm$ 46.8 | 346.3 $\pm$ 111.6   | 1005.3 $\pm$ 315    | 127.2 $\pm$ 80.8  | 1793.2 $\pm$ 622.3 | 8194 $\pm$ 3976  | 29124 $\pm$ 5931.9   |
|              | Min                      | 146             | 25               | 45                  | 434                 | 5                 | 764                | 1961             | 21365                |
|              | Max                      | 2913            | 230              | 515                 | 1782                | 355               | 3512               | 19164            | 46726                |
| <b>Total</b> | $\bar{x} \pm$ Std. Error | 1333 $\pm$ 599  | 102 $\pm$ 31     | 928 $\pm$ 608       | 1594 $\pm$ 706      | 225 $\pm$ 131     | 2905 $\pm$ 1431    | 11084 $\pm$ 4615 | 36979 $\pm$ 4178     |
|              | Min                      | 97              | 25               | 45                  | 434                 | 5                 | 584                | 1961             | 21365                |
|              | Max                      | 4821            | 245              | 5159                | 6378                | 1098              | 12634              | 40041            | 4910                 |



Phosphorus (P) loading, has been considered as an important limiting nutrient for phytoplankton production in lakes (Moss *et al.*, 2012). The increasing phytoplankton production in lakes causes eutrophication which is the current world-wide problem causing high phytoplankton production with severe implications for both the ecological state and drinking water quality (Søndergaard *et al.*, 2012) and for Lake Zwai, which is no exception to this problem.

**Evaluation of nutrient and balances in Lake Zwai:** Nutrient load calculation and budget of Lake Zwai is shown in Table 10. The total load of the input TP was 2918 tonsyear<sup>-1</sup> and the output was 226 tons year<sup>-1</sup>, resulting in a net retention of 2693 tons year<sup>-1</sup>, with a 92.3 % increase. The total load of input SRP was 262 tons year<sup>-1</sup> and the output was 50.2 tons year<sup>-1</sup>, resulting in a net retention of 212 tons year<sup>-1</sup> and which is an 80.8 % increase. In other words, the overall percentage of the retention value of TP was found out in the present study is about 80.8 %. Similar findings were observed in the study of phosphorus mass balance in the eutrophic Lake Paranoá (Brazil), which has a phosphorus input of approximately 115 tonsyear<sup>-1</sup> with a retention of 80 % in the reservoir (Guariento *et al.* 2007).

Furthermore, the total input load of TIN was 4657 tons year<sup>-1</sup> and the output was 750 tons year<sup>-1</sup>, resulting in a net retention of 3907 tonsyear<sup>-1</sup>, meaning 83.9 % was produced within the lake. In addition, the total input load of TN was 24733 tons year<sup>-1</sup> and the output was 4374 tons year<sup>-1</sup>, with a net retention of 20,359 tons year<sup>-1</sup>, with an increase of 82.3 % (Table 10). Therefore, the nutrients budget for Lake Zwai clearly shows that the amount of nutrients that enters the lake exceeds the output (both sinking and spilling out with River Bulbula), indicating that nutrients are being retained in the lake which might lead to eutrophication of the lake. In a similar way, Hamilton *et al.* (2004) estimated that around 86 % and 72 % of phosphorus and nitrogen entering Lake Tarawera are retained within the lake.

**Table 10:** Nutrient loads and balances of Lake Zwai within the study period (tons year<sup>-1</sup>)

| Nutrient Load Balance | TP      | SRP    | TIN     | TN       |
|-----------------------|---------|--------|---------|----------|
| Qatar River           | 1208.51 | 95.46  | 2723.63 | 11675.69 |
| Meki River            | 1709.70 | 166.25 | 1933.15 | 13057.54 |
| Total input           | 2918.21 | 261.71 | 4656.78 | 24733.23 |
| Total output          | 225.69  | 50.22  | 749.66  | 4374.06  |
| Input – output        | 2692.52 | 211.49 | 3907.12 | 20359.17 |
| Percentage (%)        | 92.27   | 80.81  | 83.90   | 82.32    |

The fluctuations in the quantities of the retained nutrients depend on the river discharge and nutrient concentrations (Havenset *al.* 2001). According to Ismail *et al.* (2011), hydraulic retention time is the major factor influencing nutrient retention in a lake ecosystem. The hydraulic retention time of Lake Zwai is 6.67 years which is suitable for phytoplankton growth. Because of the characteristically high water discharge rates of Qatar and Meki Rivers, particularly in the wet seasons, the nutrient loads from this system were dramatically higher than those of the lake.

**3.3.4 Analyses of trophic state variables:** TP ranged between 108 µg L<sup>-1</sup> to 340 µg L<sup>-1</sup> with an average concentration of 212 µg L<sup>-1</sup>. No Statistically significant differences among the six sampling sites were found (Kruskal-Wallis test,  $p > 0.05$ ). The lowest phosphorous concentrations measured were in April (108 µg L<sup>-1</sup>) during the dry season (Fig. 11). Concentration of TP fluctuated significantly during the study periods while the higher values were in July (337 µg L<sup>-1</sup>) and August (340 µg L<sup>-1</sup>) in the wet seasons (Fig. 11). The relatively high concentration of phosphorous in Lake Zwai during the rainy seasons could be attributed to fertilizer coming in with runoffs from the surrounding agricultural fields and considerable additions into the water column from internal phosphorous loads. Furthermore; the external nutrient

loads in terms of the mean TP concentration due to the two feeding rivers (Meki and Qatar) was  $0.25 \text{ mgL}^{-1}$  and  $0.76 \text{ mgL}^{-1}$  in the dry and wet seasons, respectively. From this study the mean annual TP concentration due to the two rivers is  $0.51 \text{ mgL}^{-1}$ . According to Lau *et al.* (2002), the mean annual TP of eutrophic lake is between  $0.047 < x \leq 0.13 \text{ mg L}^{-1}$  and annual TP  $> 0.13 \text{ mgL}^{-1}$  in hypertrophic lakes. Therefore, it can be concluded that Lake Zwai is currently eutrophic based on TP concentrations.



**Figure 11:** Monthly trends in TP concentrations in  $\mu\text{gL}^{-1}$  in Lake Zwai in 2014 and 2015

TN ranged from  $5.54 \text{ mgL}^{-1}$  to  $7.49 \text{ mgL}^{-1}$  with mean concentration of  $6.70 \text{ mgL}^{-1}$ . The ANOVA (Kruskal-Wallis test) results showed that TN concentrations among sites were significantly different ( $P < 0.05$ ). The lowest TN concentrations measured were in May ( $5.54 \text{ mgL}^{-1}$ ) and the highest TN concentration was recorded in July ( $7.50 \text{ mgL}^{-1}$ ) (Fig. 12). The relatively high concentration of TN in July (Fig. 12) could be from the application of fertilizers in croplands and decomposition of organic matters washed off into the lake as important source of external nutrient loads.

Limnologists and lake managers have developed a general consensus about freshwater lake responses to nutrient additions, that essentially an ambient TP concentration of greater than about  $0.01 \text{ mgL}^{-1}$  and/or TN of about  $0.15 \text{ mgL}^{-1}$  are likely to predict blue-green algal bloom problems during the growing season (O'Sullivan and Reynolds 2004). Similarly, chronic over enrichment leads to lake quality degradation manifested in low dissolved oxygen, fish kills, algal blooms, expanded macrophytes, likely increased sediment accumulation rates, and species shifts of both flora and fauna (USEPA 2000). From this study, it was found out that Lake Zwai, concentrations of TP and TN obtained are much greater than the limit of  $0.01 \text{ mgL}^{-1}$  and  $0.15 \text{ mgL}^{-1}$ , respectively, and hence the lake shows increasing trends towards eutrophication and the consequences that come with it.



**Figure 12:** Monthly trends of TN concentrations in  $\mu\text{gL}^{-1}$  in Lake Zwai in 2014 and 2015

In addition, both the internal and external TP and TN loads showed that the lake is in eutrophic state. For instance, the external TP and TN load in Lake Zwai is higher as compared to some tropical eutrophic lakes such as

Lake Lewisville (Gain and Baldys, 1995) and Ibirité Reservoir (Antonio *et al.*, 2012), Lake Kasumigaura (Havens *et al.* (2001) and Okeechobee (Havens *et al.* (2001), Lake Donghu (Havens *et al.* (2001) and many others. These sources of nutrient loads have high contributions for eutrophication. Therefore, it can be stated that reduction in nutrient concentration will be an essential mechanism to control the process of eutrophication in the lake.

The concentration of Chlorophyll-*a* (Chl-*a*) in Lake Zwai ranged from 28 to 76  $\mu\text{gL}^{-1}$  with a mean value of 42  $\mu\text{gL}^{-1}$ . The lowest measurements were in July (28  $\mu\text{gL}^{-1}$ ) and the highest in June (76  $\mu\text{gL}^{-1}$ ) (Fig. 13), whose increases were attributed to high diurnal mixing because of wind action on a tropical shallow lake like Zwai, external-internal nutrient loads thereof, turbidity, runoffs caused by tropical torrential rains, etc. in relation with plankton abundance. No significance differences among the six sampling sites were found (Kruskal-Wallis test,  $p > 0.05$ ). Therefore, relatively higher concentrations of chlorophyll-*a* were observed in the rainy season. Similar results were reported by Tilahun, (2006) in the same lake and Lake Hawassa. According to OECD, 1982 classification of trophic state, 8.00  $\mu\text{gL}^{-1}$  of chlorophyll-*a* concentration is the threshold for eutrophication and in the present study; all in the sampling sites were found to have chlorophyll-*a* concentrations beyond the prescribed limit.

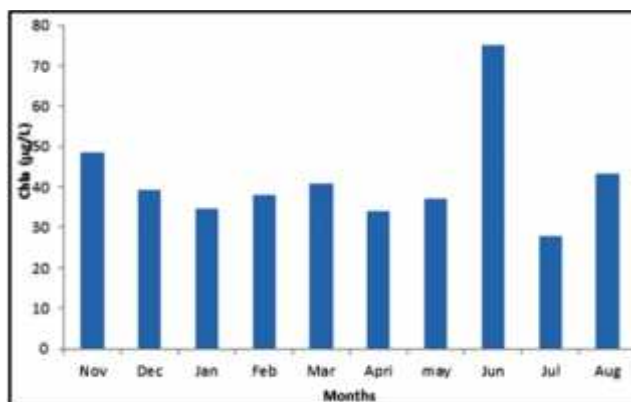


**Figure 13:** Monthly trends of Chlorophyll-*a* concentrations in  $\mu\text{g L}^{-1}$  in Lake Zwai in 2014 and 2015

According to Carlson Model (1977), the trophic state condition's using the concentrations of chlorophyll-*a* in Lake Zwai have shown three categories: before 1966, the lake was oligotrophic but between the years 1980 to 2002, the lake was approaching to hyper-eutrophic state (Table 11). For instance, high phytoplankton biomass of  $91 \mu\text{g Chl-}a\text{L}^{-1}$ , 48 to  $334 \mu\text{g Chl-}a\text{L}^{-1}$  and 150 to  $212 \mu\text{g-}a\text{L}^{-1}$  was reported by Belay and Wood (1984), Kebede *et al.* (1994) and Tilahun (1988), respectively. Gebre-Mariam *et al.* (2002) also reported a mean value of  $82.4 \mu\text{g L}^{-1}$  with a range of 23.0 to  $224 \mu\text{g L}^{-1}$  of Chlorophyll-*a* for Lake Zwai, again much higher than the values in this study. After 2006 up to the present, the lake is in continued eutrophic state. For instance, moderate phytoplankton biomass of 39.2, 38, 56.3 and  $42 \mu\text{g Chl-}a\text{L}^{-1}$  was reported by Tilahun and Ahlgren (2010), Beneberu and Mengistou, (2009), Tamire and Mengistou (2012) and the present study respectively (Table 11). Previous studies based on time series of chlorophyll-*a* analysis reported that Lake Zwai showed a progressive increase towards eutrophy (Gebre-Mariam *et al.*, 2002), the result of the present study also agreed with the trend of eutrophication condition of Lake Zwai. The eutrophication of Lake Zwai might have been

intensified after the rapid expansion of the flower industry, widespread fisheries and fast population growth with industrialization and intensive use of agrochemicals in expanding all season cultivations in the lake watershed.

**Table 11:** Trends in chl-a  $\mu\text{gL}^{-1}$  during the years from 1937 to 2015 in Lake Zwai

| Year         | Chl-a ( $\mu\text{gL}^{-1}$ ) | References                    |
|--------------|-------------------------------|-------------------------------|
| 1937 to 1938 | Clear water                   | Cannicci and Almagia (1947)   |
| 1966         | 7                             | Wood <i>et al.</i> (1978)     |
| 1980         | 91                            | Belay and Wood (1984)         |
| 1986         | 48 -334                       | Kebede <i>et al.</i> (1994)   |
| 1987 to 1988 | 150 – 212                     | Tilahun (1988)                |
| 1991         | 154                           | Kebede and Willen (1998)      |
| 2006         | 39.2                          | Tilahun (2006)                |
| 2009         | 26.3-57.9                     | Beneberu and Mengistou (2009) |
| 2011 to 2012 | 56.34                         | Tamire and Mengistou (2012)   |
| 2013 to 2015 | 28 -76                        | Original data                 |

The decrease in biomass in the present study as compared to previous results can be attributed either to zooplankton grazing pressure and other biota (e.g., Nile-tilapia) and/or increased non-algal turbidity that limited the light climate of the lake. The declining trend in SD readings is one of the indications that suggested the increasing trend in turbidity of the lake, which can be mainly attributed to catchment degradation and siltation.

The lowest SD measurements were in May (0.16 m) and Jun (0.16 m); while the deepest measurements were in November (0.26 m) and December (0.27 m) (Fig. 14). The mean SD in Lake Zwai ranged between 0.16 to 0.27 m with a mean value of 0.20 m. The SD was shallower in May to August of 2014 and 2015, which could be due to high turbidity; whereas in November and December when the turbidity was low, the SD was at 0.27 m, indicating the lake was relatively clearer than it was before due to low rainfall, low or no

runoffs, drying of River Meki and decreased siltation thereof. The ANOVA analysis (Kruskal-Wallis Test) showed that SD values among sites were not significantly different ( $P > 0.05$ ).

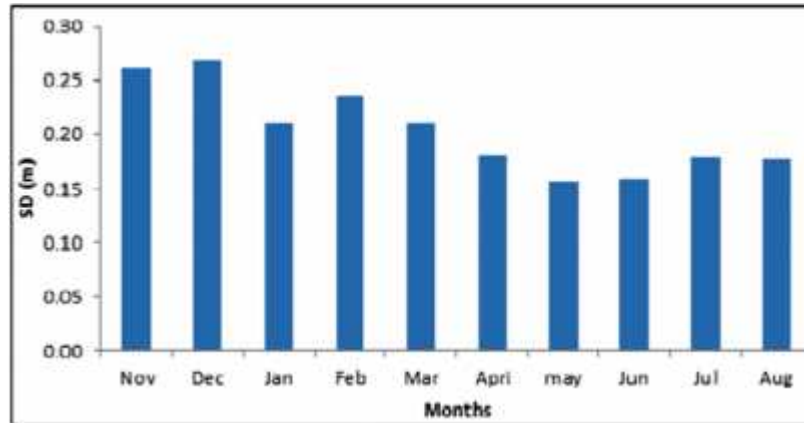


**Figure 14:** Monthly trends of  $Z_{SD}$  transparency in m in Lake Zwai in 2024 and 2015

The mean SD (0.19) reported by Tilahun (2006) is similar to the results recorded in this study; but shallower than the ranges of 0.20 to 0.35 m and 0.4 to 1.06 m reported by Dagne *et al.* (2008) and Tilahun (1988), respectively. Moreover, Dagne (2010) also reported that the mean SD value was 0.29 m in Lake Zwai. The comparison of SD values of Lake Zwai with other tropical Lakes is shown in Table 12. The declining trend in SD reading is one of the indications which suggested the increasing trend in turbidity of the lake, which can be mainly attributed to catchment degradation and siltation. Comparison of variations in SD showed that the fluctuations between the seasons were significant; whereas those across different sites in all the seasons were not significant. In general, the SD was found to be at its shallowest during the wet seasons and deepest during the dry seasons at all the sampling sites because of the large amount of silt that entered the lake in the wet seasons with runoff.



Thus, unlike the observations in different tropical freshwaters (Ishaq *et al.*, 2013), the transparency of the water in Lake Zwai showed relative improvement during the dry seasons. This is attributed to complete secession of rainfalls and the subsequent runoff entering the lake with loads and loads of silt from the watershed that is being deprived of land-cover at an alarming rate.

According to OECD, (1982) the hyper-eutrophic lakes generally showed the maximum transparency values at  $\leq 1.5$  m and minimum transparency  $\leq 0.7$  m. Therefore, the present data of 0.20 m indicate that Lake Zwai is a highly productive ecosystem having very shallow euphotic zones with a strong indication of eutrophication.

**Evaluation of the trophic status of Lake Zwai using Carlson Trophic State Index Model (CTSIM) and Kretzer and Brezonik Model (KBM):** The trophic status of Lake Zwai is computed using (CTSIM) and KBM, which assume there is a close relationship between total phosphorous (TP), chlorophyll-*a*, Secchi depth (SD), and total nitrogen (TN). The analytical results of the six sampling sites and Trophic State Index (TSI) are summarized in Table 12.

**Table 12:** Analytical results of six selected sites and trophic state index in 2014 and 2015

| Sites       | TSI-TP    | TSI-Chl- <i>a</i> | TSI-SD    | TSI-TN    |
|-------------|-----------|-------------------|-----------|-----------|
| <b>Fa</b>   | 79.92     | 66.767            | 82.67     | 79.77     |
| <b>B</b>    | 76.71     | 64.555            | 83.96     | 77.52     |
| <b>Ka</b>   | 80.41     | 65.462            | 83.69     | 81.94     |
| <b>Ma</b>   | 80.01     | 66.274            | 82.66     | 79.26     |
| <b>Ko</b>   | 79.26     | 66.956            | 82.44     | 87.34     |
| <b>C</b>    | 78.57     | 64.731            | 82.88     | 82.4      |
| <b>Mean</b> | <b>79</b> | <b>66</b>         | <b>83</b> | <b>81</b> |

ANOVA (Kruskal-Wallis Test) showed that the TSI-TN value was significantly different ( $P < 0.05$ ) among sites; whereas TSI-TP, TSI-Chl-*a* and TSI-SD values were not significantly different ( $P > 0.05$ )

The mean values of TSI-TP, TSI-Chl-*a*, TSI-TN and TSI-SD were 79, 66, 81 and 83, respectively (Table 12) and are graphically presented in Fig. 15. All the TSI values of TP, Chl-*a*, SD and TN were above the eutrophic threshold values (Fig. 15). The overall average value of TSI of Lake Zwai is found to be 77. These TSI values based on Carlson's Trophic State Classification Criteria (Table 12) (Carlson, 1977; Barki and Singa, 2014) clearly indicate that Lake Zwai is found in eutrophic stage and continuing during the entire study period. Likewise, when the TSI values computed in this study were compared with the OECD's standard (OECD, 1982), it can be seen that Lake Zwai is in eutrophic state based on the Chl-*a* and TP and in hyper-eutrophic state based on the SD and TN. The TSI of TP and TN exhibited higher trophic state probably due to the runoffs that come from the Qatar and Meki Rivers and urbanizations (Bech *et al.*, 2005, Ramesh and Krishnaiah, 2013, Matthews *et al.* 2002, Fetahi 2010, Ndungu *et al.* 2013 and Alemayehu *et al.* 2016). Furthermore, the decaying process of dead algal biomass also results in internal nutrient loads and in the depletion of dissolved oxygen in the lakes causing anoxic environment (Prasad and Siddaraju, 2012).

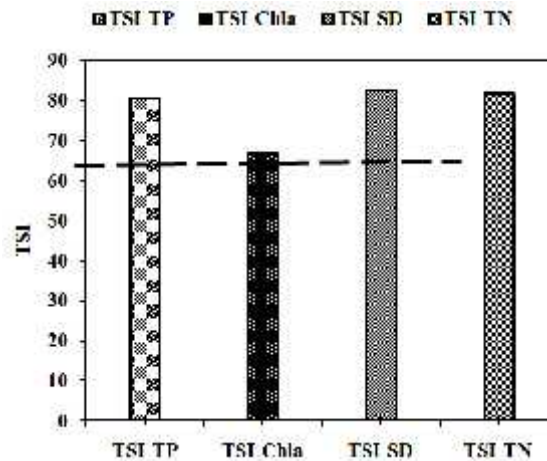


**Figure 15:** Trophic State Index of Lake Zwai in 2014 and 2015. The broken line indicates the trophic line.

### Conclusions and recommendations

Lake Zwai has shown some undesirable changes in terms of hydrology and lake water quality due to external and internal nutrient loads, dynamics and impacts of agrochemicals in the lake ecosystem. Mean nutrient concentrations showed increasing trends and were higher in Fb and Fa sampling sites during all seasons of the study. These sites were also characterized by high EC and TDS. In the multivariate statistical data analyses techniques, PCA analysis identifies the major sources of pollution responsible for water quality variations besides seasonal variations and these pollutant sources were mainly from sampling sites F<sub>b</sub> during the dry seasons and M<sub>b</sub> and K<sub>b</sub> during the wet seasons. Comparatively, the pollution status of the lake is high around the floriculture effluent discharge site and at the mouths of the two feeder-rivers, namely, Meki and Qatar. In the study the spatial and temporal variability of nutrients in the depth profiles of sediment samples were observed. The values of nutrient distributions in depth profiles were higher at the sediment top

surface and decline with depth of the sediment profiles in most of the sites. Catchments of Qatar and Meki Rivers showed the major sources of external nutrient loads to the lake ecosystem. According to Carlson and Vollenweider models Lake Zwai is under eutrophic condition.

In general it is concluded that:

- The watershed of Lake Zwai is under complete transformation with regard to its land-use land-cover conditions. This has resulted in the removal of the land-cover, exposing the top-soil to intensive erosion that enters the lake with runoffs following the tropical torrential rains.
- The level of uncontrolled fertilizer use in the increasing cultivated lands has resulted in massive external nutrient loads particularly during the rainy seasons.
- The expansion of industries like the flower farms, has added to the release of year-round concentrated external nutrient loads into the lake.
- Expansion of the settlements has increased the release of large quantities of organic matter, including, latrine wastes and wastes from livestock farms that enter the lake without any treatments.
- The increase in siltation, particularly, in the wet seasons has resulted in reduced light climate of the lake. This has reduced the phytoplankton biomass of the lake, which could have to some extent served as sinks of nutrients, if controlled not to exceed certain limits to avoid eutrophication.

Based on the findings, the following recommendations are forwarded:

- Offices of land-use land-cover management, environment bureaus, local administrators and decision-makers in development should read reports of this sort that provide baseline data on the status of watersheds and the aquatic systems contained in them.

- Researchers collecting such data must always find the way how to extend such knowledge to the above mentioned personnel and the community in the watershed.
- Catchment management should work on sustainable land-use land-cover plans to minimize exposure of topsoil to erosion (wind, runoff, etc.) to curtail the inflow of silts loaded with nutrients (external nutrient loads)
- Macrophyte growth along the shores of Lake Zwai should be improved to stabilize the sediment so that internal nutrient loads are reduced.
- Sewage diversion systems for effluents of floriculture industry and local domestic wastes should be developed to avoid direct injection of wastes and nutrients into the lake.
- As the local populations that make the majority of the population in the watershed should increase use of phosphorus-free detergents and work towards the restoration of the wetlands along the shores of Lake Zwai.
- Further research should be done with special focus on the dynamics of the responses of the watershed to runoffs due to the overwhelming volume of non-point agrochemical pollution sources of Lake Zwai watershed.

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## Chapter 2

### **Assessment of surface and ground waters for irrigation water quality for small scale irrigation in East Shoa Zone of Oromia, Ethiopia**

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#### **Abstract**

Irrigation with poor quality waters may bring undesirable elements to soil in excessive quantities affecting its fertility. The seasonal variation in surface and groundwater quality of different district in East Shoa zone has been evaluated for two years from 2013/14 to 2014/15 for assessing the suitability of water for irrigation purposes. In the present study, water samples were collected from Lake and groundwater and analyzed for ten parameters of physical and chemical properties. The analyzed water quality parameters show seasonal variation and high concentration in dry season compared to wet season due to dilution effects. Electrical conductivity, pH, ionic composition, sodium adsorption ratio (SAR) and total dissolved solids (TDS) were calculated using the standard equations. Analysis showed a wide range of electrical conductivities that varied from 332-2627.5  $\mu\text{S}/\text{cm}$  and salinity ranged between 197.9-1681.6  $\text{mgL}^{-1}$ . The SAR in the study area lies between 1.42 and 22.09 in most irrigation water sources. Considering SAR as important parameter of suitability for irrigation, most of the results are under usual range compared to the irrigation water standards, except for some samples collected from

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underground. The mean pH values of almost all water sources were between 7.58 and 8.19 which can be categorized as normal range for irrigation purpose. The results concluded that water quality at some of the locations is above permissible limit for irrigation and needs proper monitoring to preserve and maintain its quality for agricultural purposes. It is therefore recommended that extension workers should train the farmers on sustainable management practices such as a pre-planting irrigation, use of salt tolerant crop varieties, using soil or water amendments.

**Keywords:** Irrigation groundwater, surface water, Lake Zwai, soil salinity, seasonal variations, ionic composition

## Introduction

Water quality is becoming of increasing concern both from a supply point of view and with respect to the environmental impacts. Definition of water quality depends on the desired use of water (Kirda, 1997; Jainet *al.*, 2009). Therefore, different uses require different criteria of water quality as borehole as standard methods for reporting and comparing results of water analysis (Singhet *al.* 2004). The water quality for agricultural purposes is determined on the basis of the effect of water on the quality and yields of the crops, as they have effect on soil characteristics (Ayers and Westcot 1985).

There is increasing need to use waters of mid Rift Valley of Oromia Region for agricultural purpose; but, there seems to be little knowledge as to whether these water bodies are chemically suitable for agricultural purposes. Utilization of water bodies without information on the chemical composition could be a threat and cause for the degradation of the environment (Gebremariam. and Dadebo 1989). The importance of water quality becomes more significant in arid and semi-arid climates due to the lack of natural leaching of deposited salts and high rate of evaporation (Qayyum 1970). All irrigation waters whether diverted from surface streams, collected from lakes, wetlands or

pumped from wells, carry certain chemical substances in solution, dissolved originating from weathering of the rocks and soil and dissolution of lime, gypsum and other salt sources as water passes over or percolates through them (Wilcox 1955). The amount and kind of these dissolved constituents determine the quality of the water for irrigation use. Thus, evaluation of water bodies for their suitability, particularly with regard to their chemical compositions, is critical. Although, information on major ions and nutrients are available for Ethiopian rift valley (Wodajo and Belay, 1984; Kebede *et al.*, 1994), these information are mostly from short-time studies and do not reveal the full picture of the chemical composition of different irrigation water sources in the mid-rift valley of Oromia region, such as the Zwai watershed over an extended period of time. Quality of irrigation water is not constant over the seasons. Salt concentrations of rivers, lakes and manmade reservoirs may increase toward the end of summer. Relative change of the concentration depends on storage volume of the reservoirs and on water residence time. Salt concentration change is 10-20% in large bodies of water, whereas as high as 100% in small ponds, lakes and reservoirs (Kirda 1997). Deep groundwater wells show the least fluctuations in salt concentration; while, shallow wells may show considerable changes. Thus, quality of irrigation waters must be assessed considering their seasonal fluctuations with regard to their salt concentration.

Therefore, knowledge of the chemical composition and quality-related issues of water bodies' to be used for irrigation purposes are of great importance. In this study, water bodies like lakes and groundwaters of the mid-rift valley of Oromia region have been assessed during dry and wet regime for two consecutive years. Thus, this study aimed to assess the irrigation water quality of surface and groundwaters and provide information on future proper use of various sorts of waters for irrigation purposes and management interventions.

### **Materials and methods**

**The study area:** The study was conducted in mid rift valley of Ethiopia; East



Shoa Zone in some districts namely, Dugda and Adami Tulu Jido Kombolcha (Fig. 16). These districts were selected based on some saline indicators on irrigated farm and yield reduction raised by farmers during problem identification stage. The water bodies studied here were in the watershed of Lake Zwai and its groundwater in East Shoa. Before collecting water samples, the sampling areas were classified based on source of water for irrigation. This is required to determine the effect of the sources of water for irrigation on the buildup of soil salinity and other problems in the area.



**Figure 16:** Location map of east Shewa and Lake Zwai: The inset in the map of Ethiopia is Oromia Regional State which is magnified with the study area of East Shewa and Lake Zwai (from: <http://www.Ethiodemographyandhealth.org/Oromia.html>)

**2.2. Water Sampling:** As part of a study on seasonal changes in the irrigation water quality, the chemical composition of water bodies were determined

during wet and dry seasons between 2013/14 and 2014/15 years. Lakes and groundwater were used as sampling points. At each such point, water temperature; electrical conductivity and pH were measured in situ using portable multi meter. Then, two liters of water sample were collected using labeled and clean polyethylene bottle every quarter of the year. Methods of sampling were varied depending on different sources of water. For instance, the samples from lakes were taken from where it is assumed to be a central part. Samples from deep boreholes have been taken after spilling away some minutes of pumped out water (Kirda 1997). All samples collected from lakes were from surface layer except for deep boreholes, which were between 10-13 meters deep. Finally, irrigation water samples were immediately preserved after collection and transported in ice boxes. Samples brought to the laboratory in such methods were analyzed without delay to prevent biological activities that would otherwise change the water quality.

**Methods of Analysis:** Carbonate ( $\text{CO}_3^{2-}$ ) and bicarbonate ( $\text{HCO}_3^-$ ) were determined by the titration method.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  were determined by the EDTA titration method while  $\text{Na}^+$  was determined by flame photometry. The  $\text{Cl}^-$  was determined by barium sulfate turbidimetric or gravimetric method (American Public Health Association *et al.* 1998), depending on concentrations in the samples. Then sodium adsorption ratio (SAR), an important empirical measure of the suitability of water for irrigation, was calculated according to the formula given by Rishards 1954 and Ayers and Wescot, 1985, below:

$$SAR = \frac{Na}{(\text{Ca}^{2+} + \text{Mg}^{2+})^{1/2}}$$

The TDS values were calculated from electrical conductivity measured on the field according to the formula developed by Lloyd and Heathcote, 1985 and Iyasele and Idiata 2015):

$$\text{TDS in mgL}^{-1} = \text{EC} \times K() \text{ TDS (ppm)} = 0.64 \times \text{EC}$$

Where TDS is expressed in  $\text{mgL}^{-1}$  and EC in  $\mu\text{Scm}^{-1}$  and constant K is equal to 0.64.

The measurements made according the above stated methods were then compared to the permissible limits for classifying the suitability of irrigation water (from Ayers and Westcot, 1985) (Table 13).

**Table 13:** The permissible limits for classifying the suitability of irrigation water (from Ayele and Westcot 1985)

| Water quality parameters                                  | permissible limits for irrigation water |
|-----------------------------------------------------------|-----------------------------------------|
| SAR                                                       | 0-15                                    |
| Ec ( $\mu\text{Scm}^{-1}$ )                               | 0-3000                                  |
| TDS ( $\text{mgL}^{-1}$ )                                 | 0-2000                                  |
| pH                                                        | 6.5-8.4                                 |
| $\text{Na}^+$ ( $\text{meq L}^{-1}$ )                     | 0-40                                    |
| $\text{Ca}^{+2}$ ( $\text{meq L}^{-1}$ )                  | 0-20                                    |
| $\text{Mg}^+$ ( $\text{meqL}^{-1}$ )                      | 0-5                                     |
| $\text{CO}_3^{=} + \text{HCO}_3^-$ ( $\text{meqL}^{-1}$ ) | 0-10                                    |
| Cl ( $\text{meqL}^{-1}$ )                                 | 0-30                                    |

**Statistical Analyses:** Descriptive statistics such as mean and range were used to describe the irrigation water quality parameters.

## Results and discussions

**Table 14:** Mean values of conductivity ( $\mu\text{Scm}^{-1}$ ) and pH of groundwater in the study area. Values in brackets are permissible limits for irrigation waters. N represents sample size.

| Sites        | N | EC ( $\mu\text{Scm}^{-1}$ ) (0-3000) |        | TDS ( $\text{mgL}^{-1}$ ) (0-2000) |        | pH (6.0-8.5) |      |
|--------------|---|--------------------------------------|--------|------------------------------------|--------|--------------|------|
|              |   | Range                                | Mean   | Range                              | Mean   | Range        | Mean |
| Tuchisumayan | 8 | 1825.5-2330                          | 2050.0 | 1168-1491                          | 1312.0 | 7.73-8.16    | 7.95 |
| Shubigamo    | 8 | 1196-1335                            | 1252.0 | 765.4-854.4                        | 801.3  | 7.61-8.18    | 7.89 |
| Korke Adi    | 6 | 2379-2970                            | 2627.5 | 1522.5-1900.8                      | 1681.6 | 7.32-8.08    | 7.78 |

**Table 15:** Mean values of conductivity ( $\mu\text{Scm}^{-1}$ ) and pH of lake water of the study area. Values in brackets are permissible limits in irrigation water. N represents sample size.

| Sites       | N | EC ( $\mu\text{S/cm}$ ) (0-3000) |       | TDS ( $\text{mg/L}$ ) (0-2000) |       | pH (6.0-8.5) |      |
|-------------|---|----------------------------------|-------|--------------------------------|-------|--------------|------|
|             |   | Range                            | Mean  | Range                          | Mean  | Range        | Mean |
| Korke Adi   | 8 | 600-1359                         | 947.4 | 384-869.8                      | 606.3 | 7.79-8.5     | 8.04 |
| Wayu gebrel | 8 | 649.5-995                        | 836.5 | 415.7-636.8                    | 535.4 | 7.39-8.3     | 7.78 |
| Zwai        | 8 | 380-549.5                        | 466.9 | 243.2-351.7                    | 220.6 | 7.76-8.7     | 8.19 |

**Table 16:** Mean composition of seasonal variation of groundwater quality parameters over two consecutive years of study period

| Sites (PA)   | Year | Parameters |                                          |                                            |                                           |                                                                                          |                                           |      |       |            | TDS<br>(mg L <sup>-1</sup> ) |
|--------------|------|------------|------------------------------------------|--------------------------------------------|-------------------------------------------|------------------------------------------------------------------------------------------|-------------------------------------------|------|-------|------------|------------------------------|
|              |      | N          | Na <sup>+</sup><br>(meqL <sup>-1</sup> ) | Ca <sup>2+</sup> (meq<br>L <sup>-1</sup> ) | Mg <sup>2+</sup><br>(meqL <sup>-1</sup> ) | (CO <sub>3</sub> <sup>=</sup> + HCO <sub>3</sub> <sup>-</sup><br>) (meqL <sup>-1</sup> ) | Cl <sup>-</sup><br>(meq L <sup>-1</sup> ) | PH   | SAR   | EC (µS/cm) |                              |
|              |      | Mean       | Mean                                     | Mean                                       | Mean                                      | Mean                                                                                     | Mean                                      | Mean | Mean  | Mean       |                              |
| Tuchisumayan | 2014 | 4          | 22.2                                     | 0.9                                        | 1.3                                       | 15.0                                                                                     | 2.0                                       | 7.9  | 21.4  | 1783.3     | 1141.3                       |
|              | 2015 | 4          | 22.4                                     | 0.9                                        | 1.0                                       | 15.2                                                                                     | 1.5                                       | 8.0  | 22.8  | 2316.7     | 1482.7                       |
| Shubigamo    | 2014 | 4          | 14.6                                     | 0.8                                        | 1.2                                       | 11.4                                                                                     | 0.7                                       | 7.8  | 14.7  | 1250.0     | 800.0                        |
|              | 2015 | 4          | 12.0                                     | 0.6                                        | 0.8                                       | 11.5                                                                                     | 0.5                                       | 8.0  | 14.45 | 1254.0     | 802.6                        |
| Korke Adi    | 2014 | 4          | 7.4                                      | 1.0                                        | 0.8                                       | 8.0                                                                                      | 1.0                                       | 8.0  | 7.89  | 868.0      | 555.5                        |
|              |      | 3          | 25.8                                     | 1.6                                        | 0.8                                       | 16.6                                                                                     | 2.0                                       | 7.8  | 23.45 | 1980.0     | 1267.2                       |
|              | 2015 | 4          | 10.9                                     | 1.82                                       | 1.3                                       | 8.1                                                                                      | 1.2                                       | 8.1  | 8.7   | 1026.7     | 657.01                       |
|              |      | 3          | 26.0                                     | 2.25                                       | 1.3                                       | 18.1                                                                                     | 1.2                                       | 7.7  | 19.6  | 3275.0     | 2096.0                       |
| Wayu gebrel  | 2014 | 4          | 5.1                                      | 1.29                                       | 1.3                                       | 6.7                                                                                      | 0.9                                       | 7.8  | 4.5   | 816.7      | 522.7                        |
|              | 2015 | 4          | 5.2                                      | 1.69                                       | 1.3                                       | 6.9                                                                                      | 0.6                                       | 7.8  | 4.1   | 856.3      | 548.0                        |
| Zwai         | 2014 | 4          | 2.6                                      | 0.84                                       | 1                                         | 3.8                                                                                      | 0.8                                       | 8.0  | 2.67  | 460        | 189.9                        |
|              | 2015 | 4          | 2.9                                      | 1.26                                       | 0.9                                       | 3.9                                                                                      | 0.6                                       | 8.4  | 2.8   | 473.7      | 251.03                       |

**Table 17:** Mean concentration of (meqL<sup>-1</sup>) of major ions, Sodium adsorption ratio (SAR) in the groundwaters of Oromia mid rift valley irrigation water sources. N is sample size values in brackets are permissible limits in irrigation water. Values in bold and under line are above permissible limits in irrigation water.

| Sites               | N | Na <sup>+</sup> (0-40) |      | Ca <sup>2+</sup> (0-20) |      | Mg <sup>2+</sup> (0-5) |      | CO <sub>3</sub> <sup>=</sup> +HCO <sub>3</sub> <sup>-</sup> (0-10) |      | Cl <sup>-</sup> (0-30) |      | SAR (0-15) |      |
|---------------------|---|------------------------|------|-------------------------|------|------------------------|------|--------------------------------------------------------------------|------|------------------------|------|------------|------|
|                     |   | Range                  | Mean | range                   | mean | range                  | mean | Range                                                              | mean | Range                  | Mean | range      | mean |
| <b>Tuchisumayan</b> | 8 | 17.4-27.2              | 22.3 | 0.6-1.2                 | 0.9  | 0.8-1.8                | 1.1  | 14.1-16.3                                                          | 15.1 | 1.3-2.                 | 1.7  | 20.5-22.3  | 22.1 |
| <b>Shubigamo</b>    | 8 | 10.1-19.5              | 13.3 | 0.4-0.9                 | 0.7  | 0.5-1.4                | 1.0  | 10.7-12.8                                                          | 11.5 | 0.4-1                  | 0.6  | 15.2-18.1  | 14.6 |
| <b>Korke Adi</b>    | 6 | 14.5-35.4              | 9.2  | 0.75-2.7                | 1.4  | 0.3-1.7                | 1.1  | 15.9-20.6                                                          | 18.1 | 0.6-1.                 | 1.1  | 20.5-23.5  | 21.6 |

**Table 18:** Mean concentration of major ions (meqL<sup>-1</sup>), sodium adsorption ratio (SAR) in Oromia mid rift valley irrigation water sources. N is sample size values in brackets () are permissible limits in irrigation water. Values in bold and under line are above permissible limits in irrigation water.

| Sites              | Sample source | N | Na <sup>+</sup> (0-40) |      | Ca <sup>2+</sup> (0-20) |      | Mg <sup>2+</sup> (0-5) |      | CO <sub>3</sub> <sup>=</sup> +HCO <sub>3</sub> <sup>-</sup> (0-10) |      | Cl <sup>-</sup> (0-30) |      | SAR (0-15) |      |
|--------------------|---------------|---|------------------------|------|-------------------------|------|------------------------|------|--------------------------------------------------------------------|------|------------------------|------|------------|------|
|                    |               |   | Range                  | Mean | Range                   | Mean | Range                  | Mean | Range                                                              | Mean | Range                  | Mean | Range      | Mean |
| <b>Korke Adi</b>   | LakeZwai      | 8 | 5.8-11.5               | 8.3  | 0.9-1.6                 | 1.9  | 0.2-1.6                | 1.0  | 5.2-11.2                                                           | 8.0  | 0.76-1.6               | 1.6  | 8.26-8.5   | 8.3  |
| <b>Wayu Gebrel</b> | LakeZwai      | 8 | 2.9-7.0                | 5.1  | 1.17-1.9                | 1.5  | 0.8-1.9                | 1.3  | 5.0-8.3                                                            | 6.8  | 0.5-1.1                | 0.6  | 2.89-5.1   | 4.3  |
| <b>Zwai</b>        | Lake Zwai     | 8 | 2.2-3.16               | 2.8  | 0.94-1.3                | 1.1  | 0.7-1.3                | 0.9  | 3.2-4.3                                                            | 3.8  | 0.6-1.0                | 0.7  | 2.43-2.6   | 2.6  |

**Table 19:** Sodicity and salinity class of water samples collected from different sites and water bodies

| Sites        | Sample source | SAR  | Sodicity class | EC ( $\mu\text{Scm}^{-1}$ ) | Salinity class |
|--------------|---------------|------|----------------|-----------------------------|----------------|
| Tuchisumayan | Groundwater   | 22.1 | High(S3)       | 2050.0                      | High (C3)      |
| Shubigamo    | Groundwater   | 14.6 | Medium (S2)    | 1252.0                      | Medium (C2)    |
| Korke Adi    | Groundwater   | 21.6 | High(S3)       | 2627.5                      | Very High (C4) |
| Korke Adi    | LakeZwai      | 8.3  | Low (S1)       | 947.4                       | High (C3)      |
| Wayu gebrel  | LakeZwai      | 4.3  | Low (S1)       | 836.5                       | High (C3)      |
| Zwai         | Lake Zwai     | 2.8  | Low (S1)       | 466.9                       | Medium (C2)    |



### Salinity and conductivity of irrigation water source

**Salinity and conductivity of groundwater:** The irrigation water samples collected from groundwater of different sites of mid rift valley show a wide range of salinity and conductivity measurements that varied from 801.3 to 1681.6 mgL<sup>-1</sup> and 1252.0µScm<sup>-1</sup> and 2627.5µScm<sup>-1</sup> respectively (Table 14). Irrigation water samples collected from groundwater of two peasant associations (Tuchi-sumayan and Korke Adi) which are found in Dugda District (*woreda*) showed that the area are under increasing water quality problem (Table 14). The chemistry of those groundwaters is probably influenced by their leaching and accumulation of dissolved salts. Unless appropriate evidence-based management practices are taken, using groundwater for irrigation purposes in Tuchi-sumayan and Shubi-gamo PA will result in sever salinity problems in the very near future.

**Salinity and conductivity of lake water:** Irrigation water samples collected from Lakes Zwai and Koka at different sites show a wide range of salinity and conductivity measurements that varied from 197.9 to 606.3 mgL<sup>-1</sup> and 308.3µScm<sup>-1</sup> and 947.4µScm<sup>-1</sup>, respectively (Table 15). The mean values of salinity and conductivity of the lakes at different sites are within the expected range for irrigation in terms of their TDS and EC (Ayers and Westcot, 1985). Therefore, these lakes could be regarded as suitable for irrigation purposes. The salinity and conductivity of water sample from the lakes were found to be in decreasing order if one goes from Lake Zwai at Kore Adi Site to Lake Zwai at Wayu Gebrel and to Lake Zwai at Municipality Site. The high mean values for both the salinity and conductivity for Lake Zwai at Korke Adi Site is probably influenced by saline surface runoffs and accumulation of dissolved salts from agricultural land and runoffs from tarmac roads. On other side, the lake is under great pressure at this site by the surrounding huge number of cattle that flock to the lake to graze along the shoreline and for drinking, which eventually add organic and inorganic salts into the lake system. This should be further investigated to know the exact sources of additional salts to this part of the lake.

The study on the seasonal variations of salinity of Lake Zwai has shown that the salinity values of irrigation water from Lake Zwai at different sites varied during the wet and dry seasons. Seasonal analyses of electrical conductivity measurements of the water used for irrigation showed that the waters of the wet regimes had lower values than the dry regimes. The wet season salinity results approached the lower limits of the permissible range for irrigation purposes, while the results from the dry regimes approached the upper limits. The reason for this could be due to the dilution effect of low salt contents of surface runoffs caused by the tropical torrential rains and less evaporation rates during the wet seasons due to cloud cover and cooler air temperatures.

**The pH of irrigation waters:** The mean pH values of groundwater at different sampling sites was 7.9 (Table 14). This is then categorized under usual ranges for irrigation purpose (Ayers and Westcot 1985). The same is true for Lake Zwai with pH value of 8.0 (Table 15), which is observed to increase by the year. But, there was a large fluctuation over the study period. This suggests that the suitability of the water source for irrigation, with respect to their pH values, is seasonally variable.

### **Ionic Composition of Irrigation Water**

**Ionic Composition of Groundwater:**  $\text{Na}^+$  and  $\text{CO}_3^{2-} + \text{HCO}_3^-$  (total alkalinity) were the most dominant cations and anions ranging from 9.2 to 22.3  $\text{meqL}^{-1}$  and 8.1 to 15.1  $\text{meqL}^{-1}$  in all groundwater used for irrigation (Tables 16 and 17). Total alkalinity ( $\text{CO}_3^{2-} + \text{HCO}_3^-$ ) from two PA of Dugda District was found to be higher than the permissible limits for irrigation (Table 17), while in the results obtained from the rest of study areas were found to be within the range of permissible limits to be used for irrigation (Ayers and Westcot 1985). In these PA it is also possible to note that the composition of  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  were lower as compared to other sites, while composition of  $\text{Na}^+$  was found to be higher. The lower results in  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$  were possibly due to

precipitation. That however got by transpiration and evaporation. The concentrations of cations of water samples from groundwaters of of Korke Adi were found in a decreasing order as  $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ , while they were found in decreasing order as  $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$  in Tuchisumaya and Shubigamo Sites (Table 15). Similarly, the concentrations of anions were found in decreasing order of  $(\text{CO}_3^{2-} + \text{HCO}_3^-) > \text{Cl}^-$  in all groundwaters used for irrigation.

Although, the concentrations of  $\text{Na}^+$  were found to be in the permissible ranges for irrigation water of the study sites, there are however some indications for potential sodium hazards in the future. That is likely to be the case for those PAs in the Dugda District, where further follow up work must be done so long as groundwater continues to be used for irrigation purposes.

**Ionic composition of lake-water:** Similar to river and groundwaters used for irrigation,  $\text{Na}^+$  was the most dominant cation in lake-waters with a range 1.5 to 8.3  $\text{meqL}^{-1}$  at all location of lake sampling sites and  $\text{CO}_3^{2-} + \text{HCO}_3^-$  (total alkalinity) were the major anions with a range of 2.8 to 8.0  $\text{meqL}^{-1}$  (Table 18). Most of the lake-waters used for irrigation originate from the highlands of Zwai watershed and dilute the lake-waters and hence the inflows have very low ionic composition as compared to groundwater sources.

In contrast, concentrations of  $\text{Cl}^-$  in all the sampled irrigation waters were found to be lower than the permissible limits (Table 15 and 16) (Ayers and Westcot, 1985).

#### **Sodium adsorption ratio (SAR) of irrigation water sources**

**Sodium adsorption ratio (SAR) of groundwater:** The sodium adsorption ratio (SAR) of groundwaters used for irrigation from the sampled boreholes showed variations from 5.6 to 22.1 (Table 17). The samples taken from Tuchi-Sumayan, Korke Adi and Shubi-Gamo PAs' had high SAR readings and hence these waters are regarded as unsuitable for continuous

irrigation based on their SAR values (Table 15) (Ayers and Westcot, 1985).

**Sodium adsorption ratio (SAR) of lake-water:** Sodium adsorption ratio (SAR) content in lake used for irrigation showed variation from 1.4 to 8.3 (Table 19). Similar to water samples collected from Awash River at different sites, water sample taken from all the lake sites can also be considered suitable for irrigation according to the recommendations of Ayers and Westcot (1985).

### Conclusions and recommendations

Lake Zwai can be suitable for irrigation based on almost all aspects of their chemical composition. Based on their SAR values water samples taken from groundwater of two PA Sites (Korke Adi and Tuchi-sumayan) of Dugda District were regarded as unsuitable for irrigation purposes. This unsuitability of irrigation water was due to total alkalinity ( $\text{CO}_3^{2-} + \text{HCO}_3^-$ ), which was above permissible limits for irrigation.  $\text{Cl}^-$  which is one of the toxic ions for irrigated crops was below the permissible limits and this information would be important if any of these water sources are used for irrigation.

It is therefore recommended that extension workers should train the farmers on sustainable management practices such as regularly testing waters before starting irrigation projects, use of salt tolerant crop varieties, using soil or water amendments (e.g. application of calculated amounts of gypsum, sulphur, sulphuric acid, etc.) and other techniques.

Finally, although this paper deals with the suitability of the irrigation waters of mid rift valley of Oromia Region in light of their chemical composition only, one must consider plant varieties, improving soil types, following up climatic conditions and so on, as the quality of borehole waters and the existing agronomic and irrigation practices change over time.

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## Chapter 3

### **A revisit of seasonal studies of phytoplankton biomass and primary production in Lake Zwai: Changes after 15 years**

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#### **Abstract**

Biomass and primary production of phytoplankton measured at monthly intervals in Lake Zwai in 2005. The results were then compared with those recorded in similar studies conducted on the same lake before fifteen years. Phytoplankton biomass was measured as Chlorophyll-*a* (Chl-*a*) concentration while primary production was estimated by the light-dark bottle technique and the Winkler Method of oxygen determination. Mean values of Chl-*a* biomass for Lake Zwai in 2005 were more than five folds lower and phytoplankton primary production recorded was two folds lower than those reported in a similar study made in 1987/88. The study revealed an increase in abiotic turbidity from 47% of 1987/88 to 92 % of 2005. Although decline in levels of nutrients has importance in the long term change, the remarkable variation in the underwater light regime, which is associated with land degradation seems to have an overriding effect in making the lake light limited. The long-term trends of the biological parameters are largely attributable to the changes in the underwater light climate and ambient concentration of algal nutrients, whose variations were linked to human

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activities which have been intensified on the watershed of the lake. Thus, regular monitoring of the lake is not only important for the sustainable use of the lakes; but also the watershed deserves immediate attention with a view to halt the ever-increasing degradation of the lake drainage basin.

**Keywords:** Abiogenic, Biomass, Ethiopia, phytoplankton, primary production, underwater light regime

## Introduction

Lakes of semi-arid climate regions are located in regions where rainfall is low and highly variable and evaporation rates are very high in comparison to precipitation (Gophen 2008). They typically vary in size, depth, salinity and turbidity as they cycle through wet and dry periods, with the ecology of their aquatic biota tied to this cycle (Gardiner 2010). Lake Zwai of the Ethiopian Rift Valley is such lake (Billi 1998, Ayenew 2004) located at the vicinity of fast growing city (now known as Batu). The main management issues affecting semi-arid lakes are water abstraction affecting local and/or regional hydrology and land degradation due to high grazing pressure and deforestation (Gebre-Mariam 2002, Ayenew 2004).

Lake Zwai is one of the Central Ethiopian Rift Valley Lakes, which has been subjected to climate variability and ever-increasing anthropogenic impacts from a rapidly growing population (Gebre-Mariam 2002, Gebre-Mariam *et al.* 2002, Tadele 2009). Rapid population growth, urbanization and increased development of floriculture and intensive irrigation-fed horticulture surrounding the lake have increased the per capita demand for land and water (Ayenew 2004, Hengsdijk and Jansen 2006, Muzein 2006). Consequently, there has been a long-term trend of land degradation and loss of vegetation due to clearance aimed at creating the additional space required for the various sectors and production of charcoal and firewood (Woldu and Tadesse 1990, Asfaw 1998, Gebre-Mariam 1998, Ayenew 2001, Gebre-Egziabher 2006, Muzein 2006).



There were anecdotal accounts by local inhabitants, which associated the recent fish-kill incidence at Lake Zwai with effluents of a floriculture industry, which uses the lake's littoral zone as a waste-disposal system (Tadele 2009). An equally grave anthropogenic impact is the overexploitation of the lakes' fisheries, which is the economic mainstay for thousands of people living in the drainage basins of the lake. Persistent over-fishing of tilapia due to excessive fishing efforts, inappropriate fishing method and fishing gear in Lake Zwai (Reyntjens and Wudneh 1998, Tigabu 2003, Spliethoff *et al.* 2009) has been shown by stock assessment studies.

Studies on the extent to which the physical, chemical and biological characteristics of a lake may have changed as a result of natural and/or anthropogenic threats are important in elucidating their ecological health (Rumes 2010). Good data sets generated at intervals of time, which can be used to assess the ecological health of aquatic ecosystems are meagre for tropical lakes of semi-arid regions (Talling and Lemoalle 1998) in general and Ethiopian lakes in particular (Gebre-Mariam 2002). Few studies have addressed long-term changes in the physico-chemical features of volcanic crater lakes (Gebre-Mariam, 2002) and other lakes of Ethiopia (Gebre-Mariam *et al.* 2002, Lemma 2002, 2003). Phytoplankton is the first community of organisms affected both quantitatively and qualitatively by changes in the environment of lakes (Anna-Lisa and Galina 1999, Wen-Seng *et al.* 2004), and is consequently used as a bio-indicator of ecological changes (Danielson 1998, Apfelbeck 1999). This is, however, the only study that addressed the long-term changes in biomass and primary production of phytoplankton in Lake Zwai for which phytoplankton primary production was found to be a good predictor of fish yield (Tilahun and Ahlgren 2010).

This study was, therefore, conducted to assess changes in phytoplankton biomass and primary production in Lake Zwai, which has been impacted by both natural and ever-increasing human-induced environmental changes.

**Materials and methods**

**The study site:** Lake Zwai (Fig. 17) lies within the Ethiopian Rift Valley, which is situated in the northern section of the Great Rift Valley of Africa. Some morphometric and physico-chemical features of the study lake are presented (Table 20).

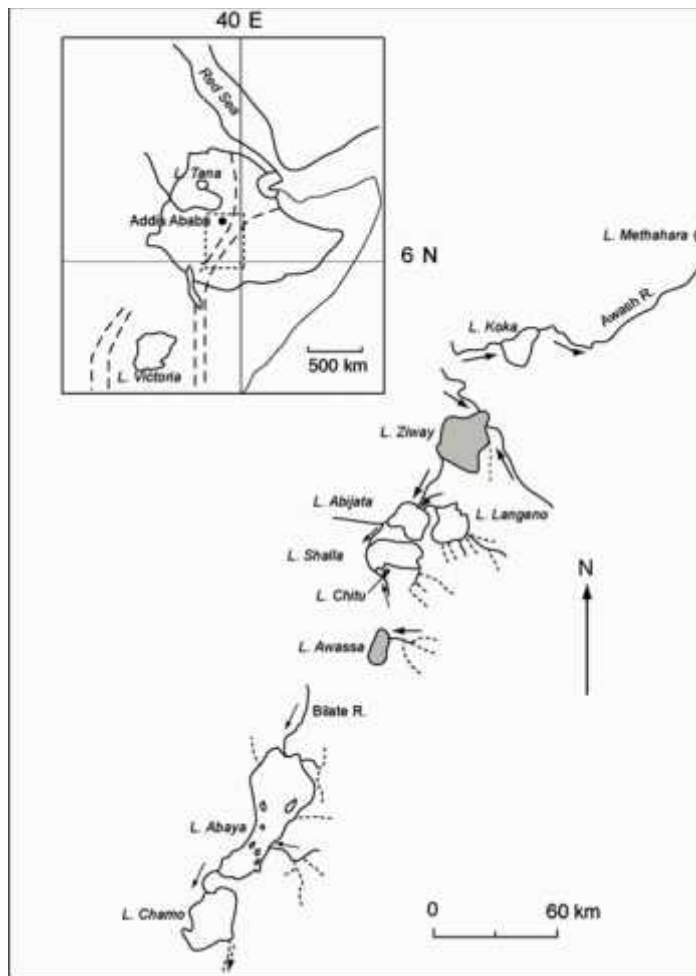


**Figure 17:** Lake Zwai in relation to other rift valley lakes of Ethiopia

Lake Zwai has two major sources of inflow, the River Meki from west and River Qatar (also written as Qatar or Ketar) from southeast and is drained by River Bulbula, which flows into another rift valley lake, Abijata (Ayenew 2001). The mean annual precipitation and air temperature of the

area were estimated at 600mm and 25°C, respectively, and potential evaporation greatly exceeded precipitation during most of the year (Billi 1998, FAO 2001). The study area had alternating dry and wet periods, with the rainy period extending from March to October and precipitation peaking in March-May and July-October (Ayenew 2004, Gissila *et al.* 2004).

**Table 20:** Some morphometric and chemical data of the study lakes (Source: Kebede *et al.* 1994, Tilahun 2006, Tilahun and Ahlgren 2010)

| Parameter                                               | Hawassa<br>(Awassa) | Zwai |
|---------------------------------------------------------|---------------------|------|
| Altitude (m)                                            | 1680                | 1640 |
| Catchments areas<br>(km <sup>2</sup> )                  | 1250                | 7025 |
| Surface area (km <sup>2</sup> )                         | 88                  | 434  |
| Max. depth (m)                                          | 22                  | 7    |
| Mean depth (m)                                          | 11                  | 2.5  |
| Alkalinity (meqL <sup>-1</sup> )                        | 7.73                | 4.95 |
| Conductivity (K <sub>25</sub> ,<br>μScm <sup>-1</sup> ) | 830                 | 410  |
| Salinity (gL <sup>-1</sup> )                            | 0.8                 | 0.4  |

Lake Zwai had relatively large littoral zones fringed with submergent, floating and emergent vegetations consisting primarily of *Cyperus*, *Nymphaea*, *Paspalidium*, *Phragmites*, *Potamogeton* and *Typha* spp. (Tudorancea *et al.* 1989; Tudorancea 2002). The phytoplankton communities were composed primarily of blue-greens, greens and diatoms (Kebede and Willén 1998). Major taxa of the zooplankton communities in the lake included the genera *Brachionus*, *Diaphanosoma*, *Mesocyclops*, *Moina* and *Thermocyclops* (Defaye 1988, Dagne *et al.* 2008). Lake Zwai supported the commercially important phytoplanktivorous cichlid, *Oreochromis niloticus*, which

accounted for 60 to 80% of the total fish landings in African lakes (Vander Borsches and Bernice 1991).

**Sampling and in situ measurements of physico-chemical parameters:**

Lake Zwai was sampled at monthly intervals from January to December, 2005. The GPS marks, Water samples were collected from depths distributed within the euphoric zone, which was approximated as euphoric depth ( $Z_{eus}$ ) = Secchi depth ( $Z_{SD}$ ) $\times$  3 (Talling and Lemoalle 1998), with a 2-litre Plexiglas Ruttner sampler and mixed in equal proportions to produce composite samples. Aliquots of composite water samples were used for the estimation of phytoplankton biomass as *Chl-a* concentration and primary production and analysis of major algal nutrients. Sampling was usually conducted between 10:00 and 11:00am local time, during which *in situ* measurements of the following physical parameters were also made. Lake water transparency (vertical visibility or Secchi depth) was estimated with a standard Secchi disk of 20 cm diameter. Photosynthetically active radiation (PAR) was measured in  $\mu E\ m^{-2}s^{-1}$  with underwater LI-COR quantum photometer (LI-189) connected to underwater quantum sensor (LI-192SA). Mean vertical extinction coefficient ( $K_{PAR}$ ) was calculated from the readings of photosynthetic photon flux density (Kirk 1994) and used in the estimation of euphotic depth (Kalff 2002). Light extinction due to algae ( $K_s$ ), as per cent of  $K_{PAR}$ , was estimated assuming an extinction value of 0.016 ln units ( $mgChl-a^{-1}$ ) (Dubinsky and Berman 1976).

**Analysis of major algal nutrients:** Soluble reactive phosphate ( $PO_4-P$ ), reactive silica ( $SiO_2$ ) and nitrate-nitrogen ( $NO_3-N$ ) were analysed using filtrates, which passed through Whatman glass fibre filters (GF/F). Concentrations of  $PO_4-P$  and  $SiO_2$  were determined as their respective molybdate complexes by the Ascorbic Acid and Molybdosilicate methods respectively (APHA *et al.* 1999).  $NO_3+NO_2-N$  was determined as nitrite after reduction with copper-cadmium (APHA 1999).

**Measurement of biomass and *in situ* primary production of phytoplankton:** Triplicate sub-samples of 200 to 250 mL were filtered through Whatman glass fiber filters (GF/F, 47 mm diameter) for the spectrophotometric estimation of phytoplankton biomass as *Chl-a* concentration. Calculation of *Chl-a* concentration was made from absorbance readings taken at 665 and 750 nm using the empirical formula of Talling and Driver (1963). The oxygen light-dark bottle technique with the Winkler method of oxygen determination was used to estimate primary production of phytoplankton (Wetzel and Likens 2000). A composite lake water sample collected from the euphotic zone was siphoned into 130 mL transparent and opaque (covered with dark cloth) Pyrex glass bottles. A series of paired transparent glass bottles were fastened along a metal bar suspended from a buoy. Since temperature variation within the euphotic zone was normally small, respiration was estimated from only one pair of dark bottles suspended at the lower end of the euphotic zone. The *insitu* incubation lasted for 2.5 hours, usually between 10:45 a.m. and 01:45 p.m. local time.

## Results

**Optical and chemical parameters:** The ranges and means of parameters related to the underwater light climate and concentrations of inorganic nutrients recorded in 2005 for Lake Zwai, in comparison with those reported for 1980s is given in Table 22. The average Secchi depth ( $Z_{SD}$ ) of Lake Zwai has been reduced from 0.19 to 0.18 m, while its euphotic depth from 0.67 to 0.58 m (Table 21).

**Table 21:** Comparative t-test between mean values of some parameters related to the underwater light climate and nutrient in Lake Zwai during 1987/88 and 2005. Ranges and means (in bracket) of recorded values are indicated (NS = Not significant, \*\*\* Significant at 0.1% level)

| Parameters                     | 1987/88    | 2005       | Df | t-value | P-value   |
|--------------------------------|------------|------------|----|---------|-----------|
| $K_{PAR}$ (ln units $m^{-1}$ ) | 4.6 – 10.4 | 6.8 – 16.7 | 28 | 1.6     | 0.133(NS) |

| Parameters                      | 1987/88               | 2005                  | Df | t-value | P-value   |
|---------------------------------|-----------------------|-----------------------|----|---------|-----------|
| $Z_{eu}$ (m)                    | (7.5)<br>0.38 – 0.98  | (8.8)<br>0.28 – 0.68  | 28 | 1.8     | 0.085(NS) |
| $Z_{SD}$ (m)                    | (0.67)<br>0.13 – 0.27 | (0.56)<br>0.14 – 0.22 | 28 | 0.4     | 0.730(NS) |
| $Z_{mix}/Z_{eu}$                | (0.19)<br>2.3 – 8.8   | (0.18)<br>2.0 – 10.9  | 28 | 0.3     | 0.807(NS) |
| % light extinction due to algae | (4.6)<br>32 – 79      | (5.1)<br>6.4 – 11.1   | 28 | 11.1    | 0.000***  |
| $NO_3-N$ ( $\mu g L^{-1}$ )     | (53)<br>28 – 166      | (8.0)<br>11 – 50      | 28 | 5.3     | 0.000***  |
| $PO_4-P$ ( $\mu g L^{-1}$ )     | (78.6)<br>5.5 – 16.2  | (20.2)<br>2 – 20      | 28 | 0.4     | 0.708(NS) |
| $SiO_2$ ( $mg L^{-1}$ )         | (9.5)<br>18.6 – 49.7  | (10.1)<br>14.3 – 41.6 | 28 | 1.1     | 0.285(NS) |
|                                 | (27.2)                | (23.8)                |    |         |           |

Although the transparency of Lake Zwai was shallower in 2005 than in 1987/88, the differences between the two sets of total extinction coefficient, euphotic depth and Secchi depth values were not statistically significant (Table 21). However, the mean percentage light extinction due to algae in Lake Zwai had declined significantly from its value in 1987/88 with concomitant increase in abiogenic turbidity. The mean-light attenuation due to algae ( $K_S$ ) in LakeZwai, as per cent of total  $K_{PAR}$ , has been reduced from 53% to 8 %, which is nearly seven folds. This is equivalent to increase in abiogenic turbidity from 47% to 92 %

Although concentration Orthophosphate ( $PO_4-P$ ) and Molybdate reactive Silica ( $SiO_2$ ) did not change much while  $NO_3+NO_2-N$  showed marked decline and was less than  $50 \mu g L^{-1}$  throughout 2005 ( Table 21).

**Biomass and primary production of phytoplankton:** Table 22 presents means and ranges of *Chl-a* biomass and parameters of photosynthetic primary production of phytoplankton recorded in 2005 in comparison with those reported for the 1980s. The average value of *Chl-a* biomass of phytoplankton

(B, in  $\text{mg m}^{-3}$ ) in LakeZwai decreased from 186.8 to 36.4, which is more than five - folds.Monthly depth-distribution of volumetric rates of gross photosynthetic production of phytoplankton for Lake Zwai (Fig. 18) are typical for turbid water systems, with depth profiles vertically compressed into shallow euphotic zones, occupying the top 50 to 70 cm depth. As compared to mean value recorded in the 1980s, volumetric gross photosynthetic production ( $\text{mg O}_2\text{m}^{-3}\text{h}^{-1}$ ) in Lake Zwai showed a two-fold decrease from 788 to 381and more than two fold decline in light utilization efficiency ( $\text{mmol O}_2/\text{E PAR}$ ) from 4.7 to 1.9 (Tables 22 and 23).



**Table 22:** Comparative t-test between mean phytoplankton biomass and primary production values recorded in Lake Zwai in 1987/88 and 2005. Ranges and means (in bracket) of recorded values are indicated (\*\*\*)Significant at 0.1% level).

| Parameters                                                                                    | 1987/88              | 2005               | Df | t-value | P-value  |
|-----------------------------------------------------------------------------------------------|----------------------|--------------------|----|---------|----------|
| <b>B</b> (mg Chl- <i>a</i> m <sup>-3</sup> )                                                  | 149.5 - 212.0(186.8) | 22.9 – 57.5 (36.4) | 27 | 24.7    | 0.000*** |
| <b>ΣB</b> (mg Chl- <i>a</i> m <sup>-2</sup> )                                                 | 81.1 – 191.6 (129.2) | 15.4 –26.9 (19.4)  | 27 | 12.3    | 0.000*** |
| <b>ΣA</b> (mg O <sub>2</sub> m <sup>-2</sup> h <sup>-1</sup> )                                | 288 – 1625 (788)     | 182 – 592 (381)    | 27 | 4.3     | 0.000*** |
| <b>ΣΣA</b> (mg O <sub>2</sub> m <sup>-2</sup> d <sup>-1</sup> )                               | 3.1 – 17.6 (8.4)     | 2.0 – 6.4 (4.0)    | 27 | 4.3     | 0.000*** |
| <b>A<sub>max</sub></b> ( mg O <sub>2</sub> m <sup>-3</sup> h <sup>-1</sup> )                  | 1640 – 4670 (2965)   | 478 – 1232 (865)   | 27 | 8.6     | 0.000*** |
| <b>P<sub>max</sub></b> mg O <sub>2</sub><br>(mg Chl- <i>a</i> ) <sup>-1</sup> h <sup>-1</sup> | 11.0 – 22.5 (15.8)   | 14.9 –38.0(24.4)   | 27 | 4.0     | 0.000*** |
| <b>Light utilization efficiency</b> (mmol O <sub>2</sub> /E PAR)                              | 2.4 – 9.6(4.7)       | 0.6 – 4.1(1.9)     | 27 | 4.3     | 0.000*** |

**Table 23:** time series record of phytoplankton biomass in Lake Zwai obtained from seasonal studies made by different researchers.

| Date/Year of sampling | Biomass (mgChl- <i>a</i> m <sup>-3</sup> ) | Reference                         |
|-----------------------|--------------------------------------------|-----------------------------------|
| Feb.'87 – Feb.'88     | 186.8 (149.5 – 212)                        | Tilahun (1988)                    |
| 1990 - 2000           | 82.4 (23 – 224)                            | Gebre-Mariam <i>et al.</i> (2002) |
| 2005                  | 36.4 (22.9 – 84.9)                         | Original report                   |

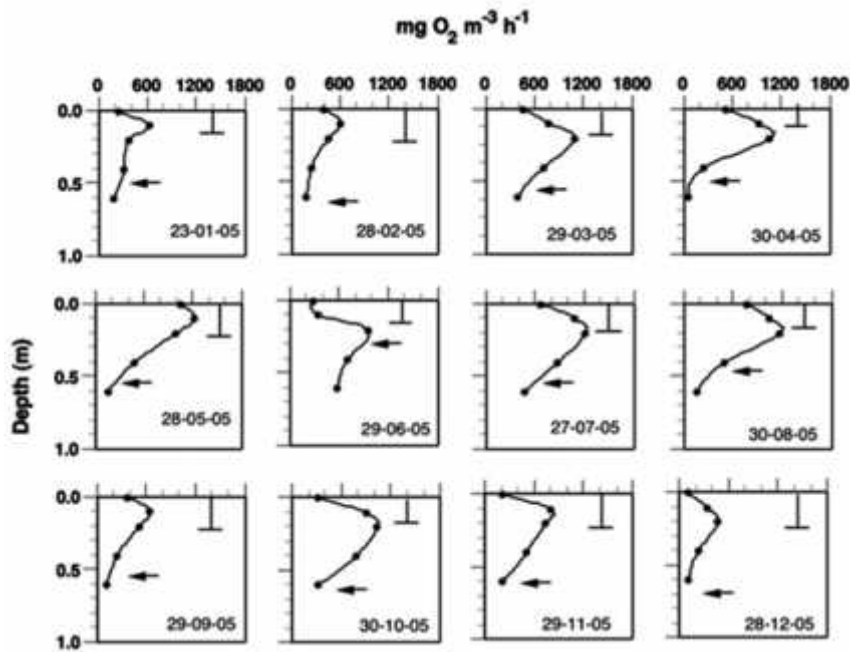


**Figure 18:** Depth profiles of gross photosynthesis production per unit water volume of Lake Zwai measured in 2005

## Discussions

Variations in the composition, biomass and productivity of phytoplankton are imminent in lakes perturbed by natural and/or human-induced changes. The phytoplankton communities of both lakes were constituted primarily by green and blue-green algae, with species of *Microcystis* and *Cylindrospermopsis* dominating the algal assemblages in both lakes (Tilahun 2006), a situation with contrasts with the predominance of green algae and diatoms reported for the 1980s (Mihret-Ab 1988)

The shallow and polymictic Lake Zwai (Kebede and Willen 1998, Tilahun 2006) is a very turbid system, with very shallow mean Secchi and euphotic depth, which are less than 0.2 m and 0.7 m respectively. This indicates that the underwater light regime should be expected to have considerable effect on phytoplankton primary production. The lowest and highest  $Z_{SD}$  values of Lake Zwai were observed in June and February, 2005 coinciding with the rainy and dry periods respectively (Tilahun 2006). Lower values of  $K_S$  (6 to 8%), as per cent of  $K_{PAR}$ , were recorded during the rainy and/or windy months (Tilahun 2006), indicating that runoff from degraded watershed coupled with shallowness and polymictic nature of Lake Zwai.

The noticeably low mean  $K_S$  obtained in 2005 (8%) suggests that the turbidity of the lake was largely of abiotic origin. As a result of the nearly complete removal of vegetation cover, which may have acted as a filter for dissolved and particulate materials coming to the lake through runoff and feeder rivers, enhanced erosion of the drainage basin contributed directly to the increased suspended solids in Lake Zwai (Hengsdijk and Jansen 2006, Tilahun 2006). It is well documented that such shallow lakes commonly exhibit high turbidity due to the re-suspension of inorganic particles from the sediment by

frequent mixing or loading from the catchments through runoff and feeder rivers (Dokulil 1994, Scheffer 1998). The phytoplankton community of the lake in 2005 was dominated by species of *Microcystis* and filamentous cyanobacteria such as *Cylindrospermopsis* spp. (Tilahun 2006), which are known to be favoured by turbid and nutrient-rich warm water column conditions of such lakes (Scheffer 1998). These species, besides being unpalatable to herbivorous zooplankton, they have low nutritive value and include some species which produce toxic substances. The introduction of alien fish species such as *Tilapia zillii*, which was reported to graze primarily on green algae and diatoms (Negassa and Getahun 2004 and references cited therein), may have also influenced the phytoplankton community structure of the lake.

The remarkable decrease in phytoplankton biomass of Lake Zwai in 2005, which became evident when comparisons of data generated in different years (See Table 3.4) was made. This seems to indicate that the lake has experienced a change in the underwater light regime that did not favour phytoplankton growth over the last 15 years. Thus, the long term changes in phytoplankton biomass and productivity are largely attributable to the changes in the underwater light climate and ambient concentration of algal nutrients. As reported by different researchers, such changes seem to be linked to human activities intensified on the watersheds of lakes (Woldu and Tadesse 1990, Asfaw 1998, Gebre-Mariam 1998, Ayenew 2004, Gebre-Egziabher 2006, Muzein 2006). The situation in Lake Zwai has been further worsened by the marked decline in the water level of the lake due to upstream water diversion and excessive abstraction of the lake water for irrigation (Zinabu Gebre-Mariam *et al.* 2002, Ayenew 2004).

If the current human-induced threats go unchecked, the ecological integrity of the lakes will be drastically affected as the phytoplankton form the base of the food webs in aquatic ecosystems. More importantly, the commercial fishery is based largely on the phytoplanktivorous Tilapia and to which the livelihood of thousands of people is tied, will be curtailed. Thus, regular monitoring of not only the lakes but also their watersheds must be carried out concurrently through the involvement of researchers from all relevant disciplines with a view to halt the ever-increasing degradation of the lakes' drainage basins and hence their ecosystems.

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## Chapter 4

### Composition, abundance and biomass of zooplankton in Lake Zwai

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#### Abstract

Zooplankton species composition, abundance and biomass changes with time and space were studied in Lake Zwai, a shallow turbid tropical rift valley lake, on biweekly basis between October 2008 and September 2009. Species composition of zooplankton in Lake Zwai reflects typical tropical aspects where rotifers were the dominant, 49 species and only 10 crustaceans (7 cladocerans and 3 cyclopoids). Larger *Daphnia* and calanoid species are absent. Crustaceans were dominated by one species *Thermocyclops decipiens*. *Moina micrura*, *Diaphanosoma excisum*, *Ceriodaphnia cornuta* and *Daphnia barbata* being typical representatives of the cladocerans in the lake. *Ceriodaphnia cornuta* and *Daphnia barbata* were absent from the plankton following the decline in the water transparency. Copepods and rotifers comprised about 96% of the total zooplankton numeric abundance. Temporal variation of cladocerans biomass was associated with the water transparency with a general decline towards the rainy season but copepods biomass peaked during the rainy season. Large adults and ovigerous

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*Mesocyclops aequatorialis* were almost absent from day samples and rare in the inshore station. They showed a clear diel vertical migration in response to predation from fish and *Chaoborus*. Spatially crustaceans showed three peak biomass in the inshore but a single (less than half that of the inshore) in the offshore of the lake. Annual mean zooplankton biomass of Lake Zwai ranged from 42.7 to 188.9 mg dwt m<sup>-3</sup> with mean 93.1 mg dwt m<sup>-3</sup>. Seasonal rainfall that leads to an increase in turbidity (reduced water transparency) favors large colonial forms like *Microcystis* species and filamentous *Anabaena* species to dominate the phytoplankton community. Generally, high turbidity, low food quality, structural complexity (dense macrophytes) in the littoral and perhaps the effects of predation from fish and the invertebrate *Chaoborus* sp. could be the reasons for the observed spatio-temporal variation in zooplankton species composition, abundance and biomass in Lake Zwai.

**Keyword:** Zooplankton, crustaceans, predation, spatial, temporal, turbidity, Lake Zwai, zooplankton

## Introduction

Long term quantitative studies on zooplankton of tropical water bodies on the basis of short sampling intervals are still scarce. Studies so far indicated that in deep, stratified lakes high abundance of zooplankton coincided with the mixing cycle and hence redistribution of nutrients and subsequently phytoplankton growth (Seyoum Mengistou and Fernando, 1991; Irvine and Waya, 1999; Isumbisho *et al.*, 2006). However, in shallow turbid lakes lacking stratification fluctuations in zooplankton populations are related to complex processes mediated by interactions between abiotic and biotic factors. In most shallow tropical lakes turbidity and water level fluctuations associated with seasonal rainfall events affect composition and distribution of

zooplankton (Kalk, 1979; Saint-Jean, 1983; Hart, 1986, 1988, 1996; Eshete Dejen *et al.*, 2004). It has been indicated that sediment carried in suspension influences complex biotic food web interactions, thereby affect community structure (Threlked, 1986). The frequent depression of zooplankton standing stocks in turbid waters is readily attributable to subsequent depression of algal food resources by light limitation (Allanson *et al.*, 1990). Compositional shifts in zooplankton dominance with change in turbidity levels reveal differential susceptibilities to resource depression (Hart, 1988) associated with algal light limitation. Experimental studies showed the decline in *Daphnia* filtering rates with rising suspended sediment concentrations (Arruda *et al.*, 1983; Hart, 1988; Levine *et al.* 2005) and a general negative-relationship between zooplankton and turbidity particularly among copepods and cladocerans but less constantly among rotifers. Kirk (1991) also indicted the detrimental effects of suspended particles in *Daphnia* filtering.

Abiotic factors which have strong effect on the vertical gradients in deep lakes (Burks *et al.*, 2002) do not shape horizontal gradients in shallow lakes. However, in shallow turbid lakes where water transparency is generally low diel vertical migration is muted. On the other hand the presence of vertical migration of zooplankton in turbid water is also reported (Dodson, 1990) although limited in its amplitude. Besides the abiotic factors, biological factors such as quantity and quality of food (Lewis, 1979) and predation by fish and invertebrates are also shown to influence zooplankton population. Typical zooplanktivorous fish is absent in Lake Zwai except the dominant indiscriminate feeder catfish. However, zooplanktivory by catfish that lead to significant reduction in population density has been reported from Lake Kinneret, Israel (Gophon 1988). Earlier studies reported the absence of invertebrate predator in Lake Zwai but the presence of *Chaoborus* is

confirmed in this study. Zooplanktivory by the larvae of dipteran genus *Chaoborus* have been reported to play an important role in structuring zooplankton community in tropical lakes (Lewis 1977; Irvin 1997). Blooms of Cyanobacteria such as *Microcystis aeruginosa* are a wide phenomenon in the eutrophic lakes and reservoirs (Oh *et al.* 2000; Haade, *et al.* 2007). As there is a scarcity of large cladocerans (*Daphnia*) and calanoids in shallow tropical freshwater ecosystems (Lewis 1979; Fernando 1980b; this study) the main zooplankton grazers are small cladocerans and rotifers (Aka *et al.*, 2000; Fernando, 2002). The littoral zone with different types of structural complexity is also one of the factors to structure the distribution patterns of lake organisms. It is well known that macrophytes may act as a refuge from predation for both small fish and zooplankton such as *Daphnia* (Lauridsen and Buenk, 1996). The objective of this paper is therefore to investigate the spatio-temporal variations in species composition, abundance and biomass of zooplankton in Lake Zwai.

### Materials and Methods

**The study site:** Lake Zwai (7°55'N and 38°43'E) is a turbid shallow freshwater lake situated in the most northern section of the Ethiopian part of Rift Valley at an altitude of 1636 m above sea level. The lake has a surface area of 442 km<sup>2</sup>, maximum depth of 7 m, an average depth of 2.5 m and volume of 1.1 km<sup>3</sup>. The lake is mainly fed by the two rivers from the highlands Meki North West and Qatar North East and drains into Lake Abijata through Bulbula River in the south (Fig.19). The latter usually falls dry during the dry season. According to Tenalem Ayenew (2004) the annual inflows from Meki and Qatar rivers into Lake Zwai are 264.5 and 392 million m<sup>3</sup>, respectively. The author also indicated that the inflow into the lake has an annual deficit of 74 million m<sup>3</sup> over the overall water loss from the lake. An

increasing demand and uncontrolled water abstractions from the inflowing rivers as borehole as lake water for irrigation, outflow through River Bulbula, domestic use (drinking water supply to Zwai town, watering cattle) and loss through evaporation from the lake contribute for the deficit. The littoral area has a ring of macrophytes (emergent, sub-merged and floating) in which the reeds are the dominant. According to Girum Tamire and Seyoum Mengistou (2014) Lake Zwai also have macrophytes like *Typha latifolia*, *Cyperus papyrus*, *Arundo donax*, *Echinochloa colona*, *Cyperus articulatus*, *Nymphaea lotus*, *Potamogeton schweinfurthii*, *Ludwigia erecta*, and *Ludwigia stolonifera* species.

The weather in the lake region is frequently windy. Due to the large surface area relative to the shallow depth which lacks wind break, a slight wind can cause complete mixing of the lake. We frequently observed strong wind-induced water currents, especially in the afternoon which supports the temperature and dissolved oxygen result that showed absence of thermal stratification. The lake is highly turbid, with an average secchi depth of less than 30 cm due to re-suspended sediment particles and algal community. Details on the chemical features of Lake Zwai can be found in Elizabeth Kebede *et al.*, 1994; Zinabu Gebremariam *et al.*, 2002). The lake region is characterized by a semi-arid to sub-humid type of climate with mean annual precipitation and mean annual temperature varying between 650 mm and 25°C close to the lake and 1200 mm and 15°C on the humid plateaus escarpment, respectively (Dagnachew Legesse *et al.*, 2004). However, meteorological records from Zwai station indicated a declining trend in the annual precipitation (courtesy of the National Meteorological Agency-Awassa branch). According to Golubistov *et al.* (2002) Lake Zwai has eleven fish species of which *Oreochromis niloticus*, *Tilapia zilli*, *Clarias garipenus* and

*Barbus intermedius* are commercially important. According to Yared Tigabu (2003) there is a continuous decline in the annual fish catch from Lake Zwai since 1997 and an increasing population of *Clarias gariepinus* which was also observed from the fishermen catches during the study period.

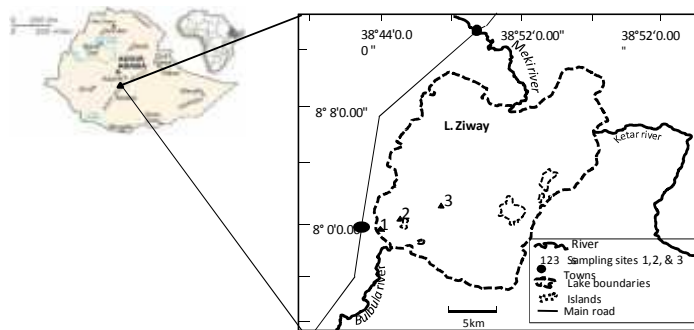


**Figure 19:** Map of Lake Zwai and the sampling stations indicated with numbers (indicated with numbers)

**Field sampling and measurement:** Water samples collection and limnological parameters measurement were carried out fortnightly from three stations (S1 within the macrophytes and S2 and S3 in the open water of the lake) from October 2008 to September 2009. Samples were taken usually between 09:00 and noon using plankton nets of 40  $\mu\text{m}$  and 100  $\mu\text{m}$  mesh size and 30 cm mouth diameter and 10 L Schindler sampler. Water samples were from Schindler were filtered through plankton gauze of 40  $\mu\text{m}$  and preserved with 4% final concentration formalin solution. Night samples were taken from the offshore station (S3) on 4 to 5 July, 2009 between 17:00 pm to 08:00 am



to investigate the presence and/or absence of diel vertical migration. Water temperature, dissolved oxygen, conductivity and pH were measured on the field at each station and sampling depth on biweekly basis with a combined sensor probe model HQ 40 HAC Instrument. Lake water transparency was measured with 30 cm diameter black and white Secchi disc. Turbidity and chlorophyll-*a* concentration were determined in the laboratory from Schindler samples collected in each sampling date. Chlorophyll *a* was concentrated by filtering 300 ml lake water through Whatman glass micro fiber filter pore size 47 mm in diameter. Because of the high clogging of sestons on the filter paper, 300 ml was filtered twice. Chlorophyll-*a* content was extracted using 90% acetone and determined spectrophotometrically and turbidity with turbidity meter model LP 2000 HANNA measuring FTUs. No corrections were made for the degradation products. Chlorophyll-*a* expressed as  $\mu\text{g l}^{-1}$  was estimated according to Talling and Driever (1963). Fish stomach contents of dominant and commercially important fish species were examined to find out the possible impacts on zooplankton. Identifications of plankton were done using various identification keys, journals and books some of which are: Fernando (2002); Jeje (1988); Korovchinsky (1992); Koste (1978); Nogrady *et al.* (1995); Defay (1988); Van de Velde (1984); Fernando (2002). Developmental stages of all copepod species were grouped together as nauplii and copepodites, while for cladocerans all stages were counted as one age class. Total counts were made for all samples and counts were expressed as individuals per liter.

**Dry weight determination and biomass estimation:** Body lengths of individuals from *Ceriodaphnia cornuta*, *Moina micrura*, *Maesocyclops aequatorialis* and *Thermocyclops decipiens*, copepodites and nauplii were measured with a calibrated ocular micrometer from the tip of the head to the

base of the tail spines for cladocerans and from the tip of the head to both the base of the furcal rami and base of caudal spines for copepods. After length measurement, group of individuals, 20 for adults of *M. micrura*, *M. aequatorialis* and *T. decipiens*, 50 individuals for larger *C. cornuta*, small *M. micrura*, small *T. decipiens* and copepodides and 100 individuals for small *C. cornuta* and nauplii, were grouped per size per species and transferred into small glass vials and further washed with distilled water for a minimum of half an hour before transferred into pre-dried hand-made aluminum pans (see detailed procedures in Adamneh Dagne, 2010). Weighing pans with zooplankton were placed in a crucible and then into a drying oven at 100°C for overnight. In the subsequent day the crucible containing samples were cooled in desiccators and then pans with dried samples were weighed on a Mettler Toledo XS 205 Dual Range electronic microbalance. Since the balance has an accuracy of 10µg, animals were weighed in batches to get more accurate biomass estimates than weighing of individuals. Dried group weights were then computed by subtracting the dried weights of each aluminum pans from the weight of dried aluminum pans plus specimens on it and then divided by the number of individuals within the group to get dry weight (µg) per individual. Length-weight relations were then obtained from those species and stages by applying the following equation

$$\ln W = \ln a + b \ln L$$

Where  $W$  is dry weight as  $\mu\text{gInd}^{-1}$  and  $L$  is body length ( $\mu\text{m}$ ),  $a$  is intercept and  $b$  is slop of the regression line.

## Results

**Environmental conditions, Chlorophyll-*a*:** Since there was no significant difference in most parameters between the two offshore stations (S2 & S3) results and discussions are made based on the two stations (inshore S1 and offshore, average of S2 and S3). Turbidity, water transparency (Secchi depth), conductivity, dissolved oxygen (inshore station) and chlorophyll-*a* showed marked seasonal variation (Table 24). Turbidity which was generally high (mean value 81.7 FTU) but nearly uniform during the dry period started to increase progressively from March till its peak at the end of July as high as 8 times greater than the minimum turbidity recorded in April. Short duration in the main rain at the time of the study period lead to a decrease in the turbidity shortly after the peak where three fold reduction was observed within two weeks interval. Lower value in dissolved oxygen with a wider range 3.2 to 8.4mgL<sup>-1</sup> was recorded in the inshore station where there is dense vegetation compared with the relatively uniform record from the offshore. On the other hand, depth profile in the offshore station showed little variation in dissolved oxygen a difference of less than 1 mgL<sup>-1</sup> between top 0.5 m and bottom 2.5 m water column (ranged between 0.02 and 0.94mgL<sup>-1</sup>) throughout the study period. Conductivity of lake water (mean 423.7  $\mu$ Scm<sup>-1</sup>) increased progressively between December and March and declined during the rainy season. The temperature between the upper 0.5 m and bottom 2.5m water column was only less than 1<sup>0</sup>C. The mean water temperature for the study period was 22<sup>0</sup>C. Mean chlorophyll-*a* concentration during the study period was 23.5 $\mu$ gL<sup>-1</sup>. Temporal variation was high in chlorophyll-*a* concentration that ranged between 3.5 and 75.1 $\mu$ gL<sup>-1</sup>, generally higher values during the wet periods.

**Table 24:** Mean standard deviation and ranges of physico-chemical variables and chlorophyll-*a* with sample size N in Lake Zwai (October 2008 to September 2009).

| Parameters                                     | Mean $\pm$ SD    | Range     | Min.      | Max.     | N0  |
|------------------------------------------------|------------------|-----------|-----------|----------|-----|
| Water temperature, °C                          | 22 $\pm$ 1.6     | 18.9-27.3 | Dec., 15  | Mar.,30  | 245 |
| Rainfall, mm                                   | 59.2 $\pm$ 49.5  | 0-187.4   | Dec.,Feb. | Jul.     | 12  |
| Secchi depth, cm                               | 29.3 $\pm$ 0.1   | 11- 44    | Jul., 30  | Apr., 14 | 72  |
| Dissolved oxygen, mgL <sup>-1</sup>            | 7.6 $\pm$ 0.7    | 3.2-8.8   | Jul., 30  | Sept.,30 | 245 |
| Conductivity, $\mu$ Scm <sup>-1</sup>          | 423.7 $\pm$ 20.6 | 385-463   | Nov., 30  | Jun., 15 | 245 |
| Turbidity, FTU                                 | 81.7 $\pm$ 53.5  | 45.4-342  | Apr., 14  | Jul., 30 | 81  |
| Chlorophyll- <i>a</i> , $\mu$ gL <sup>-1</sup> | 23.5 $\pm$ 13.3  | 3.5-75.1  | Dec., 14  | Jun., 30 | 190 |
| pH                                             | 8.8 $\pm$ 0.2    | 7.9- 9.2  | Feb., 14  | May 29   | 245 |

**Plankton community composition:** Phytoplankton composition of Lake Zwai consisted of mainly diatoms, green algae and blue-green algae. From 42 phytoplankton species (16 diatom species, 13 green algae and 9 blue greens and 4 from other genera) identified during the study period, only a few species mainly blue green algae were dominant throughout the study period (Table 25). Large colonial types like *Microcystis* species dominated all year round, *Anabaena* and *Oscillatoria* species were co-dominant during the wet periods through the rainy season. Two diatom species *Fragilaria* and *Synedra* were also co-dominant with *Microcystis* during the dry periods (Table 25). A total of 59 zooplankton species: 49 rotifers, 7 cladocerans and 3 cyclopoid copepods comprised zooplankton community of Lake Zwai (Tables 26 and 27). Zooplankton community of the lake was dominated by small bodied where rotifers and cyclopoid nauplii stages which accounted 75% of the total zooplankton abundance. Cyclopoid copepods and rotifers were the most important fraction of the total zooplankton abundance, comprising 96% and

the rest is contributed by cladocerans, which exceeded 10% of the total zooplankton only in one sampling occasion at the start of the study.

**Table 25:** Phytoplankton taxa identified from Lake Zwai (\*\*\*) dominant and \* common species)

| Green algae                | Blue-greens               | Diatoms                 | Others                 |
|----------------------------|---------------------------|-------------------------|------------------------|
| <i>Botryococcus</i> sp.    | <i>Anabaena</i> sp.***    | <i>Asterionella</i> sp. | <i>Peridinium</i> sp.  |
| <i>Closterium</i> sp.      | <i>Chroococcus</i> sp.    | <i>Aulacoseira</i> sp.  | <i>Euglena</i> sp.     |
| <i>Coelastrum</i> sp.      | <i>Gloeocapsa</i> sp.     | <i>Cyclotella</i> sp.   | <i>Lepocinclis</i> sp. |
| <i>Cosmarium</i> sp.       | <i>Lyngbya</i> sp.        | <i>Cymatopleura</i> sp. | <i>Phacus</i> sp.      |
| <i>Dictyosphaerium</i> sp. | <i>Merismopedia</i> sp.   | <i>Cymbella</i> sp.     |                        |
| <i>Kirchneriella</i> sp.   | <i>Microcystis</i> sp.*** | <i>Diatoma</i> sp.      |                        |
| <i>Micractinium</i> sp.    | <i>Oscillatoria</i> sp.*  | <i>Epithemia</i> sp.    |                        |
| <i>Mougeotia</i> sp.       | <i>Pseudoanabaena</i> sp. | <i>Fragilaria</i> sp.*  |                        |
| <i>Pediastrum boryanum</i> | <i>Spirulina</i> sp.      | <i>Gyrosigma</i> sp.    |                        |
| <i>Pediastrum duplex</i>   |                           | <i>Melosira</i> sp.     |                        |
| <i>Pediastrum simplex</i>  |                           | <i>Navicula</i> sp.     |                        |
| <i>Pediastrum</i> sp.      |                           | <i>Nitzschia</i> sp.    |                        |
| <i>Scenedesmus</i> sp.     |                           | <i>Pinnularia</i> sp.   |                        |
| <i>Spirogyra</i> sp.       |                           | <i>Stauroneis</i> sp.   |                        |
| <i>Staurastrum</i> sp.     |                           | <i>Surirella</i> sp.    |                        |
| <i>Zygnema</i> sp.         |                           | <i>Synedra</i> sp.*     |                        |

**Table 26:** Rotifera records (+) from Lake Zwai (1931–2004). References: (1) Bryce (1931), (2) Cannicci and Almagia (1947), (3) Semeneh Belay (1988), (4) Green *et al.* (1991), (5) Adamneh Dagne *et al.* (2008), (6) present study and crustacean species identified. Major biogeographical regions: *Af*: Afrotropical, *Au*: Australian, *Na*: Nearctic, *Nt*: Neotropical, *O*: Oriental, *P*: Palearctic; additional regions: *Ant*: Antarctica, *Pac*: Pacific. *Cos*: cosmopolite (recorded from all six major regions). World records after De Ridder (1986, 1991), De Ridder and Segers (1997); tropicopolitan: largely restricted to tropical and subtropical latitudes, but occasionally found in suitable habitats in temperate regions.

| Rotifera Species                                | References |   |   |   |   |   | Biogeographic comments                                    |
|-------------------------------------------------|------------|---|---|---|---|---|-----------------------------------------------------------|
|                                                 | 1          | 2 | 3 | 4 | 5 | 6 |                                                           |
| <i>Anuraeopsis coelata</i> (DE BEAUCHAMP, 1932) | +          | - | - | + | + | + | Tropicopolitan (Cos)                                      |
| <i>A. fissa</i> (GOSSE, 1851)                   | -          | - | - | + | + | + | Cos (+Pac)                                                |
| <i>Ascomorpha saltans</i> (BARTSCH, 1870)       | -          | - | - | + | - | - | Cos                                                       |
| <i>Ascomorpha</i> sp.                           | -          | - | - | - | + | + | Af: probably un-described species                         |
| <i>Asplanchna brightwellii</i> (GOSSE, 1850)    | +          | - | - | - | + | + | Cos (+Pac)                                                |
| <i>A. sieboldii</i> (LEYDIG, 1854)              | -          | + | - | + | - | - | Cos: These records may actually be <i>A. brightwellii</i> |
| <i>Brachionus angularis</i> (GOSSE, 1851)       | +          | + | + | + | + | + | Cos                                                       |
| <i>B. bennini</i> (LEISSLING, 1924)             | -          | - | - | - | + | + | Cos                                                       |
| <i>B. bidentatus</i> (ANDERSON, 1889)           | -          | - | - | - | + | + | Cos (+Ant)                                                |
| <i>B. calyciflorus</i> (PALLAS, 1766)           | +          | + | + | + | + | + | Cos (+Ant)                                                |
| <i>B. caudatus</i> (BARROIS & DADAY, 1894)      | +          | - | + | + | + | + | Cos                                                       |
| <i>B. dimidiatus</i> (BRYCE, 1931)              | +          | - | - | - | - | - | Cos: Type localities: lakes Abijata, Shalla, and Zwai     |
| <i>B. falcatus</i> (ZACHARIAS, 1898)            | -          | + | + | - | - | - | Cos                                                       |
| <i>B. forficula</i> (WIERZEJSKI, 1891)          | -          | + | - | - | - | - | Cos (introduced in Na)                                    |
| <i>B. plicatilis</i> (MÜLLER, 1786)             | +          | - | - | - | - | - | Cos (+Pac): doubtful record                               |
| <i>B. quadridentatus</i> (HERMANN, 1783)        | -          | - | - | - | + | + | Cos (+Ant, Pac)                                           |
| <i>B. rubens</i> (EHRENBERG, 1838)              | -          | - | - | + | - | - | Cos                                                       |
| <i>Conochilus</i> sp.                           | -          | - | - | + | - | - |                                                           |
| <i>Cephalodella catellina</i> (MÜLLER, 1786)    | -          | - | - | - | + | + | Cos (+Ant)                                                |
| <i>C. forficata</i> (EHRENBERG, 1832)           | -          | - | - | - | + | + | Cos (+Ant, Pac)                                           |

| Rotifera Species                                                   | References |   |   |   |   |    | Biogeographic comments                                                                                               |
|--------------------------------------------------------------------|------------|---|---|---|---|----|----------------------------------------------------------------------------------------------------------------------|
|                                                                    | 1          | 2 | 3 | 4 | 5 | 6  |                                                                                                                      |
| <i>C. gibba</i> (EHRENBERG, 1830)                                  | -          | - | - | - | + | =  | Cos (+Ant, Pac)                                                                                                      |
| <i>Collotheca ornata</i> (EHRENBERG, 1832)                         | -          | - | - | - | + | +  | Cos (+Ant, Pac)                                                                                                      |
| <i>C. pelagica</i> (ROUSSELET, 1893)                               | -          | - | - | - | + | +  | Cos                                                                                                                  |
| <i>Colurella obtusa</i> (GOSSE, 1886)                              | -          | - | - | - | + | +  | Cos (+Ant, Pac)                                                                                                      |
| <i>C. uncinata</i> (MÜLLER, 1773)                                  | -          | - | - | - | + | +  | Cos                                                                                                                  |
| <i>Diplois daviesiae</i> (GOSSE, 1886)                             | +          | - | - | - | - | -? | Reliable records are missing.                                                                                        |
| <i>Eosphora najas</i> (EHRENBERG, 1830)                            | -          | - | - | - | + | +  | Cos (+Ant)                                                                                                           |
| <i>Epiphanes brachionus</i> var. <i>spinosus</i> (ROUSSELET, 1893) | -          | - | - | - | + | +  | P, E, O, Nt                                                                                                          |
| <i>Euchlanis dilatata</i> (EHRENBERG, 1832)                        | +          | - | - | - | - | -  | Cos (+Ant, Pac)                                                                                                      |
| <i>E. oropha</i> (GOSSE, 1887)                                     | +          | - | - | - | + | +  | Cos (+Ant): (1) as <i>Euchlanis parva</i>                                                                            |
| <i>Filinia longiseta</i> (EHRENBERG, 1834)                         | +          | + | - | - | + | +  | Cos                                                                                                                  |
| <i>F. novaezealandiae</i> (SHIEL & SANOAMUANG, 1993)               | -          | - | + | + | + | +  | Tropicopolitan (Af, Au, Nt, O, Pac) *records of <i>Filinia terminalis</i> PLATE (3, 4)probablyrefers to this species |
| <i>F. opoliensis</i> (ZACHARIAS, 1898)                             | -          | - | - | - | + | +  | Cos                                                                                                                  |
| <i>Hexarthra intermedia brasiliensis</i> (HAUER, 1953)             | -          | - | - | - | + | +  | Af, Nt, O                                                                                                            |
| <i>H. mira</i> (HUDSON, 1871)                                      | +          | - | + | + | - | -  | Cos (+Pac)                                                                                                           |
| <i>Keratella tropica</i> (APSTEIN, 1907)                           | +          | + | + | + | + | +  | Tropicopolitan (Cos) (+Pac)                                                                                          |
| <i>Lecane aculeata</i> (JAKUBSKI, 1912)                            | +          | - | - | - | + | +  | Tropicopolitan (Cos) (+Pac)                                                                                          |
| <i>L. acus</i> (HARRING, 1913)                                     | +          | - | - | - | + | +  | Cos: doubtful record (acidophilic species)                                                                           |
| <i>L. bulla</i> (GOSSE, 1851)                                      | -          | - | + | + | + | +  | Cos (+Pac)                                                                                                           |
| <i>L. closterocerca</i> (SCHMARDA, 1859)                           | +          | - | - | - | + | +  | Cos: (1) as <i>Lecane zwaiensis</i> n. sp.                                                                           |
| <i>L. flexilis</i> (GOSSE, 1886)                                   | +          | - | - | - | - | -  | Cos (+Ant, Pac)                                                                                                      |
| <i>L. furcata</i> (MURRAY, 1913)                                   | +          | - | - | - | + | +  | Cos: (1) as <i>Monostyla elachis</i>                                                                                 |
| <i>L. hamata</i> (STOKES, 1896)                                    | -          | - | - | - | + | +  | Cos (+Pac)                                                                                                           |
| <i>L. leontina</i> (TURNER, 1892)                                  | -          | - | - | - | + | +  | Cos                                                                                                                  |

| Rotifera Species                                     | References |   |   |   |   |   | Biogeographic comments                                |
|------------------------------------------------------|------------|---|---|---|---|---|-------------------------------------------------------|
|                                                      | 1          | 2 | 3 | 4 | 5 | 6 |                                                       |
| <i>L. luna</i> (MÜLLER, 1776)                        | +          | - | + | + | + | + | Cos (+Pac)                                            |
| <i>L. lunaris</i> (EHRENBERG, 1832)                  | +          | - | - | + | - | + | Cos (+Ant, Pac)                                       |
| <i>L. papuana</i> (MURRAY, 1913)                     | -          | - | - | + | + | + | Tropicopolitan (Cos (+Pac))                           |
| <i>L. pyriformis</i> (DADAY, 1905)                   | -          | - | - | - | + | + | Cos (+Pac)                                            |
| <i>L. undulata</i> HAUER, 1938                       | -          | - | - | - | + | + | tropicopolitan (Cos)                                  |
| <i>L. ungulata</i> (GOSSE, 1887)                     | +          | - | - | - | - | - | Cos                                                   |
| <i>Lepadella apsicora</i> (MYERS, 1934)              | -          | - | - | - | + | + | Tropicopolitan (Af, Au, Na, Nt, O)                    |
| <i>L. ehrenbergii</i> (PERTY, 1850)                  | -          | - | - | - | + | + | Cos                                                   |
| <i>L. patella</i> (MÜLLER, 1773)                     | -          | - | - | - | + | + | Cos (+Ant, Pac)                                       |
| <i>L. triptera</i> (EHRENBERG, 1832)                 | -          | - | - | - | + | + | Cos (+Ant, Pac)                                       |
| <i>Mytilina mucronata</i> (MÜLLER, 1773)             | +          | - | - | - | - | - | Cos (+Ant)                                            |
| <i>M. ventralis</i> (EHRENBERG, 1830)                | +          | - | - | + | - | - | Cos (+Pac)                                            |
| <i>Plationus patulus</i> (MÜLLER, 1786)              | +          | - | - | - | + | + | Cos: (1) as <i>Brachionus patulus</i> MÜLLER          |
| <i>Polyarthra indica</i> (SEGERS & BABU, 1999)       | -          | - | - | - | + | + | Af, O, Pac                                            |
| <i>P. vulgaris</i> (CARLIN, 1943)                    | +          | - | - | - | + | + | Cos (+Pac): (1) as <i>Polyarthra trigla</i> EHRENBERG |
| <i>Pompholyx complanata</i> (GOSSE, 1851)            | -          | - | - | - | + | + | Cos                                                   |
| <i>Proalides</i> cf. <i>wulferti</i> (SUDZUKI, 1959) | -          | - | - | - | + | + | E, P, Pac                                             |
| <i>Scaridium longicaudum</i> (MÜLLER, 1786)          | +          | - | - | - | - | - | Cos (+Ant)                                            |
| <i>Trichocerca gracilis</i> (TESSIN, 1890)           | -          | - | + | + | + | + | Cos                                                   |
| <i>T. pusilla</i> (JENNINGS, 1903)                   | +          | - | + | + | + | + | Cos (+Pac)                                            |
| <i>T. ruttneri</i> (DONNER, 1953)                    | -          | - | + | + | + | + | Cos                                                   |
| <i>T. tenuior</i> (GOSSE, 1886)                      | -          | - | - | + | - | - | Cos (+Pac)                                            |
| <i>Trichocerca</i> sp.                               | -          | - | - | + | - | - |                                                       |
| <i>Wolga</i> sp.                                     | -          | - | - | - | + | + |                                                       |



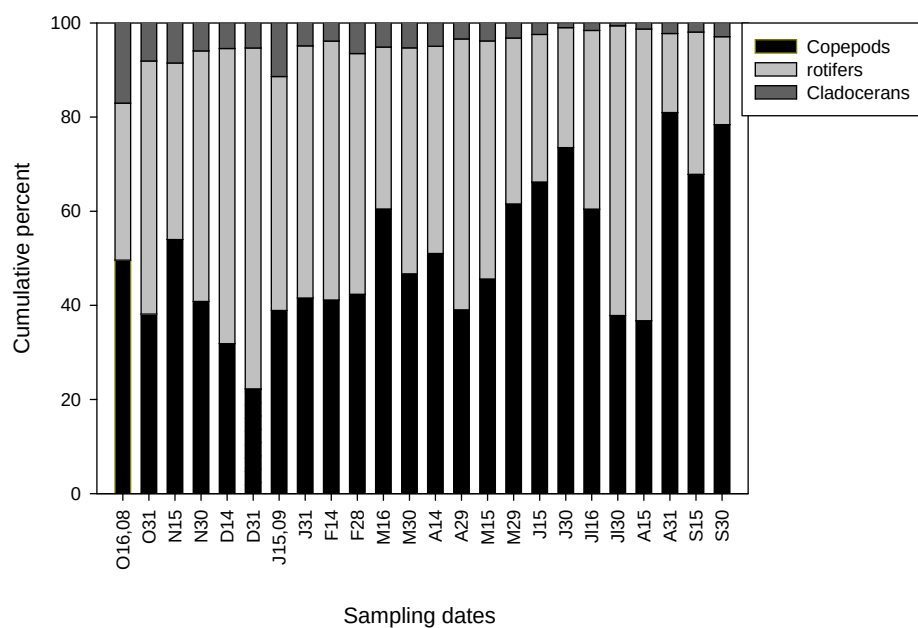
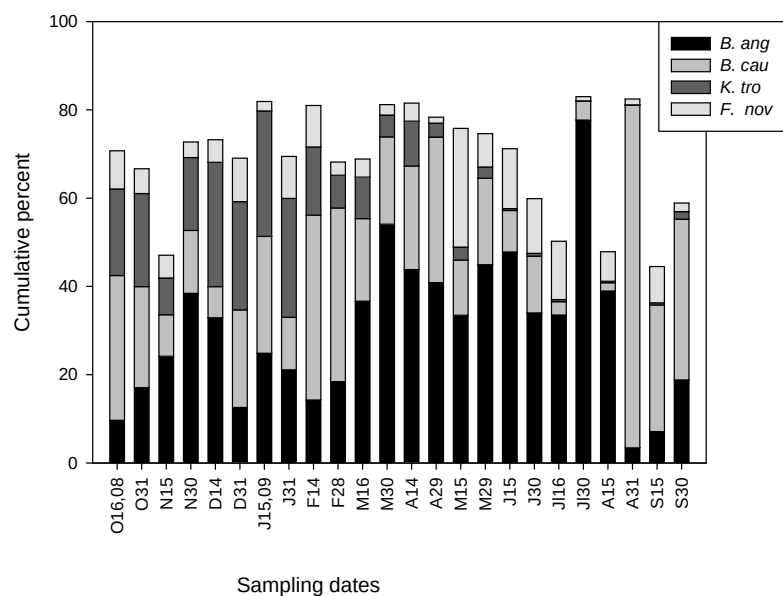
**Table 27:** Cladocera and copepoda species of Lake Zwai

| Cladocera                       | Copepoda                         |
|---------------------------------|----------------------------------|
| <i>Ceriodaphnia cornuta</i>     | <i>Mesocyclops aequatorialis</i> |
| <i>Ceriodaphnia cornuta</i>     | <i>Afrocyclus gibsoni</i>        |
| <i>Alona</i> sp.                | <i>Mesocyclops aequatorialis</i> |
| <i>Daphnia barbata</i>          | <i>Thermocyclops decipiens</i>   |
| <i>Diaphanosoma excisum</i>     |                                  |
| <i>Diaphanosoma mongolianum</i> |                                  |
| <i>Moina Micrura</i>            |                                  |
| <i>Pseudosida szalay</i>        |                                  |

Zooplankton of Lake Zwai showed conspicuous variations in species composition and abundances over time. From 21 rotifer species routinely counted, *Brachionous angularis*, *Brachionus caudatus* and *Keratella tropica* were dominant and were greater than two-third of the total rotifers abundance in the 54% of the sampling period, but the first two varied inversely to each other (Fig. 20). This agrees with the observation of Fernando that *Brachionus* and *Keratella* species typically contribute greater than 50% of the rotifer species in tropical lakes (Fernando, 1980b).

From seven species of cladocera, *Moina micrura* was the dominant that contributed 52% of the abundance, *Alona* sp. and *Diaphanosoma excisum* commonly occurred. *Daphnia barbata* and *Ceriodaphnia cornuta* were absent from the plankton community starting from March and May, respectively. *Diaphanosoma mongolianum* and *Pseudosida szalay* were very rare and hence they were not counted. Copepods were represented with only three species of cyclopoids: *Thermocyclops decipiens*, *Mesocyclops aequatorialis* and *Afrocyclus gibsoni*. Among the copepods, *A. gibsoni* was very rare as they are observed in only 8 samplings. Among the adult copepods *T. decipiens* dominated the group in all stations throughout the sampling periods. A common feature observed in the species composition of zooplankton in Lake Zwai was the temporal fluctuations in their assemblage.

*D. barbata* and *C. cornuta* from the cladocerans, *A. gibsoni* from copepods and several species of rotifer were absent from most samples. *P. szalay* and the invertebrate predator *Chaoborus*, which were not reported in previous studies (Fernando *et al.*, 1990; Adamneh Dagne *et al.*, 2008), are recorded in this study. *Chaoborus* was rare from day samples, but it was possible to see them in samples collected during the night. *D. mongolianum* was reported from Lake Zwai by Korovchinsky (1987) but was not reported by Adamneh Dagne *et al.* (2008). It was however identified in the present study but rarely occurred in the samples. Large bodied planktivores particularly *Daphnia* and calanoid species were absent in Lake Zwai.



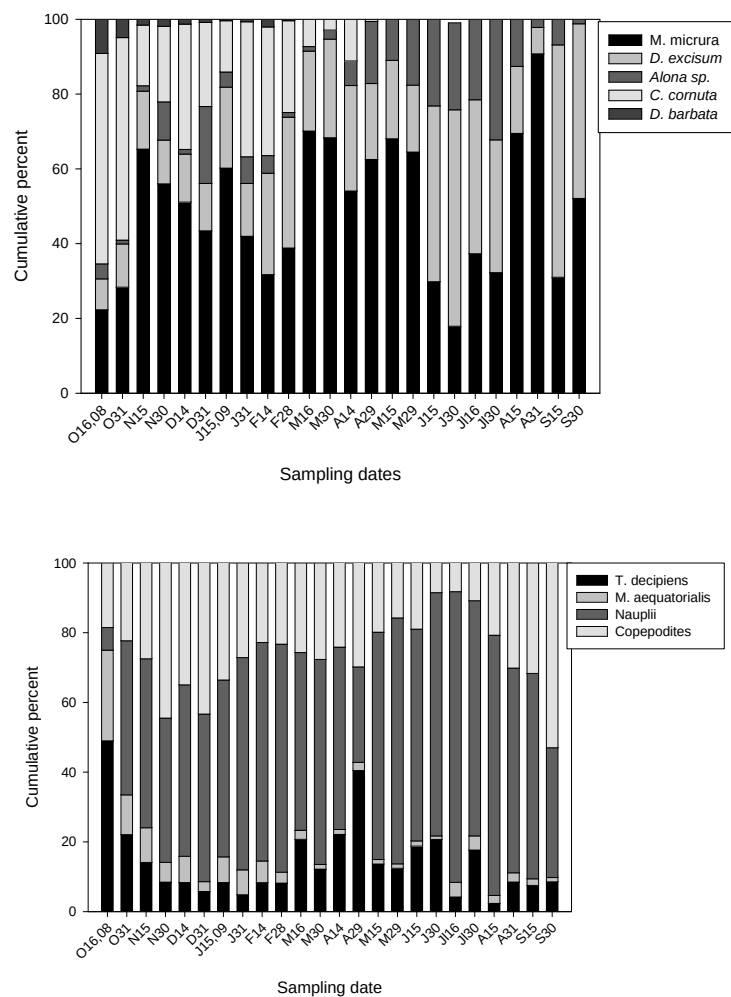
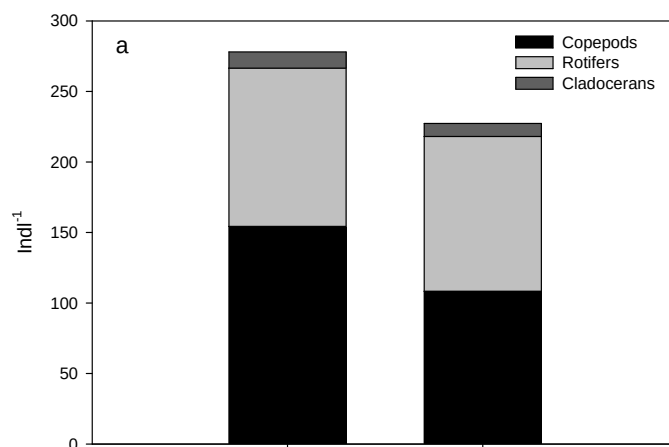
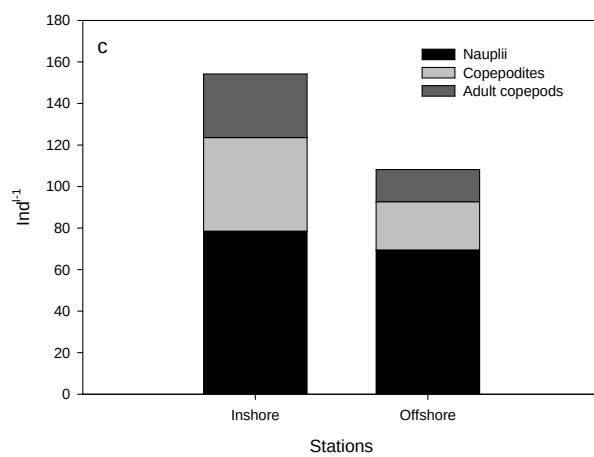
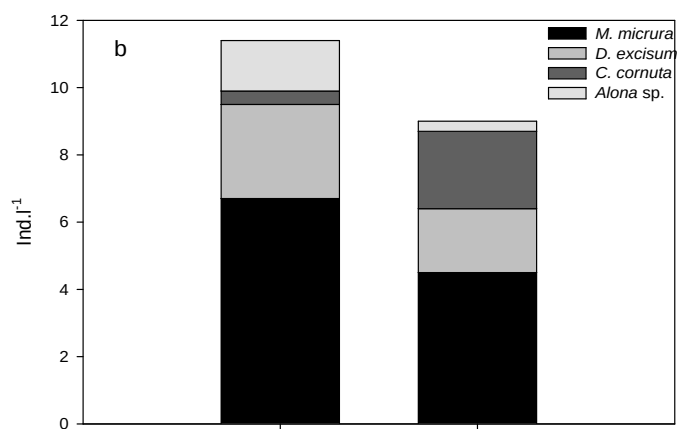


**Figure 20:** Relative contributions of rotifers, cladocerans and copepods to the total zooplankton (top-down) to the respective groups from 16 October to 30 September 2009

**Spatial and temporal changes of zooplankton:** To understand the spatial and temporal changes in the composition and abundance of zooplankton species in Lake Zwai, the fluctuations of individual species was recorded based on their average abundances. Generally, there was the tendency by zooplankton to aggregate in the inshore or littoral zones of Lake Zwai sampling sites among the dense macrophytes; rather than in the offshore or pelagic areas (Fig. 21a). From 29 zooplankton species routinely counted, *Ceriodaphnia cornuta*, *Daphnia barbata*, *Brachionus angularis* and *Brachionus calyciflorus* showed their maximum peaks and higher proportions of abundances at the littoral sampling stations, while the rest were observed in the open waters (Fig. 21 b, c, d). *Brachionus caudatus*, however, showed peak abundances in the open waters (pelagic areas) (Fig. 21b). Besides the variations in horizontal gradients (distributions) of crustaceans, variations in their vertical distribution were consistent with previous reports.





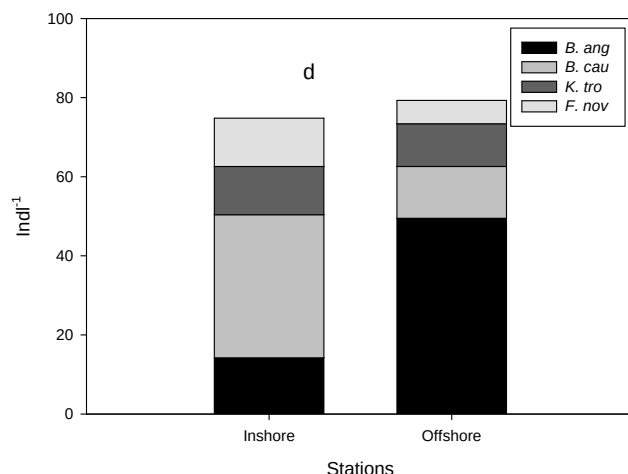


**Figure 21:** Spatial distribution of (a) zooplankton groups (b) rotifers, (c) cladocerans and (d) copepods from 16 October 2008 to 30 September 2009.

Although Lake Zwai is a shallow turbid lake with a mean depth of 2.5 m and mean Secchi depth of 29.3 cm, larger adults and egg-carrying *Mesocyclops aequatorialis* showed clear variation in their vertical distribution. In most cases, the species tended to stay in the lower parts of the lake, i.e., at 2 m depth and below. The presence of diel vertical migration (DVM) was also clearly evident from night samples where the number of ovigerous females, clutch size and body size of *M. aequatorialis* were markedly varied from day samples values (Fig. 25a). Ovigerous females with higher clutch were in the lower water column during the day and rose up to the upper water columns and surfaces at night (Fig. 25b). Body length measured from the day samples revealed that smaller size *M. aequatorialis* usually males, copepodites and last copepodite stages were common while adults and egg-carrying females were very rare in illuminated upper water column. Pronounced sharp decline in nauplii was observed in both stations at the end of May which was the result

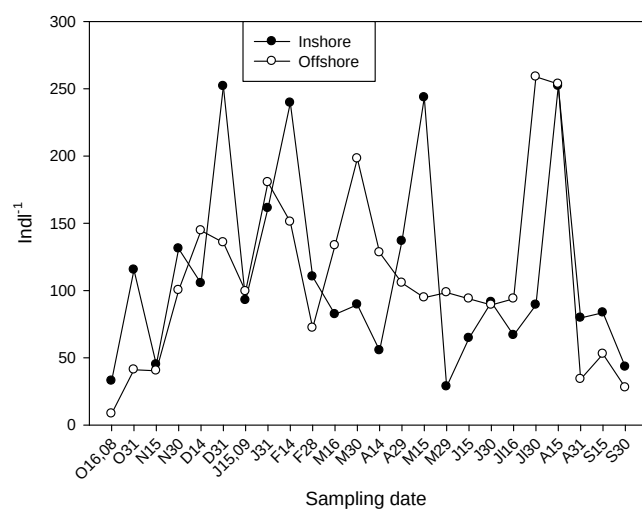
of lowest total numbers of eggs by ovigerous cyclopoids between ends of February to March and could be due to predation during the relatively high water transparency. However, pre-adult copepods were by far dominant throughout the study period. They contributed 77.2% of the total crustaceans and 42.2 % of the total zooplankton abundance.

The peak abundance periods of the zooplankton showed a clear pattern. Rotifers showed their peak abundances during the dry season and reached their maximum ( $253 \text{ indL}^{-1}$ ) during the rainy seasons (Fig. 22). Cladocerans on the other hand showed a single peak ( $19.6 \text{ indL}^{-1}$ ) during the dry season with a progressive decline towards the rainy season. Copepods showed three abundance peaks with a progressive increase and with the maximum ( $259.3 \text{ indL}^{-1}$ ) at the beginning of the rainy season and the second ( $241.8 \text{ indL}^{-1}$ ) during the rainy season (Fig. 22). However, consistency in the abundance of species was not common except for very rare species that occurred with low numbers.

Spatial variation in peak abundances was also observed where almost all groups showed their peak abundances in the inshore (littoral zones) except the rotifers which also showed four peaks in the inshore and two peaks in the offshore (pelagic zones) sampling station (Fig. 22).

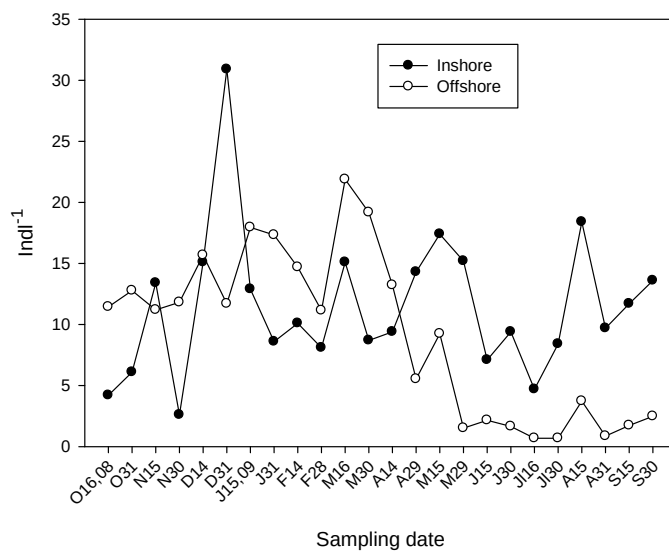


## Rotifer



Sampling date

## Cladocera



Sampling date

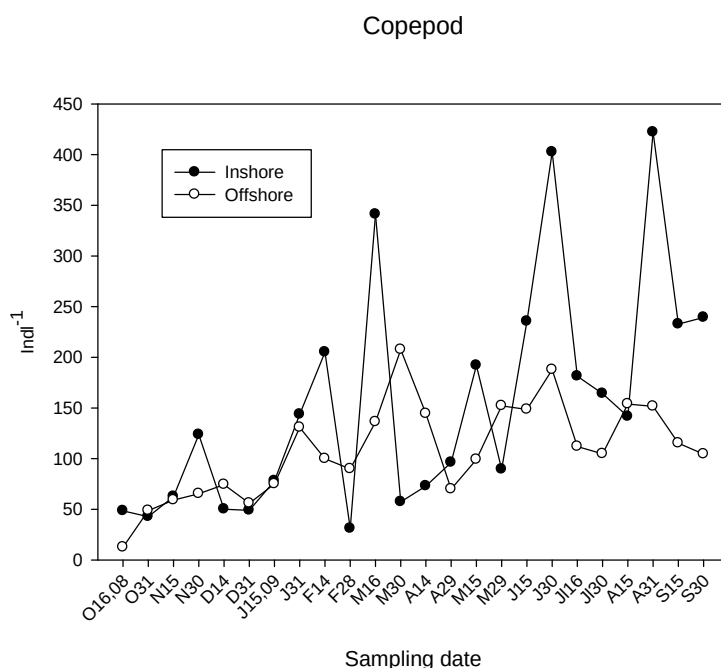


**Figure 22:** Mean abundance of rotifers, cladocerans and copepods in Lake Zwai from 16 October 2008 to 30 September 2009

*M. micrura*, *T. decipiens* and *M. aequatorialis* contributed 90.8 % of the total annual zooplankton biomass (86% of which is by copepods). Spatio-temporal variation was observed in crustaceans' biomass. Cladoceran biomass peaked during the dry season (18.5 mg dw m<sup>-3</sup>) with minimum (2.6 mg dw m<sup>-3</sup>) during the wet season. Copepods on the other hand showed two major peaks 174.7 and 155.4 mg dw m<sup>-3</sup> during the wet season but the minimum biomass 23.4 mg dw m<sup>-3</sup> during the dry period. Cladocerans species biomass showed a decreasing pattern in the rainy season and the reverse by copepods (Fig. 23).

Total cladoceran biomass and water transparency showed similar pattern, an increase in the dry season and a decrease in the rainy season (Fig. 24). On the other hand crustacean biomass showed spatial variation, three peak abundances were recorded inshore but a single (less than half that of the inshore) in the offshore sites. Large-sized and egg-carrying female *M. aequatorialis* were rare from day samples which were abundant from night samples (Table 28). Length and dry weights of crustacean species and pre-adult stages and their mean biomass are presented in Table 28.

**Table 28:** Mean lengths (range), individual dry weight ( $\mu\text{g}$ ), mean  $\pm$ SD dry biomass ( $\text{mgm}^{-3}$ ) of Crustaceans (\*only from night samples)

| Species/stages                     | Mean length( $\mu\text{m}$ ) | Mean dry weight ( $\mu\text{g}$ ) | Mean+sd biomass ( $\text{mgm}^{-3}$ ) | Sample size |
|------------------------------------|------------------------------|-----------------------------------|---------------------------------------|-------------|
| <i>Ceriodaphnia cornuta</i>        | 295 (170-487)                | 0.5                               | 1.3 $\pm$ 1                           | 569         |
| <i>Moina micrura</i>               | 435 (212-742)                | 0.9                               | 4.2 $\pm$ 2.7                         | 1256        |
| <i>Mesocyclops aequatorialis</i>   | 890 (742-1504)               | 3.2                               | 13.3 $\pm$ 8.8                        | 385         |
| <i>Thermocyclops decipiens</i>     | 641 (424-890)                | 1.6                               | 28.8 $\pm$ 26.3                       | 1047        |
| Cyclopoid copepodites              | 432 (212-742)                | 0.7                               | 21.8 $\pm$ 16                         | 1393        |
| Cyclopoid nauplii                  | 174 (106-297)                | 0.2                               | 14.4 $\pm$ 9.9                        | 1197        |
| <i>Mesocyclops aequatorialis</i> * | 1212 (763-1526)              | 7.0                               |                                       | 179         |

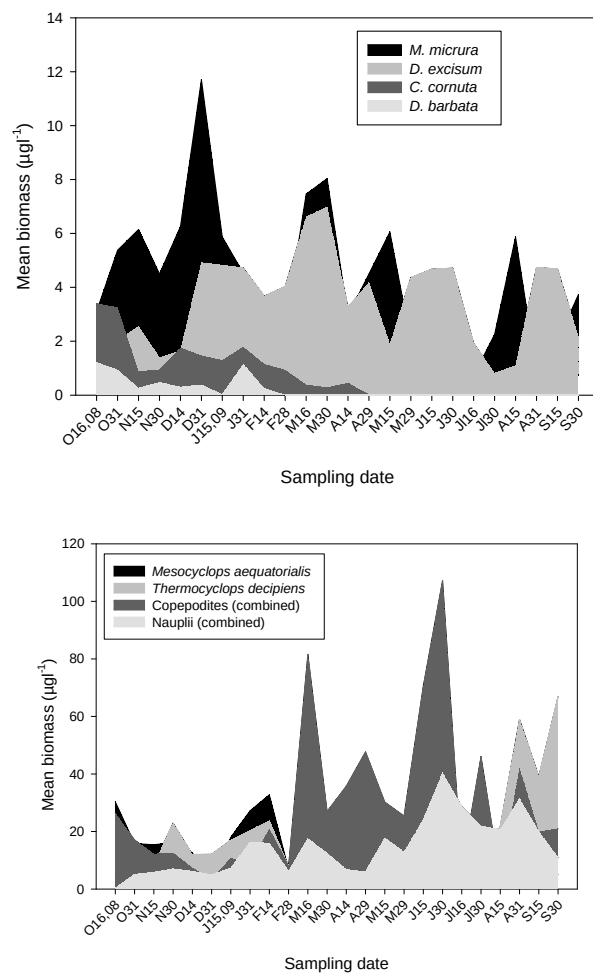


**Figure 23:** Temporal biomass patterns of crustaceans from 16 October 2008 to 30 September 2009

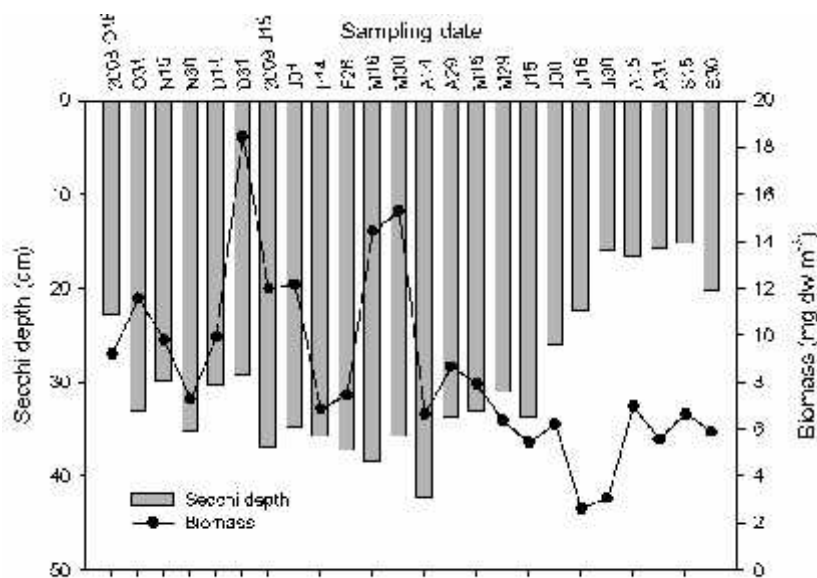


**Figure 24:** Temporal variation in cladoceran biomass and water transparency in Lake Zwai from 16 October 2008 to 30 September 2009

## Discussions

**Physico-chemical and Chlorophyll-*a* measurements:** Limnological measurements in Lake Zwai displayed spatial and temporal variations. Conductivity, turbidity, water transparency (Secchi depth), dissolved oxygen (inshore or littoral zones) and chlorophyll-*a* concentration measurements showed that there are fluctuating results. On the other hand, water temperature, dissolved oxygen (offshore or pelagic zones) and pH showed little variation temporally and much more uniform vertically with a difference of less than one in each case. No thermal strata and dissolved oxygen gradients were observed along the water column resulting from wind-induced frequent mixings in shallow systems such as Lake Zwai. The observed

variation in dissolved oxygen inshore than offshore could be due to decomposition of macrophytes facilitated by the high temperature throughout the year and evapo-respiration. Progressive increase in the conductivity during the dry period and a decline towards the rainy season could be explained by lake level fluctuations and more evaporative concentration of ions during the dry periods. Despite the observed fluctuations in volume in the rainy and dry seasons, during this study period, conductivity of the lake water varied from 385 - 463  $\mu\text{Scm}^{-1}$ . This range comparable to the long time records of 372-427  $\mu\text{Scm}^{-1}$  in 1937/8 by Cannicci and Almagia (1947); 300-400  $\mu\text{Scm}^{-1}$  by Martens and Tudorancea (1991) and 295-468  $\mu\text{Scm}^{-1}$  by Zinabu Gebremariam *et al.* (2002).

Frequent wind-induced mixing together with sediment laden inputs from surface runoffs and inflows from rivers during the main rainy seasons have substantially impacted the turbidity and hence low water transparency of the lake. The maximum turbidity (342 FTU), which was greater than four mean previous measurements, is suspected to be the major cause for the decline in biotic components of the lake. The shallowest records of Secchi depth, the lowest records of dissolved oxygen and sharp decline in chlorophyll-*a* concentration were recorded at the time of high turbidity. Most zooplankton species showed varied levels of decline in their abundance in the dry seasons and just slight increase by a few amounts in the wet seasons (Fig. 22). Nevertheless, abiotic conditions such as water temperature, dissolved oxygen, conductivity and pH were less likely to influence zooplankton community structure in Lake Zwai because of the weaker gradients of these variables spatio-temporally. The increase in chlorophyll-*a* concentration following the rains of the wet seasons was associated with nutrient inputs with runoffs that stimulated the increase in the numbers and biomass of phytoplankton and the presence of co-dominancy. The increase in chlorophyll-*a* concentration shortly after the peak turbidity could be for two reasons. First, the

phytoplankton species in Lake Zwai were mainly dominated by blue-greens which can stand some levels of turbid conditions.

**Plankton community composition:** Besides the data on physico-chemical variables, information about the phytoplankton community of Lake Zwai is essential to evaluate the fluctuation in composition and abundance of the herbivorous. Phytoplankton community of Lake Zwai is reported to be dominated by blue green algae mainly large filamentous and colonial forms (Schröder, 1984; Wood and Talling, 1988; Adamneh Dagne *et al.*, 2008). The arguments suggested as to why the blue greens dominate over other algal species are their ability to survive under different environmental conditions. According to Tilman *et al.* (1986) blue greens are able to grow under low light intensities or more turbulent conditions (Allonson *et al.*, 1990). Their shade tolerant ability could enable them to grow in high turbidity than other algae (Scheffer, 1998). Large herbivorous zooplankton species are rare in the tropics as compared with the temperate (Fernando, 1994, Sarma *et al.* 2005) and small body size zooplankton with low grazing pressure would be less likely to control the large colonial and filamentous blue greens (Lazzaro, 1987). Even the filter-feeder Nile tilapia had no effect on the biomass of large blue-green algae (Okun *et al.*, 2008). In shallow lakes like Lake Zwai, continuous stirring of the bottom sediments by the turbulent could ensure the availability of nutrients in the water column and subsequent algal production. Internal recycling of nutrient via tilapia excretion is also reported to contribute up to 12% of the external TP load in a reservoir in Brazil (Starling *et al.*, 2002) which could also be in Lake Zwai as the tilapia are the dominant fish species. With all those reasons together with high temperature, high light intensities with no marked seasonal variation could favor blue greens to persist all year round in Lake Zwai.

Species composition of zooplankton in Lake Zwai reflects typical tropical aspects, i.e., the rotifers are dominant in terms of species richness. Rotifers

and pre-adult copepod stages or nauplians were also numerous, comprising of 87.5% of the total zooplankton. Dominancy of rotifer species numbers over the crustaceans has also been reported in the Ethiopian Rift Valley like lakes, such as, Awassa Hawassa) which has 8 copepods and 5 cladocerans but 40 rotifer species (Seyoum Mengistou and Fernando, 1991), Lake Abijata 4 copepods and 13 rotifer species (Kassahun Wodajo and Amha Belay, 1984), Lake Guiers, Senegal in West Africa; 9 copepods, 5 cladocerans and 14 rotifer species (Kâ *et al.*, 2006).

The number of cladoceran species in Lake Zwai is similar with other reports from Lake Naivasha, Kenya, 3 copepods, 11 cladocerans and 12 rotifer species (Mavuti and Litterick, 1981). Similar high numbers of rotifers over cladocerans were also reported from deep tropical lakes such as Kivu 12 rotifers, 3 copepods and 4 cladocerans (Isumbisho *et al.*, 2006). It is also shown that zooplankton in tropical freshwaters is dominated by smaller planktonic organisms such as rotifers (Green, 1993; Fernando, 1994). These smaller zooplankters can co-exist along with blue green algae in the lake as they both fit into different niches of the aquatic environment (Bouvy *et al.*, 2000).

Considerable inconsistencies were observed in reporting the composition of zooplankton of Lake Zwai. Two cladoceran species *Ceriodaphnia cornuta* and *Daphnia barbata* which were not reported in Fernando *et al.* (1990) were later reported by Adamneh Dagne *et al.* (2008). In this study the same was confirmed during the first year, but later these two species disappeared from the samples. In this study, two other cladoceran species *Diaphanosoma mongolianum* and *Pseudosidaszalayi* which were not reported in earlier studies (e.g. Adamneh Dagne *et al.*, 2008) could be identified for Lake Zwai. The littoral species *Alona* which was reported to be dominant in the open waters of Lakes Zwai and Awassa (Fernando *et al.*, 1990) was not confirmed in the present study. It occurred at higher density in the inshore station (littoral zone)



(maximum  $7.9 \text{ indL}^{-1}$ ) than the offshore station (pelagic zone) which reached only up to  $1.1 \text{ indL}^{-1}$ . Such distribution patterns of littoral species into pelagic waters could be due to the violent and frequent wind-induced turbulence in Lake Zwai. Absence of invertebrate predators was reported in Lake Zwai in the earlier studies of Fernando *et al.* (1990) and Adamneh Dagne *et al.* (2008). These were recorded in this study from night samples possibly due to differences in methodological approaches. The current composition of the rotifer species in Lake Zwai was found in good agreement with previous records with little changes in the cases of some species numbers over past decades (Table 4.3). From bio-geographical perspectives, spatially wide-ranging rotifers were observed that showed distributions in the cold temperate and even hot lowland waters of the world (see also Adamneh Dagne *et al.*, 2008). In the present study in addition to species numbers and biomass variations in zooplankton composition, it was also evident that larger adults and ovigerous *Mesocyclops aequatorialis* were absent from day samples and rarely seen in the inshore samples. A combination of factors could be cited as reasons for the variations or inconsistencies in reporting. Among these factors could be increasing turbidity due to siltation of the lake that impacted the ecological relations of zooplankton, technically time of sampling (in a 24-hour day and seasonality), depth of sampling, inconsistencies in sampling, selection and number of sampling sites, the required expertise in identification, limitations in field and laboratory facilities and so on.

#### **Abundance, spatial and temporal distribution of zooplankton:**

Comparison of the temporal distribution patterns of zooplankton between two different sampling intervals (biweekly and monthly) revealed the importance of sampling strategy as indicated by others (e.g. Twombly 1983; Avois *et al.*, 2000). This distribution pattern (Fig. 24) would have been missed if monthly samplings had been employed. In the present study there were distinct spatial and temporal distribution patterns in the abundances of zooplankton species.

A progressive decline in cladoceran abundance towards the rainy season and their fluctuating to be gradually replaced by a general increase of the rotifers and copepods, particularly the juvenile stages. It was also observed that rotifers can coexist with cladocerans in shallow lakes because these two groups do not share the same food resources during the episodic sediment re-suspension periods (high turbidity) (Kirk and Gilbert, 1990) and copepods are suggested to be highly tolerant to turbidity (e.g. Hart, 1988). The declining trend in cladocerans standing stock was associated with the progressive decline in the water transparency due to increasing turbidity (Fig. 24). The difference in the response of cladoceran species to the increasing turbidity (e.g. disappearance of *Daphnia barbata* and *Ceriodaphnia cornuta* at low water transparency but a relative increase by *Moina micrura* and *Diaphanosoma excisum*) could be that these species were affected unequally. Similar results have been reported by Threlkeld (1986). Despite the increase in phytoplankton production as observed from increased chlorophyll-*a*, the decline in cladocerans could be due to low food quality since most of the un-gazeable blue green algal species were dominant during the reduced water transparency. The case of *C. cornuta* is difficult to explain; probably these changes are due to predation by *Chaoborus* and turbidity effects. *Chaoborus* are reported to switch from day time predation on copepodites to night time predation on cladocerans (Lewis, 1977). Disappearance of *Daphnia* for months and even years could be associated with high turbidity and deterioration of food quality due to increasing turbidity has been reported from different water bodies (Kalk, 1979; Hart, 1986, Levine *et al.*, 2005).

Many studies indicated that the formation of large colonies or filaments of blue-greens which have a physical constraint on ingestion, nutritional inadequacy and toxicity limits their exploitation by zooplankton (e.g. Hanazato, 1991). This is possible as large colony forming and filamentous Cyanobacteria from tropical lakes are shown to produce cyanotoxins (Haande

*et al.*, 2007). According to Haney *et al.* (1994) cladocerans reduce filtering rate or avoid depths where toxic *Microcystis* species are abundant and/or cladocerans and especially *Daphnia* species respond to changes in phytoplankton composition and food quality (Sterner *et al.*, 1992b). However, copepods and rotifers were the major components of the total zooplankton throughout the study period, comprising of 96% of the zooplankton community. Such a situation is also indicated by Morgan *et al.* (1980) in his review that in shallow warm turbulent waters, relatively smaller cyclopoids exceeded cladocerans in numbers. It is also in agreement with reports from tropical lakes where copepods had larger contributions to total zooplankton over cladocerans (e.g. Twombly, 1983; Carmouze *et al.*, 1983; Seyoum Mengistou and Fernando, 1991a; Irvine and Waya; 1999; Aka *et al.*, 2000; Ka *et al.*, 2006; Isumbisho *et al.*, 2006; Adamneh Dagne *et al.*, 2008). In the present study, the contributions of cladocerans to the total crustaceans and total zooplankton were 7.4 and 4.1%, respectively. Copepods abundance at reached their maximum of 259.3 indL<sup>-1</sup>, which is low when compared with values reported from other tropical lakes (e.g. Lake George, 880 indL<sup>-1</sup>, Lake Chilwa, 800 indL<sup>-1</sup>, Lake Chad, 318 indL<sup>-1</sup> but higher than Lake Hawassa (Awassa), 180 indL<sup>-1</sup> and previous report from Lake Zwai 200,6 indL<sup>-1</sup>). Fish and *Chaoborus* predation on copepods mainly egg carrying *Mesocyclops aequatorialis* limited the maximum copepod abundance in Lake Zwai which was also evident from the total numbers of eggs that was continuously low during the relative transparent water during dry period and maximum number recorded only during low transparency as the numbers of egg carrying females were increased in the sample. Cladocerans however, were lower in their abundance as compared with value form Lake Hawassa. *Diaphanosoma* during its maximum peak period reached a density of 18 indL<sup>-1</sup> in Lake Hawassa but it was 5 indL<sup>-1</sup> in Lake Zwai also lower than the previous report of 13 indL<sup>-1</sup>. *Moina micura* the dominant among the cladocerans in the present study were counted to be 13.4 indL<sup>-1</sup>; which are three-folds lower than the

earlier report. This could be the adverse effects of complex interacting factors like high turbidity and hence low food quality in Lake Zwai. Fluctuations in the abundance of zooplankton in shallow tropical lakes are related to periodic events such as dry and wet seasons (e.g. Lake Chilwa, Kalk, 1979; Lake Nivasha, Kenya, Mavuti and Litterick, 1981; in Rift Valley lakes, Kassahun Wodajo and Amha Belay, 1984; Lake Tana, Eshete Dejen *et al.*, 2004 and this study).

Horizontal gradient in zooplankton distribution with increasing density in the inshore sites as high as two to five folds indicates the advantages of macrophytes as a refuge against predation (see also Lauridsen and Buenk, 1996; Burks *et al.*, 2002). On the contrary the relatively large bodied crustaceans (e.g. *Daphnia barbata* and egg carrying *Mesocyclops aequatorialis*) were rare and/or absent from the inshore station within the macrophytes and could probably be high predation pressure from benthic and epiphytic invertebrate predators (Sih *et al.*, 1998). It could also be possible that the presence of year round reproduction by *Tilapia* (Zenebe Tadesse, 1988) which is enhanced by the high, relatively constant temperature and the juvenile of which inhabited the littoral macrophyte to feed and seek refuge against their predator that exclude the larger crustaceans. The numeric abundance data of ovigerous female *M. aequatorialis* also revealed this same fact. From 24 samples conducted from inshore station, only 14 *T. decipiens* and one *M. aequatorialis* ovigerous females were found which indicated the presence of clear avoidance of the macrophytes by the large-sized copepods. On the other hand, the dominance of the smaller raptorial *T. decipiens* in all stations throughout the sampling period could be due to its omnivorous feeding habits which are reported to feed on *Microcystis* and *nauplii* in Lake George Uganda (Burgis, 1969) and have gained an advantage from the dominant blue greenalgae. According to Adamneh Dagne and Herzig (2013),

*M. micrura* and *T. decipiens* sampled from inshore were significantly ( $p < 0.0001$ ) than those in the offshore station.

A clear diel vertical migration was observed by larger adults and egg carrying *M. aequatorialis* in Lake Zwai (Figs. 25a, b and 26). Although typical zooplanktivore fish is absent in Lake Zwai, the presence of substantial numbers of large size copepods in the stomachs of the indiscriminate feeder catfish couldn't be considered as incidental. One can add Nile-tilapia, particularly the juvenile stages that feed on macro-zooplankton, particularly the daphnids. As high as 2054 individual copepods were counted from a single stomach of a catfish, 14 copepods from the stomachs (those in good body condition) were measured for their body lengths. They were all found out to be greater than 1060  $\mu\text{m}$  up to 1378  $\mu\text{m}$  which is obviously the size of large gravid females of *M. aequatorialis*. The probable explanation could be that if the catfish fed on them during night, it must have collected them from the upper column of the lake-water or if it collected the copepods in daylight, it must have collected them from the bottom as the copepods are known to make diel migration (see adamneh Dagne *et al.* 2008 and Brook Lemma 2004, 2007 and 2008). Similar results of zooplanktivory by catfish where significant reductions in the biomass of adult *Mesocyclops* species, particularly females, have been reported from Lake Kinneret, Israel (Gophon, 1988). On the other hand, phytoplankton mainly blue green algae and detritus were found to form the entire contents of the stomachs of juvenile stages of Nile-tilapia ( $n=120$ ). However, the juvenile stages of Tilapia are also reported to feed on zooplankton, too (Tudorancea *et al.*, 1988; Chapman and Fernando, 1994). A recent study on Lake Hashenge one of the highland Ethiopian lake also indicated the presence of abundant zooplankton species in the stomach contents of *Oreochromis niloticus* (Nile-tilapia) (Zenebe Tadesse, 2010). There is also evidence from an experimental study that tilapia selectively feed

on large cladocerans (Okun *et al.*, 2008) and impacted biomass of both phytoplankton and zooplankton (Menezes *et al.*, 2010).

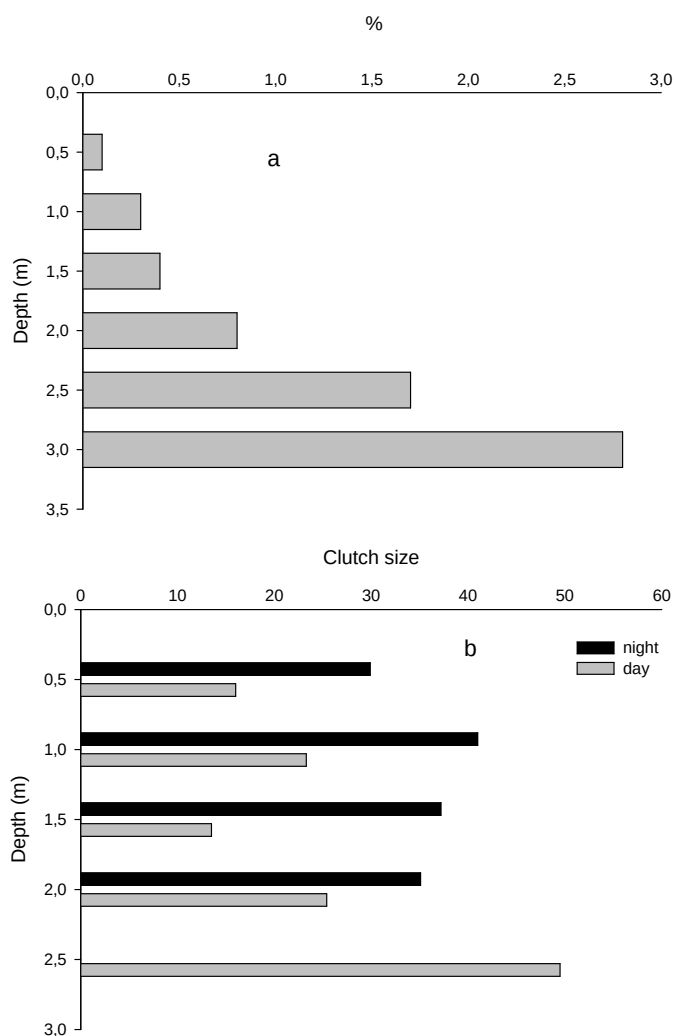


**Figure 25:** (a) Vertical distribution of proportion of gravid females by day and (b) diel variation in clutch sizes of *Mesocyclops aeruatorialis* at offshore station, Lake Zwai

The invertebrate predator *Chaoborus* has been reported to be a major component of the limnetic food web in tropical lakes (e.g. in Lake Chad by Saint-Jean, 1983; in Lake Malawi by Irvine, 1997; or in shallow reservoirs (Aka *et al.*, 2000; Pagano *et al.*, 2003). However, *Chaoborus* was not reported from Lake Zwai in earlier studies. This time, it was confirmed from night samples and was found to undergo diel vertical migration. Turbidity of the lake and its ability to migrate deep in the water column (Irvine, 1997; MacQueen *et al.*, 1999) could help this invertebrate to co-exist with fishes. It was also confirmed in this study that low numbers of *Chaoborus* were found in the stomachs of catfish as compared to copepods and other benthic zooplankton (Fig. 26). It is therefore reasoned that the effects of *Chaoborus* on the zooplankton of Lake Zwai could reach to as much as 90% of the population per day (Pastorok, 1980), and 20-29 prey per individual per day of the prey population (Pagano *et al.*, 2003). An experimental study on *Chaoborus* predation on zooplankton indicated that large zooplankton like cladocerans, and adult *Mesocyclops* species were significantly affected (Brook Lemma 2004). Consistent high selection of *Chaoborus* for cyclopoid *Mesocyclops aequatorialis* is also reported from Lake Malawi (Irvine, 1997) which could be one of the reasons for the observed diel vertical migration and low abundance of this species in Lake Zwai.



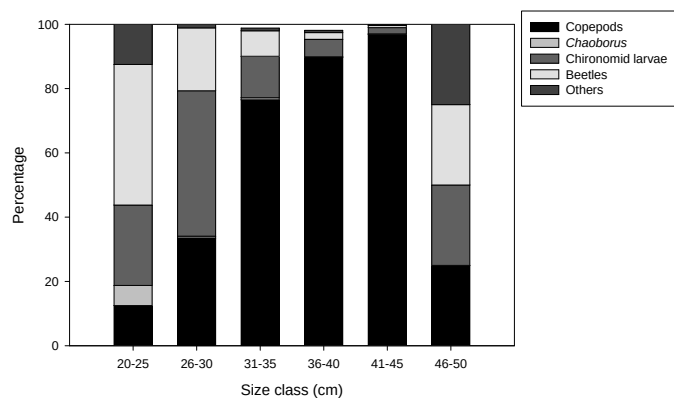


**Figure 26:** Percentage occurrence of different food items in the stomachs of *Clarius gariepinus* of Lake Zwai

## Conclusions

Species composition of zooplankton in Lake Zwai reflects typical tropical aspects where micro-zooplankton (like rotifers and pre adult copepods) were by far the dominant ones. In Lake Zwai, turbidity and food quality have impacted the abundance and composition of cladocerans, but not to juvenile copepods and rotifers. Cladocerans showed marked variation between dry and rainy seasons with a general decline following the shallowness in the water transparency; where apparently two species, namely, *Ceriodaphnia cornuta* and *Daphnia barbata* disappeared from the plankton community. Presence of diel vertical migration by large and gravid *Mesocyclops aequatorialis* in the highly turbid and shallow Lake Zwai suggests high predation pressure on them by fish and the phantom midge larvae *Chaoborus*. To understand such dynamics in zooplankton species composition and their distribution patterns in shallow tropical lakes, studies should continue for the purposes of biologically monitoring the ecological system and sustainability of water quality for improved services to humans in terms of fish production, water supply for

irrigation and household use, maintaining the microclimate of the area and so on.

### Acknowledgments

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## Chapter 5

### Macrophyte Community Diversity, Distribution and Production in Lake Zwai, Ethiopia

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#### Abstract

Macrophytes play a great role in maintaining ecological integrity of shallow lakes by interacting with biotic and abiotic components of lake ecosystems. A study was made on the species composition, distribution, diversity and production of macrophytes in Lake Zwai between 2010 and 2012. Fourteen macrophyte species were identified with low species diversity for the lake ( $H'$  value of 1.805). The composition of the macrophyte community has undergone many changes during the last few decades. *Arundo donax*, which was never reported earlier, attained the highest relative density (30.7%) and frequency (30.5%) in this study, followed by *Echinochloa colona*, *Potamogeton schweinfurthii*, *Cyperus articulatus*, *Typha latifolia* and *Cyperus papyrus*. Canonical Correspondence Analysis (CCA) showed that the average densities of *A. donax*, *C. articulatus*, *E. colona* and *Pistia stratiotes*, which are invasive species (except *E. colona*), were positively correlated with nutrients. The biomass and productivity of most macrophytes were low when compared to the literature on similar species in other freshwater systems. Aboveground biomass and primary productivity of *Typha latifolia* ( $813.3 \pm 27.8$  g DW m<sup>-2</sup>,

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2394 g DW m<sup>-2</sup>y<sup>-1</sup>) and *C. papyrus* (795.1 ± 189 g DW m<sup>-2</sup>, 2196 g DW m<sup>-2</sup>y<sup>-1</sup>) were the highest compared to other macrophytes in the lake although their distribution was restricted to only a few parts of the lake. Nutrients, rather than physical parameters (conductivity and temperature) were found to be relatively more important in determining biomass and productivity. The study suggested that if nutrient levels continue to increase and water levels continue to decline, the present status of the lake may shift to undesirable conditions; where invasive macrophytes may take over and further changes in macrophyte composition, which in the long run influence the ecology of the littoral zones of Lake Zwai..

Keywords: *Arundo donax*, aquatic macrophyte, invasive species, Lake Zwai (Zwai)

## Introduction

Macrophytes play an important role in the function of shallow lake ecosystems. They are important for the production of oxygen, control of water quality by buffering nutrient influx, stabilizing sediment inflow and providing the habitat for aquatic organisms ranging from the microscopic bacteria to large vascular plants and vertebrates such as birds and mammals (Mohan and Hosetti, 1999). Macrophytes are also important indicators of environmental conditions and long-term ecological changes as they are sensitive to physical and chemical changes in the ecosystem (Solimini *et al.*, 2006). On the other hand, invasive macrophyte species have negative aspects as they affect the function, structure and composition of aquatic ecosystems (Dudley and Collins, 1995). The function of macrophytes in lake ecosystems is related to their species composition, distribution, abundance, diversity and production which in turn depend on various environmental factors such as light, water temperature, substrate composition, disturbance and quality of the lake-water (Barko and Smart, 1986; Jafari *et al.*, 2003). Determining productivity of

macrophytes is important to describe the functions of the littoral zone of a lake ecosystem and provide a quantitative base for further research on the whole lake-ecosystem (Cronin *et al.* 2006).

Lake Zwai, with an extensive vegetated shoreline, has been the second most important landing site of the Ethiopian fishery for many years, producing on average 2,234 mt of fish per year (LFDP, 1997). It is also home for many birds and hippopotamus populations. However, the lake ecosystem is being affected by catchment degradation, siltation, imbalance between water inflow and outflow and uncontrolled fishing practices (IBC, 2005). The many studies of the lake have focused on phytoplankton and zooplankton ecology and on hydrology (e.g. Girma Tilahun, 2006; Tenalem Ayenew and Dagnachew Legesse, 2007; Adamneh Dagne *et al.*, 2008). These studies have generated sufficient evidence of some undesirable changes that have occurred in the lake, such as decline in phytoplankton biomass (Getachew Beneberu and Seyoum Mengistou, 2010), increase in dominance of toxin-producing blue-green algae such as *Microcystis* and *Cylindrospermopsis* spp (Girma Tilahun, 2006) and imbalance between water inflow and outflow, which was mainly attributed to higher lake evapotranspiration and water abstraction for irrigation purposes (Tenalem Ayenew and Dagnachew Legesse, 2007). However, the role of macrophytes in the functioning and structuring of the lake ecosystem and assessment of the current macrophyte status of the lake have not been investigated in considerable detail that for decision making at management levels.

Because large lakes potentially provide diverse types of habitats than smaller ones, a more diversified macrophyte flora could be expected in Lake Zwai. Historical data on macrophyte distribution of the littoral zone of Lake Zwai are scarce, except the work of Makin *et al.* (1976) who listed the dominant macrophyte species in the lake. However, the data available on the distribution pattern, abundance and diversity of the macrophytes are not

conclusive in this and other related works (e.g. Hughes and Hughes, 1992). Many limnological and other ecological changes are being observed in the lake, which could also affect macrophyte dynamics. Therefore, this study was undertaken to assess the status of macrophytes and their long-term changes in the lake which will help to suggest appropriate measures that will promote the conservation and sustainable utilization of the lake resources. The specific objectives of this study were to assess the current macrophyte species composition, relative abundance and distribution in relation to physicochemical factors, their seasonal variation in distribution, and to compare the current macrophyte composition and distribution with previous studies. In addition, the study attempted to determine productivity of macrophytes to the contribution of macrophyte primary productivity to the total photosynthetic carbon fixation in the lake.

### Material and Methods

**The study area:** Lake Zwai is a shallow freshwater lake located in the Ethiopian rift valley at 8°01'N/38°47'E (Fig. 27) and at an altitude of 1636 m asl (Von Damm and Edmond, 1984). The lake has a surface area of 442 km<sup>2</sup>, a maximum depth of 8.9m and an average depth of 2.5m (Von Damm and Edmond, 1984). During the last few decades, Lake Zwai has begun to show reduction in its water level because of excessive water abstraction for horticulture and irrigation developments (Tenalem Ayenew and Dagnachew Legesse, 2007).

The region of Lake Zwai has a semi-arid to sub-humid type of climate and has mean annual precipitation varying between 650 mm and 1,200 mm and mean annual temperature between 15 and 25°C. The lake is fed by Qatar (also written as Qataar or Qataar) and Meki Rivers that drain from the south-eastern and north-western highlands, respectively (Fig. 27). Qatar River contributes 392 million m<sup>3</sup> of water, whereas Meki River contributes 264.5 million m<sup>3</sup>

annually. The lake drains into Lake Abijata through the Bulbula River in the south. Other small streams also feed the lake.

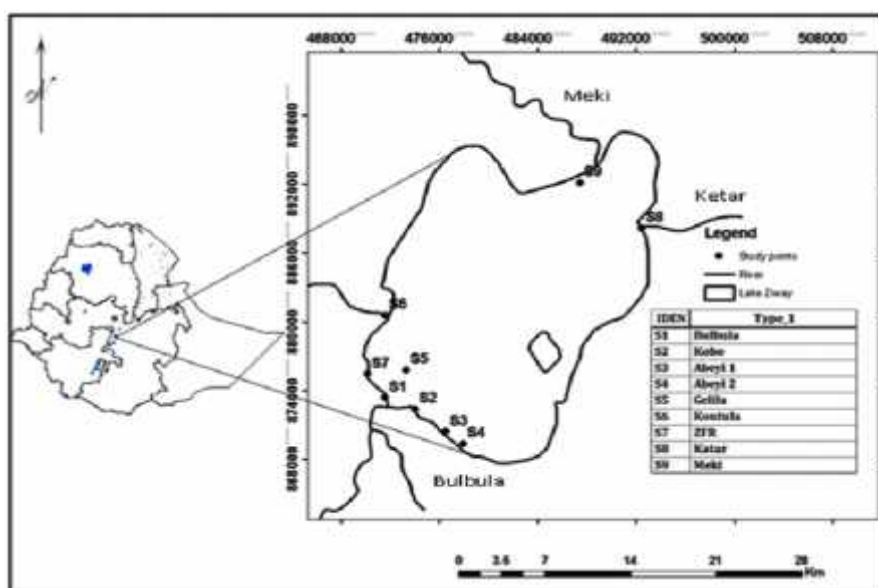


**Figure 27:** Map of Lake Zwai including the study sites with indication of the location of the lake in Ethiopia

**Sampling design:** The lake was sampled three times, at the end of the dry season in 2010, monthly between March and May and three times at the end of the wet season, from October to December 2010. Macrophytes were collected manually from nine sites (Fig. 27). These sites were selected based on their distance from human settlements and anthropogenic effects and accessibility for quantitative study. Bulbula, ZFR (near to Zwai Fisheries Research Center) and Kontula sites are close to human settlements and some industries, whereas the other sites are relatively far from such impacts. In addition, Meki and Qatar sites were selected in order to compare the species composition between the regions around the river mouths and other parts of



the lake. After collection, the macrophyte samples were rinsed *in situ*, blotted, pressed and transported to the National Herbarium, Addis Ababa University (AAU), Ethiopia, for identification. Identification was made to the species level using keys of the Ethiopian flora compiled by Hedberg and Edward (1989) and Edward *et al.*, (1995) and the collections in the AAU Herbarium. *Potamogeton schweinfurthii* was authenticated by Klaus van der Wey and Zdenek Kaplan (Institute of Lanaplan, Nettetal, Germany, and Institute of Botany, Pruhonic, The Czech Republic).

**Determination of abundance and diversity:** Quantitative study was carried out at all sites (Fig. 27). As recommended by IEP, a belt transect method was employed to analyze the macrophyte community (2009). Two transects were laid at all the sites. Each transect was taken from the shore towards the open water of the lake as far as the depth where submerged species were seen or emergent and floating macrophyte coverage ended, following the procedures described in Burlakoti and Karmacharya (2004). Variable numbers of quadrates (3–7) were laid at each transect depending on the area coverage of the vegetation. The size of the quadrat used was 2m<sup>2</sup> at all the study sites, following the suggestion of Sutherland (1997). The quadrates were laid along the transects at 25m intervals following Gaudet and Muthuri (1981). Macrophytes in each quadrat were counted by hand picking. The relative frequency and relative density of each species were calculated as in the study by Mueller-Dombois and Ellenberg (1974) and Martin (1995).

**Net aboveground primary productivity:** Net aboveground primary productivity (NAPP) of macrophyte species was determined at seven sites (Fig. 27), where the quantitative study was done except at Qatar and Meki sites. NAPP of each macrophyte species was estimated between August 2010 and July 2011 with the method of Weigert and Evans (1964) as described in Cronk and Fennessy (2001). The method sums live and dead materials produced during each sampling intervals. To this sum, estimated amounts are

added (calculated from 'litterbag' decomposition experiments, see below) to compensate for the decomposed plant materials that could take place between sampling intervals. A quadrat with 0.625 m<sup>2</sup> area was used, as in Lee (1990) to harvest the macrophytes along transects that extended from the shore towards the open water of the lake as far as the depth where submerged species were found. At least four quadrats were laid in each site at 25m intervals along transects following the procedures in Gaudet and Muthuri (1981) and the quadrat samples were averaged for analysis. All aboveground parts of the plants, dead and live, were harvested and placed in plastic bags and taken to the laboratory for determination of dry weight. The aboveground dry weight biomass of each macrophyte species was measured monthly by drying in an oven at 105°C for 24 hours (Wetzel and Likens 1991).

Net Primary Productivity was calculated using the formula:

$$Y_i = \Delta b_i + d_i$$

Where,  $Y_i$  is net aboveground primary productivity;

$b_i$  is standing crop of live material after

time of  $i$  (a month in the case of this study) and

$d_i$  is mortality of live materials. Further,  $d_i$  is equal to standing crop dead material plus decomposed materials between sampling intervals, which is one month (which was estimated from 'litterbag' decomposition experiment).

**'Litterbag' decomposition experiment:** Fresh macrophyte samples of each species were harvested from the littoral sites of the lake, washed to remove debris and other attached materials, chopped and weighed. 30g of culm of each species was used for the study after drying for 3 hours in the air. The macrophyte litters were transferred to litter bags made of nylon net (replicated for each species) with standard size of 15 x 20 cm and a mesh size

of 1.5 mm after Kufel *et al.* (2004). The bags were incubated *in situ* underwater near the sediment by tying them up with cemented stands. Two litter bags of each species were retrieved at two week intervals for the determination of change in dry weight over the sampling time.

**Physicochemical parameters:** Temperature and pH of lake water were measured using a portable digital pH meter (Hanna 9024). Conductivity was measured using CC-411 conductivity meter, and transparency was estimated using a 20-cm Secchi disc. Water samples were collected from each site to analyze for nitrate, nitrite, ammonium and soluble reactive phosphate (SRP). Analyses of these nutrients were carried out following procedures in Roberg and Edwards (1983) and APHA (1999). Sediment samples were also taken, from each study site, for analysis of total nitrogen and phosphorous concentration in the sediment, using a 40 cm diameter PVC corer after Powel (2008) from approximately 15cm of the sediment surface. When the depth didn't allow the use of the PVC corer, an Ekman grab was used. Total nitrogen was determined using the Kjeldahl procedure following Bremner and Mulvaney (1982); while total phosphorous was determined using vanadate-molybdate yellow method after ashing and nitric acid digestion following the procedure of Chapman and Pratt (1961).

**Data analysis:** The relationship between macrophyte species abundance and physicochemical variables was evaluated by canonical correspondence analysis (CCA) using CANOCO for windows 4.5 version. Redundancy analysis (RDA) was performed to observe the relationship of species biomass and productivity data to environmental factors using CANOCO 4.5 software. Principal components analysis (PCA) was employed to observe the difference among the study sites with respect to their physicochemical properties using PAST software. Significant differences in the abundance of macrophytes between the dry and wet seasons were verified using two-sample t-tests. Macrophyte species diversity in the lake was computed using Shannon and

Weiner Diversity Index following Shannon and Weiner (1963). An Analysis of Variance (ANOVA) was used to test if aboveground biomass of the macrophytes varied between sites followed by a Tukey's test to identify which sites were significantly different from the others in terms of biomass.

## Result

**Physicochemical parameters in the study sites:** The nutrients displayed more variation among sites than did the physical parameters (Table 29). The mean values ranged between 14.01–64.47, 33.79–89.06, 2–24.06 and 56.5–212.11  $\mu\text{gL}^{-1}$  for SRP, nitrate, nitrite and ammonium, respectively. The minimum and maximum mean values recorded were 7.85 and 8.72 for pH, 11.3 and 16.6 cm for Secchi depth reading and 399.45 and 450.6  $\mu\text{Scm}^{-1}$  for conductivity. Axis 1 and axis 2 of the principal components analysis explained 56.3% of the total variance (Fig. 5.2) regarding the sites versus physicochemical association, where the first axis and second axis contributed 32.9% and 23.4% of the variation, respectively. The result of the analysis discriminates Bulbula, ZFR and Meki sites from the others (by axis 1), owing to higher values of nitrate, conductivity and SRP, which had highest loading factor on this axis (0.84, 0.72 and 0.68, respectively). Secchi depth was negatively correlated (-0.35) with the first axis. Other sites occurred on the opposite side of axis 1 (Fig. 28), indicating that they had lower values of these ions. Kontula and Qatar sites had greater Secchi depths (Fig. 28).



**Table 29:** Mean and standard error values of physico-chemical variables of the study site (ZFR is for the site near to Zwai Fisheries Research Center)

| Sites          | pH       | Temp.<br>(°C) | SRP<br>(µg/ L <sup>-1</sup> ) | NO <sub>3</sub> <sup>-</sup><br>(µg/ L <sup>-1</sup> ) | NO <sub>2</sub> <sup>-</sup><br>(µg/ L <sup>-1</sup> ) | NH <sub>4</sub> <sup>+</sup><br>(µgL <sup>-1</sup> ) | Conductivity<br>(µS <sub>cm</sub> <sup>-1</sup> ) | Secchi depth<br>(cm) |
|----------------|----------|---------------|-------------------------------|--------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------|---------------------------------------------------|----------------------|
| <b>Qatar</b>   | 7.85±0.2 | 23.87±1       | 29.05±19                      | 33.79±9                                                | 7.47±11                                                | 56.5±37                                              | 424.5±5.9                                         | 12.3±0.7             |
| <b>Bulbula</b> | 8.72±0.1 | 27.86±1       | 40.83±9                       | 70.43±23                                               | 3.98±12                                                | 145.6±37                                             | 445.2±25                                          | 12.95±0.7            |
| <b>ZFR</b>     | 8.62±0.1 | 26.97±1       | 64.47±32                      | 88.92±33                                               | 12.95±6                                                | 125.8±21                                             | 432.5±11                                          | 11.98±0.4            |
| <b>Meki</b>    | 7.95±0.2 | 26.07±1       | 24.38±6                       | 89.06±16                                               | 13.19±2                                                | 212.11±29                                            | 450.6±13                                          | 12.3±0.9             |
| <b>Kontula</b> | 8.64±0.1 | 24.98±1       | 30.5±10                       | 72.19±25                                               | 5.35±1.3                                               | 134.13±13                                            | 415.3±12                                          | 16.6±1               |
| <b>Gelila</b>  | 8.51±0.2 | 24.11±1       | 25.65±8                       | 43.8±15                                                | 6.73±2.9                                               | 146.2±19                                             | 399.5±18                                          | 14.4±0.5             |
| <b>Kobo</b>    | 8.41±0.2 | 26.19±1       | 14.01±4                       | 36.54±20                                               | 2.00±0.9                                               | 118.65±21                                            | 402.83±6                                          | 13.38±1.6            |
| <b>Abeye 1</b> | 8.68±0.2 | 27.13±1       | 17.49±3                       | 36.83±17                                               | 24.1±11                                                | 154.56±37                                            | 393.3±11                                          | 11.3±0.9             |
| <b>Abeye 2</b> | 8.59±0.1 | 26.63±1       | 22.79±3                       | 39.11±21                                               | 5.4±1.8                                                | 196.3±29                                             | 408.3±6.3                                         | 12.7±0.8             |

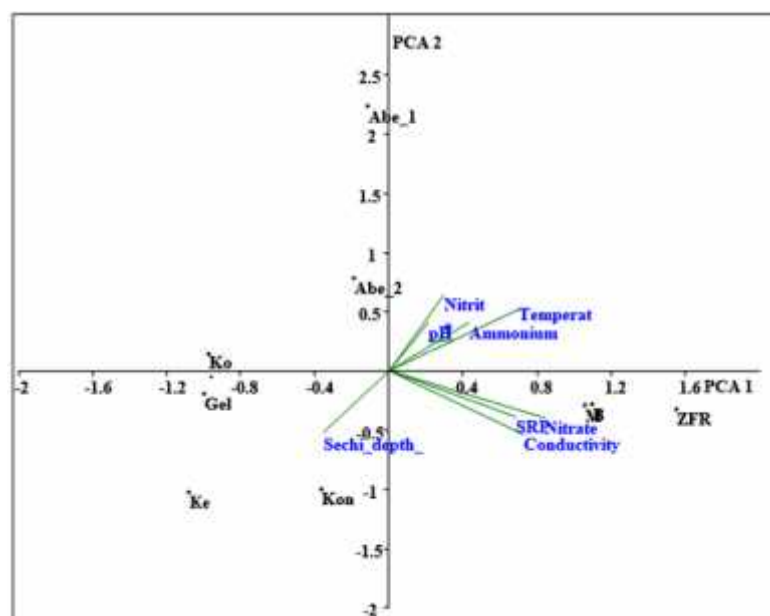


**Figure 28:** Principal components analysis ordination diagram of the physico-chemical factors at the study sites (Abbreviations: Ke – Qatar, Kon –Kontula, Gel – Gelila, Kob – Kobo, Abe 1 – Abeye 1, Abe 2 – Abeye 2, M – Meki, B – Bulbula, ZFR – near to Zwai Fisheries Research Center and SD – Secchi depth)

**Species composition, abundance and distribution:** Fourteen macrophyte species were identified and their relative frequency and density were determined (Table 30). Two of the macrophytes are rooted with floating leaves (*Nymphaea lotus* and *Pistia stratiotes*), one is free floating (*Nymphoides indica*), one is submerged (*Potamogeton schweinfurthii*), and the others are emergent. All the sites were dominated by emergent macrophytes that attained the highest relative frequency and density, followed by submerged species and other forms. The relative frequency and density of the macrophytes (Table 30) indicated that the littoral zone of the lake was highly dominated by *Arundo donax* (emergent), which had the largest relative frequency (30.5%) and density (30.7%) and occurred in all the study sites. It

was followed by *Echinochloa colona* (emergent), *P. schweinfurthii* (submerged), *Cyperus articulatus* (emergent), *Typha latifolia* (emergent) and *Cyperus papyrus* (emergent), in respective order.

**Table 30:** Macrophyte species present at Lake Zwai during 2010 survey and their relative frequency and density

| Species                                                      | Common names       | Relative frequency (%) | Relative density (%) |
|--------------------------------------------------------------|--------------------|------------------------|----------------------|
| <i>Arundo donax</i> L.                                       | Giant reed         | 30.48                  | 30.66                |
| <i>Cyperus articulatus</i> L.                                | Jointed flat sedge | 9.53                   | 12.64                |
| <i>Cyperus papyrus</i> L.                                    | Papyrus sedge      | 2.86                   | 8.05                 |
| <i>Echinochloa colona</i> L.                                 | Jungle rice        | 16.97                  | 19.24                |
| <i>Echinochloa stagnina</i> (Retz.) P.Beauv                  | Hippo. grass       | 0.953                  | 0.186                |
| <i>Ludwigia erecta</i> (Linnaeus) H.Hara                     | -                  | 0.953                  | 0.098                |
| <i>Ludwigia stolonifera</i> P.H.Raven                        | Creeping ludwigia  | 0.953                  | 0.085                |
| <i>Nymphaea lotus</i> L.                                     | Water lily         | 9.53                   | 3.873                |
| <i>Nymphoides indica</i> (L.) O.Kuntze                       | Banana plant       | 2.867                  | 0.206                |
| <i>Persicaria senegalensis</i> (Meisn.) Sojak                | -                  | 0.953                  | 0.124                |
| <i>Pistia stratiotes</i> L. (Khudipana)                      | Water lettuce      | 0.953                  | 0.043                |
| <i>Potamogeton schweinfurthii</i> A.Benn                     | Pond weed          | 14.33                  | 19.20                |
| <i>Schoenoplectus corymbosus</i> (Roth ex Roem. And Schult.) | Sedge              | 0.953                  | 0.248                |
| <i>Typha latifolia</i> L.                                    | Broadleaf-cattail  | 7.66                   | 5.328                |

**Relationship between physicochemical parameters and density of macrophyte species:** Canonical correspondence analysis (CCA) indicated that the first two axes make 73% of the cumulative percentage of variance in species–environmental relationship (Fig. 29). The first axis, which contributed 46.1% of the variance, was positively correlated with conductivity and Secchi depth and the second axis with ammonium and temperature. The density of A.



*donax*, *C. articulatus*, *E. colona* and *P. stratiotes* was positively related with nitrite, nitrate, pH and SRP, although the association was not very strong, whereas the density of other species had negative but strong species environment association (Fig. 29). Particularly, ammonium, temperature and pH showed strong and negative association with *C. papyrus*, *E. stagnina*, *N. indica* and *S. corymbosus*. The density of *P. schweinfurthii* had negative association with SRP, nitrate and nitrite. *L. erecta*, *L. stolonifera*, *P. senegalensis* and *T. latifolia* showed positive association with Secchi depth and conductivity. This study indicated that macrophyte species diversity of Lake Zwai was low ( $H'$  value of 1.805). Relatively, Bulbula site had the highest macrophyte diversity and Gelila the least. There was no variation in macrophyte species composition between the dry and wet seasons in the lake, and also no significant seasonal variation was observed in density of the macrophytes ( $t$ -test,  $P > 0.05$ ).

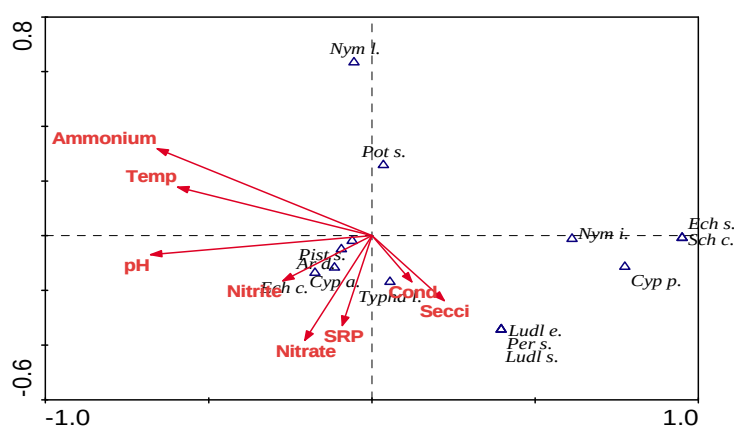


**Figure 29:** Plots of the first two axes of the canonical correspondence analysis (CCA) for macrophyte species and physico-chemical variables (Abbreviations: Ar d – *Arundo donax*, Cyp a – *Cyperus articulatus*, Cyp p. – *Cyperus papyrus*, Ech c – *Echinochloa colona*, Ech s. – *Echinochloa stagnina*, Ludl e. – *Ludwigia erecta*, Ludl s. – *Ludwigia Stolonifera*, Nym i. – *Nymphaea indica*, Nym l. – *Nymphaea lotus*, Per s. – *Persicaria senegalensis*, Pist s. – *Pistia stratiotes*, Pot s. – *Potamogeton schweinfurthii*, Sch c. – *Schoenoplectus corymbosus*, Typha l. – *Typha latifolia*, SRP – soluble reactive phosphate, Cond. – conductivity).

**Macrophytes biomass:** Mean macrophyte biomass of the lake was estimated to be  $1020.2 \pm 214.7 \text{ g DW m}^{-2}$  and the highest biomass was recorded at Kontula ( $1996.7 \text{ g DW m}^{-2}$ ) and the lowest at Kobo site ( $581.3 \text{ g DW m}^{-2}$ ). *T. latifolia* and *C. papyrus* were found to be dominant in terms of aboveground biomass ( $813.3 \pm 27.8 \text{ g DW m}^{-2}$  and  $795.1 \pm 189 \text{ g DW m}^{-2}$ , respectively) on the sites where they occurred (Fig. 30). *T. latifolia* was found at Kontula and Bulbula site whereas *C. papyrus* at Kontula. On the other hand, in spite of their dominance in relative abundance and frequency and wider occurrence in the lake, the biomass ( $\text{g DW m}^{-2}$ ) of *A. donax* ( $251.7 \pm 52.4$ ), *E. colona* ( $211.2 \pm 36.7$ ), *C. articulatus* ( $201.9 \pm 39.7$ ), *N. lotus* ( $139.1 \pm 39.4$ ), and *P.*

*schweinfurthii* ( $167.8 \pm 39.1$  g DW m<sup>-2</sup>) was relatively low. The lowest macrophyte biomass was recorded for *L. erecta* and *L. stolonifera*, 44.3 and 39.2 g DW m<sup>-2</sup>, respectively, which occurred only at one site (the same site).

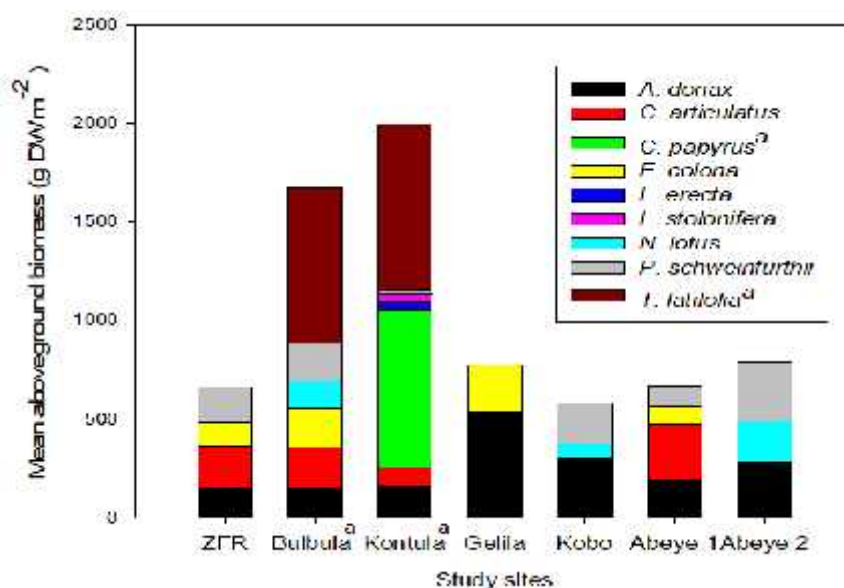


**Figure 30:** Mean aboveground biomass of macrophytes at Lake Zwai sites (<sup>a</sup>refers to sites and macrophytes that had significantly higher biomass than other groups, Tukey Games-Hoboreholetest,  $p < 0.05$ )

There was statistically significant variation in biomass of the macrophytes among the sites (one way ANOVA,  $F_{6,77} = 17.36$ ,  $P < 0.05$ ). Biomass of macrophytes was considerably higher at Kontula and Bulbula sites where *T. latifolia* contributed significantly to the total biomass (Fig. 30). On the other hand, Kobo, ZFR and Abeye 1 had lower macrophyte biomass than the other sites.

**Macrophyte aboveground biomass in relation to environmental variables:**

The first two axes of the RDA explained 70 % of the species-environment variance. The RDA ordination (Fig. 31) of the species-biomass association indicated that Secchi depth, SRP, nitrate, ammonium and total nitrogen of the sediment, conductivity, and temperature were positively correlated with the first axis. Except for the last two variables, the others were strongly correlated with the axis. The biomass of *C. papyrus*, *L. erecta*, *L. stolonifera*, and *T. latifolia* was associated with relatively high values of secchi depth, SRP, nitrate, ammonium, and total nitrogen of the sediment. *T. latifolia* biomass was strongly and positively correlated with SRP concentration and it occurred only at Kontula and Bulbula sites where SRP concentration was relatively high. The biomass of *C. articulatus* was more strongly correlated with nitrate than other environmental variables. On the other hand, biomass of *A. donax* was inversely associated with SRP and nitrate concentrations of the water. Nitrite, total phosphorous of the sediment, and pH were negatively correlated with the first axis. The second axis was positively correlated with all environmental variables used in this study except pH, nitrate, and nitrite. Relatively high biomass of *A. donax* was associated with relatively high values of total phosphorous in the sediment. Biomass of *E. colona* had a positive but very weak correlation with conductivity, and pH and a negative association with the other environmental variables.

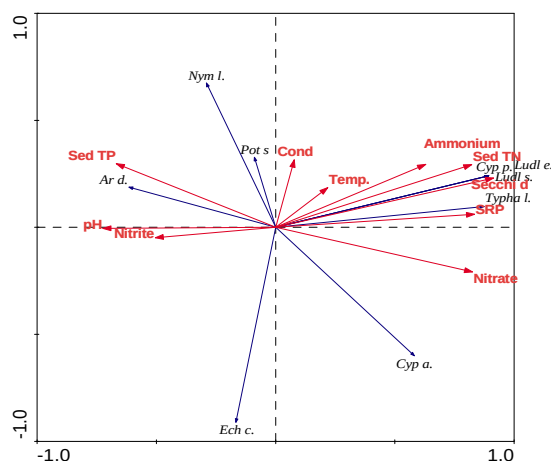


**Figure 31:** Bi-plots of the first two axis of Redundancy Analysis showing the association of macrophyte species biomass and environmental variables (For Abbreviation see Legends is Fig.29).

**Net aboveground primary productivity:** The mean NAPP of macrophytes at the study sites was found to be  $3623.7 \text{ g DW m}^{-2}\text{y}^{-1}$ . The highest NAPP was recorded at the Kontula site ( $7224 \text{ g DW m}^{-2}\text{y}^{-1}$ ) and the lowest at the Kobo site ( $2192.6 \text{ g DW m}^{-2}\text{y}^{-1}$ ) (Fig. 32). *T.latifolia* and *C. papyrus* had the highest NAPP, 2394 and 2196  $\text{g DW m}^{-2}\text{y}^{-1}$ , respectively, followed by *A.donax* ( $864.2 \text{ g DW m}^{-2}\text{y}^{-1}$ ) and *P. schweinfurthii* ( $774.2 \text{ g DW m}^{-2}\text{y}^{-1}$ ). The RDA analysis indicated that the first two axes explained 69.6 % of the cumulative percentage of variance of NAPP of the macrophytes versus physico-chemical factors correlation. The first axis was positively related with Secchi depth, total nitrogen of the sediment, SRP, ammonium, nitrate, conductivity, and temperature. Except temperature and conductivity, the other parameters were strongly correlated with the axis. The second axis, which explained 29.7 % of the variance, was positively correlated with Secchi depth, total nitrogen of the

sediment, SRP, ammonium, total phosphorous of the sediment, and nitrite. Nitrite had a weak association with this axis.

Factors that affected the productivity of the macrophytes were variable for different macro phytes. Productivity of *T. latifolia*, *C. papyrus*, *L. erecta*, and *L. stolonifera* were strongly and positively related to secchi depth, SRP, ammonium, total nitrogen in the sediment, and nitrate. On the other hand, productivity of *A. donax*, *C. articulatus*, *P. schweinfurthii*, and *N. lotus* was positively related with conductivity, temperature, and nitrate, though the correlation between conductivity and temperature and the productivity of the macrophytes was weak (Fig. 33). Conductivity and temperature seem also to have little influence in affecting both biomass and productivity of the other macrophytes as their correlations with the macrophytes were low (Fig. 33).

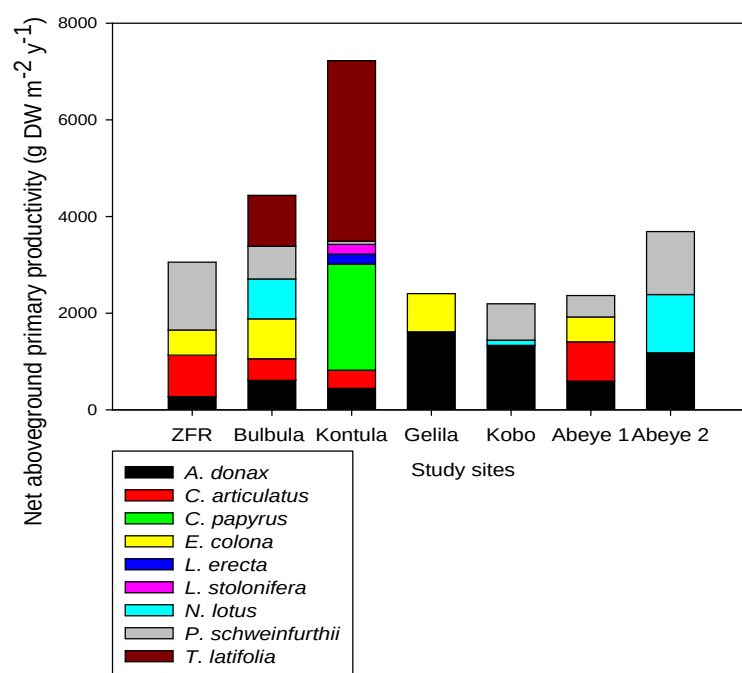


**Figure 32:** Net aboveground primary production of the macrophytes of Lake Zwai

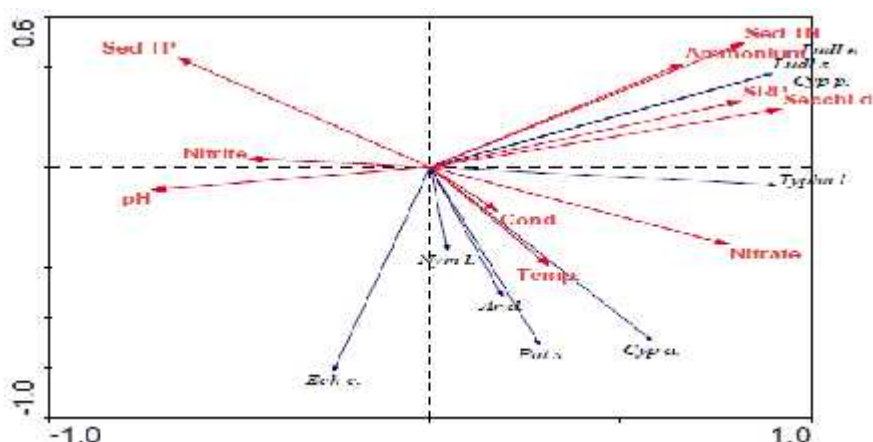


**Figure 33:** Bi-plots of the first two axes of the redundancy analysis showing the association of macrophytes species productivity and environmental variables (For abbreviations, see the Legend at Fig.31)

## Discussion

**Physicochemical condition in comparison with past data:** Conductivity and pH showed almost no change during the last two decades as the mean values found in this study ( $419.10 \mu\text{S cm}^{-1}$  and 8.44, respectively) were comparable with the values ( $410 \mu\text{S cm}^{-1}$  and 8.5, respectively) reported by Elizabeth Kebede *et al.* (1994). On the other hand, Secchi depth has lowered considerably even when compared with some recent results. For example, the mean Secchi depth reading (19 cm) reported by Girma Tilahun (2006) is higher than the result in this study (13.1 cm). Also, Adamneh Dagne *et al.* (2008) have reported that the Secchi depth of the lake ranged between 20 and 35 cm. The declining trend in Secchi depth reading suggests that turbidity in the lake is increasing, which can be attributed to catchment degradation and siltation. For instance, it was reported that vegetation around the shore of the lake was being harvested for different purposes in many of the sites (IBC, 2005). In addition, Girma Tilahun (2006) has reported that turbidity in Lake Zwai is not mainly because of algal attenuation. The mean SRP and nitrate



values found in this study (29.6 and 56.7  $\mu\text{gL}^{-1}$ , respectively) were higher than those values (10.1 and 3.2  $\mu\text{gL}^{-1}$ , respectively) reported by Girum Tilahun (2006). The increasing trend in SRP is probably because of nutrient enrichment of the littoral zone of the lake from anthropogenic sources in the catchment area.

**Emergent macrophyte dominance in Lake Zwai:** Lake Zwai is highly dominated by emergent macrophytes, which could be due to their high tolerance for water-level fluctuation (Van Der Valk and Davis, 1976). At present, because of excessive abstraction of water for floriculture and irrigation developments, the water level of Lake Zwai has been declining (Tenalem Ayenew and Dagnachew Legesse, 2007). The width of the lake is shrinking. Blundell (1906) reported that the width of the lake was about 50 miles (80.46 Km). It was also reported that high lake evaporation, which was estimated at 890 million  $\text{m}^3$  annually, contributed to imbalance between water inflow and outflow, and the lake showed a net loss of 74 million  $\text{m}^3$  volume of water annually (Tenalem Ayenew and Dagnachew Legesse, 2007). There is also high seasonal variation in water level in the lake, which is attributed to seasonal rainfall.

The higher dominance of emergent macrophytes in terms of species diversity (compared with floating and submerged macrophytes) also indicates the advancement of littoral vegetation (Burlakoti and Karmacharya, 2004). Some workers have reported that this condition indicates a succession towards a marsh and is associated with decreasing water level (Wetzel, 1983). This condition is a threat to the lake-biota and fishery. Advancement of littoral vegetation may reduce the core area of the lake in the long run (Burlakoti and Karmacharya, 2004). An increasing trend in anthropogenic activities like irrigation and water abstraction around the lake and siltation could further aggravate the condition.

**Density of macrophyte species in relation to physicochemical factors:** The sites at Bulbula, Research Center (ZFR) and Meki were different from other

sites and were characterized by having higher nitrate, SRP and conductivity. However, *A. donax*, *E. colona* and *P. schweinfurthii* were found in both nutrient-rich and nutrient-poor sites. The occurrence of these macrophytes in the lake seems not to be affected by differences in the nutrient condition among sites, and their ability to colonize these varied sites indicates their potential to adapt to diverse trophic conditions. Nevertheless, their density was higher in sites where nutrient concentrations were higher, which implies that if the anthropogenic activity around the lake increases nutrient concentration of the lake to a certain level, it would further encourage infestation by these macrophytes (even though they can also exist under low nutrient conditions). On the other hand, *C. articulatus* was restricted to sites where there was higher nutrient concentration, which suggests that this species needs high nutrient levels. Similarly, the abundance of *P. stratiotes* was positively correlated with nutrients (except ammonium), especially with nitrite. *P. stratiotes* is one of the worst invasive floating macrophytes and is well known for invading new habitats within a short period of time under high nutrient loading, impeding water movement, hosting some mosquito genera and changing both physical and biological components within aquatic systems (Henry-Silva *et al.*, 2008). Denny (1985) asserted that eutrophication has led to increased biomass of *P. stratiotes* and other similar invasive water weeds such as water hyacinth with subsequent damaging impacts in many African lakes. The increase in nutrient concentration and further reduction in water level may create a conducive environment for *P. stratiotes* and other invasive floating macrophytes. The abundance of *A. donax*, *E. colona*, *C. articulatus* and *P. stratiotes* had a positive association with SRP, nitrate and nitrite, which implies that these macrophytes flourish under higher concentration of these nutrients, although *A. donax* and *E. colona* can also occur at low nutrient status. However, the abundance of other species had a negative but strong correlation with these parameters (Fig. 32). The result indicated that the increase in ammonium concentration, temperature and pH could significantly and negatively affect the abundance of *C. papyrus*, *E.*

*stagnina*, *N. indica* and *S. corymbosus*. Similarly, the abundance of *P. schweinfurthii* could be affected negatively if the concentration of SRP, nitrate and nitrite increases.

**Possibility of infestation of Lake Zwaiby water hyacinth (*Eichhornia crassipes*) and *P. stratiotes*:** The possibility of infestation of water hyacinth into Lake Zwai is very high as some of the nearby waterbodies, such as Koka Reservoir and Awash River, are already infested by this weed. In fact, this weed has recently (2016) established at an irrigation canals of Lake Zwai, very close to the mouth of River Meki. The probability of its infestation to mid-lake area is low at present condition due to seasonal nutrient limitations (TN:TP ratio), high pH (>8), competition from emergent macrophytes and turbulence during the rainy season. However, unregulated macrophyte harvesting and nutrient enrichment particularly from the point sources can change the current condition and may create conducive condition for the expansion of water hyacinth to the shore and also to open water to some extent. As can be learned from the case of similar lakes such as Lake Naivasha, such trends will lead to severe ecological consequences unless prompt mitigation is taken on time. Currently, Lake Naivasha is encountering many adverse changes that are associated with enrichment of nutrients from run-off, horticulture and other sources around the lake region (Jimoh *et al.*, 2007). As a consequence, rapid proliferation of water hyacinth and other invasive weeds, excessive increase in algal biomass and reduced transparency are already observed in the lake (e.g. Mirongaet *al.*, 2012). It is evident that such changes are a huge threat to fisheries, ecological integrity of lakes and public health of lake-side communities.

**Macrophyte species diversity in Lake Zwai:** Larger lakes are potentially expected to have a wider range of habitats than smaller lakes, and therefore, more polymorphic flora could be expected in such lakes (Toivonen and Huttunen, 1995). However in Lake Zwai, higher turbidity, fluctuations in water level and other factors seem to limit the macrophyte distribution to

mainly turbidity tolerant species, for example *N. lotus* (Nurminen, 2003) and emergents. The macrophyte species diversity of Lake Zwai was low ( $H'$  value of 1.805) when compared other similar studies (e.g. Zerhun Woldu, 2000; Burlakoti and Karmacharya, 2004).

Lake Zwai is highly turbid, and as a result, the growth of many submerged species is limited. In general, low diversity is expected in lakes that have an outflow, because accumulated nutrients produced from different sources could be flushed out (Burlakoti and Karmacharya, 2004), although the effect on rooted species could be less pronounced. Lake Zwai has a shorter water retention time (about 1.5–2 years) (Spliethoff *et al.*, 2009), and establishment of new macrophytes could be hindered. Cronk and Fennessy (2001) have generalized that macrophyte diversity depends on the ability of each species to become established and persist under sustained environmental conditions. In addition, the absence of significant heterogeneity among sites can induce lower diversity of macrophytes, which was also corroborated with physicochemical data in this study.

**Historical change in species composition:** It is difficult to compare the result of this work with previous ones, as there is scarcity of information on macrophyte studies in Lake Zwai. The only available information is the report of Makin *et al.* (1976). *C. papyrus*, *Phragmites mauritianus* and *Typha domingensis* were reported to be the dominant species in that study. The most dominant species in the current study, *A. donax*, *E. colona*, *P. schweinfurthii* and *C. articulatus*, were not reported in that work. However, Makin *et al.* (1976) predicted that the distribution of these macrophytes may change considerably over a period of a few years because the distribution of emergent vegetation along the banks was influenced by fluctuations in lake water level. The reduction in water level and change in limnology of the lake could have contributed to this conspicuous shift in macrophyte composition of Lake Zwai during the last four decades.

*Arundo donax* and *C. articulatus* are widely reported in most ecosystems as invasive weeds that have impact on sensitive riparian ecosystems (e.g. Kissmann, 1997; Guthrie, 2007). *A. donax* has altered plant species diversity and composition and reduced invertebrate and bird species richness in some ecosystems (Herrera and Dudley, 2003). The relatively low diversity of other macrophytes and lower invertebrate species (e.g. zooplankton and chironomids) around the stands of this species (personal observation) indicates the potential inhibitory effect of this macrophyte on the biodiversity of the lake. Previous authors (e.g. Hughes and Hughes, 1992) had reported the presence of dense beds of *Potamogeton* species in the lake but the plant was not identified at species level. Therefore, whether *P. schweinfurthii* was present in Lake Zwai in the past is not certain; however, it is a species with extensive distribution in African freshwaters (Kaplan, 2005) and was reported to be indicator of good water quality (LVBC, 2011). The current environmental condition of Lake Zwai with higher pH and temperature (5.1) seems conducive for this species as it is efficient in extracting inorganic carbon at these conditions (Kahara and Vermaat, 2003). The experience of Lake Kariba and many other similar lakes has shown that nutrient enrichment could lead to a shift in dominance from *P. schweinfurthii* to floating invasive macrophytes (e.g. Machena, 1989), and this threat should be taken seriously in Lake Zwai, as nutrients enrichment appears to be increasing recently (e.g. Malefia Tadele, 2009).

*Cyperus papyrus*, which was reported to be the dominant macrophyte by Makin *et al.* (1976), is still present in the lake but is not dominant. *C. papyrus* and *T. latifolia* are known to serve as important silt and nutrient filters in aquatic ecosystems (e.g. Chale, 2003). This could account for the relative higher transparency around Kontula site (Table 29), where the two species were found abundantly.

**Aboveground biomass:** *Typha latifolia* attained the highest biomass among the macrophytes in Lake Zwai during the present study. Biomass of *T.*

*latifolia* ( $813.3 \pm 27.8 \text{ g m}^{-2}$ ) observed in this study was in the range estimated for the species by Pratt *et al.* (1984) (4.3- 14  $\text{t ha}^{-1}$ ). On the other hand, *T. Latifolia* biomass in this study was lower compared to the biomass recorded in some fresh water systems (e.g., Boyd and Hess 1970; Kleopatic and Stearns 1978). The biomass of *T. latifolia* seems to be stunted mainly due to the lower SRP in most sites of Lake Zwai and this agrees with the observation of Atkinson *et al.* (2010). Macek and Rejmankova (2007) hypothesized that phosphorous input into wetlands will result in expansion of *T. latifolia* biomass and can even lead to competitive exclusion of other co-occurring species. Plants can uptake phosphorous only when dissolved in water as ortho-phosphates or poly-phosphates (Shuman 1994).

Mean aboveground biomass of *C. papyrus* ( $795.1 \pm 189 \text{ g DW m}^{-2}$ ) in Lake Zwai was low compared to biomass of the same plant in many similar African lakes. For example, Jones and Muthuri (1997) reported the total standing biomass of the papyrus in Lake Naivasha to be  $7800 \text{ g DW m}^{-2}$ . Mnaya *et al.* (2007) reported the average value of above ground biomass of the plant in Lake Victoria to be  $5789 \text{ g DW m}^{-2}$ . According to Perbangkhem and Polprasert (2010), papyrus can attain aboveground biomass of 2200 to  $3100 \text{ g DW m}^{-2}$  in tropical climate area with abundant sunlight. This signifies the importance of other factors (mainly nutrients) in limiting the biomass of this species in the lake rather than factors associated with geographical location of the lake (e.g., light and temperature).

RDA analysis suggested that relatively high total nitrogen concentration of the sediment, ammonium, and SRP were important factors which may support the high biomass of *C. papyrus* and *T. latifolia*. These species were absent in sites where the total nitrogen of the sediment, ammonium, and SRP concentrations were low. Similarly, in Lake Naivasha, the concentration of ammonium ions and soluble reactive phosphate were higher in papyrus swamp water than in other regions of the lake (Muthuri and Jones 1997). *Cyperus papyrus* biomass was negatively associated with pH and nitrite. El Ghani *et al.* (2010) stated

that the plant grows in fresh water with pH varying from 6.6 to 7.5. The presence of relatively high pH in Lake Zwai (7.8 - 8.6) may be negatively affecting the biomass of *C. papyrus* and most of other macrophytes in Lake Zwai. pH affects the rate of nutrient uptake by macrophytes. Titus and Stone (1982) observed that the increase in pH from 7.0 to 9.0 significantly reduced the rate of uptake of inorganic carbon by *Myriophyllum spicatum*. Van *et al.* (1976) also observed negative relationships between increases in pH and decreases in CO<sub>2</sub> availability and the photosynthetic rate for *Hydrilla verticillata*, *Myriophyllum spicatum*, and *Ceratophyllum demersum*. According to Shuman (1994), the rate of uptake of orthophosphates or polyphosphates by plants is highly pH-dependent and optimal uptake occurs at 6.5. Thus, a relatively high pH might have hindered the expansion of macrophytes such as *T. Latifolia* which require higher soluble phosphorous. It is highly possible that the relatively high pH in Lake Zwai could be one factor that has limited the biomass of macrophytes. pH and nitrite were not only negatively correlated with *C. papyrus* and *T. latifolia* biomass, but also with most of the macrophytes in this study.

*Arundo donax* biomass in this study (1.495-5.31 t h<sup>-1</sup>) was much lower than biomass of the species reported in many water bodies, both tropical and temperate (Giessow *et al.*, 2011; Sharma *et al.*, 1998; Spencer *et al.*, 2006). Sharma *et al.* (1998) reported the aboveground biomass of the plant to be 36-167 t hr<sup>-1</sup> in India, whereas Spencer *et al.* (2006) and Giessow *et al.* (2011) reported the biomass of the species to be 171 and 155 t hr<sup>-1</sup>, respectively, in different lake sites in the USA. The biomass of *A. donax* was associated with total phosphorous concentration of the sediment. It was recorded that the biomass of perennial plants such as *A. donax* was higher where there were higher nutrients (e.g. Ercoli *et al.*, 1999).

**Net aboveground primary productivity:** NAPP of most of the macrophytes investigated in this study was lower than similar species in other water bodies. The productivity of *A. donax* (864 g DW m<sup>-2</sup> yr<sup>-1</sup> or 8.64 t ha<sup>-1</sup>yr<sup>-1</sup>) and *C.*

*papyrus* ( $2196 \text{ g DW m}^{-2} \text{ yr}^{-1}$  or  $21.96 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) was below the range observed by Westlake (1975) in freshwater systems. Productivity of *A. donax* was most highly correlated with nitrate in this study. A study on the impact of nutrient enrichment from residential and agricultural land use types on *A. donax* infestation throughout several watersheds in Southern California showed that water systems with enriched soil nitrate supported *A. donax* infestation whereas sites with lower nitrogen levels did not (Coffman, 2007). Decruyenaere (2000) reported that the plant invaded more readily in areas where soil nitrogen was high, growing rapidly with elevated nutrients. In this study, such a strong association was not observed between productivity of *A. donax* and nitrogen concentration of the sediment, most probably due to the low nitrogen level of the sediment in most of the study sites, except Kontula. In addition, only Kjeldahl total nitrogen was determined in this study. Sediment nitrate must be measured to characterize the relationship between *A. donax* productivity and total sediment nitrogen. However, nitrogen concentration in the sediment could increase in the lake from catchment erosion as some of the farms are expanding and using inorganic fertilizers which can facilitate the infestation of the reed. But, currently, the productivity of *A. donax* seems to be low in the lake. The productivity of *T. latifolia* ( $23.94 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) was within the range estimated by Westlake (1975) ( $11\text{--}33 \text{ t ha}^{-1} \text{ yr}^{-1}$ ). The high productivity of *T. latifolia* can be explained in a number of ways. The most important reasons are that *T. latifolia* is not limited by the shortage of water in a natural wetland and the canopy arrangement of the leaves appears to increase the efficiency with which directly incident and reflected sunlight can be utilized in photosynthesis (Sheehy and Cooper, 1973). Because of the upright leaf angle orientation, a greater proportion of the leaf area is exposed to direct sunlight.

#### **Comparison of macrophyte and phytoplankton primary productivity:**

Girum Tilahun and Ahlgren (2010) estimated the primary production of phytoplankton in Lake Zwai to be  $390 \text{ g C m}^{-2} \text{ yr}^{-1}$  which is equivalent to  $780 \text{ g DW m}^{-2} \text{ yr}^{-1}$  following the conversion factor of Strickland (1966).



Phytoplankton productivity was much lower when compared to the mean macrophyte productivity of the lake ( $3623.7 \text{ g DW m}^{-2} \text{ yr}^{-1}$ ). Furthermore, mean NAPP of macrophytes of Lake Zwai was also higher than phytoplankton mean gross integral photosynthesis or gross oxygen production with the concomitant production of carbon dioxide ( $3978.4 \text{ g O}_2 \text{ m}^{-2} \text{ yr}^{-1}$ ) obtained by Matheos Hailu (2011). The value was equivalent to  $1193.5 \text{ g C m}^{-2} \text{ yr}^{-1}$  or  $2387.04 \text{ g DW m}^{-2} \text{ yr}^{-1}$ . These results suggest that macrophytes contribute more primary production to the lake system than phytoplankton. It also supports the supposition that the lower biomass of phytoplankton in Lake Zwai might be due to the competitive dominance of macrophytes over phytoplankton for available resources or through production of repressive chemicals and increased turbidity (Getachew Beneberu and Seyoum Mengistou, 2010). The contribution of epiphytes and macrophytes to the total annual primary production is often significant in shallow lakes with large littoral zones such as Lake Zwai (Galanti and Romo, 1997).

## Conclusion

It was observed in this study that even slight nutrient-level differences can bring significant change in the abundance of *A. donax*, *E. colona*, *P. stratiotes* and *C. articulatus*, although the first two can also occur under low nutrient conditions. The density of the other species had a strong but negative association with most of the physicochemical parameters determined in this study. The expansion of *A. donax*, which can affect the biodiversity of the lake negatively, can be threat to both the flora and fauna of the lake. Reducing nutrient input at its more productive sites may prevent further expansion of this macrophyte, as its abundance was found to be relatively higher at such sites in the lake. The lake is so far free from the infestation of the worst invasive macrophytes such as water hyacinth (except for the rare occurrence of *P. stratiotes*). But if the nutrient levels become higher and the water level is further reduced, there is high probability for the lake to be invaded by such macrophytes in future, given the proximity of the lake to waterbodies that are

already invaded by this macrophyte. Therefore, excessive abstraction of lake water and anthropogenic activities that could add nutrients to the lake should be regulated.

Macrophyte production in Lake Zwai is low, though the macrophyte community may be contributing more carbon to the system than phytoplankton. The low macrophyte productivity is likely due the low availability of nutrients in the lake because aquatic ecosystems that have lower dissolved nutrients in the system generally exhibit low macrophyte primary productivity. RDA analyses suggested that nutrients were relatively more important in affecting productivity and biomass of macrophytes than physical factors such as conductivity and temperature, whereas pH and nitrite status of the lake negatively affected the biomass and production of most macrophyte species. In addition, the current practice around the lake, such as harvesting macrophytes by the lakeside community for different household purposes should be prohibited, since the biomass and production of most of macrophyte species is already low in the lake, even in the sites where the biomass and productivity was considerably higher (Bulbula and Kontula sites) than other studied sites.

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## Chapter 6

### Status and trends of fishes and fishery of a shallow rift valley lake, Lake Zwai, Ethiopia

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#### Abstract

Lake Zwai is an economically important lake in the country. However, the physico-chemical parameters of the lake seem to be threatened by anthropogenic and climatic factors, which in turn affect biotic factors as reflected in fish catches. A study was made to assess the status and trends of fishes and fishery during October 2012 to September 2014 in Lake Zwai. Ten fish species were identified with low species diversity for the lake ( $H'$  value of 1.67). The composition of the fishes has undergone considerable changes as compared to the last few decades. For instance, *Carassius auratus* and *Labeobarbus microterolepis* were not caught in this study. In addition, *Cyprinus carpio*, which was never reported in earlier catch earlier, attained the highest relative frequency (25.19 %) in this study, next to *Oreochromis niloticus* (27.88%), and then followed by *Carassius carassius* (20.71%) and *Clarias gariepinus* (20.51%). Canonical correspondence analysis showed that the average abundance of *C. carpio*, *C. carassius* and *C. gariepinus* were positively correlated with nutrients, whereas the abundance of *Labeobarbus ethiopicus* and *Labeobarbus intermedius* had negative correlation with most of the physico-chemical variables. The fish catch of Lake Zwai currently declined from 3180 tons in 1997 to 1157.14 tons in 2014. Most of the threats

resulted from the anthropogenic impactson the lake including pressure of fishing. Currently, plenty of pumps are abstracting fresh water from the lake by state and private commercial farms through most of the year that are critically impacting the water level of Lake Zwai. As a result, the lake ecosystem is being affected by catchment degradation and siltation. The study suggested that if nutrient levels continue to increase and water levels continue to decline, further changes in fish composition can be expected in the lake, especially with a shift towards fish that are mainly turbidity-tolerant species such as *C. carpio*. Hence, appropriate management is an urgent requirement that could assist in sustainable exploitation of the resources, so that the resource could contribute to food security in the study area in particular and in the country in general.

**Keywords:** Fish abundance, fish catches, composition, fish, physic-chemical factors, Lake Zwai, Ethiopia

## Introduction

Ethiopia has a number of lakes and rivers with substantial quantity of fish stocks. Many artificial water bodies have also been stocked with fish for fishery (Brook Lemma, 2012). Most of the lakes are located in the Ethiopian Rift Valley, which is part of the Great East African Rift Valley system. Lake Zwai is one of the lakes in the rift valley used for multiple purposes like irrigation, fishing, domestic water supply, transportation, recreation, supply of fresh water to Lake Abijata through the out flowing Bulbula River and most recently indoor flower farming.

There are seven indigenous fish species in Lake Zwai comprising of *Barbus paludinosus*, *Garra dembecha*, *Garra makiensis*, *Labeobarbus ethiopicus*, *Labeobarbus intermedius*, *Labeobarbus microterolepis* and *Oreochromis niloticus* (Golubtsov *et al.*, 2002; Abebe Getahun, 2010). Of these, *L. ethiopicus*, *G. makiensis* and *L. microterolepis* were reported as endemic to the lake (Golubtsov *et al.*, 2002 and Abebe Getahun, 2010). The lake also harbors five exotic fish species (*Tilapia zillii*, *Cyprinus carpio*, *Carassius*

*carassius* and *Carassius auratus*) which were introduced to enhance its production, and *Clarias gariepinus* that slipped into the lake accidentally (Abebe Getahun and Stiasny, 1998; Golubtsov *et al.*, 2002). Therefore, the lake has several important fish species for fisheries. The fish yield potential of the lake estimated from 3000 to 6680 tons per year (FAO, 1982) and the fisheries production has been the second largest from the Rift Valley lakes, which accounted for 3180 tons, next to Lake Chamo that produced 4500 tons per year (LFDP, 1998). However, according to Yared Tigabu (2003), there was a continuous decline in the annual catch of some fish species like *O. niloticus* from the lake since 1997, but on the other hand an increase of *C. gariepinus* was observed in the fishermen catches since 2010 (Mathewos Hailu, 2011). In the same way, very recently increase in the catches of *C. carpio* was recorded (Lemma Abera *et al.*, 2014).

For all these there are several evidences in the lake, such as decline in phytoplankton biomass (Getachew Beneberu and Seyoum Mengistou, 2009), increase in dominance of toxin-producing blue-green algae (Girma Tilahun, 2006), imbalance between water inflow and outflow (Tenalem Ayenew and Dagnachew Legesse, 2007) and decreased lake water volume (Girum Tamire and Seyoum Mengistou, 2012). Also commercial fish production in the lake was intensified through the support acquired from Lake Fisheries Development Project and onwards, the fish stocks of the lake have declined for a variety of reasons.

Although several studies were conducted on Lake Zwairegarding its various aspects, the changes on the lake are fast and hence the information on the lake gets obsolete quickly. Therefore, regular updating, monitoring and control are essential and this study becomes important and relevant for better management and sustainable use of the resources. Therefore, this paper attempts to assess the variations in some physico-chemical factors that influence the fish community structure; to update the species composition, distribution and relative abundance of the fishes; and finally to assess the

trends of the commercial catch in relation to some environmental factors that were recorded earlier.

### **Materials and methods**

**The study area:** Lake Zwai belongs to the Central Ethiopian Rift. On the average, the lake is located at an elevation of 1650 meter above sea-level, 7°89' - 8°05' N latitude and 38°72' - 38°92' E longitude located at about 163 km south of Addis Ababa. The lake is shallow and has an open water area of 434 km<sup>2</sup>, shoreline length of 137 km and an average depth of 2.5 m (Von Damm and Edmond, 1984). The maximum length and width of the lake is 32 km and 20 km, respectively (LFDP, 1997).

The lake region in general is arid and even during the rainy seasons dry periods of several weeks are common. According to the data obtained from National Meteorological Agency, during the study period the mean monthly minimum air temperature ranged from 11.9 to 16.4 °C, while the maximum mean monthly air temperature varied from 24.6 to 29.8 °C (Fig. 34). Monthly total rainfall also varied from 1.9 mm (November 2013) and 249 mm (July 2014) (Fig. 34).

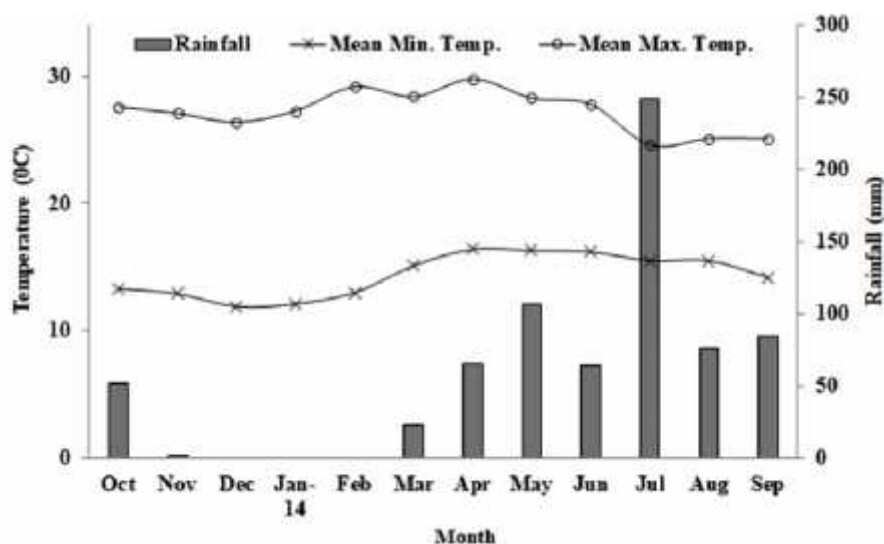


**Figure 34:** Monthly total rainfall, mean minimum and maximum air temperature of the lake region (from October 2013 to September 2014)  
Source: (National Meteorological Agency).

**Site selection:** To assess the variation in physico-chemical factors that influences the fish community structure of the lake, six sampling sites were selected based on geographical proximity and/or habitat similarity, their distance from human settlements and anthropogenic effects. Based on these, the detailed characteristics of each site are described as follows:

**Site 1** is located in the western part of the lake and the shoreline is characterized by intensive cultivation with horticulture and field crops including flower farm. The depth was between 1.5 to 2.9 meter and on average the vegetation cover around the shoreline is degraded.

**Site 2** is located around the mouth of River Bulbula in the area between intensively and moderately cultivated shorelines. The depth was between 1.5 to 2.3 meters.

**Site 3** is located on eastern part of the lake in ZwaiDugda district in between Yerera landing site and Tulu Gudo Island. The sampling site depth was between 1.5 to 3.10 meter and the vegetation cover around the shoreline is almost conserved woodland.

**Site 4** is located around the river mouth of Qatar. As is the case with the other sites, the area is also characterized as moderately cultivated. The depth was between 1.5 to 3.20 meters.

**Site 5** is located at the northern part of the lake and characterized by high human interference with horticulture and field crop activities next to site one. The water depth of the sampling site was 1.5 to 2.9 meter.

**Site 6** is located almost at the center of the lake at a depth of 3.2 to 4.8 meters. The site was characterized by the activities of some fishermen using gillnets and long-lines.

### **Field sampling and measurements**

**Physico-chemical parameters:** Physico-chemical parameters of the water were measured monthly from each site for two consecutive years (October 2012 to September 2014). Temperature, pH and conductivity of the lake were measured *in situ* during sampling periods at each sampling site. Transparency was measured with a Secchi disc of 20 cm diameter. Depth was also recorded at each sampling station. Water samples were collected from each site in dark plastic bottles, washed with acid and rinsed with distilled water several times in duplicates for nutrient analysis.

**Fish parameters:** Parallel to the physico-chemical sampling, every month the fishes were collected at all sites using variety of fishing gears, which included gill nets of various mesh sizes (6, 8, 10 and 12 cm stretched mesh size), monofilament nets with various stretched mesh sizes (5 mm to 55 mm stretched mesh size) and multiple long-lines with hooks of different size (9, 10, 11 and 12). The gears were set in the afternoon (4:00 pm) and were collected in the following day (7:00 am). Immediately after capture, some

morphometric measurements were measured and the fish samples were put in plastic jars containing 10 % formalin and labeled with all necessary information. Then the preserved specimens were soaked in tap water for many days to wash the formalin away. Then, they were transferred to 75 % ethanol before species identification was conducted. The specimens were identified to species levels using taxonomic keys of Shibru Tedla (1973), Golubtsov *et al.* (1995); Witte and Wim (1995); Stiassny and Abebe Getahun (2007) and Redeat Habteselassie (2012).

**Catch and effort:** Catch and effort data were recorded from the landing sites of the lake between October 2012 and September 2014. Data collection was done by the staff members of Zwai Fishery Resource Research Center as borehole as the selected cooperative in each district (Adami Tullu Jiddo Kombolcha, Dugda and Zwai Dugda). Total landing by species in kg, the number and type of gears used for fishing and the number of settings for each gear were recorded. The number of gears in a community was monitored by the data collector responsible for it. Total effort per gear type was estimated based on the number of gears (gill net and hooks), settings (beach seine) and time (the number of days the gear was deployed in the month). The number of gears and settings in relation to fish catch in each gear were obtained through interviews with the fishermen. These data were also used as raising factor in the estimation of annual yield. A review was also made on the long-term trend of fish production from various published results and unpublished data collected by Zwai Fisheries Resource Research Center.

Some previous physico-chemical variables were reviewed to assess the effects on the fish production. Monthly and yearly rainfall and temperature for the study area was obtained from National Meteorological Agency. Surface water level was also measured by a standard calibrated vertical scale to refer surface level gauge.

**Data analysis:** Species abundance at each sampling station was presented as a numerical contribution by each species. This was determined by calculating



the percentage of each species represented in the total catch for each station. Redundancy analysis was performed to observe the relation of species abundance data to environmental factors using CANOCO for windows 4.5 version software. Fish species diversity in the lake was computed using Shannon and Wiener Diversity Index following Shannon and Wiener (1963). Descriptive statistics were also used to analyze the remaining collected data using SPSS software (SPSS V.19.0).

## Results and discussions

**Distribution and diversity of fishes:** Ten species of fishes in the Families Cyprinidae, Clariidae and Cichilidae were identified from the different sites in the lake (Table 6.1). The species were *B. paludinosus*, *C. carassius*, *C. carpio*, *G. dembecha*, *G. makiensis*, *L. ethiopicus* and *L. intermedius* from the Family Cyprinidae, *C. gariepinus* from the Family Clariidae and *O. niloticus* and *T. zillii* from the Family Cichilidae. The status (presence/absence) of the species from the sampling sites is provided in Table 31.

**Table 31:** Fish species identified from lake Zwai (Present (+) and absent (-))

| Family     | Fish species                   | Sampling sites |        |        |        |        |        |
|------------|--------------------------------|----------------|--------|--------|--------|--------|--------|
|            |                                | S<br>1         | S<br>2 | S<br>3 | S<br>4 | S<br>5 | S<br>6 |
| Cyprinidae | <i>Barbus paludinosus</i>      | +              | +      | +      | +      | +      | +      |
|            | <i>Carassius carassius</i>     | +              | +      | +      | +      | +      | +      |
|            | <i>Cyprinus carpio</i>         | +              | +      | +      | +      | +      | +      |
|            | <i>Garra dembecha</i>          | +              | +      | +      | -      | -      | -      |
|            | <i>Garra makiensis</i>         | +              | +      | +      | +      | -      | -      |
|            | <i>Labeobarbus ethiopicus</i>  | -              | +      | -      | +      | -      | +      |
|            | <i>Labeobarbus intermedius</i> | +              | +      | +      | +      | +      | +      |
|            | <i>Clarias gariepinus</i>      | +              | +      | +      | +      | +      | +      |
| Cichilidae | <i>Oreochromis niloticus</i>   | +              | +      | +      | +      | +      | +      |
|            | <i>Tilapia zillii</i>          | +              | +      | +      | +      | +      | -      |

A total of 7,741 fish specimens were recorded from the three families during the study period. The species were *B. paludinosus*, *C. carassius*, *C. carpio*, *G. dembecha*, *G. makiensis*, *L. ethiopicus* and *L. intermedius* from the family Cyprinidae (50.73 %); *O. niloticus* and *T. zillii* from the family Cichilidae (28.76 %); and only *C. gariepinus* from the family Clariidae which accounts 20.51% (Fig. 35). Among the species that have been currently captured, *C. carpio*, *C. carassius*, *C. gariepinus* and *O. niloticus* are commercially important fishes. *Oreochromis niloticus* was the major species of the sample accounting for 94 % in previous studies (Schroder, 1984). However, the contribution of the fish has gradually declined to 89.3 % of total catch in 1994, 50.9 % in 2010 and 42 % in 2010 (Mathewos Hailu, 2013); and 31 % in

2012 (Lemma Abera *et al.*, 2014) and 27.88 % in this study (Fig. 36). On the contrary, the catch composition of *C. gariepinus* was 8.1 % in 1994 and increased to 41.8 % in 2010 (Mathewos Hailu, 2013) and currently decreased to 20.51 % (Fig. 36).

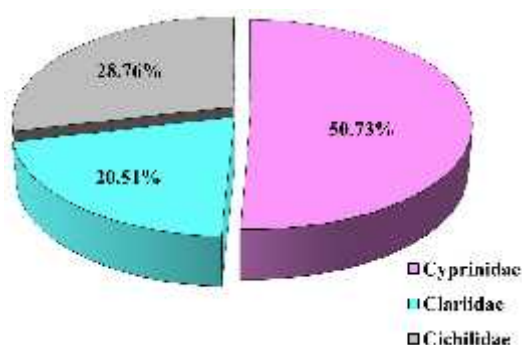


**Figure 35:** Percent coposition of fish at family level in Lake Zwai

The fish species diversity of Lake Zwai was low ( $H'$  value in between 1.5127 to 1.66681 on different sites) (Table 32) compared with some published data of similar works on lake ( $H'$  value in between 1.9 to 2.4) (Sylvester and John, 2010). Sylvester and John (2010) also reported that homogeneity of habitats favored lower diversity of fishes in water courses of Uganda. The lower fish diversity around the two inlets of the rivers was due to both lower fish abundance. On the other hand, relatively higher fish diversity was observed at the southern part of the lake (S2) around the outlet of Bulbula River, and this may be due to the relatively high densities of fishes.

**Table 32:** Shannon Weiner Density Index,  $H'$  value and number of fosh species (N) in Lake Zwai

| No. of species and $H'$ values | Study sites |        |        |        |        |        |
|--------------------------------|-------------|--------|--------|--------|--------|--------|
|                                | S 1         | S 2    | S 3    | S 4    | S 5    | S 6    |
| N                              | 9           | 10     | 9      | 9      | 7      | 7      |
| $H'$                           | 1.5472      | 1.6681 | 1.5473 | 1.5213 | 1.5142 | 1.5127 |

**Abundance of fish species in relation to environmental variables:** The numerical abundance from the three families that exist in the lake, *O. niloticus*, *C. carpio*, *C. carassius* and *C. gariepinus* each as a group contributed to the bulk of the fishes (Fig. 36) The details of the remaining species were also described in the same figure.

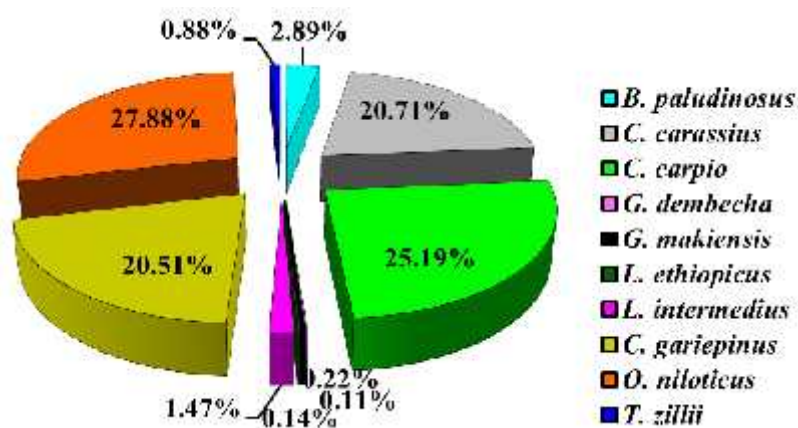


**Figure 36:** Fish species composition by percent

The RDA ordination of the species-environmental association indicated that nitrate, conductivity, nitrite, SRP, *Chl-a*, temperature and pH were negatively correlated with the first axis. Secchi depth was positively correlated to *L. ethiopicus* and *L. intermedius* with the axis, which contributed 88.4% of this variance (Table 33 and Fig. 37). The remaining environment factors and fish species were negatively correlated with this axis (Table 33 and Fig. 37).

**Table 33:** Results of redundancy analysis of abundance of fish and physico-chemical associations including eigenvalues and percentage variances expressed by the two axes as correlations between environmental values and the axes (strong correlations are marked bold)

| Variables   | Canonical coefficients |        |
|-------------|------------------------|--------|
|             | Axis 1                 | Axis 2 |
| Eigenvalues | 0.8840                 | 0.0930 |

| Variables                                                      | Canonical coefficients |                |
|----------------------------------------------------------------|------------------------|----------------|
|                                                                | Axis 1                 | Axis 2         |
| Cumulative percentage variance of species-environment relation | 0.8840                 | 0.9770         |
| Temperature                                                    | -0.0289                | -0.4912        |
| Secchi depth                                                   | 0.0263                 | <b>-0.7482</b> |
| Nitrate                                                        | <b>-0.5869</b>         | 0.3866         |
| Nitrite                                                        | <b>-0.6302</b>         | 0.5450         |
| SRP                                                            | <b>-0.9191</b>         | -0.3350        |
| Chlorophyll- <i>a</i>                                          | -0.4406                | -0.4658        |
| pH                                                             | -0.0853                | -0.4518        |
| Conductivity                                                   | -0.4804                | 0.3651         |

The second axis was positively correlated with the environmental variables nitrite, nitrate and conductivity that were associated with relatively high abundance of the two carp species (*C. carpio* and *C. carassius*) (Table 33; Fig. 37). The remaining fish species (*O. niloticus*, *T. zillii*, *C. gariepinus* and the two *Garra* species) were negatively correlated with the two axes of the environment variables such as *Chl-a*, SRP, pH and temperature.

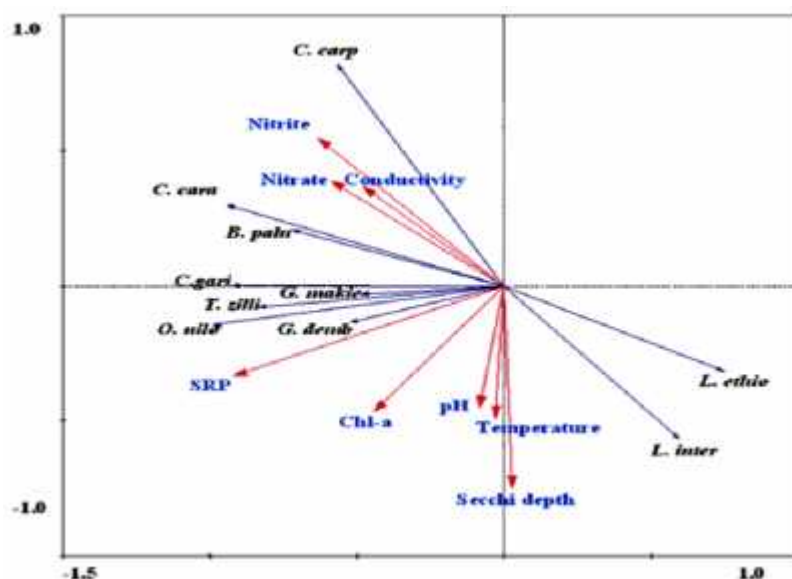


**Figure 37:** Bi-plots of the first two axes of correspondence analysis showing the association of fish species numerical abundance and environmental variables (Abbreviation: *L.ethio.* - *Labeobarbus ethiopicus*, *L.inter.*- *Labeobarbus intermedius*, *B.palu.*-*Barbus paludinosus*, *G.makie.*-*Garra makiensis*, *G.demb.*-*Garra dembecha*, *O.nilo.*- *Oreochromis niloticus*, *C.carp.*-*Cyprinus carpio*, *C.cara.*- *Carassius carassius* and *C.gari.*-*Clarias gariepinus* and SRP - Soluble Reactive Phosphate).

Hence, abundance of fish species in the lake was probably affected by changes in physico-chemical properties of the lake. Some parameters were correlated significantly with the abundance of fish species (Table 33 and Fig. 37). Similar trend was highlighted by other authors (Schoener, 1988; Whitefield, 1990) who suggested that physico-chemical parameters influence the aquatic system.

**Species composition of the commercial catch:** Very recently, the catch composition of the most commercially important fishes is estimated to be about 42.5 % *O. niloticus*, 27.1 % *C. carpio*, 16.4 % *C. carassius* and 14.1 %

*C. gariepinus* (Table 34). The long-term trends of the species composition of the catch are described in Fig. 38.

**Table 34:** Catch percentages of fishes by species and gears in 2013/14

| Total catch ( metric tons) |                     |                      |                     |                  |         |                           |
|----------------------------|---------------------|----------------------|---------------------|------------------|---------|---------------------------|
| Gear                       | <i>O. niloticus</i> | <i>C. gariepinus</i> | <i>C. carassius</i> | <i>C. carpio</i> | Total   | Catch size with gears (%) |
| Gill net                   | 80.06               | 14.91                | 28.42               | 46.73            | 170.12  | 14.7                      |
| Beach Seine                | 411.48              | 94.97                | 161.2               | 266.37           | 934.02  | 80.72                     |
| Long line                  | 0                   | 53                   | 0                   | 0                | 53      | 4.58                      |
| Total                      | 491.54              | 162.88               | 189.62              | 313.1            | 1157.14 | 100                       |
| Species composition (%)    | 42.48               | 14.08                | 16.39               | 27.06            |         |                           |



Currently, the commercial catch composition has changed with a decline in *O. niloticus*, but a progressive increase in the proportion of *C. carpio* and *C. carassius* and became significant part of the landings (Fig. 39). The catch composition of *C. gariepinus* was 176 tons in 1994 and increased to 1046 tons in 1999 then decreased to 163 tons in 2014 (Fig. 38). In general, currently the contribution of the fishes to the catch has decreased (Table 35 and Fig. 38). The decreasing trend in catch sizes since 2011 (Fig. 6.6) is due to an excessive increase in effort with gill nets, beach seines and number of hooks in long line (Table 35). The catch of *O. niloticus* and *C. gariepinus* decreased from 575.82 to 491.54 tons and 487.09 to 162.88 tons during 2011/12 to 2013/14, respectively. That of carps was increasing from 93.8 to 502.72 tons (Fig. 38). This could be due to overfishing of selected fish species with inappropriate gears and degradation of the catchment area that breeding of some fish species that take place. All these leads to decline in species like Nile tilapia.

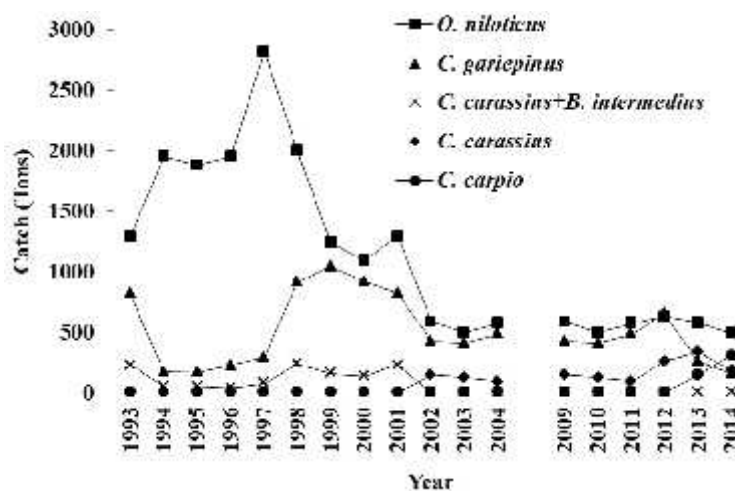


**Figure 38:** Trends in species composition of catches from Lake Zwai (after LFDP, 1998; Felegeselam Yohannes, 2003; Mathewos Hailu, 2011; Brook Lemma, 2012, and this study).

**Annual fish catch:** The annual fish catch of the lake shows different trends with time (Fig. 39). The first fishing phase was before 1994, which was a period of fisheries where the catch has been stable with a mean annual catch of 780 tons. The second phase was the growth period between 1994 and 2000, which was a period when yield increased dramatically to 2500 tons which has exceeded the recommended annual catch of 2163 tons. The third phase was the period in which fish catch declined with an average of 1200 tons in 2010 and currently, in these study years the catch again decreased to 1157.1 tons (Table 34 and Fig. 39).

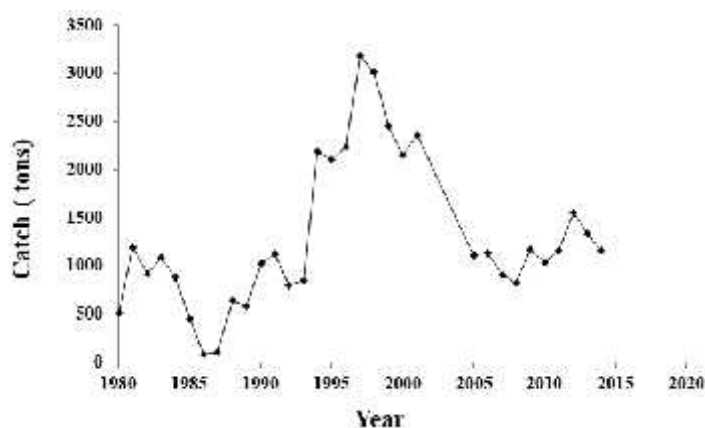


**Figure 39:** Changes in total annual fish catches from Lake Zwai between 1980 and results of this study included (after LFDP, 1998; Felegeselam Yohannes, 2003; Mathewos Hailu, 2011, Brook Lemma, 2012, and the present study).

### Factors that affect fish production

**Fishing gears:** The fishing activity of Lake Zwai was operated by three types of gears: beach seines, gillnets and long-lines (Table 35). Beach seine was the most common fishing gear used, whose presence increased from about 116 in 1993-1995 to 5596 in 2001/02 (Table 35) that most of the catch were recorded (Fig. 39). During this study, the assessment done has indicated that the

number of beach seines have decreased to 127 only (Table 35). The decline in the number of beach seines was associated with decrease in catch, which led some fishermen to move Lakes Langano, Koka and Fincha (Personal observation). The recommended minimum beach seine mesh size in the cod end was 6 cm, minimum mesh size in the wings was 8 cm, and maximum allowed length 150 meters for Lake Zwai (LFDP, 1997). However, Megersa Endebu *et al.* (2013) reported that the beach seines operating currently are twice as long as the recommended length. About 56.3 % of the fishermen use beach seine whose wing mesh size is less than 8 cm and 42% of the fishermen use beach seine whose cod end mesh size is less than 6 cm. that directly affect the production of the fish.

**Table 35:** Summary of changes in the number of fishing gears in Lake Zwai in different year ranges

| Years     | Gill nets | Beach seines | Long-line (Hooks) | Reference                  |
|-----------|-----------|--------------|-------------------|----------------------------|
| 1993-1995 | 1,810     | 116          | 1,056             | LFDP, 1996                 |
| 1996-1998 | 2,470     | 124          | 1,413             | Felegeselam Yohannes, 2003 |
| 2000-2001 | 1,098     | 5,596        | 399,995           | Yared Tigabu, 2003         |
| 2009-2010 | 104       | 68           | 56,070            | Mathewos Hailu, 2013       |
| 2012-2013 | 1,445     | 127          | 400,461           | In this study period       |

The number of gill nets has also decreased drastically from 2470 in 1996 - 1998 to 104 (2009/10) and then increased during this study period to 1445 (Table 35). The decrease in gillnet could be due to the decrease in tilapia catch in the lake's fishery. In the management plan of Lake Zwai set during LFDP 1997, the minimum stretched mesh size of gillnet was 8 cm in the first year, 9 cm in second year and 10 cm thereafter, with maximum length of 60 m. (Megersa Endebu *et al.* ,2013). Also Megersa Endebu *et al.* (2013) reported that 41.9 % of gill net users were confirmed to use gill nets whose mesh size is less than 8 cm very recently that influence the production.

In contrast to beach seines and gill nets, the number of hooks utilized in long-lines have increased from 1,056 in 1993/95 to 399,995 in 2000/01 (Table 35) and also catch were more during this period (Fig. 35). Again the number of the hooks decreased in 2009/2010 to 56,070 and currently the number increased and reached 400,461 (Table 35). The appearance of the long-line and its expansion was after the increase in *C. gariepinus* population, which was exotic to the lake. The increase in long-line fishery is associated with low labor and capital investment requiring only one person and just a raft, while using a beach seine requires three or more persons to operate with a wooden boat.

**Lake water level:** Currently, plenty of pumps are abstracting freshwater from the lake by the state, investors and private commercial farms throughout the year (personal observation). Even during the rainy seasons water for horticultural crops is collected from the lake. Hence, the current irrigation practices in the upstream areas have considerably reduced the volume of the inflowing water from Meki and Qatar River and the lake itself, critically impacting the water level of Lake Zwai. As a result, the lake ecosystem is being affected by catchment degradation, siltation, imbalance between water inflow and outflow. Even if there were high anthropogenic pressures in Lake Zwai, abundant fish species were collected when the water level of the lake increased (Fig. 40).

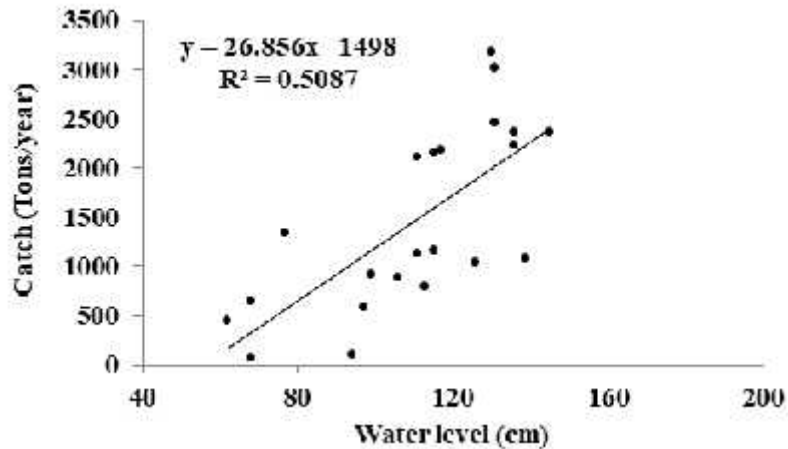


**Figure 40:** Relationship between water level and fish catch in Lake Zwai (1982-2014) (Source: LFDP, 1998; Felegeselam Yohannes, 2003; Mathewos Hailu, 2011; Brook Lemma, 2012 and the current study).

**Water quality:** Aside from problems related to decreasing water level of the lake, water abstraction started to induce salinity, due to losses of freshwater from the lake. Simultaneously, the application of agrochemicals (Personal observation) and fertilizers due to intensification of irrigation practices around the lake has increased and affected the water chemistry of the lake (Table 36).

**Table 36:** Trends in some physico-chemical factors of Lake Zwai

| Parameters   | Units             | Amounts                                     | Present study | General trend |
|--------------|-------------------|---------------------------------------------|---------------|---------------|
|              |                   | Previous records                            |               |               |
| Secchi depth | cm                | 40 -106 (Girma Tilahun, 1988)               | 17.8-22.1     | Decreasing    |
| pH           | -                 | 8.5 (Elizabeth Kebede <i>et al.</i> , 1994) | 8 - 8.4       | Decreasing    |
| D. Oxygen    | mgL <sup>-1</sup> | 7.1 (Adamneh Dagne, 2010)                   | 3.4 - 6       | Decreasing    |

| Parameters    | Units                | Amounts                                      | Present study | General trend |
|---------------|----------------------|----------------------------------------------|---------------|---------------|
|               |                      | Previous records                             |               |               |
| Chl- <i>a</i> | $\mu\text{g L}^{-1}$ | 150 - 212<br>(Girma Tilahun, 1988)           | 37 - 54.5     | Decreasing    |
| Nitrate       | $\mu\text{g L}^{-1}$ | 28 (Girma Tilahun, 1988)                     | 30.1 - 61.7   | Increasing    |
| SRP           | $\mu\text{g L}^{-1}$ | 5.5-16.2 (Girma Tilahun, 1988)               | 38.2 - 64.7   | Increasing    |
| Ammonium      | $\mu\text{g L}^{-1}$ | 36.4 (Elizabeth Kebede <i>et al.</i> , 1994) | 64.17- 258.92 | Increasing    |
| Conductivity  | $\mu\text{Scm}^{-1}$ | 347- 400<br>(Girma Tilahun, 1988)            | 361.5 - 484.5 | Increasing    |

Hence, currently, the high concentration of SPR, Ammonium and nitrate were recorded in the lake (Table 36). The farmlands located near the shore use fertilizers which are rich in nutrients, especially phosphates and nitrates, and hence can increase the concentration of SRP (Table 36). On the other hand the increment in turbidity was measured by the low Secchi depth measured during the study period as compared to previous records (Table 36). The lower Secchi depth can be partly caused by the rising levels of siltation as conductivity increased. Hence, on this line some of the physico-chemical features of the lake water were changed and some of them may affect the aquatic organisms, such as fish kills occurring at the outlets of the flower farm effluents (personal observation). Also evidence from other lakes in Ethiopia show that the longer term impact of human induced changes like deforestation increases the risk of flooding such as Hawassa Lake or even complete degradation of the lake like in the case of Haramaya (Brook Lemma, 2011).

### Conclusions and recommendations

LakeZwai has shown some undesirable changes in terms of some physico-chemical factors and shift in catch compositionof fish species. The fish fauna of Lake Zwai is dominated by Cyprinids. Of the total 12 species recorded in the lake only 10 species were sampled with the three families.Seven species are from Cyprinidae andthe rest are included in the Families ClariidaeandCichlidae. Clariidae is represented by only one species (*C. gariepinus*) and Cichlidae by two species (*O. niloticus* and *T. zillii*). *C.auratus* and *L. microterolepis* were not encountered during this study. *Oreochromis niloticus*, *C. carpio*, *C. carassius* and *C.gariepinus* were the most abundant in number, and commercially the most important fishes of the lake. Based on percentage composition, *O.niloticus* is relatively the most dominant fish in L. Zwai, which contributed to 27.88 % of the total catch. Among the Cyprinids, *C. carpio* and *C. carassius* contributed 25.19 % and 20.71 %, respectively, of the total fishes. *Clarias gariepinus* contributed 20.51 % of the samples from the lake.

Abundance of fish species in the lake was related to water quality of the lake. For instance, *C. gariepinus*, *C. carassius*, and *C. carpio* were found in relatively nutrient-rich sites. The major cause for the accelerated water quality deterioration in the lake was identified as human impact in the catchment of the lake. These include land use changes, particularly removal of vegetation cover, irrigation, diversion of inflows and industrial use of the water that release untreated effluents into the lake. These actions taken to promote development in the area became causes for the decline in water quality and quantity of the lake and started to have direct have effects on the current changes in fish catch, fish quality, composition and abundance.

Therefore, sustainable utilization and conservation measures should be taken that consider the management of wastes and excess nutrients and other agro-chemical inflows. In Lake Zwai, large numbers of small sized fishes of all species are being exploited and proper management actions are required to

protect the immature fishes. Fishing gear types and their mesh sizes should be regulated to put in place evidence-based decision to regulate fish sizes at harvesting, maintaining balanced fish stocks in the lake and to ensure fish species are not captured before spawning. Therefore, the fishery management plan such as prohibiting fishing on spawning grounds during the breeding season (fish sanctuaries or refuges) should be in place to avoid overexploitation. Thus, management tools like closed seasons, catch quota restrictions, mesh size regulations, gear restrictions and limits on the number of fishers has to be done for the sake of sustainable exploitation of the stocks. The development of aquaculture and other related alternative fisheries (Integrated-fish-horticulture-poultry farming, Aquaponics technology, etc.) to reduce the pressure on the natural system should be encouraged.

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## Chapter 7

### Ecosystem structure, trophic link and functioning of Lake Zwai, Ethiopia

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#### Abstract

A trophic model was constructed for Lake Zwai ecosystem using Ecopath with Ecosim application software. This model was used to evaluate and analyze the food web structure and other properties of this ecosystem and to assess the impacts of different fishing simulations. The trophic levels of Lake Zwai ecosystem were between 1.0 and 3.29. It was found out that the biomass flow of the ecosystem was highly restricted to I and II trophic levels which contributed 99.76%. The mean transfer efficiency was only 4.4%. The fishery catch consumed 2.5% of the primary production in the lake. Low ecotrophic efficiency (EE) of 0.47 was noted for the phytoplankton showing that most of the production remains unutilized within the system. In Lake Zwai all fish groups were highly constrained by a combination of fishing and predation mortalities as explained by high EE. Management scenarios using Ecosim analysis indicated that moderate decrease in the beach seine effort could be helpful for the thriving of carp abundance. Carps in Lake Zwai are

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under the pressure of beach seine with high harvest rate ( $EE=0.9$ ). Reducing of fishing efforts by using beach seine by half would increase their biomass to six times the current biomass in ten-year period. The food web of Lake Zwai is consumer exercised top-down control with low  $EE$  of primary producers and herbivore zooplankton.

**Keywords:** Ecopath, ecosim, Ethiopia, Lake Zwai, species introduction, transfer efficiency, trophic modeling

### Introduction

Freshwater ecosystems have been subjected to various natural and human induced changes throughout the globe for over a century now (Alfred, 2002; Magadza, 2010). The changes associated with environmental degradation ranged from loss of biodiversity to complete loss of the ecosystem (Ayenew and Legesse, 2007; Canonico *et al.*, 2005; Lemma, 2003). In recent years, the establishment of increasing human populations with intense agricultural practices within catchment has resulted in significant degradation and loss of pristine ecosystems (Harte, 2007). Similarly, interventions in fisheries management so as to meet the increasing demand for fish have resulted in overexploitation of commercially important fish species (Matsuishi *et al.*, 2006). Furthermore, introduction of exotic species has also been practiced to enhance fisheries and filling the available niche in ecosystems (Welcomme, 1988), though unintended adverse impact either to specific species or the whole ecosystem could arise due to the introduction (Witte *et al.*, 1992).

Understanding the driving forces of ecosystem functioning and the resilient capacity of natural systems to anthropogenic and/or natural changes are the fundamental goals of aquatic ecology (Nielsen and Muller, 2009), as it is important for sustainable resource management. Any change in the biodiversity could adversely affect the food web relationships that in turn could affect resource management. Since aquatic ecosystems are complex in terms of spatial, temporal and trophic organization, systematic studies

regarding ecosystem structure and functioning necessitates quantification of trophic relationships between functional groups in the system (Christensen *et al.*, 2005). Ecopath with Ecosim (EwE) model has been developed to quantify the trophic relationship and the relative simplicity and comprehensiveness of the model is apparent in its application to several marine and freshwater ecosystems as boreholeas to a farming system (Christensen *et al.*, 2005; Kipkemboi, 2006).

Freshwater ecosystem provides a broad variety of valuable goods and services for human societies, some of which are irreplaceable (Covich *et al.*, 2004). The value of this biodiversity is many fold: its direct contribution to economic productivity (e.g. fisheries); its value as a storehouse of genetic information; and its value in supporting the provision of ecosystem services (Pearce, 1998). Lake Zwai, a freshwater habitat in the rift valley, is a source of water for domestic consumption, irrigation, recreation and it has been supporting the livelihood of the surrounding communities through fishing for decades. The fisheries activity of the lake was intensified from the funding acquired from Lake Fisheries Development Project (LFDP) (Yohanes, 2003). The annual sustainable yield of the lake was estimated to be 2000 tons per year (Schroder, 1984). Lake Zwai fisheries production is the second largest fish producer of the Ethiopian rift valley lakes, next to Lake Chamo that produces 4500 tons per year (LFDP, 1997) and together these two lakes support the fish demand of the capital, Addis Ababa, Ethiopia.

Lake Zwai is relatively one of the extensively studied lakes in Ethiopia. Phytoplankton species composition, primary production and biomass in relation to limnological variables have been studied by various investigators (Kebede and Willen, 1998; Tilahun, 1988, 2006). Zooplankton species composition, abundance and production have also been studied (Dagne, 2010; Dagne *et al.*, 2008). Recently, some studies have emerged on the distribution and aboveground primary production of the dominant macrophytes in Lake Zwai (Tamire and Mengistou, 2013). The fisheries

research in Lake Zwai has focused on the taxonomy (Globstov *et al.*, 2002; Stiassny and Getahun, 2007), ecology (Abebe and Tefera, 2010; Admassu and Ahlgren, 2000; Negassa and Getahun, 2003; Tadesse, 1988) and stock assessment (LFDP, 1996, 1998; Tesfaye, 2006; Abera *et al.* 2018) of the fishes of the lake.

Despite several studies done in Lake Zwai on various organisms and limnological aspects, no attempt has been made to understand the structure and functioning of the lake through trophic interactions and analysis of ecosystem from holistic perspective. Ecosystem based management has gained a wide recognition among the scientific community, managers and decision-makers (Plaganyi, 2007; Pitcher, *et al.*, 2009). Therefore, this study aims to characterize food web structure and trophic interactions of Lake Zwai employing the ecological model Ecopath with Ecosim (EwE) as a tool.

### Materials and methods

**The study site:** Lake Zwai (7°52' to 8°8' N latitude and 7°52' to 38°56' E longitude) is situated at an altitude of 1636 m above sea level and has a surface area of 434 km<sup>2</sup> with a mean depth of 2.5 m (Wood and Talling, 1988). The littoral area of the lake is covered with emergent and submergent macrophytes composed of *Typha latifolia*, *Arundo donax*, *Echinochloa colona*, *Potamogeton schweinfurthii* and *Nymphaea lotus* (Girum Tamire and Seyoum Mengistou 2012). Lake Zwai is wind-exposed, shallow and turbid lake and 91% of light extinction is contributed by non-algal particles (Tilahun and Ahlgren, 2009). Phytoplankton species composition is diverse (Kebede and Willen, 1998). The zooplankton community in the lake consists of copepods which are dominated by *Thermocyclops decipensis* and *Mesocyclops aequatorialis* (Dagne, 2010). Forty-nine rotifer species were also recorded which were dominated by *Brachionus angularis*, *Filinia novaezealandiae*, and *Trichocerca ruttneri* (Dagne *et al.*, 2008).



There are six indigenous fish species in the lake comprising *Barbus ethiopicus*, *Barbus paludinosus*, *Labeobarbus intermedius*, *Garra makiensis*, *Garra dembecha* and *Oreochromis niloticus* (Dejen *et al.*, 2010; Globstov *et al.*, 2002, Abera *et al.* 2018). The lake also harbors four exotic fish species (*Tilapia zillii*, *Carassius carassius* and *Carassius auratus*) which were introduced to enhance its fishery production and *Clarias gariepinus* that slipped into the lake accidentally (Globstov *et al.*, 2002, Abera *et al.* 2018). Of the eleven fish species in Lake Zwai, *Oreochromis niloticus*, *Tilapia zillii*, *Carassius carassius* and *Clarias gariepinus* were commercially important supporting the livelihoods of the fishing community.

**Ecopath model description:** Ecopath models are mass-balance models that describe energy pathways in a food web. The model has been extensively used to quantify ecosystem attributes of various ecological processes or stressors (Christensen *et al.*, 2005). In this study, Ecopath with Ecosim (EwE) software (version 5.1) was used to evaluate trophic interactions and energy fluxes within Lake Zwai food web. The master equation for Ecopath is:

$$B_i \left( \frac{P}{B} \right)_i EE = \sum_{j=1}^n B_j \left( \frac{Q}{B} \right)_j DC_{ji} + B_i \left( \frac{P}{B} \right)_i (1 - EE_i) + EX_i$$

Where:  $B_i$  is the biomass of Group I (in tons  $\text{km}^{-2}$  fresh weight);  $(P/B)_i$  is the annual production to biomass ratio of  $i$  which equals the total mortality coefficient ( $Z$ ) in steady-state conditions (Allen, 1971);  $EE_i$  is the ecotrophic efficiency representing the part of the total production consumed by predators or captured in the fishery or exported;  $B_j$  is the biomass of the predator group  $j$ ;  $Q/B_j$  is the annual food consumption per unit biomass of the predatory group  $j$ ;  $DC_{ji}$  is the proportion of the group  $i$  in the diet of its predator group  $j$ ;  $EX_i$  is the export or catch in fishery of group  $i$ , that is assumed to be exploited in the fishery (Christensen *et al.*, 2005).

**Ecosim simulations:** The Ecosim routine used in EwE is a dynamic simulation approach that uses the linear equations of steady-state Ecopath model (Walters *et al.*, 1997), isolating the biomass accumulation term and setting up differential equations of the form. In Ecosim the Ecopath equation is re-expressed in a dynamic formulation:

$$\frac{\delta B_i}{\delta t} = g_i \sum_j C_{ji} - \sum_j C_{ij} + I_i - (M_i + F_i + e_i) B_i$$

Where:  $\delta B_i / \delta t$  represents the biomass growth rate,  $g_i$  is the net growth efficiency (production/consumption ratio),  $\sum_j C_{ji}$  is the total consumption rate of group  $i$ ,  $\sum_j C_{ij}$  is the predation of all predators on group  $i$ ,  $M_i$  the non-predation natural mortality rate,  $F_i$  is the fishing mortality rate,  $e_i$  is emigration rate and  $I_i$  is immigration rate. This general equation supports predictions of how biomass develops over time as a consequence of changes in fishing patterns or in other ecosystem forcing functions, e.g., gear effort (Pauly *et al.*, 2000).

Using the mass balanced Ecopath model three Ecosim scenario simulations were run. In all scenarios the simulation time was set to 10 years ahead of the present time. Ecosim requires a vulnerability setting for all predator-prey interactions which controls the rate at which a prey group moves between the vulnerable state and the state in which the group is not susceptible to predation. In this study, the vulnerability of each functional group was set proportional to its trophic level estimated by Ecopath. This setting has been used in the EwE model (Cheung *et al.*, 2002; Yunkai-Li *et al.*, 2009). Other Ecosim values were set to their default value.

**Scenario 1:** Changing the mortality of catfish. In this set of runs, the fishing mortality of catfish was set to be 1.5 and 2.0 times. Catfish was chosen because of its deleterious effect that has been seen in the mixed trophic impact analysis.

**Scenario 2:** Changing effort of beach seine. In this set of runs, the amount of fishing effort was set to be 0.75, and 0.5 times the current fishing effort. The choice of beach seine for this scenario is because it acts on wider range of ecological groups.

**Scenario 3:** Changing effort of long line. In this set of runs, the amount of long line effort was set to increase by 1.5 and 2.0 times the current fishing effort. The choice of long line for this scenario is because it only removes catfish which has negative impact on wider range of ecological groups through predation and cascading effect.

**Ecological grouping:** In Ecopath, functional groups can be composed of species, groups or ontogenetic fractions of a species (Christensen and Walters, 2004). Similarity of habitat, diet and life history characteristics were considered to formulate a total of 12 functional groups for Lake Zwai (Table 38). The biomass of commercially exploited fish species were estimated assuming equilibrium conditions, such that  $B=Y/F$ : Where Y is yield in tons  $\text{km}^{-2} \text{ year}^{-1}$  and F is the coefficient of fishing mortality. Fishing mortality (F) is the difference between total (Z) and natural mortalities (M):  $F=Z-M$ , assuming that Z is equal to production biomass (P/B) as indicated by Allen (1971).

**Table 37:** Functional groups used as inputs for EwE Model of Lake Zwai

| Functional groups | Group members                                                      |
|-------------------|--------------------------------------------------------------------|
| Waterfowls        | Great white Pelican, Cormorant, African fish eagle and king fisher |
| Catfish           | <i>Clarias gariepinus</i>                                          |
| Carp              | <i>Carassius auratus</i> and <i>Carassius carassius</i>            |
| Tilapia           | <i>Oreochromis niloticus</i> and <i>Tilapia zillii</i>             |
| Barbus            | <i>Barbus paludinosus</i>                                          |
| Garra             | <i>Garra dembecha</i> and <i>Garrama kiensis</i>                   |
| Macro-zoobenthos  | Insects, Oligochaets, Nematods and Mollusks                        |
| Carnivores        | <i>Mesocyclops aequatorialis</i>                                   |

| Functional groups | Group members                                                                                                  |
|-------------------|----------------------------------------------------------------------------------------------------------------|
| zooplankton       |                                                                                                                |
| Herbivores        | Thermocyclops, Cladocerans and Rotifers                                                                        |
| zooplankton       |                                                                                                                |
| Phytoplankton     | Cyanophyta, Chlorophyta, Bacillariophyta and Euglenophyta                                                      |
| Macrophyte        | <i>Typha</i> , <i>Arundo</i> , <i>Echinochola</i> , <i>Potamogeton</i> , <i>Cyprus</i> and <i>Nymphaea sp.</i> |
| Detritus          |                                                                                                                |

The production/biomass ratio of Carp and Catfish were estimated from length-frequency distributions using FISAT software (Gayanilo et al., 2002). Estimation of growth parameters (the asymptotic length,  $L_{\infty}$ , and the growth coefficient,  $K$ ) were calculated using the ELEFAN I application from length frequency data. Natural mortality ( $M$ ) was computed using the predictive formula of Pauly (1983):

$$\ln(M) = -0.0152 - 0.279 \ln L_{\infty} + 0.6543 \ln(K) + 0.463 \ln(T)$$

Where:  $M$  and  $K$  are parameters of Von Bertalanffy Growth Function,  $L$  is for length and  $T$  for annual mean surface water temperature of the lake.

Yield data for the commercially exploited species comprising Tilapia (*Oreochromis niloticus* and *Tilapia zillii*), Carp (*Carassius auratus* and *Carassius carassius*) and Catfish (*Clarias gariepinus*) were obtained from Zwai Fisheries Resources Research Center (unpublished data) (Table 40). Biomass of Garra (*Garra dembecha* and *Garra makiensis*) and straight fin barb (*Barbus paludinosus*) was estimated by hauling a known area along the shore line at different locations of the lake. Production biomass ratio for unexploited fish group (*Garra* and *Barbus*) was considered to be equal to natural mortality as they are not impacted by fishing mortality.

The food consumption per unit of biomass ( $Q/B$ ) was estimated using the multiple regression formula of Palomares and Pauly (1998).

$$\log\left(\frac{Q}{B}\right) = 5.847 + 0.280 \log\left(\frac{P}{B}\right) - 0.152 \log W_{\infty} - 1.360T' + 0.062A + 0.510h + 0.390d$$

Where:  $W_{\infty}$  = Asymptotic weight;  $T' = 1000/\text{Kelvin}$  (Kelvin =  $T^{\circ}\text{C} + 273$ );  $A$  = the aspect ratio of the caudal fin, indicative of metabolic activity and expressed as the ratio of the square of the height of the caudal fin and its surface area. Aspect ratio for each fish groups was made by measuring the area of their caudal tail, using the grid method and dividing to the height of the caudal fin (Palomares and Pauly, 1998).

**Table 38:** Growth and other fish parameters used for estimation of consumption biomass (NOTE:  $L_{\infty}$  is for asymptotic fish length,  $K$  for The von Bertalanffy growth function,  $A$  for aspect ratio;  $h$  for a dummy variable expressing food type (1 for herbivores, and 0 for detritivores);  $d$  for dummy variable expressing food type (1 for detritivores and 0 for herbivores and <sup>a</sup>Tesfaye (2006); <sup>b</sup>Fetahi and Mengistou (2007)

| Growt        | Tila | Catf | Car | Ga  | B |
|--------------|------|------|-----|-----|---|
| Yield        | 514  | 426. | 102 | -   | - |
| Z            | 1.9  | 1.34 | 0.7 | 2.5 | 2 |
| $L_{\infty}$ | 31.  | 100. | 49. | 10. | 1 |
| $K (y^{-1})$ | 0.4  | 0.22 | 0.1 | 1.5 | 1 |
| Aspect       | 1.7  | 1.63 |     | 3.2 | 3 |
| h            | 1    | 0    | 1   | 0   | 0 |
| d            | 0    | 0    | 0   | 0   | 0 |

Biomasses of benthic macro-invertebrates were estimated from monthly collected bottom samples between September 2010 and May 2011. Macro-invertebrates in offshore stations were sampled using Ekman grab. Macro invertebrate assemblages associated with each plant community were sampled and sorted after removing the total parts of the vegetation randomly from 0.25 m<sup>2</sup> quadrant. Each grab was sieved through a 255 µm nitex net, sorted samples of invertebrates were separated, counted and identified to the

lowest practical taxonomic level with light microscopy according to keys given by Durand and Leveque (1981) and Bouchard (2004). After sorting into different species, excess water was removed by placing them onto a filter paper and their weight was recorded to the nearest 0.0001 g. Biomass of 23.62 g WW m<sup>-2</sup> was estimated for macro-invertebrates of the lake.

Production/biomass ratios of benthic macro-invertebrates were estimated using the empirical formula of (Plante and Downing, 1989).

$$\log(P) = 0.06 + 0.79\log(B) - 0.16\log(M_{\max}) + 0.05 T$$

Where B: mean annual biomass; M<sub>max</sub>: maximum mass per individual; T: mean annual surface water temperature (°C).

Production/biomass ratio of 16.62 per year was estimated for the lake. Consumption /biomass ratio of 83.1 per year was computed for macro-zoo benthos based on assumed gross food conversion efficiency (P/Q) of 0.2 (Christensen *et al.*, 2005).

Zooplankton biomass of 0.017 and 0.97 WW tons km<sup>-2</sup> was used for carnivore and herbivore zooplankton, respectively (Dagne, 2010). Production/biomass ratio was estimated from the production of zooplankton by Dagne (2010). *Thermocyclops aequatorialis* was considered as carnivorous zooplankton and the rest of the group as herbivorous zooplankton resulting in a production/ biomass ratio of 38.35 and 272.8, respectively. Consumption/biomass ratio (Q/B) of zooplankton was estimated based on assumed gross food conversion efficiency (P/Q) of 0.2 (Christensen *et al.*, 2005) which gave 191.75 per year and 1364 per year for carnivore and herbivore zooplankton, respectively.

Phytoplankton biomass was determined from biweekly composite water samples in terms of Chlorophyll-*a* (Chl-*a*). Biomass of 70.46 µg L<sup>-1</sup> is converted to wet weight (WW) using the subsequent conversion of Chl-*a* to carbon and carbon to WW (Jones, 1979). The mean euphotic depth of 0.54 m

(estimated from the mean Secchi disk depth 0.18 m) was used to convert the volumetric value to areal biomass so as to fit the unit of Ecopath model and estimated to be 15.99 tons WW km<sup>-2</sup>. Primary production of 1.06 g C m<sup>-2</sup> d<sup>-1</sup> estimated by Tilahun and Ahlgren (2009) was used to determine P/B ratio. Yearly primary production of 3869 g WW m<sup>-2</sup> year<sup>-1</sup> was obtained after appropriate conversion and multiplication factor. Based on the mean biomass of 15.99 tons km<sup>-2</sup>, annual production/biomass ratio of 241.96 was obtained.

The fresh weight of macrophytes was estimated by harvesting above ground biomass from (0.5 m x 0.5 m) quadrant. Biomass per square meter was estimated by determining the average biomass per individual stem at each sampled location, and then multiplying this value by the number of stems per square meter (stem density) (Piedade *et al.*, 1991). The above ground fresh weight biomass of macrophyte estimate was 3011.68 tons WW km<sup>-2</sup>. Macrophytes areal distribution was estimated to be six percent of the lake from areal map, and macrophytes biomass of 180.7 tons WW km<sup>-2</sup> was used as an input for the Ecopath analysis.

Detritus biomass was calculated as a function of primary production and euphotic depth by employing the relationship suggested by Christensen and Pauly (1993).

$$\text{Log } D = 0.954 \log PP + 0.863 \log E - 2.41$$

Where D is for detritus biomass (g C m<sup>-2</sup>);

PP is for primary production (in g C m<sup>-2</sup> year<sup>-1</sup>);

E is for euphotic depth in meter.

Detritus biomass of (6.72 g WW m<sup>-2</sup>) was estimated based on euphotic depth of 54 cm which was calculated from the mean Secchi depth.

Waterfowls of Lake Zwai include cormorants, great white pelicans and the marabou stork. As no data regarding actual abundance, biomass,

consumption and mortality are available; the data from Lake George, Uganda (Moreau *et al.*, 1993) was adopted for the model.

**Parameterization and model balancing:** Once all required parameters of all functional groups are determined and entered in EwE model, the model demands mass-balancing through parameterization. In order to balance the model, parameter estimates derived from other systems and/or estimated values were modified to conform to the prerequisite of Ecopath, in which all Ecotrophic Efficiencies (EE) should be less than 1.0 and gross efficiency (P/Q) ranges between 0.1 and 0.3, which ensures mass balance of the system.

## Results

**Model output:** The basic input for each of the 12 ecological groups and their relative diet compositions are given in Table 42 and Table 43, respectively. Biomass estimates, diet compositions, and catch yields were left largely unchanged during model balancing as these parameters were directly estimated from Lake Zwai. The input data for this model was assigned an Ecopath Pedigree Index of 0.58.



**Table 39:** Input values and estimates by Ecopath (shown in bold) used in the Ecopath Model of Lake Zwai, Ethiopia (NOTE: <sup>a</sup>Moreau *et al.* (1993); <sup>b</sup>Tesfaye (2006); <sup>c</sup>Dagne (2010))

| Functional groups      | Trophic level | Biomass (t.km <sup>-2</sup> ) | P/B year <sup>-1</sup> | Q/B year <sup>-1</sup> | EE   | P/Q   |
|------------------------|---------------|-------------------------------|------------------------|------------------------|------|-------|
| Waterfowls             | 3.29          | 0.003 (0.0024)                | 0.25 <sup>a</sup>      | 58.00 <sup>a</sup>     | 0.00 | 0.004 |
| Catfish                | 3.07          | 1.090 (0.872)                 | 1.34                   | 5.97                   | 0.84 | 0.22  |
| Carp                   | 2.46          | 0.270 (0.322)                 | 0.74                   | 22.55                  | 0.99 | 0.03  |
| Tilapia                | 2.02          | 1.280                         | 1.93 <sup>b</sup>      | 28.40                  | 0.84 | 0.07  |
| Barbus                 | 2.94          | 0.120                         | 2.49                   | 24.41                  | 0.97 | 0.10  |
| Garra                  | 3.04          | 0.080                         | 2.54                   | 21.99                  | 0.05 | 0.12  |
| Macro-zoobenthos       | 2.16          | 23.620 (21.258)               | 16.62                  | 83.10                  | 0.75 | 0.20  |
| Carnivores zooplankton | 2.86          | 0.0170 <sup>c</sup>           | 38.35 <sup>c</sup>     | 191.75                 | 0.51 | 0.20  |
| Herbivores zooplankton | 2.09          | 0.970 <sup>c</sup> (1.067)    | 272.80 <sup>c</sup>    | 1364.00                | 0.39 | 0.20  |
| Phytoplankton          | 1.00          | 15.990                        | 241.96                 | 0                      | 0.47 | -     |
| Macrophyte             | 1.00          | 180.701                       | (0.29)                 | 0                      | 0.02 | -     |
| Detritus               | 1.00          | 6.720                         | -                      | -                      | 0.32 | -     |

**Table 40:** Diet composition of the functional groups in Lake Zwai ecosystem model (NOTE: <sup>a</sup>Moreau *et al.* (1993); <sup>b</sup>Tugie and Taye (2004); <sup>c</sup>Negassa and Padanillay (2008); <sup>d</sup>Mavutiet al. (1996); <sup>e</sup>Fetahi and Mengistou (2007))

| No. | Prey                                | Predator |       |       |       |       |       |       |       |       |
|-----|-------------------------------------|----------|-------|-------|-------|-------|-------|-------|-------|-------|
|     |                                     | 1        | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     |
| 1   | Waterfowls <sup>a</sup>             |          |       |       |       |       |       |       |       |       |
| 2   | Cat fish <sup>b</sup>               |          |       |       |       |       |       |       |       |       |
| 3   | Carp                                | 0.007    |       |       |       |       |       |       |       |       |
| 4   | Tilapia <sup>c</sup>                | 0.712    | 0.150 |       |       |       |       |       |       |       |
| 5   | Barbus                              | 0.211    | 0.050 |       |       |       |       |       |       |       |
| 6   | Garra                               | 0.070    |       |       |       |       |       |       |       |       |
| 7   | Macro-zoobenthos <sup>d</sup>       |          | 0.200 | 0.100 |       | 0.580 | 0.850 | 0.080 | 0.100 | 0.080 |
| 8   | Carnivores zooplankton <sup>e</sup> |          | 0.050 | 0.010 |       |       |       |       |       |       |
| 9   | Herbivores zooplankton <sup>e</sup> |          | 0.450 | 0.300 | 0.020 | 0.250 | 0.050 | 0.060 | 0.680 |       |
| 10  | Phytoplankton                       |          |       | 0.440 | 0.760 | 0.150 |       | 0.310 | 0.120 | 0.850 |
| 11  | Macrophyte                          |          |       |       | 0.200 |       |       |       |       |       |
| 12  | Detritus                            |          | 0.100 | 0.150 | 0.020 | 0.020 | 0.100 | 0.550 | 0.100 | 0.070 |

**Trophic structure and biomass flow:** The Ecopath model assigns fractional trophic levels using the weighted average of the trophic levels (TLs) of each prey item. TLs of the functional groups in Lake Zwai ecosystem were between 1.0 and 3.29 (Table 7.4). The top predators were water fowls (TL = 3.29) followed by catfish (TL = 3.07). The commercially important fish groups, Tilapia and Carp, have TL of 2.02 and 2.46 respectively; while the mean of the total fishery catch is at trophic level of 2.49. The trophic level aggregation into discrete trophic levels of Lindeman spine for Lake Zwai ecosystem is given in Fig. 41. The flow revealed that the system is phytoplankton dominated which contribute 62.9% of the total biomass flow originating from first trophic level followed by detritus which contribute 37.1%. In Lake Zwai ecosystem the biomass flow was highly restricted to I and II trophic level as they contribute 99.76%. As can be seen from the Lindeman cycle (Fig. 41.), larger proportion of material from the first two TL flows to detritus.

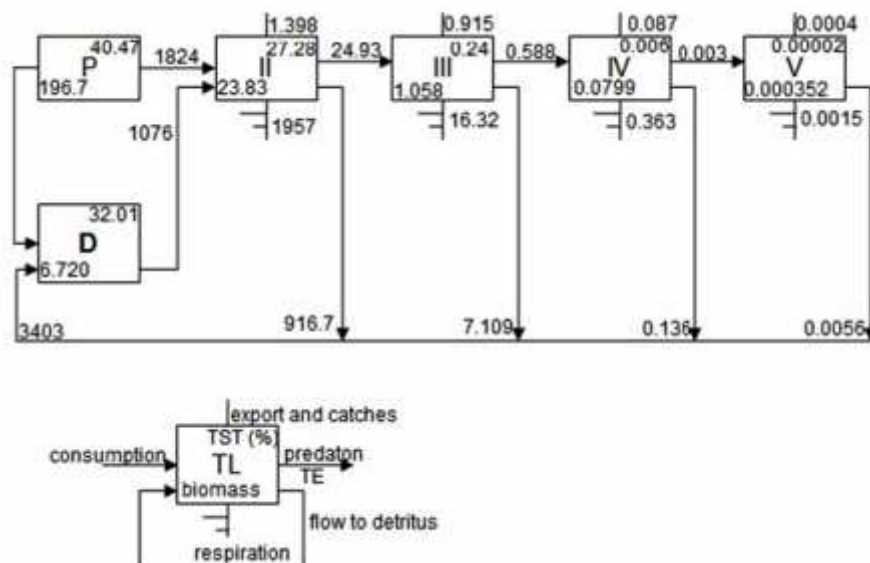


**Figure 41:** The aggregation of the flows ( $\text{t km}^{-2} \text{ year}^{-1}$ ) into a connected chain transfers

The fishery catch consumed 2.5% of the primary production in the lake, out of which 1.45% was predated by Catfish. From the total detritus formed annually,  $1076 \text{ t km}^{-2} \text{ year}^{-1}$  was consumed in the system, while the remaining  $1327 \text{ tons km}^{-2} \text{ year}^{-1}$  was exported to the sediments. The total fish biomass density obtained from the Lake Zwai ecosystem model was  $2.67 \text{ tons km}^{-2}$ , while the exploited groups have a biomass of  $2.52 \text{ tons km}^{-2}$ .

**Mixed trophic impact (MTI) analysis:** MTI analysis shows the direct and indirect impacts of a slight increase in the biomass of each impacting group on the biomass of the impacted groups (Majkowski, 1982). Macro-

zoobenthos and catfish have negative impact on wider range of groups; while phytoplankton and detritus showed positive impact to several groups (see Fig. 42.). The fishing gears operating on the lake were also included in the mixed trophic impact routine. Based on cumulative impact of functional groups on ecosystem (Fig. 43), the beach seine fishery has the most cumulative impact on the ecosystem. This phenomenon has shown the deleterious impact of beach seine on the ecosystem in general, since it is non-specific to a targeted species. The impact of long line fishery on the ecosystem is minimal because it removes only catfish, a group which has wider negative ecosystem level impact (Fig. 43).

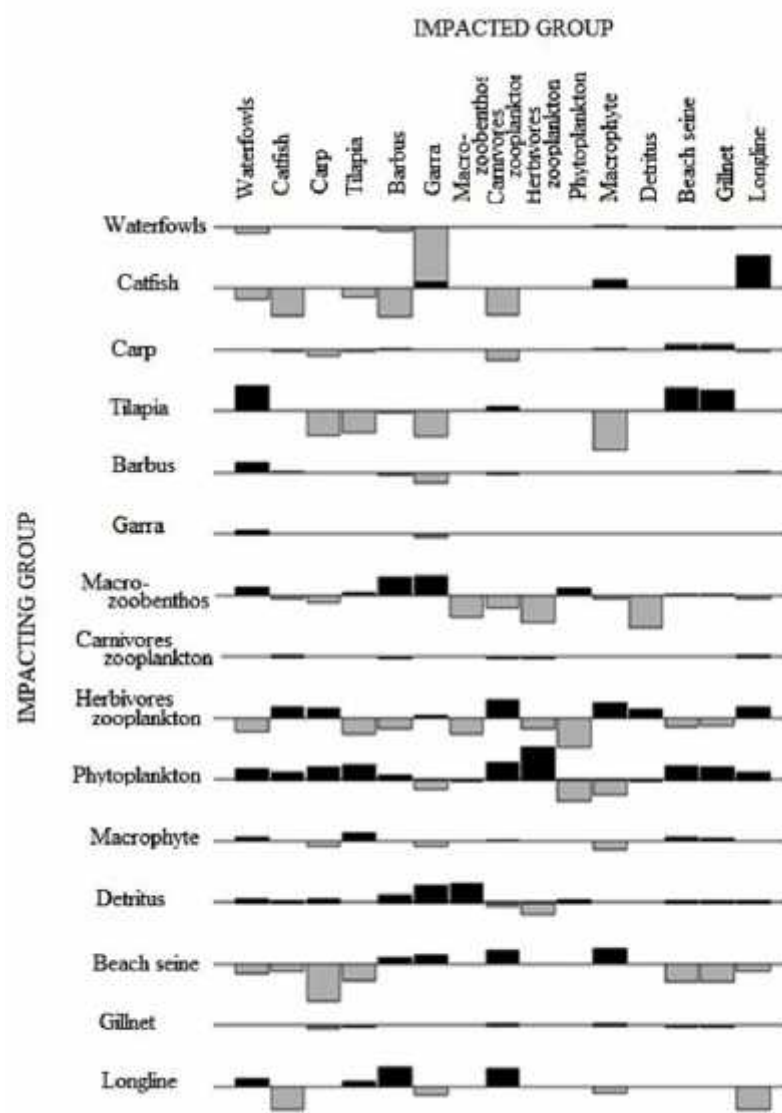
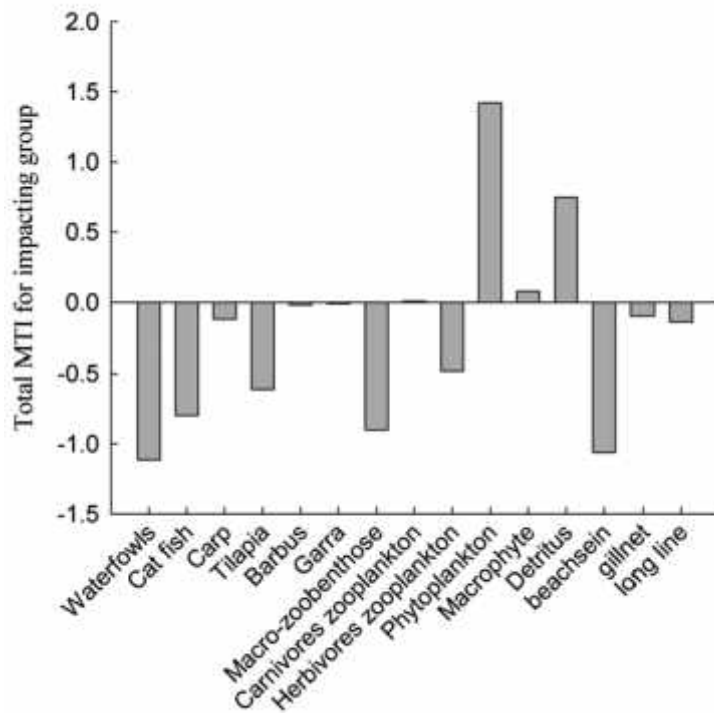


**Figure 42:** MTI of Lake Zwai ecosystem



Total MTI of each impacting groups on the ecosystem.

**Figure 43:** Total MTI of each impacting groups on the Lake Zwai ecosystem

**Ecotrophic Efficiencies (EE):** There are high fishing pressures on all commercial fish species which were reflected by high Ecotrophic Efficiencies (see Table 43). High predation mortality was noted on Barbus and macro-zoobenthos groups with EE of 0.97 and 0.75, respectively. A greater proportion of the primary production by phytoplankton remains in the system unutilized with (EE = 0.47). The lower EE for phytoplankton might be attributed to the dominance of cyclopoid zooplankton in the system

where its major diet may not be phytoplankton despite its high Production/biomass ratio of 241.94 year<sup>-1</sup>.

**Ecosystem attributes:** Ecosystem attributes describing Lake Zwai are summarized in Table 43. The total system throughput describes the ecosystem size in terms of the flows (Ulanowicz, 1986), which is important for the comparison of flow networks. Total system throughput of Lake Zwai ecosystem was dominated by detritus which contribute 30.98% and followed by consumption 29.85%. The connectance index is the number of actual links in relation to the number of possible links in the food web (Gardner and Ashby, 1970). In matured ecosystems food chains tend to become web like than linear. The omnivory index is an alternative indicator that characterizes the degree of network formation in an ecosystem (Christensen and Pauly, 1993). The connectance index of the lake Zwai was 0.3, and the omnivory index was 0.2.

**Ecosim Scenario:** In the first scenario, the mortality rate of catfish was increased by 1.5 times that resulted in increment of the Tilapia group to 1.6 times of the current biomass in a four year period and leveling of its biomass to 1.16 times at the end of the tenth year ( Fig. 44). Consequently, this also decreased the biomass of catfish to 0.29 times compared to the current biomass. Doubling mortality of catfish, on the other hand, resulted in increment of tilapia biomass to only 1.12 times but significantly decreased the biomass of catfish to a biomass of 0.021 times its current biomass. The scenario, however, did not affect Carp biomass.



**Table 41:** Ecosystem indicators describing Lakes Zwai, Hawassa (Awassa) and Haiq (NOTE: <sup>a</sup> Fetahi and Mengistou (2007); <sup>b</sup> Fetahi *et al.* (2011))

| Parameter                                  | Zwai      | Awassa <sup>a</sup> | Hayq <sup>b</sup> | Unit                                  |
|--------------------------------------------|-----------|---------------------|-------------------|---------------------------------------|
| Sum of all consumption                     | 3278.834  | 2151.517            | 21492.980         | t km <sup>-2</sup> year <sup>-1</sup> |
| Sum of all exports                         | 2328.973  | 10649.21            | 43.539            | t km <sup>-2</sup> year <sup>-1</sup> |
| Sum of all respiratory flows               | 1973.65   | 1204.062            | 10062.830         | t km <sup>-2</sup> year <sup>-1</sup> |
| Sum of all flows into detritus             | 3402.943  | 11328.46            | 8085.361          | t km <sup>-2</sup> year <sup>-1</sup> |
| Total system throughput                    | 10984.4   | 25333               | 39685.00          | t km <sup>-2</sup> year <sup>-1</sup> |
| Sum of all production                      | 4952.041  | 12370               | 17857.00          | t km <sup>-2</sup> year <sup>-1</sup> |
| Mean trophic level of the catch            | 2.49      | 2.57                | 2.46              |                                       |
| Gross efficiency (catch/net p.p.)          | 0.0005581 | 0.0001018           | 0.000475          | t km <sup>-2</sup> year <sup>-1</sup> |
| Calculated total net primary production    | 4302.623  | -                   | -                 | t km <sup>-2</sup> year <sup>-1</sup> |
| Total primary production/total respiration | 2.180034  | 9.84                | 1.004             | t km <sup>-2</sup> year <sup>-1</sup> |
| Net system production                      | 2328.973  | 10649.21            | -                 |                                       |
| Total primary production/total biomass     | 19.40659  | 5.673               | 100.974           |                                       |
| Total catches                              | 2.401356  | -                   | -                 | t km <sup>-2</sup> year <sup>-1</sup> |
| Connectance Index                          | 0.3057851 | -                   | 0.214             |                                       |
| System Omnivory Index                      | 0.146178  | -                   |                   |                                       |

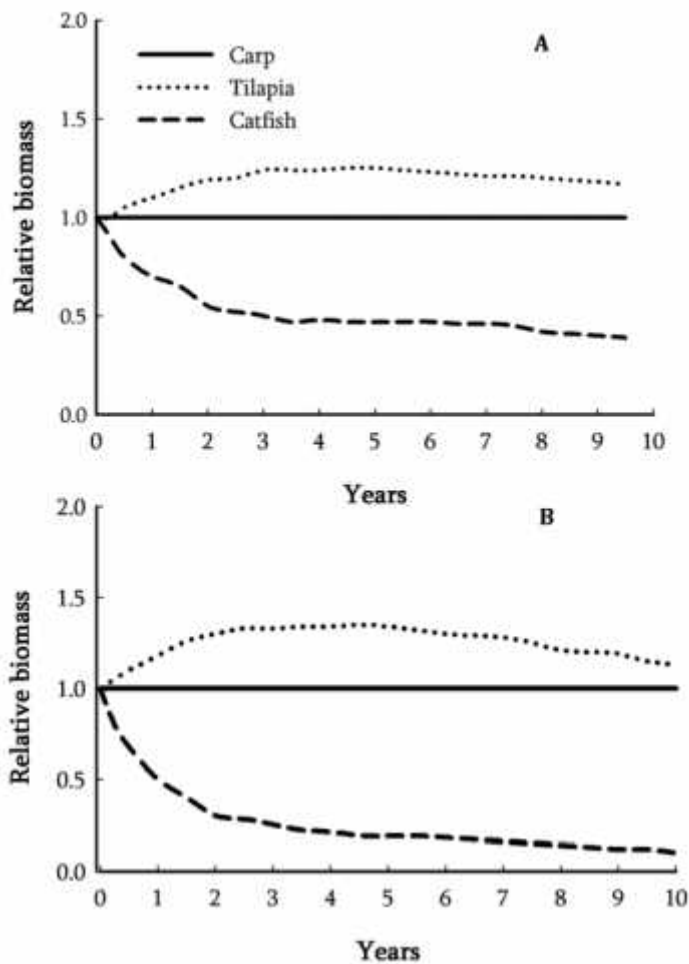


**Figure 44:** Relative changes in biomass associated with increasing mortality of catfish to (a) 1.50 times and (b) 2.00 times

The second scenario of decreasing the effort of beach seine by 0.25 and 0.50 times benefited Carp group (see Fig. 44) as their biomass

increased to 3.24 and 5.57 times the current biomass, respectively, during ten years' period. However, this scenario did not benefit to the tilapia group as their biomass declined to 0.98 and 0.66 times the current biomass with decreasing in effort of beach seine by 0.25 and 0.50 times, respectively. This phenomenon occurred due to the increment in the biomass of catfish by 1.317 and 3.02; which increased predation mortality, despite the reviving of tilapia from fishing mortality.

The final scenario of increasing the effort of long line (Fig. 44) benefited the Tilapia group and significantly decreased the catfish community from the ecosystem. The results of the first and third simulations were similar as both scenarios target the decrement of the Catfish group by setting fishing mortality and effort levels, respectively.

## Discussion

Studies on trophic efficiency and biomass transfer between functional groups are essential as they provide usable information on ecosystem structure and functions; thereby allowing the visualization of impact by certain functional groups on the whole ecosystem (Ulanowicz 1986; Christensen and Pauly, 1993). The model presented here represents only one of several possible interpretations of Lake Zwai ecosystem. Nevertheless the model represented the ecosystem boreholesince most input parameters were determined mainly from the same ecosystem including biomass, mortalities, and diet, and its quality is explained by a pedigree index value of 0.58.

The structure of Lake Zwai ecosystem, as characterized by mean TL for total fishery catch is comparable to Lake Awassa (TL=2.57, Fetahi and Mengistou, 2007) and Lake Hayq (TL=2.46, Fetahi *et al.*, 2011), a rift valley and highland lake in Ethiopia, respectively. The similarity in TL could be associated with the resemblance of the species composition and preference of the fisheries on Tilapia. Carp (*Carassius carassius* and

*Carassius auratus*) and *Clarias gariepinus* are exotic to Lake Zwai (Globstov *et al.*, 2002), but higher trophic levels in the system indicated that they have contributed in the material cycle within the system as boreholeas in ecological efficiency.

The energy transfer at lower trophic level in Lake Zwai is much less than that of other productive African lakes (Christensen and Pauly, 1993). The trophic efficiency from TL II to TL III was 19.99% for Lake Hayq (Fetahi *et al.*, 2011) and 16.9% for Lake Malawi (Dengbol, 1993) while the value was only 0.9% for Lake Zwai. The low value of transfer efficiency (TE) from TL II in this system might have also resulted from the large exploitation at TL II, which became the main part of the Lake fishery. The low Ecotrophic efficiency (0.39) of herbivorous zooplankton, which is the main component of the second trophic level in Lake Zwai, has contributed in low efficiency of the energy transfer. A similar situation in which zooplankton (cycloid copepods) acting as sinks rather than links in lake-ecosystems has also been observed in Lake Hayq (Fetahi *et al.*, 2011).

The slight increment in TE at TL III might be attributed to effective utilization of macrozoobenthos in the lake ecosystem. The introduction of *Clarias gariepinus*, *Carassius carassius* and *Carassius auratus* have improved TE in the lake as they feed on those groups that are acting as a sink in the lake ecosystem. Similarly, the energy transfer efficiency of Lake Kivu has increased following the introduction of exotic fish species (Villanueva *et al.*, 2008). The efficiency of Lake Victoria also increased after the introduction of Nile perch (Moreau *et al.*, 1993). The stocking of Tilapia in Lake Hayq, Ethiopia has also contributed to higher transfer efficiency from primary production to fish yield (Fetahi *et al.*, 2011). Hence, introduction could be beneficial if it is done after appropriate and

comprehensive study (such as fish ecology, feeding, growth, limnological/ environmental requirements etc.).

The mean TE of Lake Zwai was 4.4% which was less than Lake Nakuru (8%, Moreau *et al.*, 2001), LakeTahiu (6.9%, Yunkai-Li *et al.*, 2009) and Lake Awassa (14.2%, Fetahi and Mengistou, 2007). The overall low TE in Lake Zwai might be attributed to the low efficient utilization of the first three trophic levels, due to the low diversity of specialized fish group. This phenomenon might have resulted from the absence of feed specialization which was observed in this ecosystem and explained by the system omnivore index of 0.20.

The impact of carnivore zooplankton and Garra was low compared to other functional group in the system. In all systems, functional groups respond negatively to an increase in their own biomass, probably due to an increase in competition within the functional group (Christensen *et al.*, 2005). Phytoplankton and detritus had the highest positive impacts on other groups in the system, providing an important food source for the other groups. Talling and Lemoalle (1998) observed from their studies that the primary producers have a positive effect in all other biological groups. Nevertheless, the food web of Lake Zwai is consumer exercised top-down control due to the fact that primary producers and lower trophic level functional groups (herbivores zooplankton) were found in excess as indicated by low EE value. Incorporation of the fishery in mixed trophic impact analysis showed that fishing pressure, by beach seine had more negative impact on the functional groups considered in this study as compared with predation and competition (Fig. 43).

Species introduction can affect biodiversity either by global homogenization of regional biota or by affecting native species functions (Levine *et al.*, 2003). However, introduction can also play a crucial role in enhancing the

fishery potential (Welcomme, 1988) if done properly by studying the available open-realized niche, adequate food sources and simulating different scenarios. Lake Zwai is low in its biodiversity in terms of fishery unlike the southern rift valley lakes (Lake Chamo and Lake Abaya) (Dejen *et al.*, 2010) and other Great Lakes of Africa (Villanueva *et al.*, 2008). This phenomenon indicates that a small perturbation on fishery could affect the ecosystem in general as higher biodiversity is related to stability (Loreau *et al.*, 2001).

According to Odum (1969), the ratio between primary production and total system respiration (PP/R) would decline to 1.0 as an ecosystem develops toward maturity. Biomass accumulate as the system develops, thus lead to a lower ratio between primary production and biomass (PP/B). The PP/R of Lake Zwai ecosystem was 2.18. The PP/B ratio of Lake Zwai (19.40) is greater than Lake Awassa which has a PP/B ratio of 5.67 (Fetahi and Mengistou, 2007) indicating that it is less mature. The above two parameters suggested that the Lake Zwai ecosystem is still an immature ecosystem and at the developmental stage. The high flow of the lower TL to detritus in Lake Zwai was the major factor in the dominance of Total system throughput of by detritus which contribute 30.98%. The production to respiration ratio of 2.18 as boreholeas the 2328.97 t km<sup>-2</sup> year<sup>-1</sup> of the net system production (i.e., the difference between total primary production and total respiration) are indicative of the Lake Zwai's ability to sustain without allochthonous subsidies of organic matter from the watershed.

The primary production required in order to support the fishery was 2.51% of the total primary production of Lake Zwai, which is very low compared to an average value suggested by Christensen and Pauly (1993) for tropical lakes and rivers (23.6%). This indicated that the major energy source may not be obtained directly from phytoplankton primary production but from

other sources. Indeed, as indicated from Lindeman cycle (Fig. 41), large amount of biomass was converted to detritus and hence one of these energy sources could be microbial food web, an indispensable energy source for some ecosystem. The microbial food web was not incorporated for Lake Zwai due to absence of data and this could be a research problem for Lake Zwai and other Ethiopian lakes.

The simulation scenarios showed that decreasing or increasing effort of an operational fishing gear should be boreholeplanned as it may result in unintended result as the organisms living in the system are interrelated through the food chain. The simulation result demonstrated that restricting beach seine fishery by itself may not lead to the revival of the tilapia biomass as it has been assumed by some fisheries managers. This phenomenon occurred due to the increment in the biomass of catfish; which increases predation mortality despite the reviving of tilapia from fishing mortality. It was also noted that moderate decrease in the beach seine effort could be helpful for the thriving of carp abundance (see Fig. 45). Carps in lake Zwai are under the pressure of beach seine with high harvest rate ( $EE=0.9$ ); Decrement of fishing effort by beach sein in half would increase their biomass to six times the current biomass during ten years period. Doubling mortality (Scenarios 1 and 3) of catfish resulted in slight increment of tilapia biomass as it unleashes the predation mortality. However, doubling mortality of catfish has not affected Carp biomass. This might had resulted due to the fact that, catfish and carp group are not interrelated in a prey-predator relationship. The relationship of catfish and carp group by having similar prey on herbivores zooplankton, are found in excess at the present fish species composition and do not influence one another.

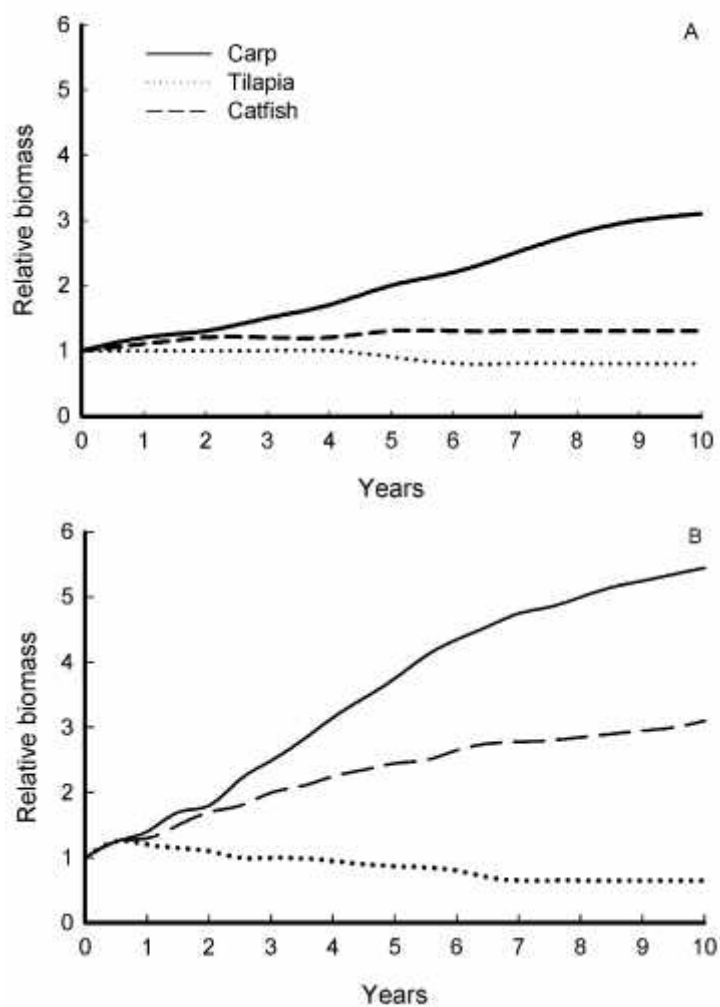


**Figure 45:** Relative changes in biomass associated with decreasing the effect of beach seine by (a) 0.25 times and (b) 0.50 times



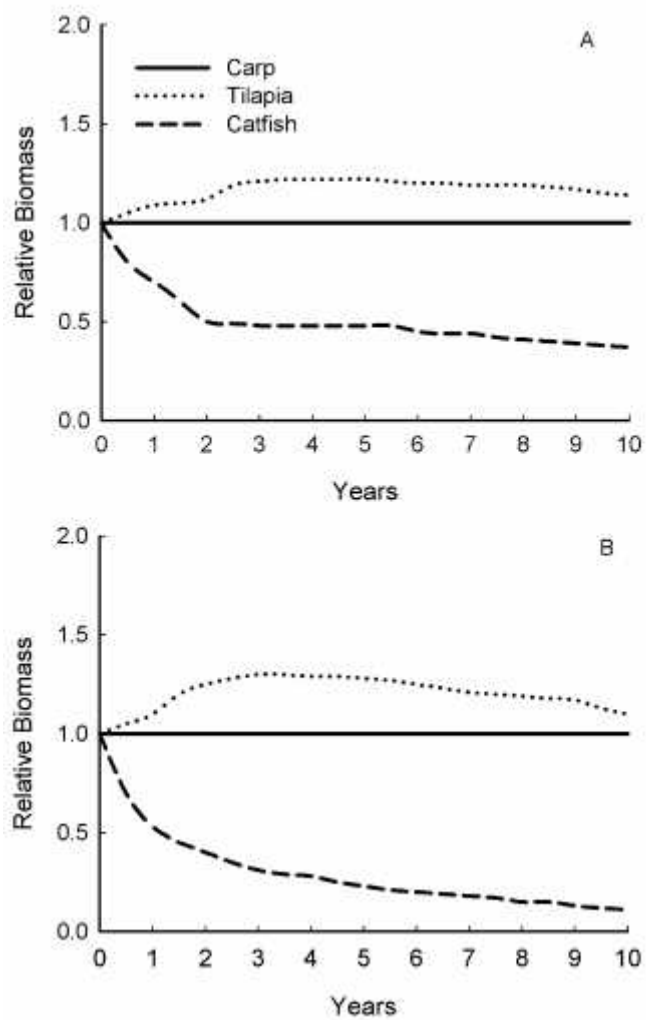


**Figure 46:** Relative changes in biomass associated with increasing the effect of longline to (a) 1.50 times and (b) 2.00 times

Predictive uses of Ecosim aiming to offer a formal examination of policy-relevant responses of the fish community (i.e., stock dynamics) raises the issue of model credibility, and usually invites a rigorous assessment of the uncertainties associated with the EwE predictions. The current Ecosim simulation is based on setting the vulnerability parameters proportional to their TL which has been applied to various ecosystems (Cheung *et al.*, 2002; Yunkai-Li *et al.*, 2009). However, the predictive ability of this type of simulation is subjected to uncertainty (Christensen *et al.*, 2005). This is due to absence of time series data on fisheries biomass which was valuable in the hind casting ability of the model that increases the quality of the forecasted scenarios.

## Conclusion

The Ecopath with Ecosim model constructed to describe the trophic relationships in Lake Zwai helped in understanding the general dynamic of the lake ecosystem. Broad-scale or ecosystem level approach is recognized as crucial in describing and understanding the trophic structure in Lake Zwai and the importance of the introduced species. It is a requirement to elucidate and, eventually predict possible impact of exotic species on natural food webs. Fish introductions in Lake Zwai have increased energy flux transfers between TL's.

The low EE of the phytoplankton indicates that most of the production remains unutilized within the system. The energy transfer at lower trophic level in Lake Zwai was also much less than other productive African lakes. Therefore, the possibility of stocking / enhancing fishery to increase energy transfer should be considered.

Despite the uncertainties associated with model prediction; the biomass/yield of Tilapia in Lake Zwai can be enhanced by increasing the catfish mortality through moderate increment in long line fishery (Scenario

3). The simulation result also revealed that restricting beach seine fishery does not help in revival of tilapia population as previously thought by managerial bodies unless it is coupled with increase in long-line fishery.

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## Chapter 8

### Occurrence of waterborne bacterial pathogens in Lake Zwai and municipal water systems of Batu (Zwai) Town, Ethiopia

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#### Abstract

Surface and drinking waters are routinely analyzed for physico-chemical parameters and indicator bacteria. However, the presence or absence of indicator bacteria may not necessarily be equally indicative of the presence of pathogens. In this study, the physico-chemical and bacterial indicators of water quality parameters were compared with the occurrences of waterborne bacterial pathogens from water and sediment samples of Lake Zwai, Meki and Qatar Rivers and the municipal water systems for drinking and household uses of Batu (Zwai) Town. Seventy eight water and sediment samples were collected from April through November 2013 and analyzed for some physico-chemical parameters, indicator and pathogenic bacteria (*Salmonella*, *Shigella*, *Vibrio cholera*, *Vibrio* spp., *E. coli* O157:H7) using standard methods. The study showed that 97 to 100% of sediment and surface water, 38% of the reservoir and 63% of tap water samples were contaminated with indicator bacteria. The highest proportion of pathogenic bacteria was detected from the lake sediment (52.7%), followed by Meki and Qatar River-sediments (50.0%), lake water (40.4%), river-waters

of Qatar (33.3%) and Meki (26.7%), tap water (4.8%) and none from reservoir water samples. *Vibrio cholera*, *Vibrio* spp, *Salmonella* and *Shigella* were commonly detected from surface water and sediment samples (48.9%), whereas, *E. coli* O157:H7 was limited to a few sources (3.3%). With respect to the microbial loads, the highest count of 4.20 log CFU/100 g of indicator bacteria was detected from river sediments and the lowest count of 0.42 log CFU/100 ml from reservoir water. Differences in concentration of indicator bacteria were statistically significant ( $P < 0.0001$ ) between sample sources. The Spearman Rank Correlations show that some indicators and physicochemical parameters were significantly correlated with the presence of bacterial pathogens. The present study showed that surface and sediment samples have high loads of indicator bacteria and harbored a variety of pathogenic bacteria. The detection of indicator bacteria in 38% of the reservoir and 63% of the tap water samples was indicative of the inadequacy of the treatment and post contamination of water in the distribution system. The statistical correlation analyses revealed that fecal coliforms were significantly correlated with *Salmonella* and *Shigella*; *E. coli* with *Shigella* and *Enterococci* with *Vibrio* spp. of surface and sediment samples.

**Keywords:** *Enterococci*, fecal coliforms, *Salmonella*, *Shigella*, waterborne diseases, Lake Zwai, Batu Town, municipal water supply, water quality

## Introduction

Water is a vehicle of many diarrheal diseases caused by a variety of pathogenic microorganisms (Woodall 2009). According to the World Health Organization (WHO), more than 88% of the burden of the diarrheal diseases is attributable to unsafe water, inadequate sanitation and poor hygiene Prüss-Üstün *et al.* (2008) Liu *et al.* (2012) reported that in 2010 waterborne diseases accounted to annual deaths of 0.801 million (10.5% of total deaths), mainly children younger than five years. Most of the waterborne diarrheal

morbidity and mortality occur in developing countries, of which the most vulnerable five countries were India, Nigeria, Afghanistan, Pakistan and Ethiopia (Liu *et al.* 2012).

It is established that water sources are polluted with wastes released from municipal domestic wastewater, agricultural run-offs and industrial discharges (Corcoran *et al.* 2010). Recent studies showed that bacterial pathogens such as *Salmonella* (Levantesi *et al.* 2012 and Momtaz *et al.* 2013), *Shigella* (Faruque *et al.* 2002) *Vibrio* (Cantel *et al.* (2013) and pathogenic *Escherichia coli* (*E. coli* O157:H7) (Benjamin *et al.* (2013) were detected from surface and drinking waters, and sediment samples (Benjamin *et al.* (2013 and Maal-Bared *et al.* 2013). The increasing detection of pathogens in surface and drinking water is troubling and needs consideration to monitor the sources of these pathogens before imposing risks on human and animal health.

Lake Zwai is one of the Rift Valley Lakes (RVL) known as source of drinking water for Batu (Zwai) Town, site of high fishing and irrigation activities and habitat to diverse bird populations. The water quality has been increasingly deteriorating from time to time due to the ever increasing anthropogenic activities and discharge of municipal, industrial and agricultural wastes into the lake (Tadele 2012 and Meshesha *et al.* 2012). Previous studies regarding the quality problem of Lake Zwai and the drinking water distribution system of Batu Town showed that the water samples were found to be contaminated with fecal bacteria beyond the level recommended by WHO guideline values and Ethiopian standards (Tadele 2012, Bedane 2008 and Roha 2008). Many of the hitherto water quality studies were based on investigation of the surrogate indicator microorganisms and physico-chemical parameters. However, the presence or absence of indicator bacteria may not necessarily corroborate with the occurrence of some protozoan and viral pathogens that over-lived the

indicators in environmental samples (Bitton (2005). Furthermore, some indicator bacteria such as total coliforms and *Enterococci* are found in soil and sand that may not show the real fecal contamination of water sources (Bitton 2005 and Whitman *et al.* 2003). It has also been shown that subtropical and tropical climates enhance indicator bacteria to multiply in the environment that may give false impression of increased microbial pollution and presence of pathogens (Whitman *et al.* 2003 and Solo-Gabriele *et al.* 2000).

Consequently, interpretation of the presence of microbial indicators is sometimes misleading, for their source is not exclusively from fecal origin. Under the circumstances, direct detection of pathogens together with measurement of indicator bacteria may guarantee establishing whether or not a water body is truly polluted by disease causing microorganisms. Hence, this study was initiated to investigate by coupling the occurrence of microbial pathogens and the presence of indicator bacteria together with some concurrent physicochemical parameters from water surface and sediment of the Lake Zwai, feed rivers and the drinking water system of Batu Town.

### Materials and methods

**Study area:** The study was carried out on drinking water distribution system of Batu(Zwai) Town and on shoreline of Lake Zwaia and its feeder rivers located in the Ethiopian Rift Valley (Lat: 7°52'–8°8'N; Long: 38°04'–38°56'E) (Fig. 47). Lake Zwai, (also referred to as Zwai or Zeway in the literature), is a freshwater wetland found at a distance of about 163 km south of Addis Ababa. The lake is 31 km long and 20 km wide, with a surface area of 440 km<sup>2</sup>. It has a maximum depth of 8.9 meters. Apart from seasonal runoffs and groundwater recharge, the lake is fed by two rivers, namely, Meki from the west and Qatar from the east, and is drained by River Bulbula

which feeds Lake Abijata to the south. The catchment area of this lake is estimated to be 7025 km<sup>2</sup> and the lake lies at an altitude of 1,636 meters above sea-level (Brook Lemma and Hayal Desta 2016).

The town of Batu lies on the western shore of the lake, extending along that shoreline and growing at a very fast rate in recent years. The present total projected population of Batu Town is estimated to be 59,746 of which 31,388 are males and 28,358 are females (CSA 2007). Lake Zwai is source of drinking water for Batu Town and its surrounding communities. There is one water treatment site on the lake to the outlet of Qatar River and it provides drinking water for Batu Town. The lake water is also used for commercial fishing, irrigation and horticulture farming.

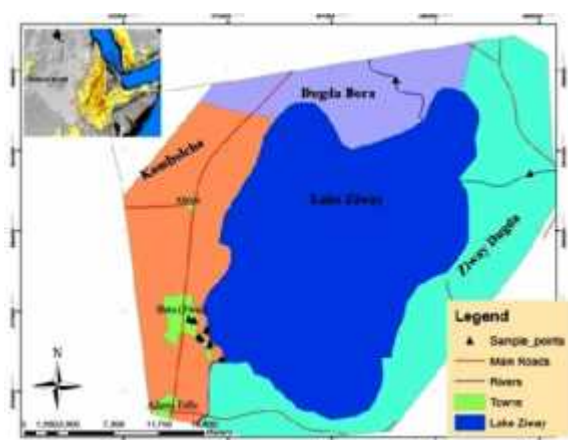


**Figure 47:** Map of the study area with sampling sites marked with dark solid triangles

**Sample collection:** Surface water, drinking water and sediment samples were collected from different sampling sites around the town, Lake Zwai and Meki and Qatar Rivers and drinking water distribution system of Batu Town during April to November 2013. The sampling sites were selected based on

the anthropogenic impact on surface water and population sizesutilizing the drinking water. The water samples were collected using pre-sterilized borosilicate bottles (1L) and transported in ice-box to the laboratory for analysis within 24 h of collection in accordance with the procedures described in standard methods for the examination of water and wastewater (APHA 1998).

Lake and river sediment samples were collected from similar sampling stations with water samples from the bottom with Eckman Grab. The Eckman Grab captures the soft sedimentwith thickness of about 20 cm from the center of which some 100 g of sedimentwas collected using hand gloves and received in sterile plastic bottles and transported in ice-box to the laboratory for analysis within 24 h of collection.

**Water and sediment physicochemical parameters analyses:** Temperature (Temp.), electrical conductivity (EC) and dissolved oxygen (DO) of both water and sediment samples were processed and measuredusing salinity-conductivity-temperature meter (YSI model 33 S-C-T meter, USA) and (YSI Model 51B Dissolved Oxygen Meter, USA), respectively. pH of the samples was recorded using portable digital pH meter (Adwa AD111, Romania, Hungary).The nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) content of water samples was determined using sodium salicylate (Monteiro *et al.* 2003); nitrite nitrogen ( $\text{NO}_2\text{-N}$ ) colorimetricmethod; ammonium nitrogen ( $\text{NH}_4\text{-N}$ ) phenatemethod and phosphate phosphorus ascorbic acid method *as per* standard methods (APHA 1998) using spectrophotometer (Jenway Ltd Flested, Dunmo, UK). Filtrates were also extracted from sediment samples and analyzed according to procedures described in environmental water and soil analysis manual (Trivedi and Raj 1992).

**Tests for indicator bacteria:** Theenumeration of indictor and pathogenic bacteria from water and sediment samples were processed by suspending

them with peptone saline solution or other appropriate diluents and filtered through 47 mm diameter and 0.45 µm pore size membrane filter (HAWG04756, Millipore, Cheshire, UK) according to standard methods unless stated otherwise (APHA 1998 and Ferguson *et al.* 2005).

The enumeration of total coliforms and fecal coliforms in water and sediment samples was carried out with a membrane filtration *as per* standard methods for the examination of water and wastewater (APHA 1998) and *E. Coli* was enumerated according to ISO 9308-1 (ISO 2000). The filtrates were placed on an absorbent pad saturated with Membrane Lauryl Sulphate Broth for total coliforms and fecal coliforms (AVONCHEM, Cheshire, UK), and incubated at 37°C for total coliforms and at 44°C for fecal coliforms for 14 – 18 h. For *E. coli*, the filtrate were placed on Tryptone Soya Agar (CM131, Oxoid, England) incubated at 37°C for 4 – 5 h and transferred to Tryptone Bile Agar containing 20 g Tryptone (L42, Oxoid, England), 1.5 g bile salts no 3 (LP0055, Oxoid, England), 15 g agar-agar (Titan Biotech, India) and incubated at 44°C for 18 to 20 h.

*Enterococci* were enumerated from samples according ISO 7899-2 (ISO 2000). The water and sediment samples were placed on Slanetz and Bartely Agar (CM377, Oxoid, England) and the plates were incubated at 37° C for 44 h. *Clostridium perfringens* was enumerated from water and sediment samples as procedures described on ASTM (ASTM 2002). The filtered samples were transferred to *Clostridium perfringens* agar (m-CP) containing 30 g tryptone (L42, Oxoid, England), 20 gm yeast extract (64271, Merck KGaA, Germany), 5 g sucrose, 1 g L-cysteine hydrogen chloride, 0.1 MgSO<sub>4</sub>·7H<sub>2</sub>O (Merck, Germany), 0.04 g bromcresol purple (Sigma, USA), 15 g agar-agar (Titan Biotech, India) and supplemented with 0.44 g D-cycloserine (SR0088E, Oxoid, UK).



**Tests for pathogenic bacteria:** *Salmonella* was qualitatively detected from samples according to ISO 19250 (ISO 2010). Water and sediment samples after being filtered using the same membrane filters (as before) were pre-enriched in 50 ml Buffered Peptone Water (M614, HiMedia, India) and incubated at 37°C for 16 - 20 h, and 0.1 ml enrichment liquid was introduced into 10 ml of Rappaport Vassiliadis Soya Peptone Broth (SRL-RM018, India), and incubated at 42°C for 48 h. Thereafter, a loopful of enrichment broth was streaked on Xylose Lysine Desoxycholate agar (CM069, Oxoid, England), and incubated at 37°C for 24 h. Four suspected discrete colonies from each plate were inoculated on Triple Sugar Iron (CM0277, Oxoid, England) and Lysine Iron Agar (CM0381, Oxoid, England) slant and incubated at 37°C for 24 h.

*Shigella* was analyzed from water and sediment samples according to the standard methods for the examination of water and wastewater (APHA 1998). The processed samples were placed on Xylose Lysine Desoxycholate agar (CM069, Oxoid, England), and incubated at 37°C overnight. Colonies of confluent growth were transferred to pre-enrichment Selenite F Broth containing 19 g selenite base medium (CM0395, Oxoid, England), 4 g biselenite (BDH, England) and incubated for 6 h and streaked on Xylose Lysine Desoxycholate agar plates. The plates were then incubated overnight at 37°C.

*Vibrio* was detected from water and sediment samples as described previously by (Sudhanandh *et al.* 2012). Filtered samples were spread plated on Thiosulphate Citrate Bile Sucrose agar containing 5 g yeast extract (64271, Merck KGaA, Germany), 10 g peptone (Uni-Chem, India), 10 g sodium thiosulfate, 10 g sodium citrate (SDFCL, Mumbai, India), 8 g ox-bile (L50, Oxoid, England), 20 g sucrose, 10 g sodium chloride, 1 g

ferric citrate, 0.04 g bromothymol blue (845 YW160095, Merck, USA) and 14 g agar-agar (Titan Biotech, India). Thereafter, the plates were incubated at 37°C for 24 - 48 h.

Enterohemorrhagic *E. coli* O157:H7 from water samples was detected according to standard method (APHA 1998). Processed samples were inoculated into 50 ml 3x Lauryl Tryptose Broth (CM451, Oxoid, Hampshire, England) and incubated at 37°C for 24 h. The samples were serially diluted ( $10^{-3}$ ,  $10^{-4}$ ) and spread plated (0.1 ml) onto Sorbitol MacConkey Agar containing MacConkey II agar (MD 21030, Becton Dickinson, USA) and D-sorbitol (MO 63178, Sigma, USA). Thereafter, the cultures were incubated at 37°C for 24 h.

**Data analysis:** Statistical analyses were performed using IBM SPSS software version 20 (SPSS Inc., Chicago, USA). All statistical analyses of indicator bacteria were performed on log-transformed data, whereas, the physicochemical parameters with ordinary data. The tests for fecal indicator bacteria were expressed as CFU per 100 ml (APHA 1998) and of sediment sample as CFU per 100 g of wet sediment (Ferguson *et al.* 2005). The bacterial pathogens were qualitatively analyzed by their absence or presence in the samples. The mean concentration of different parameters in sediment and overlying water as borehole; as in various sampling stations were compared using one way analysis of variance (ANOVA). A significance level of  $P < 0.05$  was applied at all statistical tests. The correlation between the presence of pathogens, load of indicator bacteria and physicochemical parameters was determined through Spearman rank correlation. Simple linear regression was also used to develop the standard curve for physicochemical parameters to calculate the concentration of the variables both in water and sediment samples.

## Results

**Physicochemical parameters:** The physicochemical parameters of water and sediment samples analyzed are shown in (Table .46). The pH values of all sample sources ranged from 7.45 to 8.33 and the electrical conductivity varied from 328.33 to 575.36  $\mu\text{Scm}^{-1}$ . Similarly, the temperature values of all sample types found between 21.8°C to 24.0°C and of dissolved oxygen from 1.89  $\text{mgL}^{-1}$  to 4.78  $\text{mgL}^{-1}$ . Unlike, pH (except lake water), temperature and electrical conductivity, dissolved oxygen showed significant variations ( $P < 0.0001$ ) amongst sample sources during the study period.

**Table 42:** Concentration (mean ± SD) of physico-chemical parameters of water and sediment samples (\*Values indicated with different letters are statistically significant; differences of concentration of physicochemical parameters were tested by Duncan – ANOVA; \*\*Not analyzed)

| Sample source        | Physicochemical parameters* |                           |                              |                                |                                                 |                                                 |                                                |                               |
|----------------------|-----------------------------|---------------------------|------------------------------|--------------------------------|-------------------------------------------------|-------------------------------------------------|------------------------------------------------|-------------------------------|
|                      | pH (-)                      | Temp. (°C)                | EC (µS/cm)                   | DO ( <i>mgL<sup>-1</sup></i> ) | NO <sub>3</sub> – N ( <i>mgL<sup>-1</sup></i> ) | NO <sub>2</sub> - N ( <i>mgL<sup>-1</sup></i> ) | NH <sub>4</sub> -N ( <i>mgL<sup>-1</sup></i> ) | PO <sub>4</sub> - P(µg/l)     |
| Lake water           | 8.33 ± 0.30 <sup>b</sup>    | 22.98 ± 2.04 <sup>a</sup> | 521.07 ± 244.11 <sup>a</sup> | 3.04 ± 1.51 <sup>ab</sup>      | 2.43 ± 4.21 <sup>a</sup>                        | 0.15 ± 0.21 <sup>a</sup>                        | 18.21 ± 9.96 <sup>b</sup>                      | 78.76 ± 35.22 <sup>a</sup>    |
| Meki River water     | 7.82±0.12 <sup>a</sup>      | 23.33±3.05 <sup>a</sup>   | 456.67±25.17 <sup>a</sup>    | 4.77±0.45 <sup>c</sup>         | 0.22±0.22 <sup>a</sup>                          | 0.09±0.05 <sup>a</sup>                          | 10.79±4.71 <sup>ab</sup>                       | 65.14±14.21 <sup>a</sup>      |
| Qatar River water    | 7.66±0.22 <sup>a</sup>      | 24.00±3.00 <sup>a</sup>   | 358.33±163.27 <sup>a</sup>   | 3.73±0.11 <sup>bc</sup>        | 0.15±0.10 <sup>a</sup>                          | 0.04±0.01 <sup>a</sup>                          | 13.87±8.12 <sup>b</sup>                        | 95.06±24.93 <sup>a</sup>      |
| Lake sediment        | 7.57 ± 0.30 <sup>a</sup>    | 22.54 ± 1.90 <sup>a</sup> | 575.36 ± 310.78 <sup>a</sup> | 1.89 ± 0.72 <sup>a</sup>       | 1.63 ± 1.31 <sup>a</sup>                        | NA**                                            | NA                                             | 376.22 ± 364. 71 <sup>b</sup> |
| Meki River sediment  | 7.53±0.06 <sup>a</sup>      | 23.33±1.53 <sup>a</sup>   | 420.00±10.00 <sup>a</sup>    | 3.00±1.00 <sup>ab</sup>        | 0.47±0.18 <sup>a</sup>                          | NA                                              | NA                                             | 43.32±0.82 <sup>a</sup>       |
| Qatar River sediment | 7.45±0.10 <sup>a</sup>      | 22.00±4.00 <sup>a</sup>   | 328.33±187.64 <sup>a</sup>   | 2.50±0.50 <sup>ab</sup>        | 0.39±0.25 <sup>a</sup>                          | NA                                              | NA                                             | 42.81±0.51 <sup>a</sup>       |
| Reservoir water      | 7.52 ± 0.08 <sup>a</sup>    | 21.80 ± 1.64 <sup>a</sup> | 441.25 ± 27.80 <sup>a</sup>  | 4.78 ± 1.05 <sup>c</sup>       | 0.04 ± 0.02 <sup>a</sup>                        | 0.03 <sup>a</sup>                               | 0.47 ± 0.23 <sup>a</sup>                       | 73.83 ± 56.85 <sup>a</sup>    |
| Tap water            | 7.49 ± 0.14 <sup>a</sup>    | 24.00 ± 1.15 <sup>a</sup> | 472.15 ± 188.31 <sup>a</sup> | 3.50 ± 0.52 <sup>bc</sup>      | 0.17 ± 0.17 <sup>a</sup>                        | 0.03 <sup>a</sup>                               | 0.67 ± 0.34 <sup>a</sup>                       | 114.05 ±118.64 <sup>a</sup>   |
| P-value              | <0.0001                     | 0.480                     | 0.648                        | <0.0001                        | 0.313                                           | 0.178                                           | 0.001                                          | 0.026                         |

The highest nitrate nitrogen ( $2.43 \text{ mgL}^{-1}$ ), nitrite nitrogen ( $0.15 \text{ mgL}^{-1}$ ) and ammonia nitrogen ( $18.21 \text{ mgL}^{-1}$ ) values were recorded from lake water and the lowest values of  $0.04 \text{ mgL}^{-1}$ ,  $0.03 \text{ mgL}^{-1}$  and  $0.47 \text{ mgL}^{-1}$  from reservoir water samples, respectively. The phosphate phosphorus contents of all samples were within the range of 42.81 to  $376.22 \text{ } \mu\text{gL}^{-1}$ . The maximum ( $376.22 \text{ } \mu\text{gL}^{-1}$ ) and minimum ( $42.81 \text{ } \mu\text{gL}^{-1}$ ) mean values of phosphate phosphorus were detected from the lake sediment and Qatar River sediments, respectively. Statistical analysis shows that the nitrate nitrogen and nitrite nitrogen content of samples did not show significant variations ( $P > 0.05$ ) amongst sample sources, whereas, the ammonia nitrogen in water samples showed significant variations ( $P = 0.001$ ) between the sample sources (Table 46).

**Detection of indicator bacteria:** In this study, almost all of the lake and river water and sediment samples were contaminated with total coliforms, fecal coliforms, *Escherichia coli*, *Enterococci* and *Clostridium perfringens* (Table 48). But the degree of contamination among some water sources was variable. Accordingly, only 38.2% of the reservoir and 63.0% of the tap water samples were positive for all tested indicator organisms.

**Table 43:** Occurrence (%) of indicator bacteria in different sample sources

| Sources         | Indicator bacteria |                  |                |                    |                                |
|-----------------|--------------------|------------------|----------------|--------------------|--------------------------------|
|                 | Total coliforms    | Faecal coliforms | <i>E. coli</i> | <i>Enterococci</i> | <i>Clostridium perfringens</i> |
| Lake water      | 100                | 100              | 93.3           | 94.7               | 100                            |
| Lake sediment   | 100                | 100              | 100            | 94.1               | 100                            |
| River water     | 100                | 100              | 100            | 100                | 100                            |
| River sediment  | 100                | 100              | 100            | 100                | 100                            |
| Reservoir water | 71.4               | 42.9             | 16.7           | 28.6               | 28.6                           |
| Tap water       | 90.5               | 57.1             | 35.3           | 45                 | 80.9                           |

From among the lake and river water samples examined for the indicator organisms, the mean concentration range of total coliforms (4.02 – 4.11 log), fecal coliforms (3.73 – 3.99 log), *E. coli* (2.28 – 3.00 log), *Enterococci* (3.05 – 3.26 log) and *Clostridium perfringens* (3.18 – 3.59 log) CFU/ 100 ml was detected from water samples (Table 50). Similarly, the minimum - maximum values of both lake and river wet sediment samples recorded were 4.82 – 5.07 log for total coliforms, 4.27 - 4.65 log for fecal coliforms, 3.10 – 3.16 log for *E. coli*, 3.51 – 4.25 log for *Enterococci* and 4.10 – 4.16 log CFU/ 100 g for *C. perfringens*.

**Table 44:** Concentration (mean ± SD) of indicator bacteria in water and sediment samples (\*Values indicated with different letters are statistically significant; differences of densities of indicator organisms were tested by Duncan – ANOVA)

| Sample source        | Fecal indicatorsin log CFU/ 100 ml for water and log CFU/100 g for wet sediment samples* |                          |                          |                          |                          |              |
|----------------------|------------------------------------------------------------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------|
|                      | Total coliforms                                                                          | Fecal coliforms          | <i>E. coli</i>           | <i>Enterococci</i>       | <i>C. clostrdium</i>     | Overall mean |
| Lake water           | 4.11 ± 0.41 <sup>bc</sup>                                                                | 3.90 ± 0.56 <sup>b</sup> | 2.28 ± 0.90 <sup>b</sup> | 3.09 ± 0.97 <sup>b</sup> | 3.18 ± 0.98 <sup>c</sup> | 3.41         |
| Meki River water     | 4.12±0.64 <sup>bc</sup>                                                                  | 3.99±0.66 <sup>b</sup>   | 3.00±0.30 <sup>b</sup>   | 3.05±0.39 <sup>b</sup>   | 3.56±0.25 <sup>c</sup>   | 3.54         |
| Qatar River water    | 4.02±0.71 <sup>b</sup>                                                                   | 3.73±0.99 <sup>b</sup>   | 2.76±1.02 <sup>b</sup>   | 3.26±0.45 <sup>b</sup>   | 3.59±0.21 <sup>c</sup>   | 3.52         |
| Lake sediment        | 5.07 ± 0.71 <sup>d</sup>                                                                 | 4.54 ± 0.66 <sup>b</sup> | 3.16 ± 0.76 <sup>b</sup> | 3.51 ± 1.10 <sup>b</sup> | 4.16 ± 1.02 <sup>c</sup> | 4.10         |
| Meki River sediment  | 4.82±0.39 <sup>cd</sup>                                                                  | 4.27±0.81 <sup>b</sup>   | 3.10±0.32 <sup>b</sup>   | 3.98±1.10 <sup>b</sup>   | 4.14±0.66 <sup>c</sup>   | 4.13         |
| Qatar River sediment | 4.98±0.30 <sup>d</sup>                                                                   | 4.65±0.86 <sup>b</sup>   | 3.10±0.57 <sup>b</sup>   | 4.25±0.81 <sup>b</sup>   | 4.10±0.71 <sup>c</sup>   | 4.27         |
| Reservoir water      | 0.82 ± 0.60 <sup>a</sup>                                                                 | 0.37 ± 0.49 <sup>a</sup> | 0.10 ± 0.25 <sup>a</sup> | 0.29 ± 0.50 <sup>a</sup> | 0.45 ± 0.85 <sup>a</sup> | 0.42         |
| Tap water            | 1.42 ± 0.53 <sup>a</sup>                                                                 | 0.74 ± 0.68 <sup>a</sup> | 0.25 ± 0.44 <sup>a</sup> | 0.45 ± 0.64 <sup>a</sup> | 1.80 ±1.06 <sup>b</sup>  | 0.96         |
| P-value              | <0.0001                                                                                  | <0.0001                  | <0.0001                  | <0.0001                  | <0.0001                  |              |

With regards to reservoir and tap water samples, the highest values (1.80 CFU/100 ml) of *C. Perfringens* and the lowest (0.10 CFU/100 ml) of *E. coli* were detected from tap water and reservoir water samples, respectively (Table 50). The detection of total coliforms, fecal coliforms and *Enterococci* in reservoir and tap water samples was within the range of 0.82 – 1.42 log, 0.37 – 0.74 log and 0.29 – 0.45 log CFU/100 ml, respectively. In general, the overall microbial counts of indicator organisms in both water and sediment samples were declined in the order of Qatar River sediment, Meki River sediment, lake sediment, Meki River water, Qatar River water, lake water, tap water and reservoir water with a significant variations ( $P < 0.0001$ ) amongst sources during the study period (Table 50).

**Occurrences of pathogenic bacteria in water and sediments:** The occurrence of bacterial pathogens of the different water and sediment samples showed variations amongst the sample sources (Table 51). Accordingly, 40.4% of the lake water samples were positive for *Salmonella*, *Shigella*, *E. coli* O157:H7, *Vibrio cholera* and *Vibrio* spp., whereas, 26.7% of Meki and 33.3% of Qatar River water samples were positive for all the pathogens, except *E. coli* O157:H7, *Shigella*, and *Salmonella* in some of the river water samples. The highest percentage (89.5%) of *V. Cholera* was detected from the lake water samples followed by 66.7% detection from Meki River water samples. Generally, the occurrence of *E. coli* O157:H7 was low in the river and lake water samples.

**Table 45:** Distribution of bacterial pathogens in water and sediment samples (\*Not detected and \*\*Not analyzed)

| Sample source | Percent (%) positive for water and sediment samples of pathogenic bacteria* |                 |                        |                   |                    | Overall % |
|---------------|-----------------------------------------------------------------------------|-----------------|------------------------|-------------------|--------------------|-----------|
|               | <i>Salmonella</i>                                                           | <i>Shigella</i> | <i>E. coli</i> O157:H7 | <i>V. cholera</i> | <i>Vibrio</i> spp. |           |
| Lake water    | 10.5                                                                        | 15.8            | 5.5                    | 89.5              | 78.9               | 40.4      |
| Meki River    | 33.3                                                                        | ND              | ND                     | 66.7              | 33.3               | 26.7      |



| Sample source | Percent (%) positive for water and sediment samples of pathogenic bacteria* |                 |                        |                   |                    | Overall % |
|---------------|-----------------------------------------------------------------------------|-----------------|------------------------|-------------------|--------------------|-----------|
|               | <i>Salmonella</i>                                                           | <i>Shigella</i> | <i>E. coli</i> O157:H7 | <i>V. cholera</i> | <i>Vibrio</i> spp. |           |
| water         |                                                                             |                 |                        |                   |                    |           |
| Qatar River   | ND                                                                          | 33.3            | ND                     | 33.3              | 33.3               | 33.3      |
| water         |                                                                             |                 |                        |                   |                    |           |
| Lake sediment | 15.8                                                                        | 15.8            | NA**                   | 94.4              | 88.9               | 52.7      |
| Meki River    | 33.3                                                                        | 33.3            | NA                     | 66.7              | 33.3               | 50.0      |
| sediment      |                                                                             |                 |                        |                   |                    |           |
| Qatar River   | ND                                                                          | 33.3            | NA                     | 66.7              | 66.7               | 50.0      |
| sediment      |                                                                             |                 |                        |                   |                    |           |
| Reservoir     | ND                                                                          | ND              | ND                     | ND                | ND                 | ND        |
| water         |                                                                             |                 |                        |                   |                    |           |
| Tap water     | 4.8                                                                         | 4.8             | 5.0                    | 4.8               | 4.8                | 4.8       |

With respect to sediment samples, 50.9% of the lake and river sediment samples were positive for all pathogenic bacteria except *Salmonella* that was not detected from Qatar River sediment samples. Similarly, *V. cholera* was detected from 94.4% and 66.7% of the lake and river sediment samples, respectively. However, none of the reservoir water samples showed pathogens and only 4.8% of tap water samples were positive for all bacterial pathogens, (Table 52). It is generally estimated that 48.9% of the water and sediment samples harbored pathogens of the group *V. cholera*, *Vibrio* spp., *Salmonella* and *Shigella*, whereas, *E. coli* O157:H7 was detected from 3.3% of the water samples.

**Correlation of microbial pathogens with physicochemical parameters and indicator microbes of water and sediments:** The Spearman rank correlation showed variations amongst pathogens, physicochemical parameters and indicator organisms. Accordingly, the presence of *Salmonella* in water samples was significantly positively correlated with *Shigella* ( $\rho$ : 0.43,  $P < 0.05$ ) and the log-transformed concentrations of fecal coliforms ( $\rho$ : 0.41,  $P < 0.05$ ) in the sediment samples. Similarly, there was a significant positive correlation between the occurrence of *Vibrio* spp. in the water and *Enterococci*

(rho: 0.43,  $P < 0.05$ ) in the sediment and *V. cholera* (rho: 0.70,  $P < 0.01$ ) in the water samples. The negative correlation of *V. cholera* in the sediment and dissolved oxygen in the water samples (rho: -0.51,  $P < 0.05$ ) was significant during the period of the study.

The occurrence of *Shigella* in water was significantly correlated with the concentrations of fecal coliforms in water (rho: 0.47,  $P < 0.05$ ), *E. coli* (rho: 0.47,  $P < 0.05$ ) in sediment and *E. coli* O157:H7 in water (rho: 0.47,  $P < 0.05$ ). Moreover, there was also a significant positive correlation between the detection of *Shigella* in sediment and *Salmonella* in water.

## Discussions

In the present study, almost all of the physical parameters (pH, electrical conductivity, temperature) of the water source samples (Meki River, Quatar River, Lake Zwai) and the water samples from tap water distribution (reservoir water, tap-water) were within the same range reported before pH (7.5-8.3), electrical conductivity (358.3-521.1  $\mu\text{Scm}^{-1}$ ) and temperature (21.8-24.0°C) (Roha 2008, Tilahun and Ahlgren 2010 and Tamire and Menigistu 2012). The pH of water samples was slightly alkaline and within the acceptable standard (pH 6.5-8.5) of drinking water stipulated by WHO guideline values and Ethiopian drinking water standard ES 261:2001. However, the temperature range of the water samples in this study was not within the WHO standard of  $< 15^{\circ}\text{C}$ . The higher values obtained in this and other studies in the country may be mainly due to the hot climate of the study areas that contribute to high temperature records of water samples.

The average concentration of dissolved oxygen ( $3.04 \text{ mgL}^{-1}$ ) of lake water samples was lower than values ( $8.72 \text{ mgL}^{-1}$ ) of previous report of the same place (Roba 2008) and of tap water samples ( $3.50 \text{ mgL}^{-1}$ ) followed the same

pattern compared to the dissolved oxygen of tap water samples ( $8.60 \text{ mgL}^{-1}$ ) reported from Bishoftu Town (Kassa 2009).

The mean nitrate nitrogen ( $2.43 \text{ mgL}^{-1}$ ) and ammonia nitrogen ( $18.21 \text{ mgL}^{-1}$ ) content of Lake Zwai water samples were higher than the previous report ( $0.0032 \text{ mgL}^{-1}$ ) and ( $0.111 \text{ mgL}^{-1}$ ) of the lake water, respectively (Tilahun and Ahlgren 2010). Similarly, the mean nitrate nitrogen content of tap water ( $0.17 \text{ mgL}^{-1}$ ) of the present study was lower than the average value of previous report ( $0.80 \text{ mgL}^{-1}$ ) from Batu Town (Bedane 2008) and Bishoftu Town ( $1.5 \text{ mgL}^{-1}$ ) tap water (Kassa 2009). In general, the data revealed that the concentration of both nitrate nitrogen and nitrite nitrogen in different water samples (lake, river and pipeline water) were lower than the value recommended by WHO guideline values of  $11.0 \text{ mgL}^{-1}$  for nitrate nitrogen and  $0.9 \text{ mgL}^{-1}$  for nitrite nitrogen of drinking water, whereas, the same pattern held true for ammonia nitrogen ( $1.5 \text{ mgL}^{-1}$ ) of reservoir and tap water samples (WHO 2011).

Likewise, the mean phosphate phosphorus ( $78.76 \text{ } \mu\text{g/l}$ ) content of the lake water was higher than the previous report ( $10.1 \text{ } \mu\text{g/l}$ ) from the same lake-waters (Tilahun and Ahlgren 2010). The phosphate measurement of tap water ( $114.05 \text{ } \mu\text{g/l}$ ) in this study was lower than the average values of previous work from Bishoftu Town ( $350.0 \text{ } \mu\text{g/l}$ ) (Kassa 2009).

With respect to indicator bacteria, the microbial load of total coliforms ( $4.11 \text{ log}$ ) and fecal coliforms ( $3.90 \text{ log}$ ) CFU/100ml in lake water was greater than the average values of the previous report of total coliform ( $1.79 \text{ log}$ ) and fecal coliforms ( $1.58 \text{ log}$ ) CFU/100 ml from the same place (Roba 2008). However, the results were similar with the average values of total coliforms ( $4.35 \text{ log}$ ) and fecal coliforms ( $3.10 \text{ log}$ ) CFU/ 100 ml reported by (Goshu *et al.* 2010) from Lake Tana. In lake sediment samples, the *E. coli* ( $2.28 \text{ log}$ ) and

*Enterococci* (3.09 log) CFU/100 g was lower than a recent report from Lake Geneva where the mean value ranged between 4 log to 5 log CFU/100 g (Haller *et al.* 2009).

The mean counts of total coliforms (4.08 log) and fecal coliforms (3.86 log) CFU/100 ml of Meki and Qatar Rivers water samples were in a close agreement with a report from Lagabatu River (Central Highland of Ethiopia) with total coliforms (3.45 log) and fecal coliforms (3.40 log) CFU/100 ml (Million 2008). Similarly, the mean *E. coli* (2.90 log CFU/100 ml) counts of Meki and Qatar Rivers were slightly lower than the *E. coli* (4.0 log CFU/100 ml) counts from Athi and Nairobi Rivers in Kenya (Musyoki *et al.* 2013).

The tap water harbored high proportion of indicator bacteria. The occurrence of total coliforms (90.5%) and fecal coliforms (57.10%) in tap water samples was higher than the previous report from Batu Town with total coliforms (68.0%) and none fecal coliforms (Bedane 2008). However, the values of total coliforms and fecal coliforms in this study were in a close agreement with the previous report from Bishoftu Town where 100.0% and 86.0% of tap water samples were contaminated with total coliforms and fecal coliforms, respectively (Kassa 2009). Generally, the data showed that only 69.2% of reservoir water and 52.6% of tap water samples were in compliance with WHO guideline values and national drinking water standard for samples tested for fecal coliforms and *E. coli*. The presences of indicator organisms in the finally treated water (reservoir) samples could be an indicative for the inadequate treatment of the source water. Similarly, the tap water harbored twofold more bacterial loads as compared to the reservoir water samples that may indicate the deteriorating of pipeline that led to leakages and inadequate treatments of the source water (Corcoran *et al.* 2010).

With regards to pathogenic bacteria, the detection of *Salmonella* in the lake water (10.5%) and sediment (15.8%) samples, and the rivers water (16.7%)

and sediment (16.7%) samples were higher than the values of 6.3% of surface water and 4.8% of sediment samples reported from Central California coast (Benjamin *et al.* 2013). However, the occurrence of *E. coli* O157:H7 (5.5%) of lake water in this study was lower than the detection of 13.8% *E. coli* O157:H7 using Moore swabs and higher than 1.8% using grab sample method reported by the same author. The detection of *Shigella* (15.8%) in Lake Zwai water was in a close agreement with the values of 10.9% from surface water (lake and river) of Bangladesh using PCR method (7). The finding of *Salmonella* (10.5%), *Shigella* (15.8%), *V. cholera* (89.5%) and *Vibrio* spp. (78.9%) in this study was lower than the previous report from southern Kerala coast water where the detection of the above pathogens were 33.1%, 90.1%, 97.5% and 97.5% of samples examined, respectively (Sudhanandh *et al.* 2012).

The detection of *Salmonella* (4.8%) and *V. cholera* (4.8%) in tap water samples was in consistent with southern Isfahan, Iran report where 5.5% and 8.3% were positive for *Salmonella* and *V. cholera*, respectively (Mamtaz *et al.* 2013). On the contrary, the occurrence of *Salmonella* in pipeline water was lower than the one reported from Nigeria (18.3%) (Akinyemi *et al.* 2011). The prevalence of *E. coli* O157:H7 (5.0%) in tap water was comparable with the one reported from the Netherlands (7.4%) (Heijnen and Medema 2006). Similarly, the 4.8% presence of *Salmonella*, *Shigella* and *Vibrio* spp. in tap water was much lower than the report from Dhaka city, Bangladesh where 35.0%, 60.0% and 50.0% of tap water samples were contaminated with these microbes, respectively (Shahidul *et al.* 1987).

In general, the data showed that the occurrence of the different pathogenic and indicator bacteria was higher on sediment samples than the surface water samples. Previous reports also showed that some enteric bacteria such as *Salmonella*, *Vibrio* spp. *E. coli* and *C. perfringens* can survive better in the

sediment than the overlying water column (Burton *et al.* 1987 and, Chandrana *et al.* 2011).

The Spearman rank correlations indicate that the presences of bacterial pathogens were significantly correlated with some physicochemical parameters and log-transformed indicator bacteria. *Salmonella*, *Shigella* and *Vibrio* spp. of surface water and sediment samples were significantly correlated with some indicator organisms (fecal coliforms and *Enterococci*) and physicochemical parameters. However, the presences of *E. coli* O157 in water and *V. cholera* in surface water and sediment were not significantly correlated with any of the log-transformed indicator bacteria and physicochemical parameters. Similar results were reported from Central California Coast where generic *E. coli* were not significantly associated either with *E. coli* O157 or *Salmonella* (Benjamin *et al.* 2013). Generally, the data showed that *Shigella* built better association with both indicator organisms and pathogenic bacteria in water and sediment samples.

In general, the present finding showed that 97 to 100% of surface water samples were contaminated with indicator bacteria, whereas, 38% of the reservoir and 63% of tap water samples were also positive for these organisms indicating the inadequacy of the treatment and post contamination of drinking water in distribution system. The microbial load of indicator and pathogenic bacteria was more in sediment than overlaying water samples. The statistical correlation analysis revealed that fecal coliforms were significantly correlated with *Salmonella* and *Shigella*; *E. coli* with *Shigella*, and *Enterococci* with *Vibrio* spp. of surface and sediment samples. *Shigella* showed better association with both indicator and pathogenic bacteria and a few physicochemical parameters in water and sediment samples.

The detection of pathogenic bacteria from both water and sediment samples for this study were made by cultural method which may not show the exact type of the pathogens species. Hence, extensive studies with large numbers of

samples concurrently collected samples from various water sources will be required using poly-phasic approaches (cultural and molecular methods) to determine the actual pictures of surface and drinking water quality of the study area.

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## Chapter 9

### Level of mercury in fish from Lake Zwai: Its implications in dietary exposure

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#### Abstract

Environmental contaminants in fish pose a potential threat to human health. Due to the intensive human activities like agriculture, deforestation and expansion of horticultural/ floriculture industries in the catchments of Lake Zwai, there is a risk of chemical pollution from fertilizers and pesticides. Pollution from domestic and industrial wastes (including point source of heavy metal pollution), are also threats to the lakes' biodiversity resources. Run off and erosion from the surrounding catchment could possibly release chemicals sequestrated in the soil to the lake and reaching out to the fish. Hence, the abundance and quality of commercially important fish species, an important ecosystem service of the Lake, may be at risk. Furthermore, consumption of contaminated fish by humans is one of the main routes of exposure to toxic chemicals like Hg. The objective of the present study was therefore to determine the level of total mercury (tHg) in selected fish species from Lake Zwai and its implications in dietary exposure. The

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tHg concentrations in studied fish species varied between ND and  $0.5 \text{ mg kg}^{-1}$  (ww). The concentrations of Hg found in most of the studied fish from Lake Zwai were in general lower than the International Marketing Limit (IML) ( $0.5 \text{ } \mu\text{g g}^{-1}$ ) and World Health Organization (WHO) guidelines ( $0.2 \text{ } \mu\text{g g}^{-1}$ ) for consumption. This finding is in general in agreement with most studies conducted in other African lakes. However, from among the total fish samples of each species, 27 % of *L. intermedius* from Lake Zwai contained Hg concentrations that exceeded WHO guidelines ( $0.2 \text{ } \mu\text{g g}^{-1}$ ) for consumption. Consumption of *L. intermedius* from Lake Zwai may pose a special health risk to children and expectant women. Although, *L. intermedius* has a low market demand as food fish, subsistence fishermen and their families who may regularly consume this fish could be exposed to toxic organic Hg.

**Keywords:** Fish consumption, Fish species, trophic position, mercury (Hg), Lake Zwai

## Introduction

Mercury (Hg) exists in the environment in different chemical forms: elemental (metallic), inorganic, and organic forms (primarily methylmercury (MeHg)). Inorganic Hg is converted to primarily MeHg, presumably by sulfate reducing bacteria which usually live in sediments (Gilmour *et al.*, 1992; Schäfer *et al.*, 2010). The ecological and toxicological effects of mercury depend on the chemical species present (Ullrich *et al.*, 2001). Generally, organic mercury forms are more toxic to aquatic organisms and birds than the inorganic forms (Boening, 2000). It is also documented that virtually all (> 95 %) of the total Hg (tHg) in the edible tissue of fish is in the form of MeHg (Bloom, 1992). Detailed information on the toxicology of mercury and its compounds can be found in (Clarkson and Magos, 2006).

Mercury in fish is of global concern, and a widely studied topic, because of its established relevance to human health risks. The first well-documented MeHg

poisoning from fish diet occurred in Minamata, Japan in 1953 (Ninomiya *et al.*, 2005). The negative health effects on the population in Minamata seemed to persist even thirty years after the termination of the exposure (Ninomiya *et al.*, 2005). One of the most common ways of human exposure to Hg today arises from eating fish with elevated concentrations of Hg (Counter and Buchanan, 2004; Durrieu *et al.*, 2005). MeHg is a known potent human neurotoxin because of the ability to cross the blood-brain and placenta barriers, and according to (Grandjean *et al.*, 1999) prenatal exposure to MeHg from maternal diet has been shown to result in an early detectable cognitive dysfunction in 7-year old children.

The key factor dictating total concentration of Hg in the biota (e.g. fish) is the MeHg concentration in water (Morel *et al.*, 1998), and the important sources are precipitation, runoff from wetlands and in-lake methylation (Rudd, 1995; Downs *et al.*, 1998). Hg can accumulate to elevated levels in the biota even in remote areas which are devoid of local industrial sources; due to long-range atmospheric transport followed by deposition (Fitzgerald *et al.*, 1998). Local factors such as the presence of hot springs around lakes is also thought to account for high Hg concentrations in the waters of Ethiopian Rift Valley soda lakes (Zinabu and Pearce, 2003). It is also important to take into account biological factors such as the food web structure, to explain the behavior of Hg, including bioaccumulation and biomagnification. The concentration of Hg increases through the food chain by biomagnifications i.e. the increase of Hg with trophic position in the food chain (Watras *et al.*, 1998; Campbell *et al.*, 2003d; Simoneau *et al.*, 2005). The trophic position of aquatic organisms in a food chain or food web may be assessed using the  $\delta^{15}\text{N}$  value, which usually correlates with the Hg concentrations (Cabana and Rasmussen, 1994; Atboreholeet al., 1998).

Literature survey showed that there have been several studies on Hg in fish from East African lakes. Lakes of which, for instance, published data exist

are: Lake Victoria (Campbell *et al.*, 2003a; Campbell *et al.*, 2003b; Campbell *et al.*, 2003c; Hollamby *et al.*, 2004), Lake Mburo of Uganda (Hollamby *et al.*, 2004), Lakes Turkana, Baringo, Naivasha of Kenya (Campbell *et al.*, 2003d), and Lake Malawi (Kidd *et al.*, 2003), also including some lakes in Ethiopia Lake Awassa (Zerihun Desta *et al.*, 2006, 2007, 2008) and Lake Zwai (Tariku Markos *et al.*, 2011). However, the mercury concentrations in fish may change due to spatial and temporal variations as borehole as to external supply. To address scientific and public health concerns, it is essential that biomonitoring of Hg in different fish species is carried out in the Ethiopian Rift Valley Lakes (ERVLS). The objective of the present study was therefore to quantify the tHg concentration levels in key fish species the African big barb (*Labeobarbus intermedius*), the African catfish (*Clarias gariepinus*) and the Nile tilapia (*Oreochromis niloticus*) from Lake Zwai to assess potential human health risks related to consumption of fish by the local population.

## Materials and methods

**Study area:** The study area, Lake Zwai, is located in the Ethiopian Rift Valley in the south-eastern part of Ethiopia, at 1636 m a.s.l. (coordinates 71°52'N and 38°14'5'E) (Fig. 48). It is part of the Zwai–Shala Basin and has a catchment area of about 7,000 km<sup>2</sup>, and an average surface area of 490 km<sup>2</sup> (Brook Lemma and Hayal Desta 2016). The lake has an average volume of 1.8 km<sup>3</sup>, and a maximum depth of 9 m (Vallet-Coulomb *et al.*, 2001). There are two inflowing rivers, the Meki River from the north-west, and the Qatar River from the east. The lake drains towards Lake Abijata, through Bulbula River. The climate of the region is characterized by bimodal rainfall distribution with short-term, highly variable, relatively low rainfall from February to June, and higher from July to September (Zegeye *et al.*, 2006). The mean annual air temperature is 25.5°C, and the mean annual rainfall is about 702 mm (Zegeye *et al.*, 2006). The pH of the lake ranges from 7 to 8, and the average

**Figure 48:** Map of Lake Zwai



**Fish sampling:** Fish sampling was carried out from February–April 2008. Fish were collected by partly purchasing from the local fish market and partly using our experimental gillnets. Total length ( $L_T$ ) and weight ( $W_T$ ) were measured to the nearest centimeter and gram, respectively. Fish dissection of muscle samples and handling were carried out following the EMERGE protocol (Rosseland *et al.*, 2001). Fish muscle tissues for total mercury (tHg) and stable isotope analyses were wrapped in aluminum foil, kept in a plastic bag with zipper lock and stored in an ice box until transferred to a deep freezer. Stomach contents were stored in small plastic vials, and preserved, using 90 % ethanol.

**Stomach contents analyses:** This was carried out at the Department of Biology, University of Hawassa. Large items were identified visually, and smaller items were identified under a dissecting microscope. For microscopic food items like algae, the stomach contents from each fish were first diluted with water to a known volume, mixed thoroughly, a drop of it was placed on a microscopic slide and identified. The relative importance and contribution of each food item to the diet of each fish species was determined using the frequency of occurrence method and the relative composition by volume (%) – volumetric analysis (Hyslop, 1980).

**Mercury analysis:** Tissue concentration of tHg in all fish samples was analyzed at the Environmental Chemistry Section of the Department of Plant and Environmental Sciences (IPM), Norwegian University of Life Sciences (UMB). The wet muscle tissues were first weighed, and then digested, using an Anton Paar microwave oven. tHg concentrations were analyzed using the Perkin-Elmer model FIMS 400 flow injection Hg system. Generally, calibration of the equipment was done by plotting calibration curves using the measurement values of four different synthetic standards. The curves were linear, and calibration was rechecked after every five samples. Blanks and certified reference material (DORM<sup>2</sup>, dogfish) were used for the analytical

data quality control. Results are reported in mg Hg kg<sup>-1</sup> tissue wet weight (ww). The concentrations of Hg found in the fish species from Lake Zwai were compared against the International Marketing Limit (IML) (0.5 µg<sup>-1</sup>) and World Health Organization (WHO) guidelines (0.2 µg g<sup>-1</sup>) for consumption.

**Stable isotope analyses:** The stable isotope analyses were carried out at the Environmental Chemistry Section, Department of Plant and Environmental Sciences, Norwegian University of Life Sciences (UMB) as described in (Zerihun Desta *et al.*, 2007) and (Sharma *et al.*, 2009). Fish filets of approximately 10–100 mg were homogenized with a blender, after adding about 50 mL of distilled water. Homogenized and freeze-dried muscle tissue samples were weighed (0.8–1.2 mg) in tin capsules which were sealed to avoid sample loss. The samples in tin capsules were subjected to combustion in a Flash Elemental Analyzer (EA), and stable isotopes of nitrogen (<sup>15</sup>N and <sup>14</sup>N) and carbon (<sup>13</sup>C and <sup>12</sup>C) were determined by a Continuous Flow-Infrared Mass Spectrometer (CF-IRMS) as also described in (Zerihun Desta *et al.*, 2007) and (Sharma *et al.*, 2009). The isotopic ratios (<sup>15</sup>N/<sup>14</sup>N, <sup>13</sup>C/<sup>12</sup>C) were expressed in delta-values as follows:  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  (‰) =  $[(R_{\text{Sample}}/R_{\text{Standard}}) - 1] * 1000$  where,  $R = ^{15}\text{N}/^{14}\text{N}$  for  $\delta^{15}\text{N}$  or  $R = ^{13}\text{C}/^{12}\text{C}$  for  $\delta^{13}\text{C}$ . The spatial variation of the stable isotopes of nitrogen between the two lakes was corrected by normalizing the mean value of  $\delta^{15}\text{N}$  in the main primary consumer, *O. niloticus* in the two lakes (Ermias Deribe *et al.*, 2011; Tariku Markos *et al.*, 2011).

**Statistical analysis:** Comparisons of the tHg concentrations among different fish species were performed by analyses of variance (ANOVA), using MINITAB 16. Biomagnification rate of Hg was determined by regressing the log transformed tHg concentrations against  $\delta^{15}\text{N}$  values. Log transformed Hg concentrations were regressed against  $L_T$  to see the relationship between tHg concentration and age (assuming large fish tend to be older). Differences in mean values of tHg were considered as statistically significant when  $p < 0.05$ .

## Results and Discussion

Algae were the most important food group of *O. niloticus* in Lake Zwai (Table 53), and formed 34.2 % (by volume) of the total stomach content, of which blue green algae, diatoms and green algae accounted for 19.4 %, 10.6 % and 4.2 %, respectively. Detritus and macrophytes accounted for 29.0 % and 12.6 % of the mean volume, respectively. *O. niloticus* in the lake mainly fed on algae, macrophytes and detritus, and is thus a typical herbivore. The diets of *O. niloticus* from Lake Zwai were in general comparable and in good accordance with studies from other lakes. This species was also found to be herbivorous in earlier studies made in the same lake (e.g. Tariku Markos *et al.*, 2011) and in other Ethiopian rift-valley lakes, such as Lake Koka (Ermias Deribe *et al.*, 2011) and Lake Hawassa (Zerihun Desta *et al.*, 2007; Getachew Teferra, 1987, 1989; Getachew Teferra and Fernando, 1989). The diet of *C. gariepinus* included various food items from detritus to fish, but fish, aquatic insects, and gastropods, made up 28.2 %, 24.1 %, and 16.3 % of the stomach contents by volume, respectively. The fish recorded as food items of *C. gariepinus* were mainly *O. niloticus*. *C. gariepinus* in Lake Zwai are omnivorous according to their diet preferences, but large individuals of the species include fish in their diet. Similar findings were also reported for *C. gariepinus* in Lake Hawassa (Elias Dadebo, 2000; Zerihun Desta *et al.*, 2007). Since the stomach of most individuals of *L. intermedius* was empty, the stomach content was not analyzed for this species.

**Table 46:** Summary of the concentration of tHg, stable isotop ration of nitrogen and carbon values min-Max = minimum and maximum, and SD = standard deviation and the dominant food item for each species in Lake Zwai (NOTE: Means of tHg that do not share a letter are significantly different ( $p < 0.05$ ) among fish species. ND means not detected).

| Fish Species          | N  | $\delta^{15}\text{N}$        | $\delta^{13}\text{C}$           | tHg                                              | Dominant diet                       |
|-----------------------|----|------------------------------|---------------------------------|--------------------------------------------------|-------------------------------------|
|                       |    | Mean $\pm$ SD                | Mean $\pm$ SD                   | Mean $\pm$ SD                                    |                                     |
|                       |    | (Min-Max)                    | (Min-Max)                       | (Min-Max)                                        |                                     |
| <i>B. intermedius</i> | 11 | 10.1 $\pm$ 2.7<br>(6.8-16.5) | -22.5 $\pm$ 1.1<br>(-24.5-20.0) | 0.13 $\pm$ 0.2 <sup>a</sup><br>(0.01-0.5)        | No Data                             |
| <i>C. gariepinus</i>  | 27 | 12.4 $\pm$ 1.1<br>(8.6-14.7) | -24.7 $\pm$ 3.2<br>(-34.6-20.9) | 0.06 $\pm$ 0.04 <sup>ab</sup><br>(0.02-0.16)     | Omnivorou<br>s<br>(include<br>Fish) |
| <i>O. niloticus</i>   | 24 | 10.0 $\pm$ 0.9<br>(8.7-11.6) | -23.6 $\pm$ 1.5<br>(-26.6-19.9) | 0.01 $\pm$ 0.0 <sup>b</sup><br>(0.01 $\pm$ 0.04) | Herbivorou<br>s (Mainly,<br>algae)  |

The diet compositions of the fish species from Lake Zwai were further substantiated by the  $\delta^{15}\text{N}$  signals. *C. gariepinus* were occupying a higher trophic level than *O. niloticus* and *L. intermedius* in Lake Zwai (Fig 51). The stomach contents from *L. intermedius* in Lake Zwai were not available, but the large SD of the mean  $\delta^{15}\text{N}$  value indicates a large variation between individuals as regards to food items which is consistent with the results from Lake Koka (Ermias Deribe *et al.* 2011).

The  $\delta^{15}\text{N}$  values of the three fish species ranged from 6.8 ‰ to 16.5 ‰ (Table 53). The range in  $\delta^{15}\text{N}$  signatures, being larger than 9 in the studied lake, indicates that there are about 3 trophic levels in the fish community of Lake Zwai, following a mean enrichment value of  $\delta^{15}\text{N}$  at 3–4 ‰ per successive trophic level (Vander Zanden and Rasmussen, 2001). However, recent studies by Kilham *et al.* (2009), indicated that the fraction could be much lower than 3–4 ‰ in tropical ecosystems. This is perhaps due to rapid turnover of tissue  $\delta^{15}\text{N}$  in tropical aquatic organisms (McIntyre and Flecker, 2006) or temperature dependent fractionation of  $\delta^{15}\text{N}$  (Sweeting *et al.*, 2007). Therefore, there may be more trophic levels between the most herbivorous and the most piscivorous specimens in our study. The  $\delta^{13}\text{C}$  signatures in general indicated that the studied fish species have a wide range of carbon sources in their diets that extends from pelagic to littoral resources. Some individuals had very “light” (more negative)  $\delta^{13}\text{C}$  signature, indicating a pelagic energy pathway, in contrast to those with “heavier” (less negative)  $\delta^{13}\text{C}$  signatures which are likely due to benthic carbon sources (Hecky and Hesslein, 1995; Bootsma *et al.*, 1996). However, *L. intermedius* exhibited relatively more enriched  $\delta^{13}\text{C}$  than the studied fish species, suggesting that this species obtained a large proportion of its prey from benthic sources.

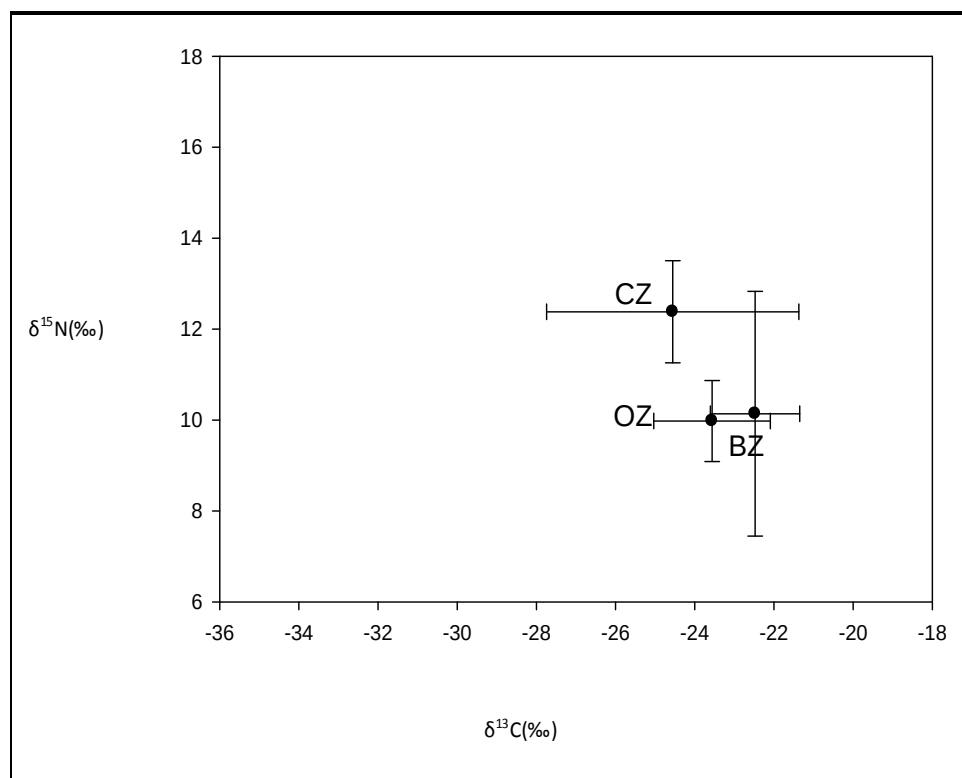


**Figure 49:** Relative trophic positions for the fish species (a) *L. intermedius* (b) *C. gariepinus* (c) *O. niloticus* sampled between February-April 2008 from Lake Zwai based on the mean and  $\pm$ SD of stable isotope ratios of nitrogen ( $\delta^{15}\text{N}$ , ‰) and carbon ( $\delta^{13}\text{C}$ , ‰)

For all fish species and individuals pooled, a significant positive relationship was found between log transformed tHg and  $\delta^{15}\text{N}$  in Lake Zwai ( $P = 0.00$ ,  $R^2 = 0.26$ ) (Fig 52). However, the biomagnification rate of tHg in the present study was lower than what has been reported from other areas (Campbell *et al.*, 2006; Campbell *et al.*, 2004; Campbell *et al.*, 2003c).

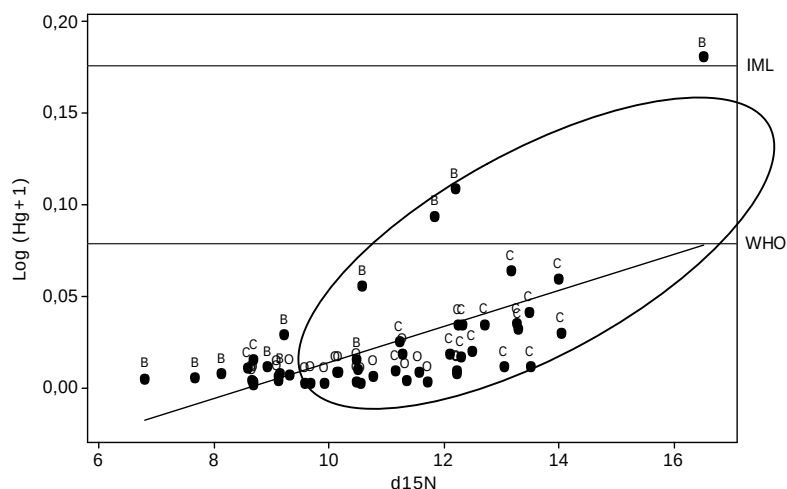


**Figure 50:** Composition of the level of tHg in different fish species sampled from Lake Zwai with WHO guideline values set for safe fish consumption (WHO: 0.2  $\mu\text{g m}^{-1}$  ww) and International marketing Limit (IML: 0.5  $\mu\text{g m}^{-1}$  ww) (B: *Laboebarbus intermedius*, O: *Oreochromis niloticus* and C: *Claris gariepinus*)

The concentrations of Hg found in *C. gariepinus* and *O. niloticus* were in general lower than the International Marketing Limit (IML) ( $0.5 \mu\text{g g}^{-1}$ ) and World Health Organization (WHO) guidelines ( $0.2 \mu\text{g g}^{-1}$ ) for consumption. This finding is, as a whole, in agreement with most studies conducted in other African lakes (Table 2). However, of the total fish samples for each species, 27 % of *L. intermedius* showed Hg concentrations that exceeded World Health Organization (WHO) guidelines ( $0.2 \mu\text{g/g}$ ) for consumption (Fig 52). The concentrations of tHg found in *L. intermedius* were not only higher than those found in the other fish species in the present study, but also in most other studies carried out in other African lakes (Table 54) - although fish size, sample size etc. varied in these studies, and may make direct comparisons difficult. This result is consistent with the report by Zerihun Desta *et al.*

(2007) for the same fish species from Lake Hawassa. However, a study in Lake Tanganyika (Tanzania, East Africa) by Campbell *et al.* (2008) showed that two individuals of the piscivorous fish species *Lates microlepis* (0.54, 0.78  $\mu\text{g/g ww}$ ) and *Polypterus congicus* (1.3  $\mu\text{g/g ww}$ ) contained a higher concentrations of tHg and exceeded the international marketing limit value of 0.5  $\mu\text{g/g ww}$ .



**Table 47:** Comparison of the mean value SD of tHg concentrations in our study with fish species from other African lakes (NOTE: Means of tHg that do not share a letter are significantly different ( $p < 0.05$ ) among fish species. ND means not detected.

| Authors                              | Lake          | Fish speies           | Mean $\pm$ SD, tHg            |
|--------------------------------------|---------------|-----------------------|-------------------------------|
| (Our Study)                          | Lake Zwai     | <i>O. niloticus</i>   | 0.01 $\pm$ 0.0 <sup>a</sup>   |
|                                      |               | <i>C. gariepinus</i>  | 0.06 $\pm$ 0.04 <sup>ab</sup> |
|                                      |               | <i>L. intermedius</i> | 0.13 $\pm$ 0.02 <sup>b</sup>  |
| (Tariku Markos <i>et al.</i> , 2011) | Lake Zwai     | <i>O. niloticus</i>   | 0.01 $\pm$ 0.01               |
|                                      |               | <i>C. auratus</i>     | 0.03 $\pm$ 0.02               |
|                                      |               | <i>C. gariepinus</i>  | 0.03 $\pm$ 0.02               |
|                                      |               | <i>T. zilli</i>       | 0.03 $\pm$ 0.03               |
| (Zerihun Desta <i>et al.</i> , 2007) | Lake Awassa   | <i>O. niloticus</i>   | 0.01 $\pm$ 0.02               |
|                                      |               | <i>C. gariepinus</i>  | 0.05 $\pm$ 0.03               |
| (Kidd <i>et al</i> , 2004)           | Lake Chad     | <i>O. niloticus</i>   | 0.01 $\pm$ 0.00               |
|                                      |               | <i>C. gariepinus</i>  | 0.03 $\pm$ 0.00               |
| (Campbell <i>et al.</i> , 2004)      | Lake Victoria | <i>O. niloticus</i>   | 0.01 $\pm$ 0.00               |
| (Campbell <i>et al.</i> , 2006)      | Lake Nkuruba  | <i>T. zillii</i>      | 0.02 $\pm$ 0.01               |
| (Campbell <i>et al.</i> , 2003d)     | Lake Baringo  | <i>C. gariepinus</i>  | 0.06 $\pm$ 0,03               |

## Conclusions

The concentrations of tHg found in *L. intermedius* were in general higher than those found in other fish species in our study, as boreholeas in most studies carried out in other African lakes, although variations in fish size, sample size etc. make direct comparisons difficult. A person with a daily intake from *L. intermedius* may be exposed to possible health hazards. However, *L. intermedius* is a less preferable fish that is not widely used by the local people; but the fishermen and their families presumably consume more of this species.

Given that the consumption rate of fish in general, and *L. intermedius* that exceeded WHO guidelines limit in particular, the local people living in the island of Lake Zwai and the family of fishermen there, are the most vulnerable community of the local people. The other species, *O. niloticus* and *C. gariepinus*, have lower tHg concentrations than *L. intermedius*, and the hazard evaluation indicates that there is no direct risk for humans using these species in their daily food at present.

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## Chapter 10

### **Seasonal prevalence of gastrointestinal helminth parasites of sheep in the wetlands along the shorelines of Lake Zwai, Ethiopia**

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#### **Abstract**

In tropical countries like Ethiopia where the wet seasons are restricted to less than five months of the year, wetlands such as those found along the shorelines of Lake Zwai provide ideal environments for year-round supply of fresh and succulent grasses for livestock. Such freshwater environments also provide the conducive conditions of the completion of the life cycles of worm parasites that can be passed to livestock throughout the year with of course possible seasonal variations. As a consequence, this study was designed to assess the role of Zwai wetlands for the seasonal prevalence of water-related gastrointestinal helminth disease of sheep. In this study, 50 experimental sheep (46 experiment tracers, two on-field control tracers and two housed control tracers) were used whose fecal samples and gastrointestinal parts, lungs and livers would be post mortem examined over a period of two years. Out of 46 experimental tracer sheep examined, 45 sheep (97.83%) were found to be infected with water-related gastrointestinal helminth parasites belonging to nematode, trematode and cestode groups. Ten different species of nematode

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parasites (97.83%) dominated by *Hemonchus contortus* and one of each of cestode and trematode parasites were collected. The results revealed that the wetlands of Lake Zwai are heavily infested with gastro-intestinal parasites. Since it provides conducive environments to such parasites of livestock, it was therefore recommended that the grazing patterns of livestock to such wetlands as around Lake Zwai should be managed in such a way the life cycles of the parasites are broken and appropriate treatment regime and awareness of losses in productivity due to parasitism should be provided to local livestock owners of the area.

**Keyword:** helminth parasites, Lake Zwai, post mortem, tracer sheep, waterborne diseases, Ethiopia

## Introduction

Wetlands provide a variety of ecosystem services that contribute the wellbeing of animals and humans (Berhanu Gebremedhin *et al.*, 2007, Clarkson *et al.*, 2013 and Gopal, 2015). Due to this reason, wetlands are meeting and interaction grounds for a wide spectrum of biodiversity. However, wetlands do not only serve as habitats and feeding grounds for animals, including livestock, but unfortunately, they also provide conducive environments for the exchange of waterborne parasitic diseases among the animals that frequent these wetlands (Jejaw Muluneh *et al.*, 2014).

In Ethiopia wetlands are serving as communal grazing areas, which predispose livestock to continuous and seasonally variable exposures to gastrointestinal helminth infections. Research conducted in tracer sheep experiments in different areas at different seasons of the year confirmed the occurrence of gastrointestinal helminth parasites in wetlands having excess fresh waters that are pre-requisites for the completion of the life cycles of helminth parasites of livestock (Brook Lemma *et al.*, 1985; Desalegn Lidetu, 2005). This study therefore aimed to assess the load and pattern of

waterborne helminth diseases of small ruminants, particularly sheep, in the wetlands of Lake Zwai.

### **Materials and methods**

**The study area:** This study was conducted in the wetlands found along the shores of Lake Zwai, which is the second largest lake in the Ethiopian Rift Valley of Ethiopia and located at 8° 01' N and 38° 47' E and an altitude of 1636 m above sea level (Von Damm and Edmond, 1984) (Fig. 53). The lake is fed by Abaya (or Abaya or Abaya) and Meki Rivers that flow from the Southeastern and Northwestern highlands, respectively, and drains into Lake Abijata through the Bulbula River in the south. The climate of the area is characterized by semi-arid to sub-humid with mean annual precipitation and temperature of 650 mm and 25°C, respectively. The specific locations of the wetlands of this study are located on the southwestern part of Lake Zwai known as Seda and Woshgula. These wetlands are also used by the local people as fishing grounds, bathing, washing clothes and watering their livestock.

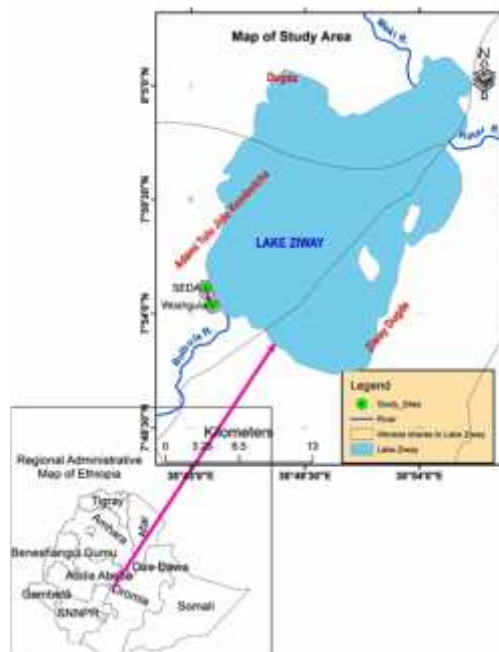


**Figure 51:** Map of Seda and Woshgula wetlands along the shorelines of Lake Zwai

**Methodology:** In this study, the tracer animal method using indigenous sheep of 4 to 6 months of age of both sexes were employed. Forty-six sheep were used as experimental tracers over a period of two years. These were purchased from the local market of Zwai town. On their arrival, the sheep were ear-tagged and their weights taken and they were treated with Albendazole at  $7 \text{ mgkg}^{-1}$  body weight and Ivermectine 0.5 ml to avoid previously acquired disease, sprayed with an acaricide for the control of external parasites and vaccinated against anthrax.

A batch of two experimental tracer sheep was released at the selected sites to graze on a monthly schedule. At the end of each month, they were housed

under parasite-free feeding and housing conditions to stay for three months to give sufficient time for any parasites picked at that grazing-month to mature. By the end of the housing period, the gastrointestinal (GI) parts, lungs and livers of were subject to post-mortem examinations (Brook Lemma, 1983). This process was repeated for 24 consecutive months.

Only two control tracer sheep were released simultaneously with the experimental tracer-sheep in the selected wetlands. At the end of each month, these sheep were treated with anti-helminth as per the above mentioned dosages and released again with the next batch of the experimental tracers. This process was repeated every month up to the end of the study period to show the effectiveness of the drugs and those lambs were also fed parasite free feeds and kept in clean houses for three months after the last grazing month. Finally, the GIs, lungs and livers of these sheep were examined by post mortem.

Two control lambs were de-wormed and kept housed and remained housed for the whole study period of two years to show the helminth-free status of the feed and housing. These too were kept housed for three months after the last month of the research period and they GIs, lungs and livers were examined by post mortem.

**Fecal egg count:** Fecal samples were taken in the morning from the rectum of the experimental sheep on days 0, 7 and 14 after treatment (Getachew Terefe *et al.*, 2013) for nematode egg counts using McMaster Technique (Hansen and Perry, 1994).

**Packed cell volume tests (PCV):** Blood samples were collected from all experimental tracer lambs for hematological analysis by collecting blood samples from their jugular veins with the help of sterile disposable syringes and transferred into 10ml EDTA (ethylene di-amine tetra acetic acid) tubes and placed on ice immediately after collection until processing. All blood

samples were labeled with identification numbers and dates of collection and transported in ice boxes to the laboratory. Packed cell volume (PCV) and plasma concentration (PC) were analyzed within 1-2 hours after collection (Jawasreh *et al.*, 2009). The results were measured using a haematocrit reader and expressed in terms of percentages.

**Collection of helminth parasites from the sheep:** The GIs, lungs and livers of a total of 50 sheep subjected in this study were examined by post mortem after procedures by Brook Lemma (1983) and Hansen and Perry (1994). Each organ was carefully trimmed from fat and mesenteries and separated at their junctions to prevent worms spilling out from one location to another, and placed in separate containers having labels of the sheep tag numbers. The organs were opened carefully with surgical scissors, not to damage the parasites within. The opened organs were washed within four hours after of removal as described by Hansen and Perry (1994). Identification of the collected helminth parasites was conducted according to keys by Hansen and Perry (1994) and Urquhart *et al.* (1996). Weather data: These were collected for the period from April 2015 to March 2017 from the meteorological station of Adami Tulu Agricultural Research Center located 7 km away from the study sites.

## Results and discussions

Generally, Lake Zwai watershed and particularly the wetlands around the lake do not have any limitations with air temperature, as it is always above 20°C (Fig. 55). That provides sufficiently warm environment for the development of parasite larvae and the growth of herbages. In contrast, rainfall is limited to specific months of the year with slight variability in terms of intensity and duration. Fig. 56, above shows that the rains in Lake Zwai area varied from the maximum rainfall periods (long-rains seasons) of June to September of 2015 and 2016; and the dry seasons split into two, each ranging from October to December of 2015 and March to May of 2016. This scenario therefore

limits the growth and coverage of herbages in the annual cycle and hatching of eggs and the development of parasite larvae to the wet seasons marked as the short-rains season of April and May of 2015 and January and February of 2016 and the long wet seasons described above. As the wet seasons (short- and long-rains periods) stimulate the hatching of fresh and resident eggs with the injection of fresh waters, they also stimulate the growth of fresh herbages that attract grazers into the wetlands. This created a situation whereby wetness with fresh waters of low salinity, succulent grazeable herbages, infective stages of helminth parasites and herbivores (in this study the experimental tracer sheep) converge at the same space and time in temperatures that were conducive to all (see Brook Lemma *et al.* 1985, 1986 and Brook Lemma 1988 and Sissay Menkir 2007).

Following this scenario, district upsurge of infections (prevalence of nematodes, trematodes and cestodes) of the tracer sheep has been recorded in the study sites as indicated in Table 56, below. Further, Figs. 56 shows the trend in the infection of the tracer sheep by nematodes belonging to seven species and Figs. 57 (3 Figs. in one) showing the cases of each of *Hemonchus contortus*, *Trichostrongylus axei* and *Trichuris ovis*, all as influenced by the changes in wet-and dry seasons.

**Table 48:** Types of gastrointestinal parasites collected from the tracer sheep during the study period

| Parasite groups | Identified parasites         | Prevalence (%) |
|-----------------|------------------------------|----------------|
| Nematodes       | <i>Haemonchus contortus</i>  | 87.0           |
|                 | <i>Trichostrongylus axei</i> | 56.5           |
|                 | <i>Trichuris ovis</i>        | 69.6           |
|                 | <i>Bunostomum</i>            | 28.3           |
|                 | <i>tringoincephalum</i>      |                |
|                 | <i>Oesophagostomum</i>       | 32.6           |
|                 | <i>columbianum</i>           |                |
|                 | <i>Dictyocaulus filaria</i>  | 10.9           |

| Parasite groups  | Identified parasites        | Prevalence (%) |
|------------------|-----------------------------|----------------|
|                  | <i>Mullerius capillaris</i> | 2.2            |
|                  | Unidentified species        | 2.2            |
| <b>Cestode</b>   | <i>Moneza expansa</i>       | 19.6           |
| <b>Trematode</b> | <i>Fasciola gigantica</i>   | 17.4           |

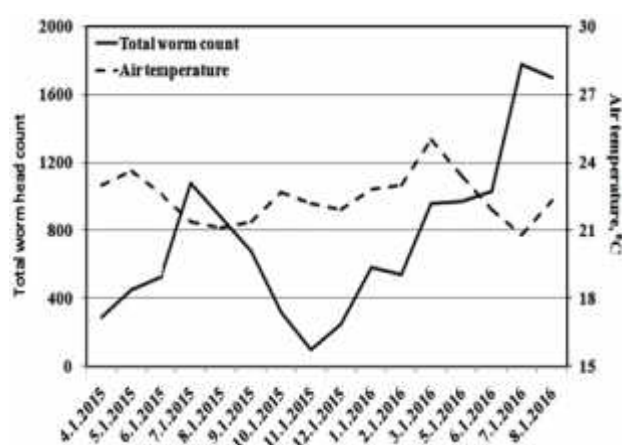


**Figure 52:** Despite variations in parasite burden of the tracer sheep, air temperature of the study sites remained warm with a range of 20 to 25°C



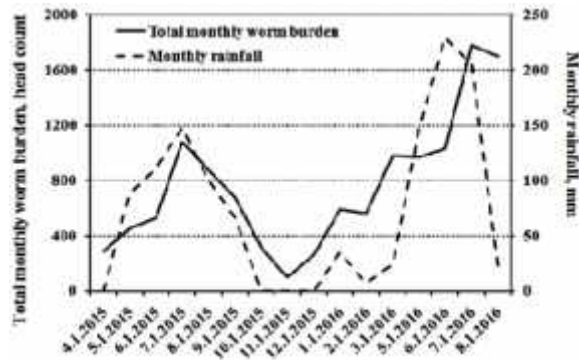
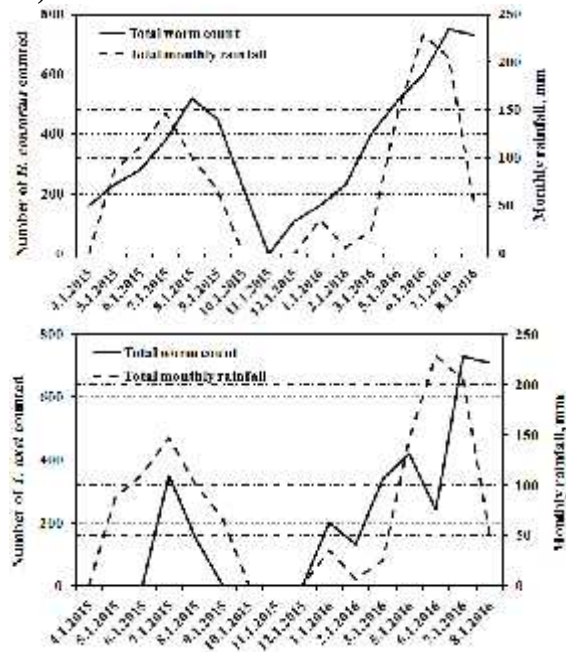


**Figure 53:** The infection of tracer sheep with parasites, particularly, nematodes, showed variations with wetness or with the onset of the rainy seasons (short and long-rains)



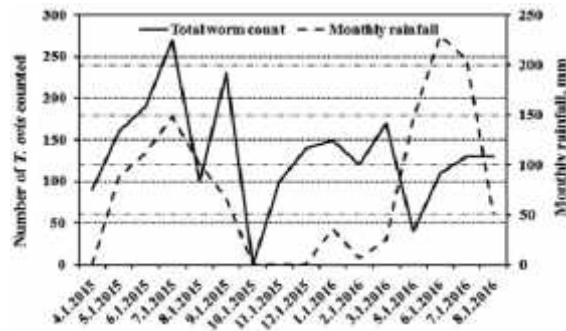


**Figure 54:** To--down- the infection of tracer sheep with parasites: (top) *H. contortus*, (middle) *T. axei* and (bellow) *T. ovis* that showed variations with the onset of the rainy seasons (short and long-rains)

Fig. 58, below, summarizes the strong relations of the wet seasons and the upsurge of helminth parasitism in the tracer sheep. This trend has been reported in other related studies conducted in different wetland areas of the country as in Brook Lemma (1983), Brook Lemma *et al.* (1985), (1986) and Brook Lemma (1988), Sissay Menkir (2007) and others.

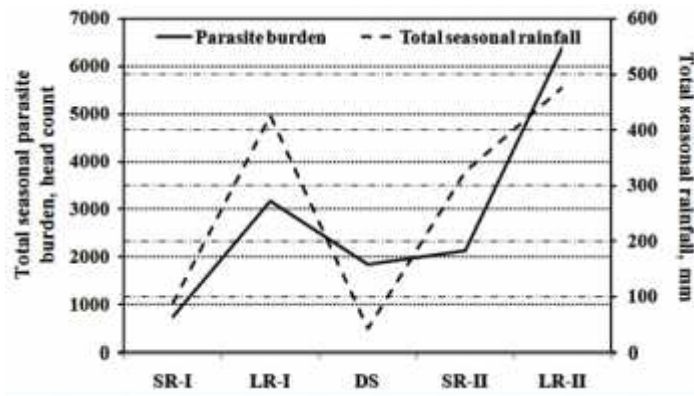


**Figure 53:** Relations of helminth parasitism and seasonal onset of short and long-rains

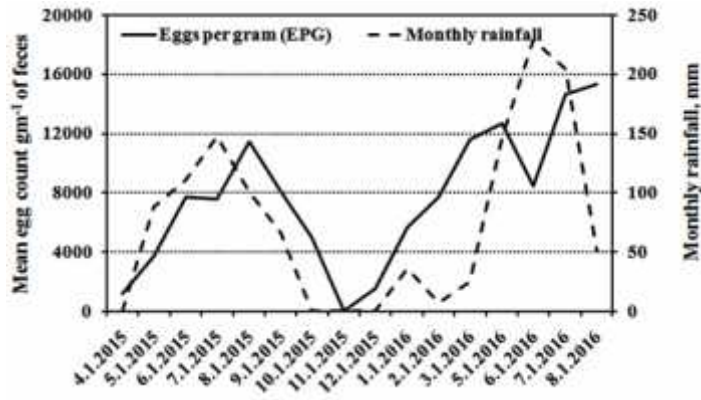


**Figure 56:** Relations of nematode parasite egg counts per gram of feces of tracer sheep and seasonal onset of short and long-rainy seasons

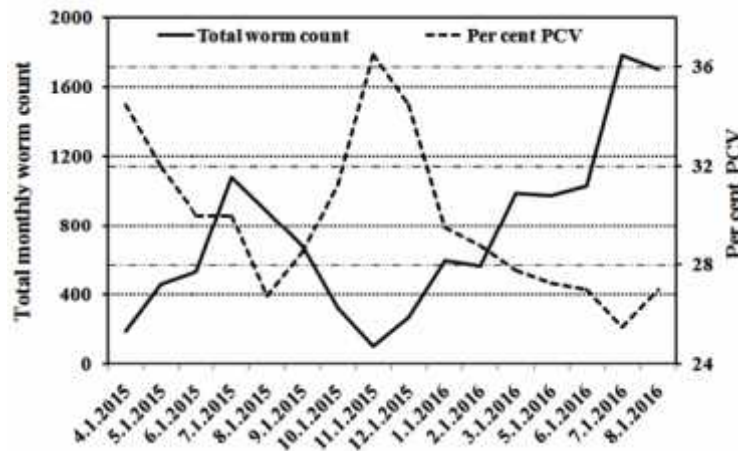


**Figure 57:** The inverse relations of packed cell volume (PCV) of tracer sheep and seasonal onset of short and long-rainy seasons

The attempt made to show how the egg counts in the feces of the tracer sheep has also corroborated with the helminth parasite loads of the tracer sheep over the two year period of alternating wet and dry seasons (Fig. 59). At the same time, it was also observed that there were strong inverse relations of packed cell volume of the tracer sheep and seasonal onset and upsurge of helminth parasitism (Fig. 60). These results therefore suggested that there was a general decline in the physiological functioning of the tracer sheep as impacted by the helminth parasite loads that, lead to the weakening of the defense mechanisms of the tracer sheep to parasite infections.

In this study, the intensity of infection of the tracer sheep reached 100 % with some parasites such as *H. contortus* and at various serious levels with other, namely, *T. axei* (100%), *T. ovis* (28.57%), *B. tringoincephalum* (70.59%) and *O. columbianum* (57.14%) were lightly affected and some (*T. ovis* (71.41%), *B. tringoincephalum* (29.41%) and *O. columbianum* (42.86%)) were moderately affected (see also Bikila Emiru 2013 and Andualem Yimer and Eyerusalem Birhan 2016). In support of this finding, Almalaik *et al.* (2008) reported that the intensity of the parasite infection on sheep in their study was

light to moderate. The probable reason for this finding might be the availability of pasture (sheep feed) in the waterfront of Lake Zwai throughout the study period reduce the degree of infection.

### Conclusion

The overall prevalence of gastrointestinal helminth parasites in the study area indicated that there was a clear health problem of domesticated grazer animals from helminth infections that severely undermined their productivities (see also Kassaye Argaw and Gebrehiwot Gebreegziabher 2014, Yemiserach Yonas and amenu Goa 2017). These infections could even cause deaths in cases of multiple infections in all ages of animals, particularly young ones, pregnant females and animals already impacted by other disease such as bacterial, viral or others.

The intensity of the infections are exacerbated by traditional livestock management of livestock of the area (e.g. Abdurezak *et al.* 2015, Abebe W. and Esayas G. 2001 and Hailegebriael Bedada *et al.* 2017), where open grazing fields are restricted in the wet seasons as the field are covered with crops by growing populations of the farming communities of Zwai watershed, the convergence of livestock to the succulent herbages of the wetlands and the increase in the number of livestock in the same watershed and the lack of alternative strategies of feeding animals such as zero-grazing periods in the year (see also Hayal Desta and Brook Lemma (2017a and b).

It is therefore recommended that regular control measures should be practiced to reduce the parasitic burdens in the affected areas, plan for rotational grazing that avoids the use of wetlands at peak parasite seasons, reduce livestock populations by putting improving their productivity and develop zero-grazing strategies as supplementary procedure of livestock management.

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## Chapter 11

### **Diversity, regeneration status and socio-economic importance of the vegetation on the islands of Lake Zwai, south-central Ethiopia**

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#### **Abstract**

This study was conducted on the islands of Lake Zwai, south-central Ethiopia. The main objective was to investigate the diversity, regeneration status, socio-economic importance and the factors that cause degradation of the vegetation resources on the islands. A total of 73 plots, measuring 20 x 20 m, were established along line transects laid down from the central part of each island to the lake edge in eight aspects (N, S, E, W, NE, NW, SE, SW). In each plot, the cover-abundance of each species was visually estimated, woody species were counted, and Diameter at Breast Height (DBH) and height of trees and shrubs were measured. Participatory Rural Appraisal Method (PRA) was employed to generate the socio-economic data. A total of 141 species belonging to 113 genera and 55 families were identified, of which 18.4% were trees, 21.3% trees/shrubs, 12.1% shrubs, 3.5% woody climbers, 4.3% herbaceous climbers and 40.4% herbs. Five species were endemic to Ethiopia, namely *Aloe pubescens*, *Laggera tomentosa*, *Leucas abyssinica*, *Urtica simensis* and *Eragrostis tef* (cultivated). The overall Shannon-Wiener diversity and evenness indices of woody species on the islands were 2.60 and 0.62, respectively. The similarity in species composition between the islands

was low, indicating that each island has its own unique flora. Nine plant communities were recognized and described. The total density and basal area of woody species were 2,979 individuals ha<sup>-1</sup> and 191 m<sup>2</sup> ha<sup>-1</sup>, respectively. The Importance Value Index (IVI) values and the DBH and height class distributions revealed that some species are threatened and need the highest priority for conservation. The island communities were highly dependent on the natural vegetation for fuelwood, construction material, farm implements, food (edible fruits), medicines, animal fodder and bee forage. On the other hand, the islanders have maintained the soil and vegetation resources for centuries through their indigenous resource management systems and practices. Free livestock grazing/browsing, farmland expansion, soil erosion and tree cutting for various purposes, all spurred by human population growth, are the major threats to the vegetation resources on the islands. This calls the need for effective conservation and management of the fragile island ecosystems.

**Keywords:** Conservation; plant diversity; islands of Lake Zwai; vegetation regeneration; socio-economics

## Introduction

An island is an area of land smaller than a continent and entirely surrounded by water. There are two main types of islands – oceanic and continental (Limolino *et al.*, 2006). There are numerous islands in oceans, seas, lakes and rivers across the world. Isolated patches of habitats on mainland scattered through the landscape – such as mountaintops, springs and caves – are also considered as islands, and can be studied in the same ways as oceanic islands for patterns of colonization and extinction (Limolino *et al.*, 2006). An island is a self-contained region whose species originate entirely by immigration from outside the region (Rosenzweig, 1995).

Islands have distinctive ecological systems. They shelter unusual relicts, strange combinations and extraordinary evolutionary radiations (Jeffries, 1997). Quite often, there is high endemism on islands (Rosenzweig, 1995; Cook and Macdonald, 2001; Cook *et al.*, 2001), which is most probably attributed to allopatric and sympatric speciation. Islands generally have low species richness, but there are some islands such as Madagascar, Mauritius, Galapagos and Hawaii which possess a very high biodiversity and endemism (Mooney *et al.*, 1995; Jeffries, 1997; Cook and Macdonald, 2001; Limolino *et al.*, 2006; Ricklefs, 2007). Flora of islands usually comprise of a specialized subset of the mainland flora, or evolutionary derivatives of these subsets, members of which have been able to gain access to the islands by means of long-range dispersal and subsequently evolve in the unique habitat conditions and unique habitats, which are usually free of intense competition (Kellman, 1980). The dynamics of island biota depend on two processes – immigration and extinction (Rosenzweig, 1995; Begon *et al.*, 1996; Jeffries, 1997; Ricklefs and Miller, 2000). Species diversity on islands depends on island size, habitat heterogeneity, species interactions like competition and predation, distance from the mainland, richness and dispersal ability of the source pool species, or combinations of these factors. Disturbance regime is also an important factor that determines species richness on islands.

Island ecosystems are extremely fragile, and the biota are sensitive to extinction (Begon *et al.*, 1996; Jeffries, 1997; Cook and Macdonald, 2001; Cook *et al.*, 2001). This is because they are vulnerable to natural calamities such as volcanic eruptions, rising sea levels, coastal erosion, deposition, floods, hurricanes, wildfires, pests and diseases, and climatic changes, and a variety of anthropogenic disturbances like habitat destruction and fragmentation, overexploitation of resources (excessive logging, overhunting, overfishing) and species introductions. Deliberate or unintentional introductions of species can be disastrous to an island's flora and fauna. For

instance, the islands of Hawaii have lost more than half of their original endemic species due to incautious introductions of other plants and animals (IUCN/UNEP, 1986). Islands of Africa like Mauritius, Reunion and Rodriguez have suffered from a devastating wave of extinctions in historic times, much of which can be attributed to introduced-species (IUCN, 1990). Today, there is increasing impoverishment of island biota mainly due to escalating human impacts. Thus, islands need urgent conservation actions.

Islands have played a historic role in the understanding of biodiversity. The Galapagos Islands are prime examples for understanding and explaining evolutionary processes. The theory of island biogeography has many implications for the conservation and management of ecosystems. Island biogeography has particular relevance in the design, selection and management of protected areas (IUCN/UNEP, 1986). Size, shape and ecosystem coverage of protected areas are important parameters since the number of species that a protected area can hold at equilibrium will depend on its size, habitat diversity, distance from other similar habitats and the dispersal power of the species concerned. Protecting islands as nature reserves has several advantages because islands have clear boundaries, have already developed a balance between their size and species number, cannot be easily encroached upon, and are relatively independent ecological units (IUCN/UNEP, 1986).

Many islands of Africa possess unique biodiversity. Madagascar, Mauritius, Comoros, Seychelles, and São Tomé and Príncipe are important centers of endemism. Madagascar has the highest level of endemism of any country in Africa (IUCN, 1990). Africa's biodiversity, however, is seriously threatened not only on the mainland but also on its islands (IUCN, 1990). This is mainly due to increasing pressure from the rapidly growing human population. The situation is more serious on the islands. This is because islands have their own

natural limitations in addition to anthropogenic influences. Therefore, island ecosystems need special attention since they are extremely fragile.

Many ecosystems of islands are quite insufficiently studied, mainly because of their inaccessibility. As a result, information on island biota is very limited and so is the case of many islands in Africa. The great evolutionary, ecological, social, economic and cultural significance of islands on the one hand and the increasing human pressure on the other necessitate greater biodiversity conservation and research.

Ethiopia has a number of lakes with islands. Islands with sizeable surface areas are found in Lakes Tana, Zwai, Langano, Shalla, Chamo, Abaya and others. These islands of inland lakes are rich in biodiversity and culture, and thus have environmental, social, economic and cultural significance. Today, the biodiversity of the islands is under threat due to natural calamities and ever increasing human impacts. However, information on the biota and socio-economic settings of the islands in Ethiopia is very limited. Therefore, the present study on the flora of the islands of Lake Zwai was undertaken with the objectives of assessing the species diversity (richness and evenness) and plant communities of the vegetation on the islands of Lake Zwai; determining the population structure and regeneration status of woody species; understanding of the socio-economic values of the vegetation resources for the island communities; assessing the indigenous resource management systems and practices used by the local people and the role of some institutions, if any, such as churches, mosques, schools, etc, in conserving the vegetation; and identifying the factors that cause degradation of the vegetation.

### **Materials and methods**

**The study area:** The study was conducted on the islands of Lake Zwai, south-central Ethiopia (Fig. 61). The Lake Zwai area lies in the Lakes Region or Main Ethiopian Rift (MER) of the Ethiopian Rift Valley (ERV), specifically

at the junction of the East Shewa Zone and Arsi Zone, within the Oromia National Regional State (ONRS). Lake Zwai is located close to Zwai (Batu) town at  $7^{\circ}52' - 8^{\circ}8' \text{ N}$  and  $38^{\circ}40' - 38^{\circ}56' \text{ E}$ , about 163 km south of the capital, Addis Ababa. It lies east of Zwai town, west of Assela town, south of Mount Bora and north of Mount Aluto. There are five main volcanic islands in Lake Zwai, namely Galilla, Debre Sina, Tullu Guddo (the largest), Funduro and Tsedacha. The former two are administered by the East Shewa Zone while the latter three are administered by the Arsi Zone. The five islands are similar in their geological formations. The altitude of the islands ranges from 1549 m asl at the lakebanks to 2033 m asl at the Tullu Guddo summit, where this peak is locally known as Woizero.

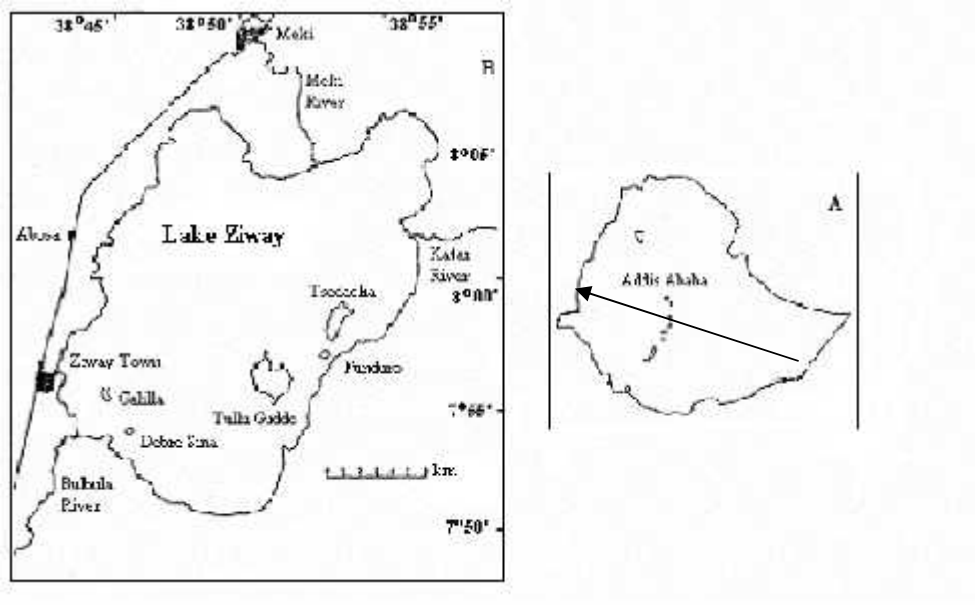


**Figure 58:** Map showing: (a) location of the study area, and (b) Lake Zwai and its islands

The islands and immediate areas to the eastern and northeastern sides of Lake Zwai are similar in geological structure. They consist of basaltic lavas and cinder cones as borehole as silicic flows and domes formed during the Quaternary age as a result of fissure eruptions (Street, 1979). The rocks of the areas to the west of Lake Zwai are composed of alluvial material and lacustrine sediments. The waterbed of Lake Zwai and the swampy areas around the lake are mainly composed of coarse pumice material (Makin *et al.*, 1976). Most parts of the islands of Lake Zwai are covered by volcanic rocks, mainly basalt and pumice. Soils of volcanic origin, particularly ash, are common on the slopes while soils of colluvial and lacustrine origin are common along lake-banks of the islands. Generally, the soils are shallow and sandy, and are characterized by low organic matter. The color of the soils is mostly grey, whitish or brown depending on location.

Lake Zwai watershed is characterized by arid climate. It has bimodal rainfall distribution with short-term, highly variable “small” rains from February to June and “big” rains from July to September (Daniel Gamachu, 1977). The dry season extends from October to January. Strong and persistent winds are characteristic feature of the Lake Zwai area. Data obtained from the National Meteorological Services Agency (NMSA) for the study area showed that the mean annual temperature is 20.5°C and the mean annual rainfall is 702 mm.

Open *Acacia* woodland vegetation is characteristic of the Rift Valley area (Zerihun Woldu and Mesfin Tadesse, 1990). The vegetation of the Lakes Region of the ERV varies with the climate from open *Acacia* woodland in the plains of the rift floor to forest areas on the escarpments. Predominant vegetation types are *Acacia* woodland, bushland, shrubland and wooded grassland (Zerihun Woldu and Mesfin Tadesse, 1990; Friis, 1992). Most of the shorelines of Lake Zwai are covered with a belt of lush marshy vegetation. The vegetation on the islands of Lake Zwai is a mosaic of woodlands, bushlands, shrublands, forests and swamp vegetation. It consists of various

trees and shrubs interspersed with climbers and herbs. Lake Zwai harbours fishes, hippopotamus and Nile monitor, and is a habitat for a variety of birds. The islands are habitats for monkeys, warthog, porcupine and various kinds of birds.

The inhabitants of the islands of Lake Zwai are the Zayee people. They inhabited the islands sometime between the early 14th and the middle of the 17th centuries for different reasons (Tuma Nadamo, 1982). They speak Zayigna, which belongs to one of the main language groups called Semitic. The Zayee people are Orthodox Christians strongly dedicated to their religion. There is a church in each island. The land use systems on the islands are: cultivated land, forest land (which is also grazing land), settlement area, religious site, and fishing area or the lake. The Zayee people used to inhabit all the five islands until very recently. However, at present, they live on three of the islands – Tullu Guddo, Funduro and Tsedacha. The other two islands – Galilla and Debre Sina – were abandoned for various reasons. The economy of the Zayee people is mainly based on traditional fishing and subsistence agriculture. Fishing has played a vital role not only in the subsistence economy but also in the development of the unique culture which has flourished on the islands (Tesfaye Edetto, 1988). The Zayee people have very limited access to modern health services, and thus, they partly depend on traditional medicine to fulfill their healthcare needs. They use medicinal plants, most of which are harvested from the wild, to treat various human and livestock diseases. Medicinal plants used by the Zayee people have been studied by Mirutse Giday (1999).

**Vegetation sampling:** Systematic sampling, in which plots are laid at regular intervals along line transects, was used to collect vegetation and environmental data following Sutherland (1996). In each island, line transects were laid from the central part of the island to the lake edge in eight aspects (N, S, E, W, NE, NW, SE, SW) determined using a Suunto compass. Plots,



measuring 20 m x 20 m (400 m<sup>2</sup>), were established along the line transects approximately at 100 m intervals. A total of 73 plots were sampled from the islands. Herbaceous species were sampled using a 2 m x 2 m (4 m<sup>2</sup>) subplot laid inside each plot where the vegetation was assumed to be representative. Floristic data were collected following Braun-Blanquet (1965) and Mueller-Dombois and Ellenberg (1974).

In each plot, all plant species were listed by their local and/or scientific names and the cover-abundance of each species was visually estimated using the 1-9 modified Braun-Blanquet scale (van der Maarel, 1979). Trees, shrubs and woody climbers were counted. Diameter at Breast Height (DBH)  $\geq 2.5$  cm and height  $\geq 2$  m of trees and shrubs were measured using a diameter tape and a Suunto hypsometer, respectively, following the methods described by Martin (1995) and Cunningham (2001). Individuals of trees and shrubs with DBH  $< 2.5$  cm and height  $< 2$  m were counted by species as seedlings. Plant species that occur outside the sample plots were also recorded to produce a more complete list of the plant species on the islands. The environmental variables altitude, position, slope and aspect of each plot were recorded. Altitude and position were measured with a Magellan Global Positioning System (GPS), slope with a Suunto clinometer and aspect with a Suunto compass.

Plant specimens were collected, pressed and dried, and then taken to the National Herbarium (ETH), Addis Ababa University. Identification of plant specimens was made following standard identification methods. Voucher specimens were deposited at the National Herbarium (ETH).

Plant nomenclature in this paper follows the Flora of Ethiopia and Eritrea (Edwards *et al.*, 1995, 2000, 2006; Hedberg and Edwards, 1989, 1995; Hedberg *et al.*, 1997, 2003, 2004, 2009a, 2009b).

**Socio-economic survey:** Participatory Rural Appraisal method (PRA) was employed to generate the socio-economic data following Martin (1995) and

Cunningham (2001). Data were collected using field observations; semi-structured interviews with households, key informants, clergymen and stakeholders; and group discussion. Field observations were made on land use types, extent of soil erosion and vegetation/ecosystem degradation, human impacts on the vegetation resources, and indigenous resource management systems and practices.

Interviews were undertaken using semi-structured / open-ended questionnaires prepared in advance. From a total of 294 households (130 in Tullu Guddo, 20 in Funduro, 144 in Tsedacha), 60 households (20%) were randomly selected and the household heads were interviewed. Six key informants, suggested by the local people and representatives, were selected and interviewed informally so as to enrich the data. During the interviews with key informants, emphasis was given to issues related to the vegetation resources in order to get in-depth information about the past and present status, indigenous resource management systems and practices, utilization, and major threats. Three clergymen, suggested by the local people and representatives, were selected and interviewed. Six relevant stakeholders, namely Woreda Rural Land and Natural Resources Administration Office, Woreda Agriculture Office, Woreda Administrative Office, Woreda Church Office, Zwai Fish Production and Marketing Enterprise and Zwai Fisheries Resources Research Center, were selected from the East Shewa Zone in Zwai town and interviewed.

A group consisting of elderly people, youth, women, clergymen and representatives of the local communities was formed. At the beginning of the discussion, the aim of the study was explained briefly to the participants so as to ensure openness in the discussion. During the discussion, emphasis was given to the strategies needed to conserve the vegetation resources and solve the existing socio-economic problems on the islands. The ideas and suggestions forwarded by the group participants were recorded.

**Analysis of vegetation data:** The diversity and evenness of woody species were determined using the Shannon-Wiener diversity index (H) and evenness or equitability index (E) (Krebs, 1989; Barnes *et al.*, 1998). The similarity in species composition between the islands was computed using Jaccard's Similarity Coefficient (Sj) (Krebs, 1989). Analysis of vegetation classification was made using PC-ORD software (McCune and Mefford, 1999). The density and percentage frequency of woody species were calculated. The DBH and height of trees and shrubs were categorized into nine and six classes, respectively, and presented using histograms. Basal area of trees and shrubs with DBH  $\geq 2.5$  cm was calculated. The Importance Value Index (IVI) (Lamprecht, 1989; Kent and Coker, 1994) for each species was computed.

**Analysis of socio-economic data:** Microsoft Excel Software was used for the analysis of the socio-economic data, and descriptive statistics like frequencies, percentages and averages were computed.

## Results and discussions

**Floristic composition:** A total of 141 plant species belonging to 113 genera and 55 families were identified from the islands of Lake Zwai (the list of the species can be obtained from the authors upon request). About 86% of the families were dicots, 12% monocots and 2% gymnosperms. The families with the highest number of species were Asteraceae and Fabaceae (11 species each), followed by Euphorbiaceae (10 species), Poaceae (9 species) and Acanthaceae, Boraginaceae, Capparidaceae, Lamiaceae and Solanaceae (5 species each). From the total species, 18.4% were trees, 21.3% trees/shrubs, 12.1% shrubs, 3.5% woody climbers, 4.3% herbaceous climbers and 40.4% herbs. The herbs had the largest proportion of the lifeforms. Five species were endemic to Ethiopia, namely *Aloe pubescens*, *Laggera tomentosa*, *Leucas abyssinica*, *Urtica simensis* and *Eragrostis tef* (cultivated). *Leucas abyssinica* is in the IUCN Red List category of Least Concern (LC) (Vivero *et al.*, 2005).

The flora of the islands comprises both lowland and highland species. The unique floristic composition of the islands is attributed to habitat diversity and the diverse forms of dispersal agents, which include wind, water and animals, especially birds. Jeffries (1997) pointed out that islands shelter unusual relicts and combinations of species.

**Species diversity:** The richness of families and species of the islands ranged from 24 and 43 at Funduro to 43 and 87 at Tullu Guddo, respectively (Table 1). Tullu Guddo had the highest species richness of all the islands due to its large size, altitudinal variation and ecosystem diversity. It has been reported that the number of species on an island depends on the island's area (Rosenzweig, 1995; Jeffries, 1997; Ricklefs and Miller, 2000). The larger the area is the greater the habitat diversity and, thus, the greater the species diversity. But this is not always true (Rosenzweig, 1995; Jeffries, 1997) as our results also indicated that species richness depends on human disturbance regimes.

The overall Shannon-Wiener diversity and evenness indices of woody species on the islands were 2.60 and 0.62, respectively, indicating that the diversity of woody species on the islands is relatively high whereas the evenness is low. Debre Sina had the highest diversity and evenness (Table 57), which is attributed to low human disturbance and also its flatness and relatively boreholedeveloped soil that are suitable for growth of immigrant propagules. The equitability for Tsedacha and Funduro were lower than the other islands because of human disturbance as boreholeas site and species characteristics. The low evenness can be attributed to excessive disturbance, variable conditions for regeneration and exploitation of some species (Alemayehu Wassie, 2002). The Shannon-Wiener diversity and evenness indices imply the significance of conserving the vegetation on the islands from both diversity and human disturbance perspectives.

**Table 49:** Comparison of area, richness, diversity and evenness among the islands of Lake Zwai

| Islands            | Area<br>(ha) | Richness |         | H    | E    |
|--------------------|--------------|----------|---------|------|------|
|                    |              | Families | Species |      |      |
| <b>Galilla</b>     | 20           | 35       | 57      | 2.18 | 0.62 |
| <b>Debre Sina</b>  | 30           | 37       | 78      | 2.90 | 0.78 |
| <b>Funduro</b>     | 30           | 24       | 43      | 1.79 | 0.57 |
| <b>Tsedacha</b>    | 210          | 35       | 68      | 1.78 | 0.58 |
| <b>Tullu Guddo</b> | 480          | 43       | 87      | 2.38 | 0.64 |

**Similarity between the islands in species composition:** The similarity values in species composition between the islands ranged from 0.30 to 0.51 (Table 58). The highest similarity ( $S_j = 0.51$ ) was found between Galilla and Debre Sina and the lowest similarity ( $S_j = 0.30$ ) was between Debre Sina and Tsedacha. One of the reasons for this is that Galilla and Debre Sina are close to each other, possibly having similar environmental conditions and exposure to dispersal agents while Galilla and Tsedacha are far apart. Except for one pair, the remaining similarity coefficients were below 0.5, indicating that there are low similarities among the islands and each island has its own unique flora. Thus, all of the islands are important in terms of floristic diversity and sensitive from a conservation point of view.

**Table 50:** Similarities in species composition among the five islands determined by Jaccard's Similarity Coefficient

| Islands        | Galilla | Debre Sina | Tullu Guddo | Funduro | Tsedacha |
|----------------|---------|------------|-------------|---------|----------|
| <b>Galilla</b> | 1       | 0.51       | 0.41        | 0.41    | 0.34     |

| Islands     | Galilla | Debre Sina | Tullu Guddo | Funduro | Tsedacha |
|-------------|---------|------------|-------------|---------|----------|
| Debre Sina  |         | 1          | 0.40        | 0.33    | 0.30     |
| Tullu Guddo |         |            | 1           | 0.34    | 0.36     |
| Funduro     |         |            |             | 1       | 0.41     |
| Tsedacha    |         |            |             |         | 1        |

**Species-area curves:** The number of species for each island showed a relatively sharp increase initially with increasing area except for Tullu Guddo (Fig. 62). The highest increase in the number of species with increasing area was observed for Debre Sina. The curves for Galilla and Debre Sina tended to flatten toward the end while those for Tullu Guddo, Funduro and Tsedacha showed increasing trend toward the end. The species-area curves for the latter three islands showed that species diversity increases as area increases. It has already been pointed out that species-area curves reveal the pattern of diversity with increasing area (Rosenzweig, 1995).

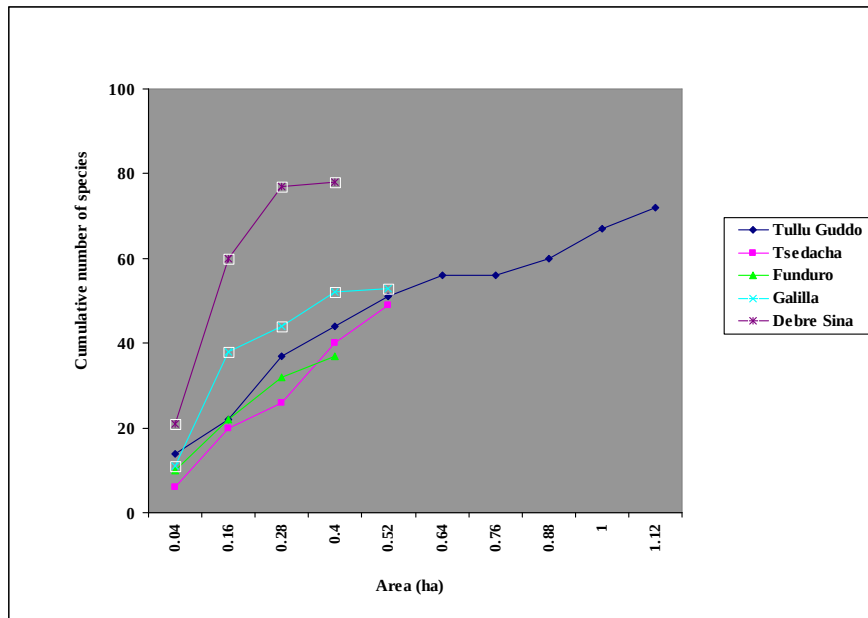


**Figure 59:** Species-area curves for the islands of Lake Zwai

**Vegetation classification:** From the analysis of classification, nine clusters were recognized at 50% similarity level (Fig. 63). The clusters were recognized as plant communities and named using two or three dominant and/or characteristic species, which occur in each group. These plant community types were:

- 1) *Euphorbia tirucalli* – *Acacia tortilis* – *Euphorbia abyssinica* type;
- 2) *Ficus vasta* – *Ficus ingens* – *Ficus sycomorus* type;
- 3) *Steganotaenia araliacea* – *Maerua triphylla* – *Cussonia holstii* type;
- 4) *Euphorbia tirucalli* – *Solanum schimperianum* – *Acacia tortilis* type;
- 5) *Justicia schimperiana* – *Pavetta gardeniifolia* – *Cordia monoica* type;

- 6) *Olea europaea* subsp. *cuspidata* – *Juniperus procera* – *Dodonaea angustifolia* type;
- 7) *Senna singueana* – *Pavetta gardeniifolia* – *Grewia velutina* type;
- 8) *Aeschynomene elaphroxylon* – *Sesbania sesban* type;
- 9) *Pappea capensis* – *Rhus natalensis* – *Maytenus senegalensis* type.



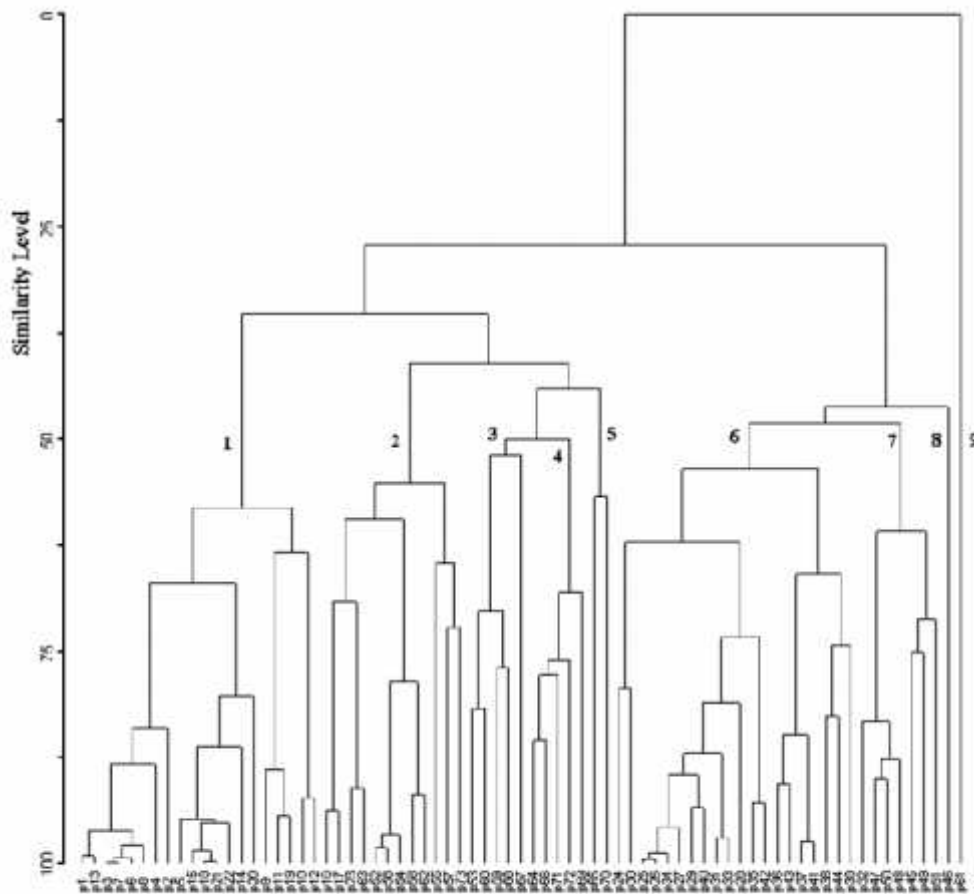


**Figure 60:** Dendrogram showing clusters of plots sampled from the islands of Lake Zwai

**Density and frequency of woody species:** The total density of the woody species on the islands was 2,979 individuals  $\text{ha}^{-1}$ . The species with the highest density was *Euphorbia tirucalli* (1,026.90 individuals  $\text{ha}^{-1}$ ), followed by

*Euphorbia abyssinica* (369.31), *Acacia tortilis* (321.72), *Opuntia ficus-indica* (157.59), *Capparis fascicularis* (127.57), *Pavetta gardeniifolia* (125.17) and *Solanum schimperianum* (111.72). The species with the highest frequency was *Acacia tortilis* (90.41%), followed by *Euphorbia tirucalli* (89.04%), *Capparis fascicularis* (75.34%) and *Euphorbia abyssinica* (57.53%). The variation in density and frequency between species may be attributed to habitat differences, habitat preferences among the species, species characteristics for adaptation, degree of exploitation, and conditions for regeneration.

**Basal area and IVI:** The total basal area of the woody species on the islands was 191 m<sup>2</sup>ha<sup>-1</sup>. The species with the highest basal area was *Ficus vasta* (54.09), followed by *F. ingens* (38.67), *F. sycomorus* (30.04), *Acacia tortilis* (27.42), *Euphorbia abyssinica* (20.39) and *E. tirucalli* (8.17). The leading species in terms of IVI value was *Euphorbia tirucalli* (48.30), followed by *Acacia tortilis* (34.87), *F. vasta* (33.16), *Euphorbia abyssinica* (29.26), *Ficus ingens* (23.78) and *F. sycomorus* (18.31). The high IVI value of *Euphorbia tirucalli* was because of its high relative density and relative frequency though it had low relative dominance/basal area. On the other hand, *Ficus* species had low relative density and relative frequency but high IVI value owing to the contribution of their high relative basal area. The species with low IVI value were *Olea europaea* subsp. *cuspidata*, *Juniperus procera*, *Steganotaenia araliacea*, *Maerua triphylla*, *Senna didymobotrya*, *Rhus retinorrhoea*, *Rumex nervosus*, *Balanites aegyptiaca*, *Ziziphus mucronata*, *Grewia bicolor*, *Acacia etbaica* and *Dodonaea angustifolia*. In other words, these species were not abundant, frequent and dominant.

IVI is an important parameter that reveals the ecological significance of species in a given ecosystem (Lamprecht, 1989). Species with high IVI value are considered more important than those with low IVI. On the other hand, values of IVI can be used for prioritizing species for conservation (Simon Shibru, 2002). Species with high IVI value need less priority for conservation

effort while those with low IVI value need high conservation effort. Our results suggest that the species having low IVI value should be prioritized for conservation.

**Regeneration status of woody species:** The DBH and height class distributions of the species exhibited different patterns (Fig. 64), and showed that there are species with high number of individuals in the lower classes, some species at the middle and others at higher classes.

From the DBH and height class distributions of the species, two types of regeneration status were recognized – good and poor regeneration. Some species possessed high number of individuals in the lower DBH classes, particularly in the first class, which suggests that they have good regeneration potential. Other species possessed either no or few number of individuals in the lower DBH or height classes, particularly in the first class, which indicates that the species are in poor regeneration status.

The DBH and height class distribution of all woody species on all the islands exhibited a more or less reverse “J” type of distribution, which is considered as an indication of stable population structure or good regeneration status (Silvertown, 1982; Silvertown and Doust, 1993; Tamrat Bekele, 1994; Demel Teketay, 1997; Alemnew Alelign, 2001; Alemayehu Wassie, 2002; Getachew Tesfaye *et al.*, 2002; Simon Shibru, 2002). However, it is important to note that some of the species are in poor regeneration status and, thus, require due attention.

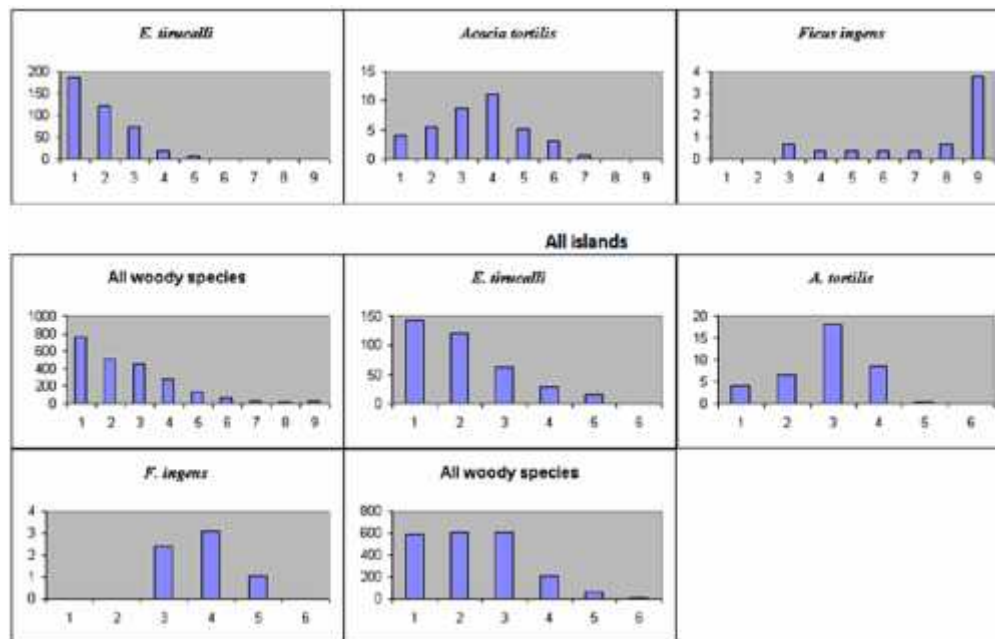


**Figure 61:** DBH and height class distribution of some selected trees and shrubs and all woody species on all islands (DBH classes: 1 = <2.5 cm; 2 = 2.5-10 cm; 3 = 10-20 cm; 4 = 20-30 cm; 5 = 30-40 cm; 6 = 40-50 cm; 7 = 50-60 cm; 8 = 60-70 cm; 9 = >70 cm; height classes: 1 = <2 m; 2 = 2-5 m; 3 = 5-10 m; 4 = 10-15 m; 5 = 15-20 m; 6 = >20 m).

### Socio-economic survey

**Household characteristics:** The 60 households had a total of 418 members, of which 49.3% were males and 50.7% females (Table 59). The mean family size per household was 7. About 75% of the households were male-headed while 25% female-headed. About 67% of the household members were in the age of  $\leq 20$  years, 31.1% from 21-60 years and 1.9% >60 years (Table 59). There was high young generation, indicating that the population is growing. The human population growth has resulted in increased pressure on the natural resources in general and the vegetation resources in particular. About

37.3% of the household members were illiterate, and 62.7% literate varying from primary to higher education (Table 60).

The mean land holding size per household was 0.79 ha. Out of the total households, 33.3% had access to  $\leq 0.5$  ha, 53.3% from 0.5-1.0 ha, 11.7% from 1.0-1.5 ha and 1.7%  $> 1.5$  ha. About 88.3% of the households had their own land, 23.3% rented land, 6.7% shared cropland, and 3.3% were landless (Table 60). Most of the land was used for crop cultivation, only a very small portion was used for fruit and vegetable production, and no land was allocated for woodlot. The shortage of land was a major problem, and led to infringing of farmlands into the natural vegetation.

The occupations of the households were diverse. The major activity was fishing (85%), followed by crop production (80%) and livestock production (75%) (Table 60). The households cultivated mainly cereal crops such as *Eragrostis tef*, *Eleusine coracana* and *Zea mays*, as boreholeas *Sorghum bicolor*, *Hordeum vulgare* and *Triticum* spp. They also cultivated leguminous crops such as *Phaseolus vulgaris*; oil crops such as *Linum usitatissimum*; cash crops such as *Gossypium* spp., *Catha edulis* and *Rhamnus prinoides*; and fruit crops such as *Citrus aurantifolia*, *Carica papaya* and *Psidium guajava*. Crops were largely produced for consumption. Generally, homegardening was very limited. The households reared cattle (81.7%), goats (80.0%), sheep (33.3%), donkeys (16.7%) and poultry (86.7%). The mean number of livestock per household was 13, and for cattle, goats, sheep, donkeys and poultry were 3, 5, 2, 1 and 5, respectively. The households reared both indigenous and improved varieties of poultry (18.3% had improved varieties). The main reasons for rearing animals were for draught power, transport, production of meat and milk for consumption, income from sale of animals and their products, as boreholeas hide and skin for bedding and mattress. The existence of diverse economic activities had relieved the pressure on the vegetation resources.

**Table 51:** Age and sex structure of households

| Age category (n = 418) | Frequency (%) |             |              |
|------------------------|---------------|-------------|--------------|
|                        | Male          | Female      | Total        |
| ≤5                     | 10.3          | 10.8        | 21.1         |
| 6-10                   | 11.0          | 9.8         | 20.8         |
| 11-15                  | 7.2           | 7.7         | 14.8         |
| 16-20                  | 3.8           | 6.5         | 10.3         |
| 21-60                  | 15.8          | 15.3        | 31.1         |
| >60                    | 1.2           | 0.7         | 1.9          |
| <b>Total</b>           | <b>49.3</b>   | <b>50.7</b> | <b>100.0</b> |

**Table 52:** Education, land holdings and occupations of the households

| Characteristics | Parameter                            | Frequency (%) |
|-----------------|--------------------------------------|---------------|
| Education       | Literacy level (n = 418)             |               |
|                 | Cannot read and write                | 34.0          |
|                 | Can read and write                   | 3.3           |
|                 | Primary school (Grades 1-6)          | 36.6          |
|                 | Junior secondary school (Grades 7-8) | 14.6          |
|                 | High school (Grades 9-12)            | 8.4           |
|                 | Grade 12 complete                    | 2.6           |
|                 | Higher education                     | 0.5           |
| Land holding    | Land holding type (n = 60)           |               |
|                 | Own land                             | 88.3          |
|                 | Rented land                          | 23.3          |
|                 | Shared cropland                      | 6.7           |
|                 | Landless                             | 3.3           |
| Occupations     | Occupation type (n = 60)             |               |
|                 | Fishing                              | 85.0          |
|                 | Crop production                      | 80.0          |
|                 | Livestock production                 | 75.0          |
|                 | Traditional brewery                  | 41.7          |
|                 | Fruit production                     | 31.7          |
|                 | Weaving traditional clothes          | 30.0          |
|                 | Casual work                          | 30.0          |
|                 | Handcraft                            | 26.7          |

| Characteristics | Parameter            | Frequency (%) |
|-----------------|----------------------|---------------|
|                 | Apiculture           | 21.7          |
|                 | Vegetable production | 20.0          |
|                 | Chat production      | 11.7          |
|                 | Trading              | 5.0           |

The mean annual income and expenditure per household were ETB 1,804.27 and 1,742.02, respectively. The contribution to the annual income from fish sale alone was ETB 1,365.60. Thus, the fishing industry was the main pillar of the economy as most of the income (75.7%) was derived from this sector. The other sources of income included sale of animals and their products, fruits, honey, handcrafts and local drinks, and casual work.

#### Values of the vegetation resources for the island communities

**Wood products:** There were no plantations on the islands of Lake Zwai. Thus, the natural vegetation was the only source of wood for various purposes: fuelwood (93.3%), construction material (81.7%) and farm implements (63.3%). The major woody species that provide fuelwood, construction material and farm implements were *Cordia africana*, *Ehretia cymosa*, *Celtis africana*, *Acacia tortilis*, *A. etbaica*, *Euphorbia abyssinica*, *E. tirucalli*, *Aeschynomene elaphroxylon*, *Maytenus senegalensis*, *Ziziphus mucronata* and *Calpurnia aurea*. *Aeschynomene elaphroxylon* and *Cyperus papyrus* (herbaceous) were economically important in making local boats, which are used as the main means of water transport.

**Food (wild edible fruits):** The local people were found to be familiar with different wild edible plants. The woody species that provide edible fruits were *Cordia africana*, *C. monoica*, *Balanites aegyptiaca*, *Ehretia cymosa*, *Pappea capensis*, *Lannea schimperi*, *Grewia bicolor*, *G. velutina*, *Rhus natalensis*, *Ximenia americana*, *Ziziphus mucronata*, *Opuntia ficus-indica*, *Ficus sycomorus*, *F. ingens* and *F. vasta*.

**Medicines:** The local people used wild medicinal plants to treat various human and livestock ailments. They use *Cordia monoica* and *Heliotropium steudneri* against human “Mich” (a febrile disease in which the main symptoms are fever, headache and sweating), *Solanum incanum* against snakebite, *Withania somnifera* against human and livestock ailments, *Asparagus africanus* against anthrax, and *Heliotropium aegyptiacum* against goat infections. Out of the plant species identified from the islands, *Acokanthera schimperi*, *Asparagus africanus*, *Capparis tomentosa*, *Commicarpus plumbagineus*, *Cordia monoica*, *Croton macrostachyus*, *Heliotropium aegyptiacum*, *Achyranthes aspera*, *Pavetta gardeniifolia*, *Senna occidentalis*, *Solanum incanum* and *Withania somnifera* have already been reported as medicinal plants used by the Zayee people (Miruste Giday, 1999).

**Animal fodder:** The island communities were highly dependent on the natural vegetation for livestock grazing/browsing, both in the dry and wet seasons.

**Bee forage:** The natural vegetation had a high potential for beekeeping as it possessed plants that provide bee feed. The woody species that are of great importance in providing bee feed were *Acacia tortilis*, *Euphorbia abyssinica*, *E. tirucalli*, *Grewia velutina*, *Capparis fascicularis* and *Aeschynomene elaphroxylon*. Among the herbs, *Hypoestes forskalii* was an important source of bee feed. Out of the plant species identified from the islands, 59 species (41.8%) have already been reported for their great values as bee forage (Fichtl and Admasu Adi, 1994).

**Indigenous resource management systems and practices:** The Zayee people have peculiar resource management systems and practices, especially in soil conservation (terracing), traditional agroforestry and vegetation management. Environmentally friendly resource management systems and practices used by the Zayee people have played a great role in the maintenance of the soil and vegetation resources on the islands for centuries.



**Terracing (soil conservation):** Terracing is widely practiced on the islands (Fig. 62). The Zayee people construct the terraces from stone and they plant trees, particularly *Euphorbia tirucalli*, to give strength to the terraces. Most edges of the lake were also terraced with stone primarily to promote the growth of pasture for livestock as boreholeas to prevent erosion by the strong waves of the lake, particularly in the afternoons, and crop damage by hippopotamus.



**Figure 54:** Terrecing on the Tulu Gudo island of Lake Zwai

**Traditional agroforestry systems:** The Zayee people have a very advanced practice of traditional agroforestry system (Fig. 63). They retain indigenous trees like *Acacia tortilis* and *A. albida* in the farmlands and on farm boundaries. *Acacia tortilis* and *A. albida* are retained in and around the

farmlands because of their desirable characteristics such as fast growth, less competition with crops and improving soil fertility. They also retain and/or plant *Euphorbia tirucalli* on farm boundaries as a live fence and because of its importance in prevention of soil erosion. Resistance to livestock, rapid growth and the ease to propagate it from branch cuttings are important characteristics of the tree for planting around the farmlands. Besides prevention of soil erosion and improvement of soil fertility, trees retained in and around the farmlands provide various products (fuelwood, construction material, animal fodder, etc.) and also serve for shade and live fence. Thus, the traditional agroforestry system provides wood and non-wood products and improves agricultural production and productivity, thereby reducing the pressure on the natural vegetation.



**Figure 55:** Traditional agroforestry on the islands of Lake Zwai

**Traditional vegetation management systems and practices:** The Zayee people have important traditional vegetation management systems and practices, which have contributed a lot for the maintenance of the vegetation resources in the absence or very little involvement of government bodies. There are important indigenous knowledge systems and practices that helped for the maintenance of the vegetation on the islands. The Zayee people construct their housewall with stone and earth. This makes the house durable and reduces the turnover of cutting trees for house construction. They use dried and fallen logs for fuel-wood. They do not cut trees for fuelwood but for construction material, farm implements and other purposes. They use fuelwood mostly for cooking and only rarely for lighting. They do not sell wood products but use them only for consumption. Charcoal production was

insignificant on the islands. Absence of cutting and use of trees for sale is partly a reflection of low pressure on the natural vegetation. The people have positive attitude towards the vegetation.

The indigenous soil and vegetation management systems and practices of the Zayee people are unique and environmentally friendly. These indigenous resource management systems are of great importance and deserve special attention for scaling up to other rural areas in the country since they have the potential to promote the conservation of biodiversity. The indigenous/traditional resource conservation and management practices of rural communities in Ethiopia have promoted the conservation of genetic resources for centuries (Demel Teketay, 1999).

**Threats to the vegetation resources:** The vegetation on the islands was intact until very recently (key informants, personal communication). However, at present, the need for more farmland and wood products, spurred by human population growth, have led to the destruction of the vegetation. According to the respondents, the major factors for degradation of the vegetation resources on the islands were free livestock grazing/browsing (93.3%), farmland expansion (80.0%), soil erosion (66.7%) and tree cutting for various purposes (58.3%). Goats damaged seedlings of trees through herbivory (defoliation, removal of meristematic tips) and trampling, and consequently, affected regeneration. They have also damaged the terraces thereby aggravating soil erosion and uprooting of trees. The damage caused by goats on the terraces and natural regeneration of trees needs special attention. As mentioned previously, the number of goats per household was high, indicating that it is a major threat to the vegetation resources. Soil erosion affects vegetation development. It also contributes to siltation of Lake Zwai.

Natural and anthropogenic disturbances have led to degradation of the vegetation resources on the islands. Rare and environmentally and economically important plant species can be lost by human activities. This

will lead to serious environmental, social and economic problems on the islands unless appropriate and immediate measures are taken.

**Role of churches in conserving the vegetation:** Christianity is deep rooted in the islanders. Theft is a taboo. Cutting trees from the sacred groves is also a taboo. This tradition has contributed to the maintenance of the sacred groves in particular and the vegetation resources on the islands in general.

The churches have played a major role in the conservation of the vegetation. They are involved in protecting the sacred groves, planting trees in churchyards and giving advice to the local communities on the importance of conserving the vegetation resources on the islands. Pressure of the local people on the sacred groves was very low because of their strong religious belief. Similarly, Alemayehu Wassie (2002) and Alemayehu Wassie and Demel Teketay (2006) noted that protection of sacred forests in South Gondar is achieved through creating religious commitment and respect among the followers and legal protection due to increased human pressure. On the other hand, the maintenance of sacred groves on the islands is attributed to the strong religious belief and respect of the communities to the church, which is considered the house of God. The survey showed that the church is the most important institution on the islands in social, economic and conservation issues besides its religious service.

### **Conclusions and recommendations**

The islands of Lake Zwai possess unique floristic composition, high species diversity and distinctive plant communities, which are attributed to habitat diversity and various modes of dispersal. The flora of the islands comprises both lowland and highland species. The floristic composition implies that the islands can serve as conservation sites for both lowland and highland species if appropriate conservation measures are applied. The species richness on the islands correlated with the island's size, habitat diversity and degree of human disturbance. The Shannon-Wiener diversity and evenness indices of woody

species indicated the need to conserve the vegetation on the islands from both diversity and human disturbance point of view. The similarity in species composition between the islands was largely dependent on their geographical proximity and similarity in environmental conditions and exposure to dispersal agents. However, the similarity in species composition among the islands was low, indicating that each island has its own unique flora. The IVI values revealed the most ecologically important woody species on the islands and those to be prioritized for conservation. The DBH and height class distributions showed that some species are in good regeneration potential while others are in poor regeneration status. Species having low IVI value and poor regeneration status need the highest priority for conservation. *In situ* and *ex situ* conservation methods have to be implemented for the conservation of the priority species. The vegetation on the islands represents one of the relicts of the pristine vegetation in the Rift Valley area, if not in the country, and, thus, requires special attention.

The island communities were engaged in diverse economic activities. The major livelihood activities were fishing and crop and livestock production. The fishing industry was the main pillar of the economy as most of the income was derived from this sector. The islanders also practiced traditional beekeeping, which was carried out entirely in the natural vegetation. However, beekeeping has a high potential for income generation for the islanders. The availability of water (the lake) and presence of plants that provide bee forage make the islands suitable for apiculture/beekeeping. Thus, there is a need to introduce modern beekeeping through provision of beehives, training and technical assistance so as to enhance the contribution of the sector for income generation and sustainable utilization of the vegetation resources. Moreover, the islands are sites of beautiful environment and cultural heritage, and thus, are ideal places for development of ecotourism. However, this potential economic alternative has not been given due attention.

The island communities were highly dependent on the natural vegetation for fuel-wood, construction material, farm implements, food (edible fruits), medicines, animal fodder and bee forage. On the other hand, the islanders have maintained the soil and vegetation resources for centuries through their indigenous resource management systems and practices. However, at present, the vegetation resources are dwindling due to free livestock grazing/browsing, farmland expansion, soil erosion and tree cutting for various purposes, all of which are driven by human population growth. It is advisable to limit the number of goats per household through provision of viable economic alternatives to the islanders. The terraces require maintenance in order to control soil erosion and thereby enhance vegetation development, and prevent siltation of Lake Zwai. Rare and environmentally and economically important plant species can be lost by human activities. This will lead to environmental, social and economic crises on the islands unless appropriate and immediate measures are taken.

The islanders are confronted with a number of socio-economic problems such as shortage of land; lack of good quality water, modern health service, transport and attractive market system; administrative problems; and lack of concern from the government. Efforts that can be made to mitigate these challenges/problems would help to ensure the existence of the island communities with their unique culture and rich indigenous knowledge and this, in turn, contributes, in one way or another, to the maintenance of the vegetation resources in particular and the biodiversity in general.

Diverse livelihood strategies, basic education, awareness and positive attitude of the island communities towards family planning, existence of environmentally friendly resource management systems and practices, absence of wood selling and efforts in tree planting are promising options for the conservation and sustainable use of the vegetation resources on the islands. The church is the central institution on the islands, playing a vital role in social, economic and conservation issues besides its religious service. Since

the islanders have high respect and trust for the church, integrating conservation and development issues with this institution would be more effective.

The islands are of great environmental, social, economic and cultural significance. On the other hand, the prevailing natural and anthropogenic factors affecting the vegetation resources on the islands necessitate effective conservation and management interventions.

Therefore, in order to ensure the conservation, management and sustainable utilization of the vegetation resources on the islands and improve the livelihoods of the island communities, the following recommendations are suggested:

- Employ complementary *in situ* and *ex situ* conservation methods for the conservation of species having low IVI value and poor regeneration status;
- Designate the islands as nature reserves;
- Encourage maintenance of the terraces through mobilization of the local people and provision of appropriate incentives;
- Limit the number of goats per household through provision of viable economic alternatives;
- Promote tree planting (with emphasis on indigenous species);
- Provide energy saving stoves and renewable sources of energy;
- Curb human population growth through provision of family planning services;
- Introduce modern agricultural technologies and extension services;
- Enhance fruit and vegetable production, poultry and apiculture / beekeeping;



- Develop and implement proper fisheries management;
- Develop ecotourism;
- Provide good quality water, modern health service, training and technical assistance, transport and attractive market system;
- Integrate conservation and development issues with the church;
- Allocate human, financial and physical resources;
- Facilitate the involvement of relevant stakeholders with proper integration;
- Ensure strong support from the government;
- Mobilize national and international organizations to mitigate the socio-economic problems the islanders are confronted with and assist their resource conservation and management practices.

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## Chapter 12

### **Ecological study on the dry afromontane vegetation of the escarpment of Central Ethiopian Rift Valley: Western half of Lake Zwai watershed**

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#### **Abstract**

This study investigated the ecology of the dry afromontane vegetation of the Western Escarpment of Central Ethiopian Rift Valley that makes part of the watershed of Lake Zwai. Plot sizes of 40 x 40 m were used for vegetation sampling. The altitude at each of the main plot was recorded using Garmin GPS. Soil samples were collected at corners of the 20 x 20 m subplots and composite samples were made thereof. Intensity of anthropogenic disturbances and grazing impacts in each plot were estimated based at scales: 0 = nil; 1 = slight; 2 = moderate; 3 = heavily and 4 = destructive. Cluster analysis was used to identify plant community types in the study area. Canonical correspondence analysis was used to examine the relationship between the plant communities and environmental variables. A total of 339 plant species belonging to 89 families were encountered in the study area. About 10 % of the plants were endemic to Ethiopia. Canonical correspondence analysis revealed that altitude, slope, disturbance, soil clay, sand and pH had significant relation with the plant communities. Analysis of variance verified that altitude, slope, disturbance, soil pH, clay and sand content of the soil were significantly related to the plant communities.



Overall, the forest patches in the study area are characterized by high floristic diversity and provides the natural environment for a good number of endemic plants.

**Keywords:** Afromontane, canonical correspondence analysis, cluster analysis, Ethiopian rift valley, Lake Zwai watershed

## Introduction

The Eastern Afromontane biodiversity hotspot is one of the 34 biodiversity hotspots, which was first recognized as globally important for species conservation by Mittermeier *et al.* (2004) when the number of global hotspots was increased from 25 to 34. It includes mountain ranges in Eastern Africa and the Arabian Peninsula, which contain about 7,600 plant species, of which more than 2,350 are endemic. More than 1000 plant species in the Eastern Afromontane are highly threatened (BirdLife International, 2012). Ethiopian highlands, which belong to the Eastern Afromontane biodiversity hotspot, harbor an estimated 5,200 plant species, of which at least 200 are endemic. Nearly 40% of the Eastern Afromontane Biodiversity hotspot occurs in Ethiopia (BirdLife International, 2012). Thus, the Ethiopian highlands include part of the world's biodiversity hotspots but one of the most degraded ones (McKee, 2007). This is partly because of the fact that the majority of subsistence agriculture practicing population in Ethiopia resides in the highlands.

The 34 hotspots once covered an area of 23.7 million km<sup>2</sup> i.e. about 15.9% of Earth's land surface. However, because of the severe habitat destruction, the natural vegetation in these areas is now reduced to 2.3 % (3.4 million km<sup>2</sup>) of the world's land area (Mittermeier *et al.*, 2011). For instance, most of the original forests and grasslands in the Eastern afromontane hotspot have been converted to agricultural land. Similarly, the Ethiopian Highlands have experienced considerable conversion of natural habitat to agriculture and much of the original natural forests of Ethiopia now exist only as small

remnants in southwest part of the country, steep escarpments of the Rift Valley, river gorges and the cold Afro-alpine plateaus (BirdLife International, 2012). These parts of the country are relatively less accessible for encroachment into the natural forests.

The escalating demand for forest products and forest land in Ethiopia has put the remaining patches of forests on the verge of extermination (EMA, 1988). Demel Teketay (2001) reported that one of the major challenges facing Ethiopia is environmental degradation, manifested in the degradation of land and water resources as boreholeas loss of biodiversity. Similarly, Teshome Soromessa *et al.*(2004) asserted that the vegetation resources of Ethiopia are disappearing at alarming rate even before we have a chance to study and document them. In their study in Central Rift Valley of Ethiopia, Jansen *et al.* (2007) reported an increasing trend in conversion of natural vegetation to agricultural lands. Hence, investigations on the vegetation resources of the country are inevitably needed in order to ensure sustainable management of the remnant vegetation and to abate the actual and potential consequences of loss of vegetation.

Concerns about increasing loss of biodiversity and the resulting degradation of ecosystem services have stimulated several studies (Naeem *et al.*, 1999). Specifically, a central concern of vegetation ecologists has been investigation of the factors that affect species distributions and community composition (Motzkin *et al.*, 1999) and correlation of vegetation with environmental factors (Carleton, 1984). However, there was limited study on floristic composition, pattern of plant distribution and factors that account for vegetation loss in the study area. This study was, therefore, conceived to investigate the ecology of the dry Afromontane vegetation of the Western Escarpment of Central Ethiopian Rift Valley.

## Materials and methods

**The study area:** The study area, the Western Escarpment of Central Ethiopian Rift Valley, is located partly in the Guarge Zone, Southern Nations, Nationalities and Peoples' Regional State of Ethiopia (Fig. 65). This escarpment makes the western part of Lake Zwai watershed. It happens to be the source of River Meki that supplies Lake Zwai the second highest water next to River Qatar that originates from the Esatern Escarpment marked with the Chilalo Maountains.

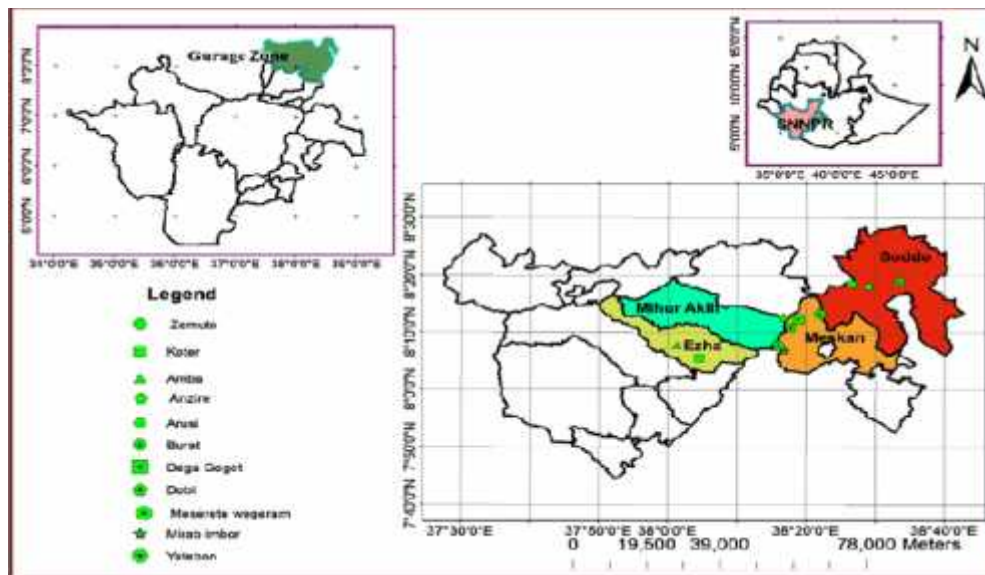


**Figure 564:** Location map of the study area: (a) regional map of Ethiopia in which South Nations, Nationalities and Peoples' Regional State (SNNPRS) is highlighted (b) Zonal map of SNNPRS (Gurage Zone highlighted) and (c) Wereda map of Gurage Zone with the Woredas considered highlighted

The study area is found within the catchments of the Ethiopian Rift Valley Lakes and Omo-Gibe River. Sub-catchments within the catchments of the Ethiopian Rift Valley Lakes and Omo-Gibe River as boreholeas the rivers

originating from the Western Escarpment of Central Ethiopian Rift Valley are presented in Table 61, below.

**Table 53:** The subcatchments in the weredas included in the present study

| No. | Wereda(s)<br>cover | Sub-<br>catchment | Kebele cover (some)                                                                                                | Tributaries originating from<br>the Western Escarpment of<br>Central Ethiopian Rift<br>Valley Mountains |
|-----|--------------------|-------------------|--------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| 1   | Mesqan,<br>Sodo    | Meki              | Meseret Wegeram,<br>Dega Nurena,<br>Endebuyu, Aymelel,<br>Bono aygede,<br>Amawute lalige,<br>Amawute giftige, etc. | Akamuja, Derek, Lebu,<br>Weldiya                                                                        |
| 2   | Mesqan             | Dobena            | Mirab Mesqan,<br>Misraq Mesqan,<br>Mirab Imbor, Yetebon,<br>Dobi, Dega Gogot,<br>etc.                              | Eresha, Erenzaf                                                                                         |
| 3   | Mesqan             | Asas<br>angerager |                                                                                                                    | Mikaelo, Wurib, Gide, Aborat                                                                            |
| 4   | Ezha,<br>Mohir     | Wabe              | Ambelta, Mamede,<br>Fenta, Wesherbe,<br>Anzire, Chimbe, etc                                                        | Gogina, Omamo, Kereb                                                                                    |
| 5   | Ezha               | Wunqiye           | Koter Gedra, Amba<br>Genet, Bozhebar, etc.                                                                         | Gotam, Gogob, Qechir,<br>Megecha, Tiliku Haram,<br>Tinishu Haram                                        |

**Data collection and analysis:** Plots of size 40 x 40 m were used for vegetation sampling. Such a large plot is of course in a range suggested by Sutherland (1998) i.e. 400-2500 m<sup>2</sup>. Large sized plots were used to capture as many species as possible in the same plot since it was assumed that human interference has thinned out the vegetation of the study area.

Nested plot design was used to survey the under-storey and canopy layer vegetation. The main (40 x 40 m) plot was divided into four 20 x 20 m subplots. From each 20 x 20 m plot, local name (or voucher specimen code if the local name was not known), diameter at breast height (at 1.30 m above

ground), height, number of individuals and cover abundance of all trees having DBH > 5 cm were recorded. The height, number of individuals and cover abundance of shrubs, younger trees and woody climbers with DBH 1.5-5 cm were collected from subplots of size 5 x 5 m (labeled as S) which were laid at nine different locations of the main plot (Fig. 65). Within 5 x 5 m subplots, 2 x 2 m plots (labeled as H) were laid to collect cover-abundance data of herbaceous plants. Abundance and frequency trees, shrubs and lianas were summarized on a plot basis. Subplot abundance data were pooled /extrapolated to the main plot by multiplying mean subplot abundance by the ratio of the area of the main and subplot. Cover-abundance values were estimated using the modified Braun Blanquet scales following weights given in van der Maarel (1979, 2005) and Eymann *et al.* (2010):

- 1 for rare, generally 1-3 individuals and cover less than 5%
- 2 for few, with less than 5% cover
- 3 for abundant, with less than 5% cover
- 4 for very abundant, with less than or equal to 5% cover
- 5 for  $5 < \text{cover} \leq 12\%$
- 6 for  $12.5 < \text{cover} \leq 25\%$
- 7 for  $25 < \text{cover} \leq 50\%$
- 8 for  $50 < \text{cover} \leq 75\%$  and
- 9 for cover >75%

Tree height was measured using Suunto clinometers and diameter at breast height using meter tape. Meter tape was used to measure heights of relatively shorter woody plants. New taxa, which were encountered outside the plots, were also collected but kept separately. Voucher specimens were collected for all plant species and were identified at National Herbarium (ETH). The nomenclature of the plants was based on the published volumes of the Flora of

Ethiopia and Eritrea (Hedberg and Edwards, 1989; Hedberg and Edwards, 1995; Edwards *et al.*, 1995; Edwards *et al.*, 1997; Edwards *et al.*, 2000; Hedberg *et al.*, 2003; Hedberg *et al.*, 2004; Hedberg *et al.*, 2006).

The slope of each plot was observed using Suunto clinometers. Altitude of each plot was noted using Garmin GPS. Aspect was codified according to Zerihun Woldu *et al.* (1989) and Tamrat Bekele (1994) where North is represented by 0, East by 2, South by 4, West by 2.5, North East by 1, South East by 3, South West by 3.3 and North West by 1.3. Following Zerihun Woldu and Backeus (1991), soil samples were taken from 0-50 cm depth whenever possible. Soil samples were taken at corners of 20 x 20 m subplots and composite samples weighing 1.5-2 Kg were made. Soils samples were collected below the surface layer of leaf litter and below root mass. Soil samples were air dried before laboratory analysis. The soil samples were analyzed at Ethiopian National Soil Laboratory. The parameters were analyzed following the standard procedures outlined in Allen (1989): total organic matter (Walkely-Black wet oxidation, % dry weight), electrical conductivity and pH (m mhos/l, in 1:1 soil-water suspension), available phosphorous (Bray No. II Method, ppm), total nitrogen (Kjeldahl method) and texture (hydrometer method; parameters clay, sand and silt expressed as % weight). Intensity of anthropogenic disturbance/grazing in each plot was estimated based on the weights of: 0 for nil; 1 for slight; 2 for moderate; 3 for heavily and 4 for destructive.

Classification and ordination methods were used to describe vegetation types and to examine the relationship between vegetation types and environmental variables. R package (R. Development Core Team, 2009) was used for cluster and ordination analysis. Canonical correspondence analysis (CCA) was used for detection of patterns of variation in species distribution and for identification of variables causing those patterns in the study sites.

## Results and discussions

**Floristic composition and species richness:** The forests in the study area harbor plants of high diversity though they are small patches surrounded by mosaics of other land use practices. A total of 339 species were identified from plots studied. The plants identified belonged to 89 families; of which only two were gymnosperms. Eight families accounted for 55% of the species in the study area. Asteraceae alone accounted for 24% of the species. The percent of species belonging to the different plant families in the Western Escarpment of Central Ethiopian Rift Valley are given in Fig. 66, below.

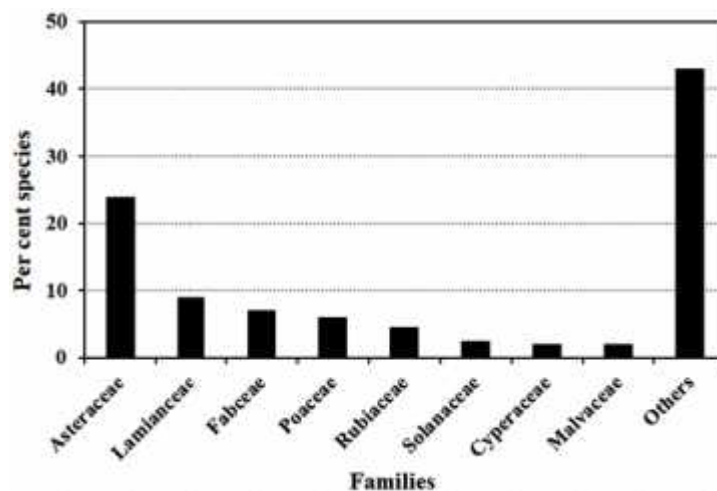


**Figure 65:** Percent of species belonging to the different plant families in the study area, western Escarpment of Central rift valley NOTE: Many of the species encountered belonged to Asteraceae, followed by Lamiaceae.

The number of species recorded as a function of studied plots is shown below in species accumulation curve of the study area (Fig. 67).

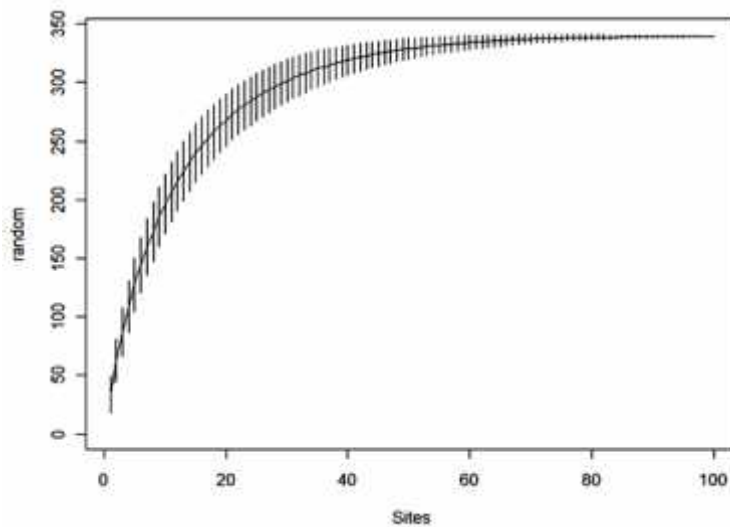


**Figure 66:** Species accumulation curve of the study area. The x-axis represents number of plots sampled whereas the y-axis represents the number of species encountered

The species accumulation curve of the study area leveled off before the total number of observations. The implication is that the study sites were adequately sampled and this inference was made based on Lau (2008); Colborehole (2009). Such curves have been used to estimate the expected number of new species to be detected given a level of additional sampling effort (Mao *et al.*, 2005). For instance, it is possible to infer from Fig. 3 that about 220 species can be recoded from the study sites after investigating 20 plots; and about 280 species after investigating 40 plots. In the species accumulation curve, the number of species recorded increased radically initially (e.g. from plot 1 to 20) whereas the change in number of species became incremental later on (e.g. from plot 20 to 40) when many of the species in the study area were sampled. Such is a common characteristic of ecological communities (Ugland *et al.*, 2003; Colborehole2009).



**Structural Analysis:** The lion's share of the plants encountered in the study sites were herbs as shown in Fig. 68. About 50% of the plants identified were herbs. Epiphytes contribute the smallest proportion in the flora of the Western Escarpment of Central Ethiopian Rift Valley.

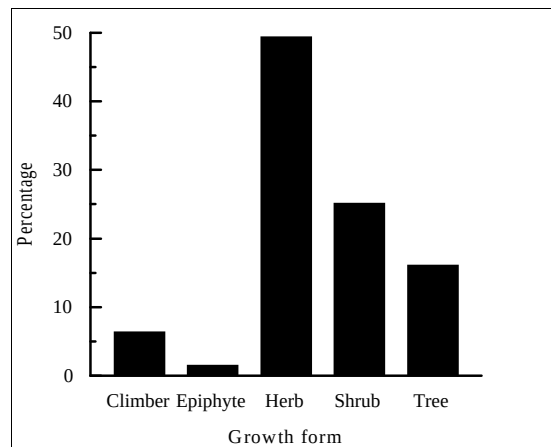


**Figure 67:** The percenatge of different growth forms in the flora of the Western escarpment of Central Ethiopian rift valley

Most of the woody plants in the study area have height class less than 10 m. Trees with height class greater than 25 m comprised a small proportion of the woody plants investigated as shown in Fig. 69.

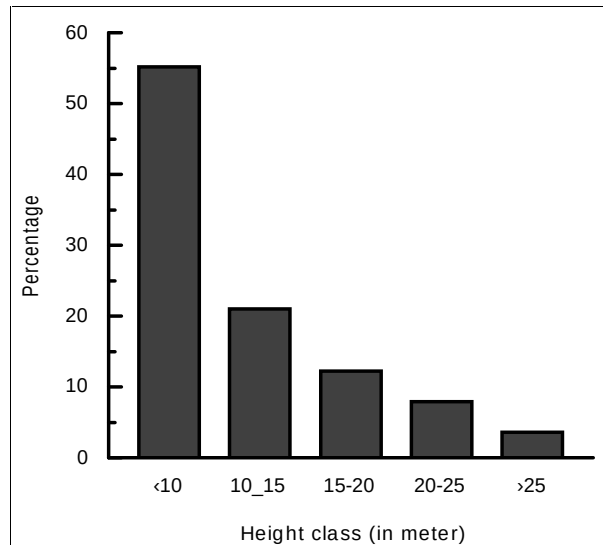


**Figure 68:** Percentage of plants of various height classes in the study area

The least representation of trees with higher height classes may also be due to selective logging of relatively large trees for various purposes. The height class distribution of the dominant woody plants in the Western Escarpment of Central Ethiopian Rift Valley is presented in Table 62.

**Table 54:** Height class distribution of woody plants in the Western Escarpment of Central Ethiopian Rift Valley (%)

| Species                   | Height Class |      |       |       |       |       |       |     |
|---------------------------|--------------|------|-------|-------|-------|-------|-------|-----|
|                           | <9           | 9-12 | 12-15 | 15-18 | 18-21 | 21-24 | 24-27 | >27 |
| <i>Dombeya torrida</i>    | 13           | 27   | 44    | 12    | 4     | 0     | 0     | 0   |
| <i>Hagenia abyssinica</i> | 0            | 0    | 0     | 27    | 39    | 30    | 4     | 1   |
| <i>Ilex mitis</i>         | 5            | 24   | 32    | 20    | 15    | 0     | 0     | 4   |
| <i>Apodytes dimitiata</i> | 49           | 49   | 18    | 0     | 0     | 0     | 0     | 0   |
| <i>Juniperus procera</i>  | 9            | 6    | 10    | 45    | 10    | 2     | 3     | 15  |
| <i>Acacia abyssinica</i>  | 46           | 19.4 | 13.2  | 14    | 7.4   | 0     | 0     | 0   |
| <i>Maesa lanceolata</i>   | 92           | 8    | 0     | 0     | 0     | 0     | 0     | 0   |
| <i>Maytenus addat</i>     | 51           | 21   | 9     | 8     | 6     | 0     | 5     | 0   |

| Species                                        | Height Class |      |       |       |       |       |       |     |
|------------------------------------------------|--------------|------|-------|-------|-------|-------|-------|-----|
|                                                | <9           | 9-12 | 12-15 | 15-18 | 18-21 | 21-24 | 24-27 | >27 |
| <i>Myrica salicifolia</i>                      | 67           | 33   | 0     | 0     | 0     | 0     | 0     | 0   |
| <i>Olea europaea</i><br><i>subsp cuspidata</i> | 8.5          | 46   | 33    | 13.5  | 0     | 0     | 0     | 0   |
| <i>Olinia rochetiana</i>                       | 44           | 24   | 11    | 17    | 4     | 0     | 0     | 0   |
| <i>Pittosporum</i><br><i>viridiflorum</i>      | 22           | 34   | 14    | 13    | 9     | 8     | 0     | 0   |
| <i>Podocarpus falcatus</i>                     | 9            | 18   | 22    | 26    | 10    | 2     | 3     | 10  |
| <i>Rhus longipes</i>                           | 67           | 24   | 9     | 0     | 0     | 0     | 0     | 0   |
| <i>Schefflera volkensii</i>                    | 11           | 19   | 28    | 22    | 4     | 8     | 2     | 6   |
| <i>Syzygium guineense</i>                      | 3            | 0    | 23    | 20    | 13    | 11    | 10    | 20  |
| <i>Brucea</i><br><i>antidysentrica</i>         | 95           | 5    | 0     | 0     | 0     | 0     | 0     | 0   |
| <i>Dovyalis abyssinica</i>                     | 100          | 0    | 0     | 0     | 0     | 0     | 0     | 0   |
| <i>Nuxia congesta</i>                          | 42           | 24   | 14    | 20    | 0     | 0     | 0     | 0   |
| <i>Myrsine</i><br><i>melanophloeos</i>         | 60           | 20   | 0     | 15    | 5     | 0     | 0     | 0   |
| <i>Prunus africana</i>                         | 3            | 20   | 44    | 14    | 3     | 5     | 5     | 6   |
| <i>Flacourtia indica</i>                       | 94.5         | 5.5  | 0     | 0     | 0     | 0     | 0     | 0   |
| <i>Croton</i><br><i>macrostachyus</i>          | 31           | 28   | 15    | 3     | 4     | 4     | 11    | 4   |

Trees which have high economical and medicinal values such as *Hagenia abyssinica*, *Prunus africana* and *Juniperus procera* were least represented in the lowest height classes which implies that their regeneration status is poor. In Table 63, the height class distribution of woody plant of the Western Escarpment of Central Ethiopian Rift Valley is compared with the height class distribution of woody plants of other afro-montane forests of Ethiopia namely Jibat, Chilimo, Menagesha and Wof-Washa forests.

**Table 55:** Composition of height class distribution of woody plants in the Western Escarpment of Central Ethiopian Rift Valley with other afro-montane forests of Ethiopia with data for Jibat, Chilimo, Menagesha and Wof-Washa Forests from Tamirat Bekele (1994)

| Height Class (%) | The vegetation in the Western Escarpment of Central Ethiopian Rift Valley | Jibat | Chilimo | Menagesha | Wof-Washa |
|------------------|---------------------------------------------------------------------------|-------|---------|-----------|-----------|
| <9               | 40.6                                                                      | 25.5  | 42.1    | 38.5      | 23.3      |
| 9-12             | 19.3                                                                      | 24    | 30.8    | 32        | 21.3      |
| 12-15            | 14.75                                                                     | 15.2  | 15.3    | 10.8      | 13.7      |
| 15-18            | 12.6                                                                      | 14    | 7.5     | 11        | 13.1      |
| 18-21            | 5.8                                                                       | 7.2   | 3.4     | 2.2       | 6.1       |
| 21-24            | 3.04                                                                      | 3.7   | <1      | 2.2       | 1.6       |
| 24-27            | 1.9                                                                       | 3.5   | 0       | 1         | 8         |
| >27              | 2.86                                                                      | 6.8   | 0       | <3        | 12.8      |

The population structure of the forest patches of the Western Escarpment of Central Ethiopian Rift Valley has relatively better resemblance with Menagesha and Chilimo forests in terms the percentage of woody plants having height class less than 9 m.

DBH class distribution of woody plants in the study area shows a similar trend as that of the height class distribution. Woody plants with DBH class less than 20 cm accounted for most of the plants investigated. Trees with DBH greater than 80 cm were least represented as shown in Fig. 70.

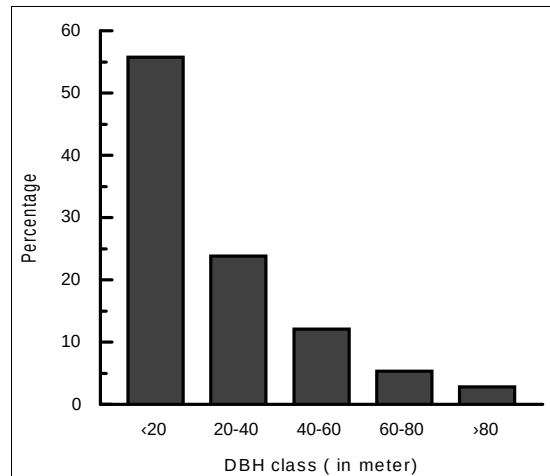


**Figure69:** Percentage of woody plants of different DBH class in the study area

As it is the case for the height class frequency distribution, there is a notable similarity in DBH class distribution between the forests of Western Escarpment of Central Ethiopian Rift Valley and other afro-montane forests of Ethiopia as shown in Table 4. The data about the DBH frequency distribution of woody plants in Jibat, Chilimo, and Menagesha and Wof-Washa forests are based on Tamrat Bekele (1994).

**Table 56:** Composition of DBH frequency distribution of woody plants in the Western Escarpment of Central Ethiopian Rift Valley with data for Jibat, Chilmo, Menagesha and Wof-Washa Forests from Tamerat Bekele (1994)

| DBH Class (%) | The Western Escarpment of Central Ethiopian Rift Valley | Chilimo | Jibat | Menagesha | Wof-Washa |
|---------------|---------------------------------------------------------|---------|-------|-----------|-----------|
| < 20          | 55                                                      | 60.8    | 48.9  | 56.9      | 32.6      |
| 20-50         | 28.8                                                    | 36.5    | 39.5  | 32.8      | 31.7      |
| 50-80         | 13                                                      | 11      | 9.8   | 6.5       | 14.6      |
| 80-110        | 2.2                                                     | 0       | 1.4   | 2.5       | 11.7      |
| >110          | 0.9                                                     | 0       | <2    | 1.1       | 9.5       |

In terms of proportion of woody plants with DBH class less than 20 cm, the forest patches of the Western Escarpment of Central Ethiopian Rift Valley have high similarity with Menagesha forest. Wof-Washa and Mengesha forests also higher resemblance with the forests of the study area in the percentage of trees having DBH class of 20-50 cm. In all of these afro-montane forests of Ethiopia, trees with higher DBH classes were least represented. The low representation of woody plants of higher DBH may be due to selective logging of those trees for various uses.

The patterns of species population structure for some of most important trees in the study area are presented in Fig. 71. Three main patterns of plant population of structures were identified.

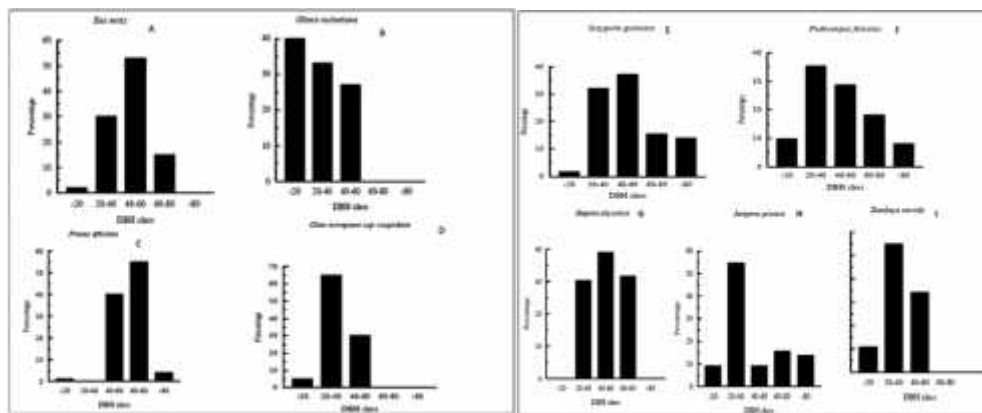


**Figure70:** The population structure of the dominant trees in the western escarpment of Central Ethiopian Rift Valley: A) *Ilex mitis* B) *Olinia rochontiana* C) *Prunus africana* D) *Olea europaea* subsp *cuspidata* E) *Syzygium guineense* F) *Podocarpus falcatus* G) *Hagenia abyssinica* H) *Juniperus procera* I) *Dombeya torrida*

Bell shaped frequency distribution is the most common pattern of species population structure for most of the dominant trees in the study area. *Hagenia abyssinica*, *Ilex mitis*, *Prunus africana*, *Podocarpus falcatus*, *Olea europaea* subsp *cuspidata* and *Juniperus procera* have bell-shaped frequency

distribution (population structure) in which number of individuals in the middle diameter classes are high and lower in lower and higher diameter classes. For *Hagenia abyssinica*, individuals with DBH class less than 20 cm were not recorded.

**Classification of the vegetation of the study area:** Hierarchical agglomerative clustering with similarity ratio as a resemblance index and Wards group linkage method resulted in a dendrogram with seven distinct communities (Fig. 72).

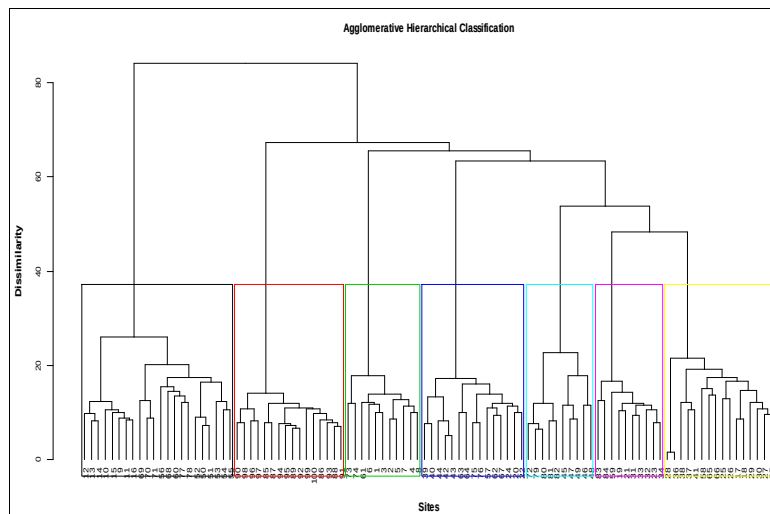


**Figure71:** Dendrogram of the vegetations of Western Escarpment of Central Ethiopian Rift Valley

Nonmetric multidimensional scaling (NMDS) resulted in an ordination diagram in which the configuration of the study plots closely matches with the result of the agglomerative hierarchical classification as shown in Fig. 73.

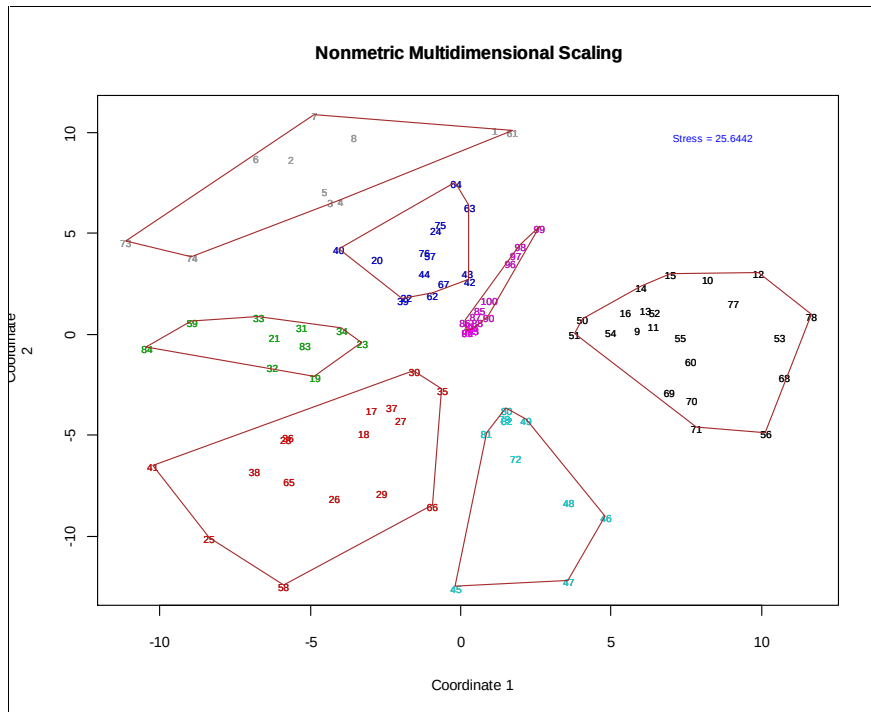


**Figure72:** The configuration of the plots in NMDS ordination diagram in which the seven plant communities recognized in the study area distinctively shown based on the floristic similarities of the plots

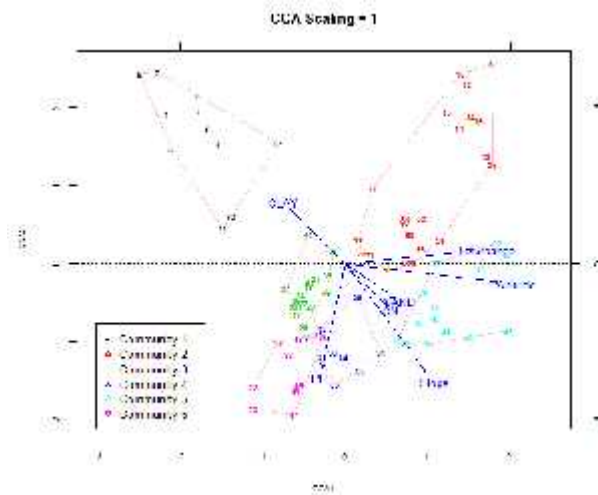
**The Relationship between plant communities and environmental variables:** Community-environment relations in the study sites were investigated using canonical correspondence analysis and analysis of variance. The afroalpine community was not included in this part of analysis as soil was not sampled in the afroalpine part of the study area. Table 65 shows that only seven variables among the thirteen variables considered in the present study (altitude, slope, disturbance, pH, phosphorus, electrical conductivity, sand, silt, clay, total nitrogen, organic carbon and carbon nitrogen ratio), were significantly related to the vegetation distribution pattern of the study area.



**Table 57:** Variables having significant relations with plant distribution patterns of the study area

| Variables                  | Df | AIC   | F   | Pr(>F) |
|----------------------------|----|-------|-----|--------|
| Altitude                   | 1  | 394.8 | 7   | 0.005  |
| Slope                      | 1  | 397   | 4.8 | 0.005  |
| Disturbance                | 1  | 397   | 4.6 | 0.005  |
| pH                         | 1  | 398.9 | 2.9 | 0.005  |
| Clay                       | 1  | 399.5 | 2.3 | 0.005  |
| Sand                       | 1  | 400   | 1.6 | 0.032  |
| CN (carbon nitrogen ratio) | 1  | 391   | 1.5 | 0.038  |

These seven variables were, therefore, used as constraining variables in canonical correspondence analysis. The CCA diagram shows the relationships between the plant communities in the study area and environmental variables (Fig. 74).

**Figure 73:** Ordination diagram displaying the first two ordination axes of CCA summarizing direction of influence of environmental variables on the plant communities of the study area showing direction of influence of the variables

As can be noted in Fig. 10, the configuration of the study plots in the CCA diagram is in agreement with the outputs of the classification. Significant correlation was found between CCA axes and all of the seven environmental variables (altitude, slope, carbon nitrogen ratio, sand, disturbance, clay and pH) which were selected through stepwise variable selection procedure which is presented in Table 66.

**Table 58:** Intraset correlation between the variables and ordination axes showing how borehole species distribution corresponds to the measured environmental variables

| Variables   | CCA1  | CCA2  | r <sup>2</sup> P | r(>r) |
|-------------|-------|-------|------------------|-------|
| pH          | -0.26 | -0.96 | 0.34             | 0.001 |
| Sand        | 0.85  | -0.5  | 0.10             | 0.017 |
| Clay        | -0.74 | 0.7   | 0.18             | 0.002 |
| CN          | 0.73  | -0.68 | 0.10             | 0.012 |
| Disturbance | 0.99  | 0.11  | 0.50             | 0.001 |
| Altitude    | 0.99  | -0.08 | 0.76             | 0.001 |
| Slope       | 0.62  | -0.77 | 0.55             | 0.001 |

Significant correlation was found between CCA axes and all of the seven environmental variables (altitude, slope, carbon nitrogen ratio, sand, disturbance, clay and pH). Hence, altitude, slope, sand, disturbance, pH and clay have significant relation with the plant communities of the study sites as they have a significant correlation with the CCA axes. The highest canonical coefficient scores on CCA axis 1 were positively related to altitude, disturbance and sand. Canonical coefficient scores on axis 2 were strongly related to slope and pH.

## Discussions

The vegetation of the Western Escarpment of Central Ethiopian Rift Valley is characterized by high floristic diversity. Most of the plants encountered in the study were herbs. Epiphytes were least represented in the flora of the Western Escarpment of Central Ethiopian Rift Valley. Anthropogenic disturbance might have contributed to the least representation of epiphytes. Diversity and abundance of epiphytes are recognized as an indicator of disturbance trends in tropical montane rainforests (Barthlott *et al.*, 2001). There was an increase in the number of species encountered as larger geographic areas were considered in the present study. One of the possible reasons for increase in number of species with an increase in area considered is that larger areas are likely to include a greater number of habitat types or ecoregions, each with its own unique or partially distinct biota (Colwell, 2009a).

As it is the case for the other afro-montane forests of Ethiopia, the woody plants of higher height classes are less represented in the population structure of the forest patches of the Western Escarpment of Central Ethiopian Rift Valley. Selective exploitation of trees with higher height class may have contributed to the less representation those trees in the afro-montane forests of Ethiopia. Such a pattern was also reported in wet afro-montane forests of Ethiopia (e.g. Feyera Senbeta, 2006). The selective exploitation of mature seed bearing trees can threaten the sustainability of the forests.

Trees with considerable economic and health importance such as *Hagenia abyssinica* have poor regeneration status. This may be due to the fact that *Hagenia abyssinica* flowers are regularly collected by the inhabitants around the forests for medical purposes which could reduce the seed source for germination and recruitment. The poor regeneration of *Ilex mitis*, *Prunus africana*, *Podocarpus falcatus* and *Juniperus procera* is probably due to selective logging of mature individuals for timber production and construction purposes, which can ultimately have negative impact on seed production and regeneration status of the species. Furthermore, seedling trampling and

selective browsing by domestic and wild animals may also have accounted for the poor regeneration status of the dominant trees in the study area.

*Dombeya torrida* and *Syzygium guineese* have J-shaped frequency distribution (population structure) which is characterized by high number of individuals in higher diameter classes and lower in the lower diameter classes. Feyera Senbeta (2006) reported that *Syzygium guineese* fruits are usually used as food by many animals and humans, which could account for the poor regeneration status of the species. Overharvesting of seed bearing individuals may also have accounted for the poor regeneration of *Dombeya torrida* and *Syzygium guineese*. In addition, uncontrolled grazing might be one of the main causes for the poor regeneration status of these species. *Olinia rochetiana* has an inverted J-shape, which shows a pattern where species frequency distribution has the highest frequency in the lower diameter classes and a gradual decrease towards the higher classes.

In forests with optimum regeneration status, the patterns of population structure is expected to an inverted J-shaped type, with a high number of individuals in the lower size classes and few individuals in the higher size classes. The reproductive capacity of the forest must be sufficient to sustain the forest, and the population structure of most species must have a reverse J-shaped distribution (seedlings/saplings are over-represented and bigger trees are present in progressively lower numbers). This pattern is an indicator of healthy regeneration of the forest and species, and shows a good reproduction and recruitment capacity (Feyera Senbeta, 2006). Most of the most important tree species of the study area do not have this type of population structure.

The dominant trees in the study area have either J-shaped or bell shaped population structures. The bell-shape population structure indicates a poor reproduction and recruitment of species, which may be associated with the overharvesting of seed bearing individuals. Similarly, the J-shaped pattern indicates poor reproduction and regeneration which may be either because of

failure to produce seed due to age of the trees or losses due to predators after reproduction (Feyera Senbeta, 2006). The poor reproduction and regeneration status of the dominant tree species can jeopardize the sustainability of the vegetation in the study area. Hence, proper conservation measures need to be applied so as to improve their regeneration.

Topographic variables, especially altitude and slope, have significant relation with the plant communities of the Western Escarpment of Central Ethiopian Rift Valley. Several researchers discussed the relation between these topographic variables and the spatial distribution of plant communities (e.g. Joseph *et al.*, 2008; Bochet *et al.*, 2009). Topographic gradients cause a notable variation in species composition. This is because topographic variations create a mosaic of microhabitat variations (Moody & Meentemeyer, 2001) and hence are considered as principal parameters in ecological specialization (Bazzaz, 1991). However, these topographic variables indirect factors as they do not have a physiological influence on species, contrary to direct factors such as temperature and soil nutrients (see Pausas and Austin, 2001). For instance, altitudinal species distributions are caused by various factors which change along with altitude such as air pressure, temperature and precipitation that in turn determine the type of vegetation to be supported (Körner, 2007). Furthermore, along with altitudinal change other environmental parameters (e.g. soil texture, nutrients, substrate stability, etc.) covary which also affect the structure and composition of the vegetation (Ramsay and Oxley, 1997). Similarly, slope determines the microclimate and thus spatial distribution and patterns of vegetation (Bochet *et al.*, 2009). Slope causes vegetation changes owing to its effect on soil characteristics (Solon *et al.*, 2007). For example, Dalling & Tanner (1995) reported that the soils at steep slopes at higher elevations are especially poor in nitrogen and phosphorous which can have impact on type of vegetation to be supported.

Physical and chemical properties of the soil such as sand and clay content of the soil, carbon nitrogen ratio and soil pH are significantly related with the

plant communities of the study area. The impacts of these soil features on the distribution of plants is widely discussed by various authors (Zare-Chahouki *et al.*, 2012) who underscored that these soil parameters strongly affect patterns of plant distribution. They affect the physiognomy, composition, and productivity of plant communities (Klinger, 1996). Physical characteristics of the soil influences nutrient retention and availability, organic matter retention, microbial biomass and other soil properties which in turn influence vegetation distribution patterns (Hamarashid *et al.*, 2010). Similarly, soil pH influences the growth and distribution of plants as it greatly affects the absorption of inorganic nutrients by plants. For instance, plant growth in acid soils may be limited by the effect excess H ion concentration as boreholeas pH-induced toxicities (e.g., Al, Mn) and/or insufficiencies (e.g., Ca, Mg, P). Excess H ion concentration causes a decrease in the rate of absorption of cations, probably as a result of competition between the similarly charged ions for binding and carrier sites. High pH has also been considered as detrimental in causing nutrient deficiency and ionic imbalance (Alam *et al.*, 1999). High pH and smaller C/N ratio can increase net N mineralization. Low C/N ratios show N mineralization more than those with wide C/N ratios (Khalila, 2005). Soil pH has a significant impact on the species of the Western Escarpment of Central Ethiopian Rift Valley. This is because of the fact that it has an effect on plant nutrient and toxic element availability (Alam *et al.*, 1999). For instance, Grime (1973) noted that species richness declines towards both acidic and alkaline soils. He concluded that few species are adapted nutritionally to exploit highly acidic or alkaline soils.

Disturbance plays a significant role in plant community formation in the study area. Disturbance may determine community patterns by (1) directly changing the environment and resource distributions, (2) creating opportunities for the establishment of new species or (3) reducing populations of established species (Motzkin *et al.*, 1999). Anthropogenic disturbance also influences the soil, nutrient and water conditions as boreholeas microenvironment of the area

(Pokhriyal *et al.*, 2012) which in turn determines the types of vegetation to be supported.

### **Conclusions and recommendations**

The Western Escarpment of Central Ethiopian Rift Valley does not have large tracts of land that are under forest cover. But there are patches of forests especially in areas that are topographically less accessible to human encroachment. Though small patches, the forests in the study sites comprise species of high diversity and house a good number of endemic plants. All of the richness estimators predict higher richness than the observed which further indicates the high floral diversity of the study sites. The regeneration status of the dominant trees of the study area is found to be poor. Hence, appropriate conservation measures need to be taken so as to improve their regeneration. Plant species richness and distribution in the study sites were influenced by altitude, disturbance, edaphic factors and other environmental variables. The species richness of the study area was strongly influenced by disturbance implying that disturbance mitigation should be one of the main measures in conservation planning in the study sites.

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## Chapter 13

### Carbon sequestration potentials of selected wetlands along the shorelines of Lake Zwai, Ethiopia

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#### Absracrt

Wetlands are known for their high productivity owing to their high biomass content per unit area. This is however changing due to human needs to convert them to various land use types. The objective of this study was therefore to investigate the impact of wetland conversion on carbon sequestration potentials of selected wetland sites along the shores of Lake Zwai. Five sites were selected purposefully and triplicate vegetation and soil core samples were collected from each site in July and August 2015 and analyzed for above ground biomass, above ground plant carbon, and soil organic carbon contents. In addition to this, a short survey was also undertaken to investigate the community perceptions on wetland degradation. The results indicated that the least impacted wetland had significantly higher ( $p < 0.05$ ) plant and soil organic carbon content than the other land use categories. The above ground plant carbon ranged between  $49.23 \text{ g C m}^{-2}$  in the converted grazing land to  $2066.17 \text{ g C m}^{-2}$  in the least impacted wetland. Soil organic carbon content ranged between  $7.36 \text{ g C kg}^{-1}$  in the converted cultivated land to  $91.43 \text{ g C kg}^{-1}$

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<sup>1</sup> in the least impacted site. Soil organic carbon content was positively correlated ( $p < 0.01$ ) with above ground biomass and soil moisture; whereas soil temperature showed significant negative correlation ( $p < 0.01$ ). The view of the respondents from the survey also indicated the high conversion and loss of wetlands over time in the area due to population growth and other associated reasons. The overall results showed that a high reduction of organic carbon storage of both the soil and above ground as one goes from un-impacted to impacted land use types in wetlands of Lake Zwai, implying the need of improved management of wetlands so as to enhance the biomass carrying capacity of such areas to mitigate carbon emissions.

**Keywords:** Carbon sequestration, wetland degradation, Lake Zwai, organic carbon, Lake Zwai

## Introduction

The Earth's climate is changing, as witnessed by higher atmospheric temperatures, decreasing snow and ice cover, and increasing sea level rise in the 20<sup>th</sup> century (Mitsch and Gosselink, 2015). The cause of this climate change is the increased concentration of greenhouse gases (GHGs), primarily carbon dioxide in the atmosphere, mostly caused by anthropogenic emissions (Evans *et al.*, 2014).

Generally, wetlands play a key role in reducing the emissions of carbon dioxide to the atmosphere. There is a significant amount of carbon stored in wetland soils, peats, litter, and vegetation globally (estimated 500-700 Giga ton). This amount stored in wetlands may approach a total amount of atmospheric carbon estimated at 753 Giga ton (Kusler, 2000). Despite this, very little attention was given to wetlands regarding their role in carbon sequestration and hence wetlands were neglected and converted to other land use types due to poor management practices especially in developing countries such as Ethiopia. Complete conversion and modification of wetlands to cultivated land, improper large scale farming systems with open-land

grazing, improper farming methods, poor tillage systems, removal of grasses and trees for household uses and planting water-demanding crops are some of the major threats to Ethiopian wetlands (Gebresellassie *et al.*, 2014). Consequently, as the country is prone to sporadic drought spells, the effect of wetland loss could be more visible on the local climate pattern. Therefore, sustainable management of wetlands is a practical way of retaining the existing carbon reserves and thus avoiding emission of carbon dioxide. In order to achieve these outcomes through vegetation, soil and water management, more evidence-based information is required about carbon stock dynamics and land cover changes in wetlands.

The role of Ethiopian wetlands in carbon sequestration has not been adequately studied except the exemplary work by Afework (2013) on Tekuma wetlands and Worku (2014) on the Fogera wetlands of Lake Tana Basin. However, no recorded studies were found on carbon sequestration potentials of the rift valley wetland systems. This study is therefore focused on the impact of wetland conversion and degradation on the carbon sequestration potentials of selected sites at Lake Zwai wetlands, Ethiopia; understanding the current status of the wetlands and the community's perception on their sustainable use. These sites were selected because of the high anthropogenic pressure to convert them into other land use forms through poor wetland management practices thereby potentially affecting the carbon storage potentials of these wetlands.

## Materials and methods

**Description of study area:** Lake Zwai, one of the most important fresh water rift valley lakes, is located at an altitude of 1,850 m above-sea level (asl) (Lemma Abera, 2005). The lake lies at 8° 01' N/38° 47' E and at an altitude of 1636 m asl (Von Damm and Edmond, 1984 cited in Girum Tamir and Seyoum Mengistou, 2014) (Fig. 75). There is well-marked vegetation zonation around the shore of the lake in which it is sequenced from the margin

to the adjacent dry land. The lake is surrounded by farming communities that compete for water to supply the adjacent irrigated agricultural fields.

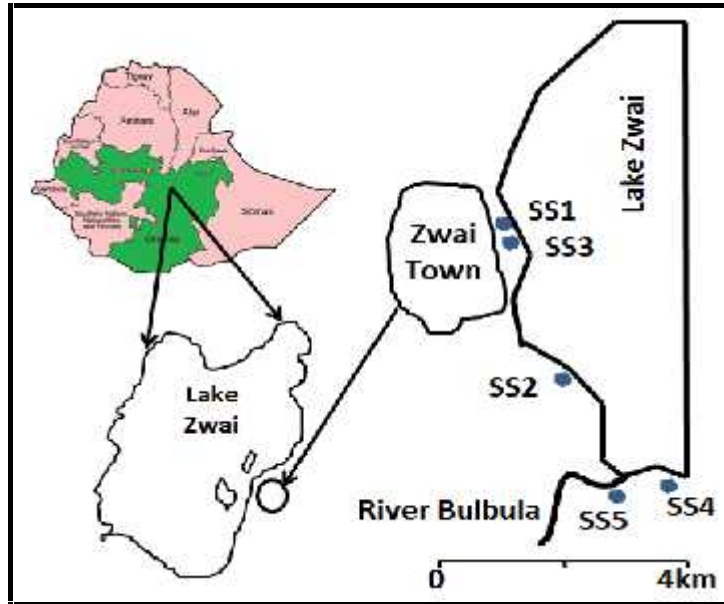


**Figure 74:** Location of map of the study area with the sampling sites represented by black dots and numbered as SS1 to SS5

**Field sample collection:** Five wetland categories (degradation levels) were selected purposefully, namely, SS1: minimally disturbed (Least-impacted wetland), SS2: moderately degraded wetland, SS3: degraded wetland, SS4: grazing land (converted wetland), and SS5: cultivated land (converted wetland) (Appendix 1). Sites were selected by preliminary field observation using criteria such as vegetation cover, water level, topography, and human and livestock intervention (Bernal, 2008; Arina *et al.*, 2013).

**Plant sample collection:** A field sampling protocol for destructive sampling of under-storey biomass designed by Hairiah (2001) was applied for this study. Accordingly, a 40-by-5 meter vegetation transect was demarcated



randomly within the purposefully selected wetland sites. Then, a one-by-one meter sampling frames were identified within the 40-by-5 m transect. The major vegetation types which were found in the study area were also collected, zipped in plastic bags, carefully labeled and then transported to Addis Ababa University National Herbarium for identification.

**Soil sample collection:** Composite soil samples were collected from the ground to only 60 cm depth (Junbao *et al.*, 2013) since it was reported that carbon profiles rapidly decrease with soil depth in tropical wetlands (Bernal, 2008; Villa, 2014). Composite sample from three soil cores per site was taken to capture variations in organic matter deposition in the area (Bernal, 2008) using standard soil sampling auger. Soil samples were taken from the same sites where plant samples were collected. Each sample was then placed in clean plastic zip-lock bags, carefully labeled and transported for laboratory analysis in ice boxes.

**Qualitative data collection (Questionnaires development):** Qualitative data were collected based on the sampling procedure according to Gemechu Bekele (2010). The first step was identifying the target group, whereby one *kebele* (local name for district) named Bochesa was purposefully selected based on preliminary observations and discussions with key informants. Bochesa kebele was selected because of the following reasons:

- The community residing in the area is very close to the lake and the wetlands, and it was assumed that they knew more about the wetlands since they are natives to the area.
- Due to high human pressure on the natural resources of wetlands, there are visible signs that they are progressively degraded.

Following this, sample size was determined, 10% of household sample size was drawn from the selected kebele. Sample respondents were selected randomly from the households registered as permanent residents of the kebele. According to the information obtained from the kebele administration office,

520 households were living permanently in the kebele, and from this 53 respondents (10% of the total) were selected randomly for this study.

Both primary and secondary data were collected from the target respondents. Primary data were collected through questionnaire surveys (with both open and close ended questions), focus-group discussions (open ended guide questions for purposefully selected community members), and also personal field observations. Available secondary data such as population number of the kebele over the years and the extent of land use types used in this study were also collected.

### **Laboratory analysis and procedures**

**Above-ground biomass and plant organic carbon:** Plant organic matter was determined using ignition method by warming the ground (<2mm), oven dried samples to 550°C for 4 hours. Once organic matter was determined, then organic carbon was obtained using a conversion factor (45%) (USDA, 2007)

**Soil sample analysis:** Physical and chemical parameters were measured according to the soil manual prepared by Kalra and Maynard (1991). Soil temperature was recorded on site at a depth of 60 cm while sampling using soil thermometer. Soil pH and electrical conductivity (EC) were determined using 1:2 and 1:5 Soil-To-Water Extraction Method with a digital HACH multi parameter meter (HQ40d model). Soil moisture was also estimated using oven-drying method. Soil texture was determined using a hydrometer method. To estimate bulk density, soil samples with a known volume were oven dried at 105°C for two days (48 hours). Bulk density was determined by dividing the dried sample to its volume (Kuffman and Donato, 2012).

**Estimation of soil organic carbon concentration:** Soil organic carbon concentration was determined using loss on ignition method (Kuffman and Donato, 2012). Ground Soil samples (<2mm) were placed in a muffle furnace at 550 °C for 4 hours to determine organic matter content of the samples and

the organic carbon content ( $\text{g C kg}^{-1}$ ) was calculated as the organic matter content divided by 1.86 (Kuffman and Donato, 2012).

**Data Analysis:** To analyze the data descriptive statistics (frequency, crosstab, mean and standard deviation) were performed. One-way Analysis of Variance (ANOVA) with Post-hoc test (Tukey) was performed for the detection of differences in carbon sequestration potential within and among different categories of wetland using SPSS software (Version 21).

Bi-variate Correlation Statistics (Pearson) was also performed to determine the strength of relationship between above-ground vegetation biomass and soil organic carbon content as well as soil physico-chemical parameters and soil organic carbon content.

## Results

**Identified vegetation:** According to the National Herbarium at Addis Ababa University, 10 emergent plant species belonging to six families were identified from the samples collected (Table 67).

**Table 59:** Major vegetation types identified from the study sites

| No. | Botanical_Name                                             | Family       |
|-----|------------------------------------------------------------|--------------|
| 1   | <i>Cyperus rigidifolius</i> Steud.                         | Cyperaceae   |
| 2   | <i>Leersia hexandra</i> Sw.                                | Poaceae      |
| 3   | <i>Persicaria senegalensis</i> (Meisn.) Sojak              | Polygonaceae |
| 4   | <i>Schoenoplectus corymbosus</i> (Roem. and Schult.) Rayn. | Cyperaceae   |
| 5   | <i>Echinochloa stagnina</i> (Retz.) P.Beauv.               | Poaceae      |
| 6   | <i>Cyperus papyrus</i> L.                                  | Cyperaceae   |
| 7   | <i>Aeschynomene elaphroxylon</i> (Guill. and Perr.) Taub.  | Fabaceae     |
| 8   | <i>Ageratum conyzoides</i> L.                              | Asteraceae   |
| 9   | <i>Cyperus latifolius</i> Poir.                            | Cyperaceae   |
| 10  | <i>Typha latifolia</i> L.                                  | Typhaceae    |

**Soil physico-chemical parameters:** Mean values for temperature, pH, soil moisture, electrical conductivity, and bulk density recorded are shown in Table 68. Temperature and moisture were inversely related with each other. Soil temperature increased as degradation level of the wetlands increased. Whereas soil moisture decreased as degradation level of the wetlands increased. The highest mean pH value was recorded at the grazing site (9.1) and the minimum mean pH in the moderately degraded wetland (8.2). A minimum value of EC was observed in the degraded wetland whereas the maximum value was observed in the moderately degraded wetland site. Soil texture in almost all the sites had a medium sandy clay texture class; except the soil of cultivated land which was very fine clay.

**Table 60:** Results of some physico-chemical parameters recorded from the study sites (Mean  $\pm$  standard deviation)

| Wetland Categories               | Temp. ( $^{\circ}$ C) | Soil moisture (%) | Soil pH         | Electrical conductivity ( $\mu$ S/cm) | Bulk density ( $\text{gcm}^{-3}$ ) |
|----------------------------------|-----------------------|-------------------|-----------------|---------------------------------------|------------------------------------|
| SS1: Least impacted wetland      | 21.0 $\pm$ 1.095      | 20.1 $\pm$ 6.280  | 8.42 $\pm$ .618 | 275.7 $\pm$ 9.235                     | 1.87 $\pm$ .342                    |
| SS2: Moderately degraded wetland | 21.5 $\pm$ .547       | 19.4 $\pm$ 5.118  | 8.20 $\pm$ .054 | 476.0 $\pm$ 17.88                     | 1.70 $\pm$ .728                    |
| SS3: Degraded wetland            | 22.0 $\pm$ 2.190      | 14.5 $\pm$ 3.234  | 8.86 $\pm$ .027 | 185.9 $\pm$ .054                      | 2.15 $\pm$ .342                    |
| SS4:Grazing land                 | 24.5 $\pm$ .547       | 13.7 $\pm$ 2.536  | 9.11 $\pm$ .887 | 384.0 $\pm$ 19.20                     | 1.84 $\pm$ .232                    |
| SS5: Cultivated land             | 27.5 $\pm$ 1.643      | 5.05 $\pm$ 1.074  | 8.41 $\pm$ .410 | 258.6 $\pm$ 5.201                     | 1.98 $\pm$ .029                    |

Significantly high temperature was recorded in the cultivated land (converted wetland); whereas the least value was recorded in the non-impacted wetland site although the difference was not significant. Soil moisture content was significantly lower in the cultivated land ( $p < 0.05$ ); whereas the highest value was obtained at the least-impacted site ( $p < 0.05$ ). There was no significant difference in bulk density and pH among sites.

**Above-ground biomass:** Above-ground biomass of the sites varied from 122.1 g DW m<sup>-2</sup> (grazing land) to 4410 g DW m<sup>-2</sup> (least impacted wetland) and the highest mean biomass value was recorded at the least-impacted wetland site which is 3252.6 g DW m<sup>-2</sup>. This is followed by moderately degraded wetland, cultivated land (cabbage biomass), degraded wetland and grazing land which accounted for 1193.6, 852.9, 457.7, 146.6 g DW m<sup>-2</sup>, respectively (Fig 76).

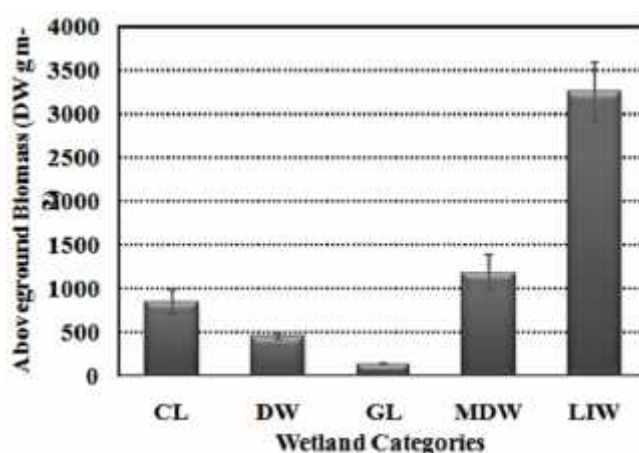


**Figure 75:** aboveground vegetation biomass (DW) of different wetland categories (Note: CL is for cultivated land, DW for degraded wetland, GL for grazing land, MDW for moderately degraded wetland, and LIW for least impacted wetland)

The least-impacted wetland showed significantly higher difference in its biotic contents and other environmental qualities than the other sites at  $p < 0.05$ . There was also a significant difference ( $p < 0.05$ ) between the sites designated as moderately degraded wetland and the grazing land. But no significant difference was observed ( $p > 0.05$ ) among sites designated as degraded wetland, grazing land, and cultivated land.

**Carbon sequestration potentials of the wetlands:** The plant organic carbon content of the study sites varied from 49.2 g C m<sup>-2</sup> to 2066.2 g C m<sup>-2</sup>. The highest mean plant organic carbon content was obtained in the least-impacted site followed by moderately degraded wetland site, converted cultivated wetland, degraded wetland and finally grazing land where plant organic carbon was 1513.6, 526.5, 207.9, 207.8, and 57.9 g C m<sup>-2</sup>, respectively (Fig. 77).

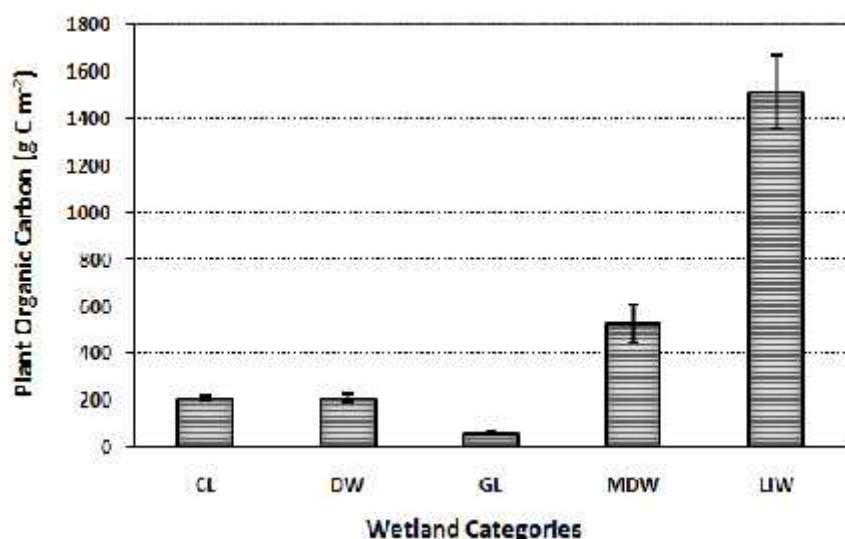


**Figure76:** Mean aboveground plant carbon of different wetland categories (Note: 'CL' is for cultivated land, 'DW' for degraded wetland, 'GL' for grazing land, 'MDW' for moderately degraded wetland, and 'LIW' for least impacted wetland)

Statistically significant differences were observed in the plant organic carbon content of the study sites ( $p < 0.05$ ). There were significantly ( $p < 0.05$ ) higher values of aboveground plant organic carbon in the least-impacted wetland than the other land use types (degradation levels) and moderately degraded

wetland with grazing land. However, there was no significance difference ( $p>0.05$ ) between degraded wetland, grazing land, and cultivated land.

**Soil organic carbon:** The highest mean organic carbon content ( $\text{g C kg}^{-1}$ ) was obtained in the least-impacted wetland site which was about  $67.5 \text{ g C kg}^{-1}$ , followed by the moderately degraded wetland site, grazing site, cultivated wetland site, and degraded wetland site which contained 39.5, 17.3, 14.5, and  $12.9 \text{ g C kg}^{-1}$ , respectively (Fig. 78).

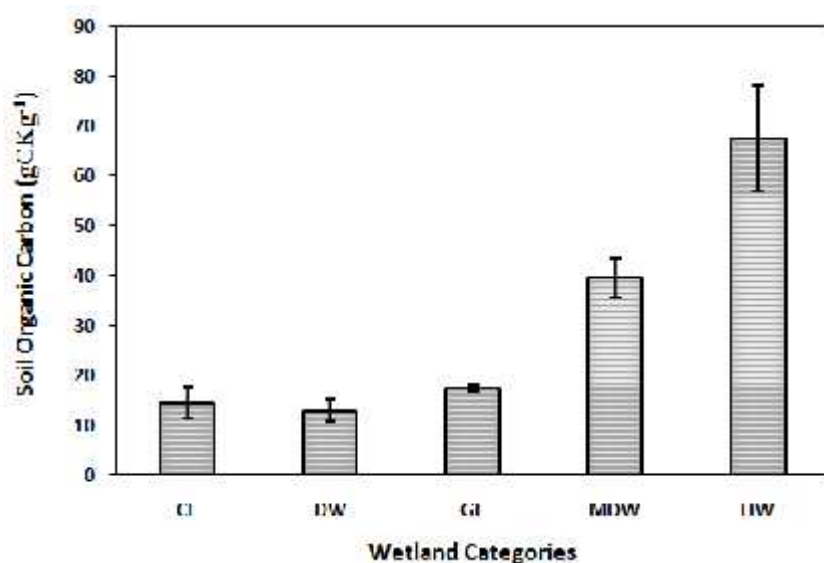


**Figure 77:** Mean soil organic carbon content of different wetland categories (Note: 'CL' is for cultivated land, 'DW' for degraded wetland, 'GL' for grazing land, 'MDW' for moderately degraded wetland, and 'LIW' for least impacted wetland)

There were significant differences ( $p<0.05$ ) between least-impacted wetland and the other land use types. But according to the post-hoc multiple comparison test there was no significant difference ( $p>0.05$ ) among degraded wetland, grazing and cultivated land types.

**Soil organic carbon in relation to aboveground biomass and soil physico-chemical parameters:** In this study, there was a significant positive correlation ( $p < 0.01$ ) between soil organic carbon content and above-ground biomass. As above-ground biomass ( $\text{g DW m}^{-2}$ ) increased, soil organic carbon content ( $\text{g C kg}^{-1}$ ) also increased. The highest value of soil organic content was found in the least impacted wetland site where the aboveground vegetation biomass was also highest.

Soil temperature ( $^{\circ}\text{C}$ ) was negatively correlated with soil organic carbon content which was significant ( $p < 0.01$ ); as soil temperature increased organic carbon content of the soil decreased. But, Soil moisture content was correlated positively with soil organic carbon content ( $p < 0.01$ ). Bulk density, pH, and electrical conductivity of the soils of the various land types were not correlated with soil organic carbon content.

#### 4.5.2 Status and Major Triggering Factors for Wetland Loss

All of the interviewed respondents (100%) and the participants of the focused group discussion agree that wetlands in the area are being encroached from time to time by the local community and other investment activities. Respondents were asked to mention the reasons about the encroachment of Zwai wetlands which included farm land scarcity (58.9 %) forcing them to cultivate by converting wetlands, implying that wetlands do not have owner as “wastelands”. Other reasons were scarcity of grazing land, lack of demarcation, soil fertility of the area, and lack of awareness according to 25.6%, 5.1%, 5.1%, and 2.5% of respondents, respectively.

As shown in Fig. 79, the major triggering factors of wetland loss which are identified by the interviewed respondents and from the focused group discussions was population growth which leads to other associated factors to happen.



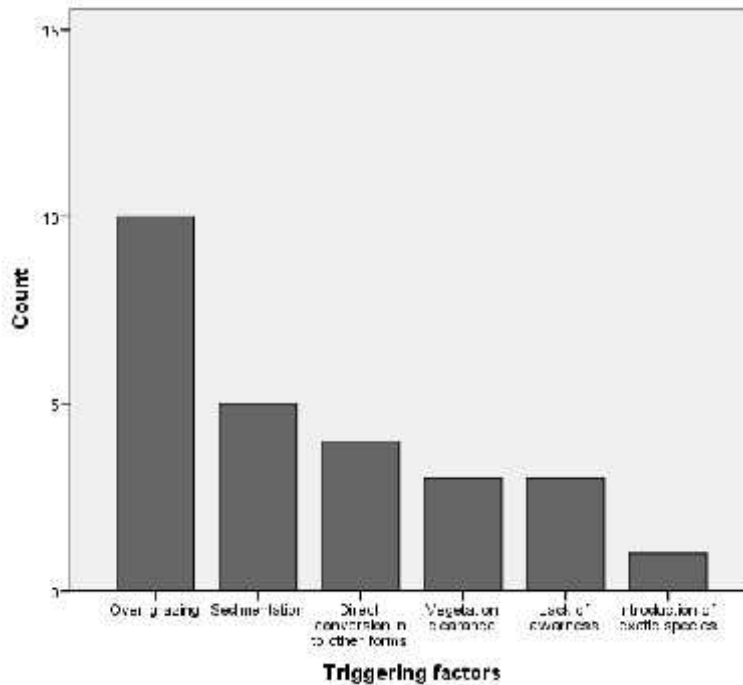


**Figure78:** major triggering factors for the loss of wetlands as identified by the respondents of the study area

In addition to the above, water abstraction for irrigation, eucalyptus plantation, to compensate water shortage caused by climatic factors like shortage of rainfall, expansion of intensive floriculture, regression of lake water level, construction of small dams in the watershed, and deforestation for settlement expansion were also identified as rare factors which are affecting the nature of the wetland in the area.

According to the views of respondents, population increase was the major cause for the above mentioned triggering factor for wetland loss in the area. The data obtained from the Agricultural Bureau of Bochesa Kebele, Zwai, showed that population number has almost doubled in the past five years

(2010-2014). The number of population in the area was 1365 by 2010 and this number increased to 2030 by 2014. However, the agricultural area remains the same so that the community is forced to convert wetlands to other land use forms as it is seen in Fig. 80, below.



**Figure79:** Degradation of wetlands along the shores of Lake Zwai

The responses collected through questionnaires, interviews and focus-group discussions indicated that with regard to how wetlands are sustainably managed, they come up with different opinions. The participants of the focus-group discussions (83.01%) and most of the interviewed respondents believe that wetlands should be conserved for sustainable use of their social, economic, cultural, as well as ecological values these ecosystems provide. These respondents indicated that wetlands should be conserved for sustainable livestock grazing spaces, fish production, biodiversity protection, regulation of local climate such as to moderation of micro-climate, for tourist attraction, recreation, vegetation for house construction, household water source, as buffer zones from erosion by wind and floods. In contrast, 16.98% of the

interviewed respondents believed that wetlands should be converted into other land-use types so as to meet the need of the highly increasing population, especially the landless youth without jobs, to supplement the shortage of grazing area, and for more production to supplement the food shortage in the country. The interviewed respondents were also fully aware of the changes that occurred in their local climate; which showed marked changes in their locality over the past number of years. According to them, some of the changes that were detected and that are still happening in the area are increasing temperature, changes in rainfall availability and variability, changes in wind direction, drought, and occurrence of diseases of livestock both in frequency and intensity. The ranked main reasons for the degradation of the wetlands of Zwai were deforestation (74.4%), expansion of land intensive investments such as floriculture (23.1 %), and general degradation of wetlands (2.5%) as consequences of some provision services of wetlands such as removal of tress, aquatic grasses, etc, for sale in the local market to supplement their family incomes.

Furthermore, when the respondents were asked if they agree or disagree on the idea of converting wetlands into other land-use types, 41.03 % and 12.82% of the respondents strongly disagreed and disagreed, respectively (a total of 53,85% disagreeing on conserving wetlands) (Fig. 81).

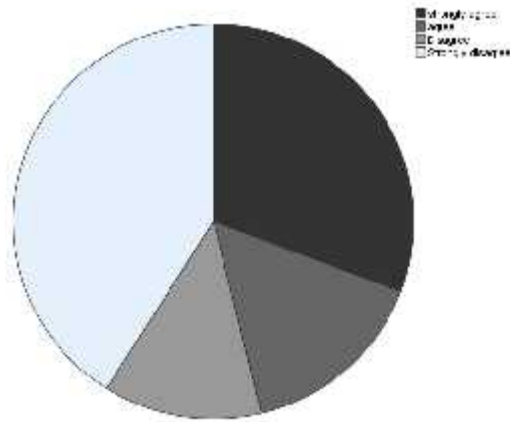


**Figure 80:** Views of the respondents on the conversion of wetlands into other land use types

These respondents said that wetlands should not be converted into other land-use types since these ecosystems are more beneficial than when converted in to other forms, as they are sources of water for the community, and for maintaining their local climate. 30.77% and 15.38% of the respondents strongly agreed and agreed, respectively (i.e., 45.92% agree on conserving wetlands) (Fig. 81).

Finally respondents were asked to rank the five wetland degradation levels (least-impacted wetland, moderately degraded wetland, degraded wetland, grazing land, and cultivated land) based on their general importance (environmental, economic, social, and cultural values) to the community. Accordingly, 66.7 % of the respondents replied that least-impacted wetlands have highest importance to the community followed by cultivated wetlands (20.5 %) and grazing land (12.8 %). Neither of the respondents regarded for moderately degraded and degraded wetland types as important.

## Discussions

Below, variability of carbon sequestration capacities among the investigated different categories of wetlands are discussed.

**Above-ground plant carbon:** Emergent macrophytes form some of the productive plant communities (Jones and Humphries, 2002) and can fix large amounts of atmospheric CO<sub>2</sub> and store carbon in their tissues. In this study, the highest value was recorded in the least-impacted and the moderately degraded wetland sites. This was not unexpected as these areas are visibly good in terms of above-ground vegetation composition due to lesser disturbances as compared to the other sites.

Results recorded in this study were higher than the earlier results reported in “Ethiopian wetlands” by Afework (2013) in the Tekuma Wetlands of Lake Tana Basin (0 to 500 g C m<sup>-2</sup>), but it is almost within the range of other reported studies. Saunders *et al.* (2014) in their study on papyrus wetlands of Lake Navishia, Kenya, found out that above-ground plant carbon ranged from 490 to 5540 g C m<sup>-2</sup>. Jones and Mathuri (1997) and Jones and Humphries (2002) also reported 3600 and 1500 g C m<sup>-2</sup> in the living vegetation of papyrus wetland, respectively in the same study area. Barbera *et al.* (2015) also reported 1900 g C m<sup>-2</sup> and 3800 g C m<sup>-2</sup> were fixed by individual plants of *Cyperus papyrus* and *Cyperus zizanioides*.

Land-use changes such as converting wetlands to grazing and cultivation land by draining and clearing the wetland biomass could result in loss of the above mentioned stored carbon to the atmosphere. According to Saunders *et al.* (2014), clearance of wetlands to other forms could result in significant emissions of CO<sub>2</sub> due to vegetation loss. In this study, the least value found in the grazing land could be due to the effect of heavy livestock grazing on the vegetation cover far beyond the carrying capacity of the land. Reeder and Schuman (2002) clearly stated that above-ground plant carbon decreased as grazing intensity increased. The study by Enriquez *et al.* (2015) also

supported the effect of long-term grazing on plant carbon and the results indicated that overgrazing has an effect on carbon storage and reduced on the average 35% of the total ecosystem carbon pool.

In this study, it was hypothesized that converted cultivated wetland site would have the least value of plant organic carbon. However, it had an average value higher than grazing and degraded wetland sites. This could be due to the seasonal cover of the area by different vegetables that can enhance fixation of carbon dioxide from the atmosphere. This indicated that better management methods of wetlands like seasonal grazing could have a big role in fixing atmospheric carbon into plant tissues.

**Soil organic carbon (SOC):** The highest SOC content was found in the least-impacted site followed by moderately degraded wetland than in other study sites. This could be due to the enhancement of the soil organic matter accumulation from the litter fall of the above-ground biomass and the presence of flooded soil in the areas. Freshwater wetlands are known to serve as carbon sinks due to their high productivity and water logged conditions (Bernal & Mitsch, 2012). Since high soil moisture and lower temperature favor reduction of aerobic decomposition, accumulation of biomass predominates in this site (Chimner & Ewel, 2004; Bernal & Mitsch, 2013; and Villa, 2014).

Results of SOC found in this study are more or less within the range of other results reported in other related studies of Ethiopian wetlands and other worldwide studies on tropical wetlands. In a similar study, Werku (2014) compared the soil carbon sequestration potentials of natural wetlands, semi-disturbed (sedimented), and agricultural land in Fogera wetlands of Lake Tana Basin; and found out that natural wetlands were the best carbon storage areas (See also the works of Bernal (2008) in tropical wetlands of Costa Rica and Eid and Shaltout (2013) in Egypt).

As Ali *et al.* (2006) stated that the conversion of wetlands could lead to loss of atmospheric carbon dioxide from wetland soils by modifying the temperature and water table of the areas which in turn could influence the microbial processes and oxidation of organic matter in the soil. In this study, despite the assumption that converted cultivated land would have the least SOC, it was degraded wetland sites that had the least SOC content. Villa (2014) suggested that it is a combination of factors that enhance CO<sub>2</sub> accumulation in wetlands besides the hydrology and vegetation status. One possible reason for this variation could be the high bulk density of soil (2.15 g cm<sup>-3</sup>) recorded in the soil due to its sandy nature (Table 2). This high bulk density could be an indication of peat loss from the soil (Drexler *et al.*, 2009). Another reason could be the texture of the soil where fine clay may have some role in protecting the SOC. Soils high in clay content are higher in SOM content than sandy soils since there is restricted aeration in fine-textured soils with reducing the rate of organic matter oxidation (McCauley *et al.*, 2009).

The outcome in this study that there is high reduction of organic carbon storage of the soil after a wetland is converted into other land use types such as grazing and cultivated land is also supported by the statement that conversion of wetlands to cultivated fields results in a significant decrease in the total carbon dioxide storage capacity (Nelson *et al.*, 2007). Further, Berhongaray *et al.* (2013) reported that there is 16% reduction of SOC after conversion of a wetland in to cultivated field. Gauangyu *et al.* (2010) also reported the decrease of SOC content by 49.3 %. The former is lower while the latter is almost similar compared to the current study which is approximately 53.01% even though the study area was being cultivated for more than 20 years.

**Soil organic carbon in relation to above-ground biomass (AGB):** The correlation statistics done for this study showed positive relations between AGB and SOC. Many studies have also indicated the same where the above-ground vegetation biomass affects the relative amount of carbon that

eventually falls to the surface of soil. The study by Junbao *et al.* (2013) and Eid and Shaltout (2013) showed that the inputs of plant litter to the soil were correlated positively ( $p < 0.01$ ) with soil organic carbon content.

Although the grazing site had the least above-ground biomass in this study (Fig. 2), it contained better soil carbon than cultivated and degraded wetlands. According to Reeder and Schuman (2002), sometimes high soil organic carbon could be found in grazing sites due to the immobilization of carbon in above-ground biomass and livestock could enhance breakdown and incorporation of litter to the soil.

**Soil organic carbon in relation to physico-chemical parameters:** Other studies conducted in wetlands also corroborate with the present study and found negative correlations among SOC and temperature (Ali *et al.*, 2006; Kirschbaum, 1995; Jobbagy and Jackson, 2000), and a positive correlation among SOC and water content (Ali *et al.*, 2006; Muniz *et al.* 2014; Murillo *et al.*, 2015; Villa, 2014; Wang *et al.*, 2011).

This study showed that as temperature of the soil decreases, SOC content increases since lower temperature limits decomposition by affecting soil microbial activities; leading to accumulation of organic matter, which is also supported by the works of Bernal (2008); Bernal and Mitsch (2012 and 2013); Franzuleberies *et al.* (2011); Jones and Humphries (2002) and Villa (2014).

In this study, soil pH was not correlated with SOC. Unlike soil temperature and water content, it is not a major factor which can affect SOC (Wang *et al.*, 2011) although the increase in pH could enhance mineralization of SOC by stimulating soil microbes (Guangyu *et al.*, 2010).



**Status of the wetlands and final recommendations of the community on wetland management:** Most of the respondents in this study mentioned that Lake Zwai shore area wetlands are being depleted from time to time due to both climatic as well as anthropogenic pressures especially the later one is clearly observed in the area. As a result, this wetland loss and other associated problems are resulting in micro-climatic changes in the area. Especially the year 2015 was a disastrous year for the surrounding community of Lake Zwai and in general to Ethiopia due to severe shortage of rainfall which lead to serious droughts (El Niño) and this has endangered the livelihoods of the local farming people. This could be due to many climatic and human mediated impacts, especially environmental degradation. The interviewed respondents are also fully aware about the changes that occurred in their local climate. Some of the changes that were detected by the respondents were increases in temperature, decrease in rainfall availability and variability at the seasons when they were expected, changes in wind direction, drought, and occurrence of disease in livestock.

Although there are many reasons that pushed the community to encroach wetlands, such an action would be a short term gain and a long term loss. It is therefore recommended that it is better to start community-based participatory wetland management practices like that of forest management practices which are being practiced in some parts of this country and have started to become successful showcases.

But in general, most of the respondents recommended the following measures could be taken to put in place sustainable management of wetlands.

- The government should work on awareness creation activities on the community through education.
- Wetlands should be conserved for enhancing and protecting the biodiversity.

- Watershed management should be intensified so as to decrease the load of sediment that enters into the lake by afforestation programs, soil and water conservation activities and other related actions that have shown positive results in some parts of Ethiopia.
- The community and different stakeholders should own the wetlands in their surrounding and should be responsible for their action and work together to sustainably manage the wetlands.
- There should be a clear demarcation between wetlands and other land-use types so that people can't degrade and convert wetlands as they will.
- The government, the local administration and communities should start restoration activities based on the interests of the local community for promoting wetland management.
- Wetlands should be conserved based on the interest of the community on the basis of economically viable plus environmentally sustainable ways.

### **Conclusions and recommendations**

From this study, it can be concluded that a high reduction of organic carbon storage of both the soil organic carbon and above-ground plant carbon were observed after wetlands were converted and degraded into other land-use types such as grazing and cultivated land. In addition, significantly positive correlations were found among soil organic carbon contents and above-ground vegetation biomass, and soil moisture; whereas negative correlations were observed between SOC content and temperature.

Wetlands of the study area, namely, Zwai wetlands, are declining in surface area over time due to many reasons. This is also having a significant impact on ecological values of the wetlands including their carbon sequestration potentials. It is therefore recommended that special attention should be given

to improve the management of wetlands in the area so as to enhance their capacity to mitigate carbon emissions. Such management schemes should however be realistic by considering the cost-benefit analysis of processing wetland products (e.g. vegetation, fishes, etc.) by local populations and allowing sufficient regeneration time and space for the sustainability of wetlands.

### Acknowledgments

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#### Appendix: Definition of different wetland categories selected for sampling

| Wetland types for sample collections | Characterization of studied wetlands in this study                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Least-impacted wetlands</b>       | These are wetlands in which human and animal disturbance are very low. There is no direct animal grazing and human pressure on these sites. As a result, they have a good volume of aboveground vegetation biomass and undisturbed soil. These areas are saturated with water since their topography is very close to the lake, and are mostly covered by two dominant emergent vegetation i.e. <i>Typha latifolia</i> (Local name; Filla) and <i>Echinochloa stagnina</i> (Local name; Kesme). Other vegetation types like <i>Schoenoplectus corymbosus</i> (Local name; Chufo), <i>Aeschynomene elaphroxylon</i> , and <i>Ageratum conyzoids</i> are also found rarely. So, it is assumed that high level of biomass, good vegetative cover or specialized vegetation types and hydric soil are common characteristics of these wetlands so that highest carbon store was expected both in the vegetation as well as in the soil compared to the other types. |

| Wetland types for sample collections | Characterization of studied wetlands in this study                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Moderately degraded wetlands</b>  | These are wetland sites in which there is human and animal disturbance to some degree of extent compared to the least-impacted sites. There is harvesting of emergent vegetation especially the dominant vegetation of <i>Typha latifolia</i> (Local name; Filla), <i>Cyperus papyrus</i> , and <i>Cyperus latifolius</i> (Local name; Ketema) to some extent by the people although it is not that much disturbed by livestock. So, due to this human disturbance, it was assumed that these wetlands lost their biomass volume and soil organic matter content to some degree, but still they are found in better condition than the degraded sites as they have already a good vegetation cover and hydrology which can moderate the soil organic carbon store. |
| <b>Degraded wetlands</b>             | These sites are still wetlands, but are highly affected by human pressure compared to the least-impacted and moderately degraded wetlands. They have less vegetation cover, especially composed of some grass groups of <i>Cyperus rigidifolius</i> (local name; kuni), <i>Leersia hexandra</i> (local name; sar), and <i>Persicaria senegalensis</i> (Local name; Obeta). Emergent vegetations like <i>Schoenoplectus corymboses</i> (Local name; Chufo) and <i>Typha latifolia</i> (Local name; Fila) are also rarely found in this wetland type. Compared to the moderately degraded wetlands, there is a very high human disturbance and many animals graze on these sites especially during the dry season.                                                   |
| <b>Grazing land</b>                  | These wetlands were highly (severely) degraded due to over-grazing. As a result, they are assumed to loss their wetland properties due to the high disturbances of the soil and the vegetation due to the high stocking density of livestock. These areas are mostly dominated by grass species of <i>Cyperus rigidifolius</i> (local name; Kuni) and <i>Leersia hexandra</i> (local name; Sar) which are grazed to the ground. Hence, their biomass production was expected to be less with lower carbon sequestration potential in the soil due to less input of organic matter from the vegetation and due disturbance of the soil profile by livestock.                                                                                                        |
| <b>Cultivated land</b>               | These lands were used to be wetlands in the past, but they were converted in to agricultural land for production of some vegetables such as cabbage, lettuce, and onions by the surrounding community. They cultivate three times a year in these areas. As a result, these lands lost the characteristics of wetland almost completely.                                                                                                                                                                                                                                                                                                                                                                                                                           |



## Chapter 14

### **Isolation and Identification of major bacteria from three Ethiopian rift valley lakes live and processed fish, and water samples: Implications in sanitary system of fish products**

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#### **Abstract**

Pathogenic bacteria of fishes, which are dominantly gram-negative and zoonotic, are growing threats to multiple aspects of human existence. They affect the wellbeing of fish species and aquatic biodiversity or ecosystem, erode the fishery industry and food security, and are direct human health risks warranting serious attention. This cross-sectional survey was designed to detect major gram-negative enteric bacteria in live-caught fish (n=210), processed fish (n=20), and water samples (n=24) of three Ethiopian rift-valley Lakes Hawassa, Langano and Zwai. Live-caught naturally infected and apparently healthy fish intestine, kidney and liver tissues were sampled. Physicochemical water quality tests were done. The mean values of physicochemical parameters were within the optimum or at least tolerance range of most freshwater fish. Out of a cumulative 674 samples, bacteria were isolated from 262 (38.87%) with significant difference in the distribution of some isolates with respect to sample origin, category, or type. Of these 262 isolates, 213 (81.3%) were gram-negative belonging to 31 species based on

morphology and a range of biochemical tests. The prevalence of gram-negative bacteria the lake water, processed fish and live fish samples were 50% (12/24), 45% (9/20) and 91.4% (192/210), respectively, with statistically significant variations. Overall, the most dominant bacterium was *E. coli* (detected in 15 samples), followed by *E. tarda* (12), *M. morganii* (12), *S. maltophilia* (12) and *salmonella* spp (12). Whereas, all positive live fish were positive at least for one isolate of all of these species, namely, *A. baumannii*, *A. baylyi*, *A. soli*, *A. hydrophila*, *A. jandaei*, *E. aerogenes*, *E. cloacae*, *E. hormaechei*, *E. fergusonii*, *M. morganii*, *P. carotovorum*, *P. mirabilis*, *P. alcalifaciens*, *P. rustigianii*, *P. stuartii*, *P. entomophila*, *P. fluorescens*, *P. hunanensis*, *P. putida*, *S. marcescens* and *S. maltophilia* were not detected in any of the water samples. On the other hand, only *E. coli*, *K. pneumonia* and *E. aerogenes* and *Salmonella* spp. were detected in processed fish. The isolates common to all the three sample types were *E. coli*, *K. pneumonia* and *Salmonella* spp. Majority of the isolates (87(41.43%)) were from fish intestine followed by kidney (54(25.7%)) and liver (51(24.3%)) with statistically significant variation. Detection of total coliforms especially in processed fish indicates the potential danger of passage of these pathogens and/or their toxins to human via infected and/or contaminated fish products. Human infection by pathogenic fish bacteria and food poisoning is possible through contamination of fish product in fish production chain due to inadequate handling, poor hygiene and contact with contaminated lake water as well as infected live fish. Therefore, fishermen, producers, consumers and all other stakeholders need to be cautious during handling, processing and consumption of fish from the study lakes and work towards improving their sanitary status.

**Keywords:** Fish bacteria, gram-negative bacteria, physico-chemical parameters, rift-valley lakes

## Introduction

Fish plays an important role in the human diet with an ever-growing need globally. World fish production has increased dramatically during the past 60 years, to around 179 million tons in 2018 with a value of \$401 billion and global fish consumption also increased from 9.0 kg per capita in 1961 to 20.5 kg in 2018 (FAO 2020). This is a tremendous change in the fishery industry. Ethiopia depends on its inland lakes and rivers for fish production, and has over 200 edible fish species with annual fish production potential of about 94,500 thousand tons (Hebano and Wake 2020) although the potential remains much higher.

From a broader perspective, fish is among the top components of aquatic biodiversity and is closely connected with several sectors of human socioeconomic life. However, fish health is a factor of aquatic ecosystem dynamics. Pathogenic fish bacteria, among other variables, disturb ecosystem dynamics and affect aquatic biodiversity and fish wellbeing; erode the fishery industry and food security. Moreover, fish consumption is associated with some serious bacterial infections mainly due to poor sanitary facilities and practices around water systems, unhygienic conditions in fishing and fish production chain. In particular, gram-negative bacteria like *Aeromonas* spp., *Flavobacterium* spp., *Pseudomonas* spp., *Edwardsiella* spp., *Vibrio* spp., *Acinetobacter* spp. and *Plesiomonas shigelloides* are a great threat to fish production (Pekala-Safińska 2018 and Ayoub *et al.* 2021).

Most of these bacterial fish pathogens are zoonotic with a potential to infect humans, and some of them are serious (Haenen *et al.* 2021). Besides, fish pathogenic bacteria influence fish population with substantial concerns for aquatic biodiversity and fish industry, and food security. Studies on fish microbial community provide a clue about the hygienic status of the environment as water quality and fish diseases are closely linked (Vatsos *et al.* 2010). Detection of fish pathogenic bacteria including novel ones, or change

in the water microflora is an important indicator of environmental contamination. This is due to negative ecological changes in the natural fish habitat. Progressive degradation of aquatic ecosystems is due to human activities associated with urbanization, industrialization, and agriculture resulting in the release of sewages of different nature and origin (Bashir *et al.* 2020). Additional factor that contributes to the emergence of novel fish pathogenic bacteria is unmanaged use of antibiotics and disinfectants (Davies and Davis 2010). Non-human factors like climate change and unpredictable natural disasters seriously affect water bodies and all life therein (Khatri and Tyagi 2015 and Akhtar *et al.* 2021).

The risk of contamination of water bodies, particularly inland closed systems like the Ethiopian rift-valley lakes, is particularly increasing due to clearly visible extensive nearby development activities, urbanization and to certain extent frequent visits for various reasons including international ecotourism. Therefore, assessment of the physicochemical components of aquatic ecosystems and their bacterial community including inside resident fish is essential to monitor fish health, product quality and related potential environmental and public health challenges. Reports on bacterial pathogens in freshwater fish, water physicochemical parameters and bacteriological quality of the Ethiopian rift-valley lakes are scant. Hence, this study was aimed to assess the occurrence, distribution, prevalence and identity of major gram-negative enteric bacteria from live-caught and commercial processed fish product of three common fish species - Nile tilapia (*Oreochromis niloticus*), common carp (*Cyprinus carpio*) and catfish (*Clarias gariepinus*) - and water samples from three Ethiopian rift-valley (inland) Lakes Lake Hawassa, Lake Langanoo and Lake Zwai in Ethiopia.

## Methods

**The Study area:** This study was based on three Ethiopian rift-valley Lakes, Lake Zwai, Lake Langanoo and Lake Hawassa, which are well-known for

their common fish catches and tourist destinations. These Lakes are some 163, 200 and 275 km to the south of Addis Ababa respectively (Fig. 82). Morphometric and other characteristics of the Lakes are shown in Table 69, below.

**Table 61:** Morphometric and other characteristics of Lakes Zwai, Langano and Hawassa (Wood and Talling 1988, Gebre-Mariam *et al.* 2006 and Brook Lemma and Hayal Desta 2016)

| Description                       | Zwai                           | Langano                        | Hawassa                        |
|-----------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Altitude (m)                      | 1635                           | 1570                           | 1680                           |
| Location                          | 7°51'-8°07'N<br>38°43'-38°56'E | 7°32'-7°43'N<br>38°42'-38°50'E | 6°58'-7°07'N<br>38°22'-38°29'E |
| Shoreline (km)                    | 102                            | 7.5                            | 52                             |
| Length (km)                       | 29                             | 23                             | 17                             |
| Width (km)                        | 20                             | 16                             | 11                             |
| Surface area (km <sup>2</sup> )   | 440                            | 230                            | 80                             |
| Catchment area (km <sup>2</sup> ) | 7025                           | 1600                           | 1250                           |
| Mean depth (m)                    | 2.5                            | 17                             | 10                             |
| Maximum depth (m)                 | 9                              | 46                             | 22                             |
| Volume (m <sup>3</sup> )          | 11 x 10 <sup>9</sup>           | 3.8 x 10 <sup>9</sup>          | 1.3 x 10 <sup>9</sup>          |
| Salinity (g/L)                    | 0.349                          | 1.88                           | 1.008                          |

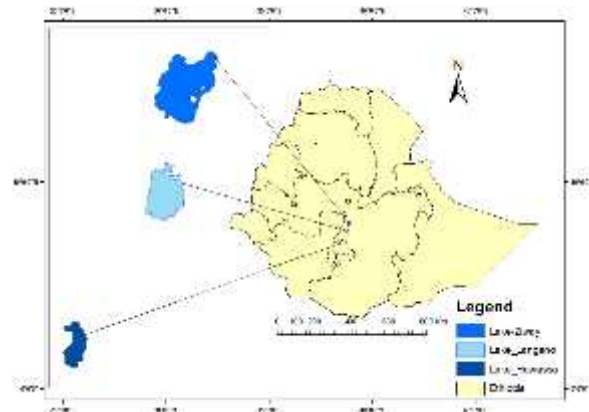


**Figure81:** The study area: Lake Zwai (above), Lake Langan (middle) and Lake Hawassa (below)

### Sample size

The sample size used to estimate the prevalence of bacterial infections in live fish samples was determined using the formula  $n = \frac{Z^2 P(1-P)}{d^2}$  (Daniel and Cross 2013), where 'n' is the sample size, 'Z' the confidence interval (1.96), 'P' the average prevalence estimate of 16.5% calculated from a review report in Ethiopia (Yimer 2000), and 'd' the expected error (0.05).

### Study design and sampling strategy

The study design was cross-sectional and its period was from February to August 2021. For sampling, the three Lakes were selected purposively that the Lakes are known for their common fish catches and from which fish are continuously harvested for subsistence and cash (Bezabeh 2021). Different sampling points of each Lake were used to measure physicochemical parameters, and collect live fish and water samples.

Overall, 12 sampling sites, four from each Lake, were selected guided by the available information. The sampling points are considered major fishing

grounds along the shorelines. Accordingly, *Amora Gedel* (S1), *Haile Resort Area* (S2), *Inlet of Tikur Wuha River* (S3) and *Referral Hospital Area* (S4) were sites of Lake Hawassa. *Dole* (S1), *O'etu* (S2), *Wabi Shebelle* (S3) and *Yakona* (S4) were sites of Lake Langanoo; and *Abosa* (S1), *Bochessa* (S2), *Cafeteria* (S3) and *Wasiko* (S4) were sites selected at Lake Zwai. These sites were located at different directions of the Lakes and were about 3-7 km apart. Thus, the sites were assumed to represent each lake.

### **Water samples for nutrient and bacteriological analysis**

The on-spot-checkable water chemistry parameters were tested *in situ* using routine methods (WHO 2017). Temperature, electrical conductivity (EC) and dissolved oxygen (DO) were measured using temperature meter (YSI model 33 S-C-T meter, USA), conductivity meter (JENWAY, Multi-3410, UK) and multi parameter (Multi-3410, Germany) respectively. The pH was recorded using a digital pH meter (HI-99130, Italy).

Surface water samples from each sampling point were collected into sterile glass bottles (100ml) as per standard sampling procedure for lake or stream surface water chemistry for nutrient content testing (Robert 2012) and bacteriological analysis (SAB 1957 and Holt *et al.* 1994). The water samples were kept dark, packed, and refrigerated. For live fish sampling, a random sampling technique was applied to represent the three target fish types (the tilapia, common carp and catfish). In case of external disease occurrence, diseased fish were purposively selected. The fish were drawn from the peripheral, mid and central regions of the sampling points using fishing boats and gears of local fishers.

### **Fish samples**

The live fish samples were inspected for external abnormalities, and were grouped into apparently healthy and clinically sick. The fish were euthanized by cervical dislocation in the fish's normal water without using anesthesia.

Trained individuals practiced the technique using appropriate equipment. Cervical dislocation is among the methods recommended for fish sacrifice as it is relatively simple and effective for not big fish Close *et al.* 1994). As our fish were small to medium in size, they were killed by inserting a rod or thumb into the mouth, holding with the opposite hand and displacing it dorsally. Death was recognized by cessation of movement, and confirmed by cessation of respiration (opercular movement) and cessation of heartbeat (palpation); and finally by destruction of the brain. The samples were separately packed in sterile plastic bags and were shipped to *Batu Fisheries and Other Aquatic Life Research Center* located at Batu town (formerly Zwai), near Lake Zwai. The fish were dissected under aseptic conditions using a sterile dissecting scissor by following established protocol (CAAHVD 2021 and Jenkins, *et al.* 2014) and standard operating procedures of bacteriology (SAB 1957 and Holt *et al.* 1994).

Examination of the internal fish anatomy was made by observing for any abnormalities including position, size, color and other signs of damage. The digestive tract, gonads and visceral organs were removed by cutting the esophagus and disconnecting them from the kidneys. Using sterile scalpel blade or forceps, tissue samples of the kidney, intestine and liver were aseptically transferred to sterile bottles (100ml) with physiological saline, and were homogenized for bacteriological analysis (SAB 1957).

Similarly, about 10g muscle was cut from processed fish in Batu town fish processing center using a sterile knife, kept in sterile universal bottles (100ml), and homogenized with 10ml physiological saline solution. From the homogenized samples of both live and processed fish, 1ml aliquot was drawn and further homogenized in a clean, dry sterile beaker containing 9ml of distilled water to have 1:10 dilution (Holt *et al.* 1994).

Finally, all the three sample types (water, live fish and processed fish) were packaged and transported on ice to Health Biotechnology Laboratory of



Institute of Biotechnology, Addis Ababa University, and were stored at 4°C for nutrient and bacteriological analysis.

### **Water nutrient content analysis**

The nitrate content of the transported water samples was determined using the sodium salicylate method and phosphate by ascorbic acid method using UV-visible spectrophotometer (Lambda, CE1021, and Australia).

### **Bacteria culture and colony morphology**

All bacteriological experiments were performed following Society of American Bacteriologists *Manual of microbiological methods* (SAB 1957), *Bergey's manual of determinative bacteriology* (Holt *et al.* 1994) and the respective media manufacturer's instructions. It was under complete aseptic conditions. All incubations were for 24 hours at 37°C.

First, sample swabs were spread or streaked across nutrient agar medium (Oxoid, England) and incubated under aerobic condition. Then, specific colonies were picked-up and inoculated on selective and differential media Xylose Lysine Deoxycholate (XLD) agar (HIMEDIA, India), and incubated further. Suspected bacterial colonies were picked-up, inoculated into tryptone soy broth (HIMEDIA, India), and incubated. Colony morphology like form, elevation, margin, surface and pigmentation were examined. Colony color was determined by visual inspection of bacterial cell suspensions using fresh culture. The colonies were screened microscopically using simple and differential (gram) staining. The morphologically presumptively identified isolates were stored at -20°C in 50% glycerol (Fine Chemical, Ethiopia) using 1.8ml cryovial (IMEC, China) for biochemical identification.

### **Biochemical characterization**

All the media used in the tests were from HIMEDIA, India. The tests began with inoculating respective media with 24-hour-old pure culture colonies. All incubations were at 37°C for 24 hours and the expected color changes

confirmed test positivity. Briefly, Indole production was tested by inoculating 10ml of Dev tryptophan broth, incubating and adding 2-3 drops of indole reagent. Methyl red (MR) test was conducted by inoculating 10ml of MR Voges-Proskauer (MR-VP) medium, incubating, and adding 2-3 drops of 0.05% MR. Voges-Proskauer (VP) test was done by inoculating 10ml of MR-VP medium, incubating, and adding 2-3 drops of 5%  $\alpha$ -naphthol followed by 40% of KOH and shaking and leaving it open for an hour.

For catalase test, a small amount of bacterial colony was transferred to clean glass slide using a sterile loop and a drop of hydrogen peroxide was added, and the formation of bubbles was checked for. For citrate utilization test, Simmons citrate agar slant was inoculated and incubated. Hydrogen sulfide or triple sugar iron (TSI) test was done by inoculating TSI by first stabbing through the center of the medium to the bottom of the tube and then streaking the surface of the agar slant, and incubating. Similarly, urea production was tested using Christensen's Urea Agarslant. Sugar fermentation test was conducted using sugar broth medium prepared by mixing 1g peptone, 0.3g meat extract, 0.5g table salt, 0.5g sugar and 0.008g phenol indicator in 100ml distilled water. Three tubes having three different sugars (glucose, sucrose, lactose) in the broth medium were inoculated, and incubated.

### **Data analysis**

Bacterial infection status of the different sample types was determined and the proportion of infected samples/isolates was compared between various categories using the Chi-squared test. Bacterial species diversity in different sample types was compared using one-way analysis of variance (ANOVA). Statistical analysis was performed using IBM SPSS software version 20 (IBM, Chicago, USA) and  $p < 0.05$  was considered statistically significant.

### **Results**

#### **Sample type and total number**

The sampled live-caught fish were 210. Of these, 42(20%) had evident external health problems and the rest were apparently healthy both externally and after dissection. In terms of species, 105 were tilapia (*O. niloticus*), 60 common carp (*C. carpio*) and 45 catfish (*C. sgariepinus*). Overall, 90, 50 and 70 of the fish were from Lake Zwai, Langano and Hawassa respectively. The diseased fish were 22 tilapia (13 from Lake Hawassa and 9 from Zwai) plus 20 carps (11 from Lake Zwai and 9 from Hawassa). Intestine, kidney and liver tissue samples were taken from each fish making the number of samples of live fish origin 630. The size of processed fish samples was 20. The total number of water samples was 36. That is, duplicate samples from each 4 sampling points of each lake making 24 samples for bacteriological analysis, and additional 12 samples from each point of each lake for water chemistry. Hence, the overall sample number undergone bacteriological analysis was 674.

### Physicochemical Parameters

The mean pH values of the three Lakes were nearly similar ranging 7.91-8.68. The temperature of Lake Hawassa was higher (25.8°C) than that of the other two that had the same measure. Lake Zwai had the lowest OD ( $3.93 \pm 0.18$  mg/ml) and Hawassa the highest ( $6.27 \pm 0.90$  mg/ml). The highest EC ( $\mu\text{S/cm}$ ) was that of Lake Hawassa ( $1673.5 \pm 0.48$ ) followed by Langano ( $1447 \pm 5.70$ ) and the least Zwai ( $289.5 \pm 14$ ). It is notable that the EC of Lake Zwai was fivefold below that of Hawassa. All records including for nitrate were highest in Lake Hawassa and least in Zwai except for pH. The highest mean phosphate level was for Lake Langano followed by Hawassa and Zwai with all the three lakes having higher values than the standard limit. However, all the measured physicochemical parameters of the three Lakes (Table 70) were at optimum level or at least within the tolerance range of most freshwater fish species.

**Table 62:** Mean SD values of physico-chemical parameters of four different sampling sites of Lakes Hawassa, Langano and Zwai (DO: dissolved oxygen and EC: electrical conductivity)

| Hawassa        | pH               | Temp., °C         | DO, mg/l         | EC, µS/cm         | NO <sub>3</sub> <sup>-1</sup> , mg/l | PO <sub>4</sub> <sup>-3</sup> , mg/l |
|----------------|------------------|-------------------|------------------|-------------------|--------------------------------------|--------------------------------------|
| S1             | 8.86±0.04        | 24.6±0.10         | 5.66±0.05        | 1961±1.90         | 4.33±0.40                            | 1.31±0.10                            |
| S2             | 9.12±0.05        | 24.1±0.10         | 6.84±0.20        | 2156±1.40         | 4.37±0.50                            | 1.44±0.04                            |
| S3             | 5.74±0.04        | 25.8±0.80         | 6.78±0.40        | 741±3.10          | 3.12±0.20                            | 1.96±0.03                            |
| S4             | 7.92±0.10        | 28.7±0.10         | 5.82±0.90        | 1836±2.60         | 3.72±0.40                            | 0.42±0.06                            |
| <b>Average</b> | <b>7.91±0.10</b> | <b>25.8±0.80</b>  | <b>6.27±0.90</b> | <b>1673.5±487</b> | <b>3.88±0.60</b>                     | <b>1.28±0.90</b>                     |
| <b>Langano</b> |                  |                   |                  |                   |                                      |                                      |
| S1             | 9.14±0.04        | 24±0.51           | 4.99±0.18        | 1522±3.20         | 2.46±0.27                            | 2.92±0.41                            |
| S2             | 9.40±0.05        | 26±0.48           | 5.47±0.21        | 1717±4.90         | 2.83±0.31                            | 4.48±0.27                            |
| S3             | 6.02±0.04        | 19±0.39           | 4.79±0.35        | 902±1.80          | 2.44±0.28                            | 2.46±0.29                            |
| S4             | 8.20±0.10        | 22±0.54           | 5.16±0.59        | 1647±7.40         | 2.31±0.26                            | 2.34±0.31                            |
| <b>Average</b> | <b>8.19±0.09</b> | <b>22.75±0.43</b> | <b>5.10±0.54</b> | <b>1447±5.70</b>  | <b>2.51±0.29</b>                     | <b>3.65±0.44</b>                     |
| <b>Zwai</b>    |                  |                   |                  |                   |                                      |                                      |
| S1             | 8.61±0.12        | 23±0.49           | 4.32±0.31        | 281±11            | 0.17±0.12                            | 0.63±0.86                            |
| S2             | 8.84±0.58        | 22±0.56           | 4.10±0.22        | 362±92            | 0.48±0.04                            | 0.76±0.06                            |
| S3             | 8.60±0.09        | 22±0.28           | 2.8±0.30         | 236±43            | 0.96±0.24                            | 0.97±0.08                            |
| S4             | 8.67±0.10        | 23±0.11           | 4.5±0.28         | 279±56            | 0.25±0.11                            | 0.21±0.04                            |
| <b>Average</b> | <b>8.68±0.11</b> | <b>22.50±0.36</b> | <b>3.93±0.18</b> | <b>289.50±14</b>  | <b>0.46±0.14</b>                     | <b>0.64±0.81</b>                     |

### Morphology of the isolates

The morphological characteristics of the bacterial isolates were determined using Gram staining, bacterial colony formations and morphology bacterial cells. Colonies of the isolates were found to be different in their form, elevation, margin, surface, colour and optical characteristics. On the basis of colony morphology, all strains were short rod and non-spore formers (Figs. 84 and 85).

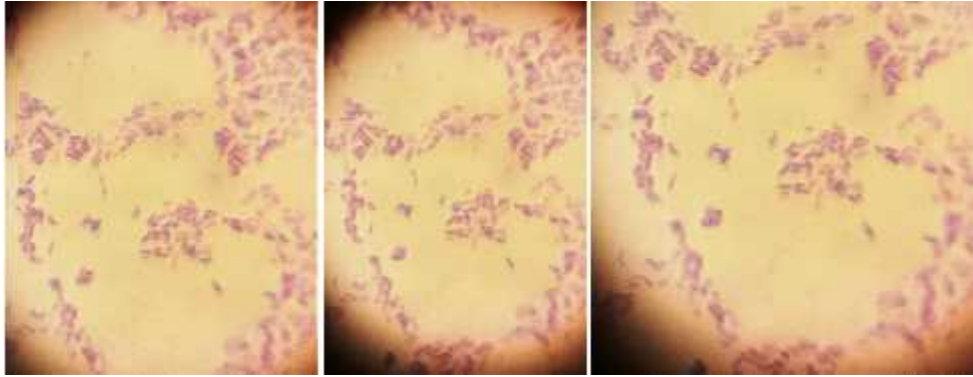


**Figure 82:** Selected microscopic morphology of gram-negative rods isolated from all samples



**Figure 83:** selected colony morphology of gram-negative rods isolated from naturally infected fish on SLD agar

### Bacterial Isolates

Among the 674 samples, 262(38.87%) bacteria were detected and 213 were confirmed as gram-negative isolates. The gram-negative bacteria were further tested and identified into 31 species. The prevalence of gram-negative bacteria among water, processed fish and live fish samples were 50% (12/24), 45% (9/20) and 91.4% (192/210), respectively. The difference was statistically significant ( $p < 0.0001$ ). *E. coli* was the dominant species with 15 isolates (12 from live-caught fish, 2 processed fish, 1 water samples) followed by 12 *E.*

*tarda* (10 live fish, 0 processed fish, 2 water sample)), 12 *Salmonella* spp. (7 live fish, 4 processed fish, 1 water sample), 12 *M. morganii* (12 live fish, 0 processed fish, 0 water sample)), 12 *S. maltophilia* (12 live fish, 0 processed fish, 0 water sample)) and 11 *A. veronii* (10 live fish, 0 processed fish, 1 water sample).

The other gram-negative bacteria were *Proteus mirabilis*, *Aeromonas hydrophila*, *Providencia alcalifaciens*, *Pseudomonas entomophila*, *Aeromonas jandaei*, *Acinetobacter soli*, *Enterobacter hormaechei*, *Klebsiella pneumoniae*, *Pseudomonas putida*, *Shigella flexneri*, *Acinetobacter baylyi*, *Enterobacter cloacae*, *Providencia rustigianii*, *Pseudomonas mosselii*, *Serratia marcescens*, *Aeromonas sobria*, *Citrobacter braakii*, *Citrobacter freundii*, *Pectobacterium carotovorum*, *Acinetobacter baumannii*, *Escherichia fergusonii*, *Providencia stuartii*, *Pseudomonas hunanensis* and *Pseudomonas fluorescens*.

While all of the above species have been isolated from live fish samples, *A. baumannii*, *A. baylyi*, *A. soli*, *A. hydrophila*, *A. jandaei*, *E. aerogenes*, *E. cloacae*, *E. hormaechei*, *E. fergusonii*, *M. morganii*, *P. carotovorum*, *P. mirabilis*, *P. alcalifaciens*, *P. rustigianii*, *P. stuartii*, *P. entomophila*, *P. fluorescens*, *P. hunanensis*, *P. putida*, *S. marcescens* and *S. maltophilia* were not detected in any of the water samples. Only *E. coli*, *K. pneumoniae* and *E. aerogenes* (the common fecal coliforms) and *Salmonella* spp. were detected in processed fish samples. *E. coli*, *K. pneumonia* and *Salmonella* spp were detected in all the three sample types.

Bacteria isolated from lake water samples but not from processed fish, were *A. sobria*, *A. veronii*, *C. braakii*, *C. freundii*, *E. tarda*, *P. mosselii* and *S. flexneri*. Conversely, *E. aerogenes* was identified from processed fish but not from water samples (Table 71). The distribution of individual bacterial species was not statistically significant with respect to sample type.

**Table 63:** The number and proportion of positive samples for Gram-negative bacteria from water (N = 24) and live fish (N = 210) of Lakes Hawassa, Langano and Zwai and processed fish samples (N = 20) from Batu (Zwai) town

| Isolated bacteria       | Sample type (n =262) |                  |                       | Total     |
|-------------------------|----------------------|------------------|-----------------------|-----------|
|                         | Water, n (%)         | Live fish, n (%) | Processed fish, n (%) |           |
| <i>A. baumannii</i>     | 0(0.0)               | 3 (1.43)         | 0                     | 3 (1.15)  |
| <i>A. baylyi</i>        | 0(0.0)               | 5 (2.38)         | 0                     | 5 (1.9)   |
| <i>A. soli</i>          | 0(0.0)               | 7 (3.33)         | 0                     | 7 (2.67)  |
| <i>A. hydrophila</i>    | 0(0.0)               | 9 (4.3)          | 0                     | 9 (3.44)  |
| <i>A.jandaei</i>        | 0(0.0)               | 7 (3.33)         | 0                     | 7 (2.67)  |
| <i>A. sobria</i>        | 1 (4.2)              | 3 (1.43)         | 0                     | 4 (1.53)  |
| <i>A. veronii</i>       | 1 (4.2)              | 10 (4.76)        | 0                     | 11 (4.2)  |
| <i>C. braakii</i>       | 1 (4.2)              | 3 (1.43)         | 0                     | 4 (1.53)  |
| <i>C. freundii</i>      | 1 (4.2)              | 3 (1.43)         | 0                     | 4 (1.53)  |
| <i>E. tarda</i>         | 2 (8.3)              | 10 (4.76)        | 0                     | 12 (4.58) |
| <i>E. aerogenes</i>     | 0(0.0)               | 5 (2.38)         | 1 (5.0)               | 6 (2.29)  |
| <i>E. cloacae</i>       | 0(0.0)               | 5 (2.38)         | 0(0.0)                | 5 (1.9)   |
| <i>E. hormaechei</i>    | 0(0.0)               | 7 (3.33)         | 0                     | 7 (2.67)  |
| <i>E. coli</i>          | 1 (4.2)              | 12 (5.7)         | 2(10.0)               | 15 (5.73) |
| <i>E. fergusonii</i>    | 0(0.0)               | 3 (1.43)         | 0                     | 3 (1.15)  |
| <i>K. pneumoniae</i>    | 1 (4.2)              | 4 (1.9)          | 2 (10.0)              | 7 (2.67)  |
| <i>M. morganii</i>      | 0(0.0)               | 12 (5.7)         | 0                     | 12 (4.58) |
| <i>P. carotovorum</i>   | 0(0.0)               | 4 (1.9)          | 0                     | 4 (1.53)  |
| <i>P. mirabilis</i>     | 0(0.0)               | 10 (4.76)        | 0                     | 10 (3.82) |
| <i>P. alcalifaciens</i> | 0(0.0)               | 9 (4.3)          | 0                     | 9 (3.44)  |
| <i>P. rustigianii</i>   | 0(0.0)               | 5 (2.38)         | 0                     | 5 (1.9)   |
| <i>P. stuartii</i>      | 0(0.0)               | 3 (1.43)         | 0                     | 3 (1.15)  |
| <i>P. entomophila</i>   | 0(0.0)               | 8 (3.8)          | 0                     | 8 (3.1)   |
| <i>P. fluorescens</i>   | 0(0.0)               | 2 (0.95)         | 0                     | 2 (0.76)  |
| <i>P. hunanensis</i>    | 0(0.0)               | 3 (1.43)         | 0                     | 3 (1.15)  |
| <i>P. mosselii</i>      | 1 (4.2)              | 4 (1.9)          | 0                     | 5 (1.9)   |
| <i>P. putida</i>        | 0(0.0)               | 7 (3.33)         | 0                     | 7 (2.67)  |
| <i>Salmonella spp</i>   | 1 (4.2)              | 7 (3.33)         | 4 (20.0)              | 12 (4.58) |
| <i>S. marcescens</i>    | 0(0.0)               | 5 (2.38)         | 0                     | 5 (1.9)   |

| Isolated bacteria     | Sample type (n =262) |                    |                       | Total             |
|-----------------------|----------------------|--------------------|-----------------------|-------------------|
|                       | Water, n (%)         | Live fish, n (%)   | Processed fish, n (%) |                   |
| <i>S. flexneri</i>    | 2 (8.3)              | 5 (2.38)           | 0                     | 7 (2.67)          |
| <i>S. maltophilia</i> | 0(0.0)               | 12 (5.7)           | 0                     | 12 (4.58)         |
| <b>Total</b>          | <b>12(50)</b>        | <b>192 (91.43)</b> | <b>9(45)</b>          | <b>&lt;0.0001</b> |

### Bacteria distribution by live fish tissue

The highest number of isolates (87 (41.43%)) were recovered from the intestines of the fishes; followed by the kidneys (54 (25.7%)) and livers (51 (24.3%)) with statistically significant difference ( $p < 0.0001$ ). The most frequently isolated bacterium from live fish was *E. coli* with 5 isolates (2.38%) in the intestine and 5(2.38%) in the liver (Table 72). *A. hydrophila* and *P. mirabilis* are the most frequent isolates isolated from the kidney (1.9%). The least frequently isolated bacterium from live fish was *P. fluorescens* (0.95%). There was no significant difference in the distribution of individual bacterial species in the three fish tissues except for *E. fergusonii* and *P. stuartii* whose prevalence in the intestine were significantly higher ( $p = 0.042$ ).

**Table 64:** Distribution of bacteria in the kidneys, livers and intestines of live fish caught from Lakes Hawassa, Langan and Zwai (N = 210)

| Isolated bacteria    | Intestine, n (%) | Kidney, n (%) | Liver, n (%) | Total, n (%) | P-value |
|----------------------|------------------|---------------|--------------|--------------|---------|
| <i>A. baumannii</i>  | 2 (0.95)         | 1(0.48)       | -            | 3 (1.4)      | 0.381   |
| <i>A. baylyi</i>     | 3 (1.4)          | 1(0.48)       | 1(0.48)      | 5 (2.38)     | 0.253   |
| <i>A. soli</i>       | 4 (1.9)          | 2 (0.95)      | 1(0.48)      | 7 (3.33)     | 0.078   |
| <i>A. hydrophila</i> | 3 (1.4)          | 4 (1.9)       | 2 (0.95)     | 9 (4.29)     | 0.194   |
| <i>A. jandaei</i>    | 3 (1.4)          | 2 (0.95)      | 2 (0.95)     | 7 (3.33)     | 0.527   |
| <i>A. sobria</i>     | 1(0.48)          | -             | 2 (0.95)     | 3(1.4)       | 0.064   |
| <i>A. veronii</i>    | 4 (1.9)          | 5 (2.38)      | 1(0.48)      | 10 (4.76)    | 0.617   |
| <i>C. braakii</i>    | 2 (0.95)         | -             | 1(0.48)      | 3 (1.4)      | 0.414   |
| <i>C. freundii</i>   | 2(0.9)           | -             | 1(0.48)      | 3(1.4)       | 0.244   |
| <i>E. tarda</i>      | 4(1.9)           | 2 (0.95)      | 4(1.9)       | 10(4.8)      | 0.332   |
| <i>E. aerogenes</i>  | 1(0.48)          | 3(1.4)        | 1(0.48)      | 5 (2.38)     | 0.394   |



| Isolated bacteria       | Intestine, n (%)  | Kidney, n (%)    | Liver, n (%)     | Total, n (%)      | P-value           |
|-------------------------|-------------------|------------------|------------------|-------------------|-------------------|
| <i>E. cloacae</i>       | 2 (0.95)          | 2 (0.95)         | 1(0.48)          | 5 (2.38)          | 0.630             |
| <i>E. hormaechei</i>    | 3 (1.4)           | 3 (1.4)          | 1(0.48)          | 7 (3.33)          | 0.641             |
| <i>E. coli</i>          | 5 (2.38)          | 2(0.9)           | 5 (2.38)         | 12(5.7)           | 0.104             |
| <i>E. fergusonii</i>    | 3 (1.4)           | -                | -                | 3 (1.4)           | 0.042*            |
| <i>K. pneumoniae</i>    | 1(0.48)           | 2 (0.95)         | 1(0.48)          | 4(1.9)            | 0.579             |
| <i>M. organii</i>       | 5 (2.38)          | 3 (1.4)          | 4 (1.9)          | 12(5.7)           | 0.210             |
| <i>P. carotovorum</i>   | 3 (1.4)           | -                | 1(0.48)          | 4 (1.9)           | 0.327             |
| <i>P. mirabilis</i>     | 2 (0.95)          | 4 (1.9)          | 4 (1.9)          | 10 (4.76)         | 0.392             |
| <i>P. alcalifaciens</i> | 4 (1.9)           | 2 (0.95)         | 3 (1.4)          | 9 (4.29)          | 0.731             |
| <i>P. rustigianii</i>   | 4 (1.9)           | 1(0.48)          | -                | 5 (2.38)          | 0.067             |
| <i>P. stuartii</i>      | 3 (1.4)           | -                | -                | 3 (1.4)           | 0.042*            |
| <i>P. entomophila</i>   | 5 (2.38)          | 1(0.48)          | 2 (0.95)         | 8 (3.8)           | 0.078             |
| <i>P. fluorescens</i>   | 2 (0.95)          | -                | -                | 2 (0.95)          | 0.081             |
| <i>P. hunanensis</i>    | -                 | 2 (0.95)         | 1(0.48)          | 3 (1.4)           | 0.187             |
| <i>P. mosselii</i>      | 1(0.48)           | 2 (0.95)         | 1(0.48)          | 4 (1.9)           | 0.782             |
| <i>P. putida</i>        | 2 (0.95)          | 3 (1.4)          | 2 (0.95)         | 7 (3.33)          | 0.671             |
| <i>Salmonella spp</i>   | 4 (1.9)           | 1(0.48)          | 2 (0.95)         | 7 (3.33)          | 0.729             |
| <i>S. marcescens</i>    | 3 (1.4)           | -                | 2 (0.95)         | 5 (2.38)          | 0.329             |
| <i>S. flexneri</i>      | 1(0.48)           | 3 (1.4)          | 1(0.48)          | 5 (2.38)          | 0.421             |
| <i>S. maltophilia</i>   | 5 (2.38)          | 3 (1.4)          | 4 (1.9)          | 12(5.7)           | 0.761             |
| <b>Total</b>            | <b>87 (41.43)</b> | <b>54 (25.7)</b> | <b>51 (24.3)</b> | <b>192 (91.4)</b> | <b>&lt;0.0001</b> |

### Bacteria distribution by fish species

Except *A. sobria*, all other isolates were recovered from Nile tilapia (*O. niloticus*) live fish catches. Similarly, all other bacterial species were isolated from catfish (*C. gariepinus*) with the exception of *A. baumannii*, *A. jandaei*, *C. braakii*, *E. fergusonii*, *P. carotovorum*, *P. fluorescens*, *P. hunanensis*, *P. mosselii*, *Salmonella spp* and *S. flexneri*. However, *C. freundii*, *P. stuartii*, *P. fluorescens* and *P. Hunanensis* were not isolated from common carps. Significant variation ( $p < 0.0001$ ) was recorded regarding the distribution of bacterial infection in the three fish species (Table 73).

**Table 65:** Number (percentage) of bacterial species isolated from three fish species caught from Lakes Hawassa, Langano and Zwai (On for *O. niloticus*, Cg for *C. gariepinus*, Cc for *C. carpio* and the asterisk (\*) represents significant at 5% level.

| Isolated bacteria       | Carps (Cc)<br>N=60 | Tilapia (On)<br>N=105 | Catfish (Cg) N=45 | Total<br>n=210     | P-value            |
|-------------------------|--------------------|-----------------------|-------------------|--------------------|--------------------|
| <i>A. baumannii</i>     | 1(1.67)            | 2 (1.9)               | -                 | 3 (1.43)           | 0.244              |
| <i>A. baylyi</i>        | 1(1.67)            | 3 (2.86)              | 1 (2.22)          | 5 (2.38)           | 0.680              |
| <i>A. soli</i>          | 2 (3.33)           | 4 (3.8)               | 1 (2.22)          | 7 (3.33)           | 0.631              |
| <i>A. hydrophila</i>    | 3 (5.0)            | 4 (3.8)               | 2 (4.44)          | 9 (4.29)           | 0.318              |
| <i>A. jandaei</i>       | 2 (3.33)           | 5 (4.76)              | -                 | 7 (3.33)           | 0.441              |
| <i>A. sobria</i>        | 2(3.33)            | -                     | 1 (2.22)          | 3 (1.43)           | 0.244              |
| <i>A. veronii</i>       | 2 (3.33)           | 7 (6.67)              | 1 (2.22)          | 10 (4.76)          | 0.082              |
| <i>C. braakii</i>       | 1(1.67)            | 2 (1.9)               | -                 | 3 (1.43)           | 0.254              |
| <i>C. freundii</i>      | -                  | 2 (1.9)               | 1 (2.22)          | 3 (1.43)           | 0.064              |
| <i>E. tarda</i>         | 3 (5.0)            | 4(3.8)                | 3 (6.67)          | 10(4.8)            | 0.770              |
| <i>E. aerogenes</i>     | 1(1.67)            | 1(1.4)                | 3 (6.67)          | 5 (2.38)           | 0.216              |
| <i>E. cloacae</i>       | 1(1.67)            | 1(1.4)                | 3 (6.67)          | 5 (2.38)           | 0.079              |
| <i>E. hormaechei</i>    | 2 (3.33)           | 3 (2.86)              | 2 (4.44)          | 7 (3.33)           | 0.881              |
| <i>E. coli</i>          | 3 (5.0)            | 6 (5.7)               | 3 (6.67)          | 12(5.7)            | 0.084              |
| <i>E. fergusonii</i>    | 1(1.67)            | 2 (1.9)               | -                 | 3 (1.43)           | 0.537              |
| <i>K. pneumoniae</i>    | 1(1.67)            | 2 (1.9)               | 1 (2.22)          | 4 (1.9)            | 0.579              |
| <i>M. morganii</i>      | 3 (5.0)            | 7 (6.67)              | 2 (4.44)          | 12 (5.7)           | 0.092              |
| <i>P. carotovorum</i>   | 1(1.67)            | 3 (2.86)              | -                 | 4 (1.9)            | 0.621              |
| <i>P. mirabilis</i>     | 3 (5.0)            | 6 (5.7)               | 1 (2.22)          | 10 (4.76)          | 0.071              |
| <i>P. alcalifaciens</i> | 3 (5.0)            | 5 (4.76)              | 1 (2.22)          | 9 (4.29)           | 0.529              |
| <i>P. rustigianii</i>   | 1(1.67)            | 3 (2.86)              | 1 (2.22)          | 5 (2.38)           | 0.662              |
| <i>P. stuartii</i>      | -                  | 2 (1.9)               | 1 (2.22)          | 3 (1.43)           | 0.514              |
| <i>P. entomophila</i>   | 3 (5.0)            | 4 (3.8)               | 1 (2.22)          | 8 (3.8)            | 0.571              |
| <i>P. fluorescens</i>   | -                  | 2 (1.9)               | -                 | 2 (0.95)           | 0.042*             |
| <i>P. hunanensis</i>    | -                  | 3 (2.86)              | -                 | 3 (1.43)           | 0.040*             |
| <i>P. mosselii</i>      | 1(1.67)            | 3 (2.86)              | -                 | 4 (1.9)            | 0.087              |
| <i>P. putida</i>        | 2 (3.33)           | 4 (3.8)               | 1 (2.22)          | 7 (3.33)           | 0.132              |
| <i>Salmonella spp</i>   | 2 (3.33)           | 5 (4.76)              | -                 | 7 (3.33)           | 0.081              |
| <i>S. marcescens</i>    | 1(1.67)            | 3 (2.86)              | 1 (2.22)          | 5 (2.38)           | 0.337              |
| <i>S. flexneri</i>      | 2 (3.33)           | 3 (2.86)              | -                 | 5 (2.38)           | 0.510              |
| <i>S. maltophilia</i>   | 3 (5.0)            | 7 (6.67)              | 2 (4.44)          | 12 (5.7)           | 0.471              |
| <b>Total</b>            | <b>51 (24.30)</b>  | <b>108 (51.43)</b>    | <b>33 (15.7)</b>  | <b>192 (92.43)</b> | <b>&lt;0.0001*</b> |

### Bacteria distribution in live fish from the three lakes

The highest number of isolates were from Lake Zwai (99 (47.14)) followed by Hawassa (56 (26.7)) and Langanoo the least with only (37 (17.62)). The prevalence of bacterial infection in the three Lakes was statistically significant ( $p < 0.0001$ ). Except *P. fluorescens* all the others bacterial species (93.55%) were isolated in this study were in Lake Zwai fish samples. Similarly, all of the species were also isolated from Lake Hawassa fish samples except *C. freundii*, *E. fergusonii*, *P. carotovorum*, *P. stuartii*, *P. fluorescens* and *P. hunanensis*. On the other hand, only 17.62% of the 31 species were detected from Lake Langanoo fish samples (Table 74). The data show the highest bacterial species composition was in Lake Zwai and the least in Langanoo.

**Table 66:** Number (percentage) of bacteria isolated from live fish samples from Lakes Hawassa, Langanoo and Zwai (N = 210) (means significant at 5% level)

| Isolated bacteria    | Lake Hawassa<br>n=70 | Lake Langanoo<br>n=60 | Lake Zwai<br>n=80 | Total     | P-value |
|----------------------|----------------------|-----------------------|-------------------|-----------|---------|
| <i>A. baumannii</i>  | 1 (1.43)             | 0 (0.0)               | 2 (2.5)           | 3(1.4)    | 0.317   |
| <i>A. baylyi</i>     | 1 (1.43)             | 0 (0.0)               | 4 (5.0)           | 5(2.4)    | 0.087   |
| <i>A. soli</i>       | 2(2.9)               | 0 (0.0)               | 5 (6.25)          | 7 (3.3)   | 0.064   |
| <i>A. hydrophila</i> | 3 (4.3)              | 2 (3.3)               | 4 (5.0)           | 9 (4.3)   | 0.714   |
| <i>A. jandaei</i>    | 2(2.9)               | 1 (1.67)              | 4 (5.0)           | 7 (3.3)   | 0.694   |
| <i>A. sobria</i>     | 2(2.9)               | 0 (0.0)               | 1(1.25)           | 3(1.4)    | 0.064   |
| <i>A. veronii</i>    | 3 (4.3)              | 2 (3.3)               | 5 (6.25)          | 10 (4.76) | 0.541   |
| <i>C. braakii</i>    | 2(2.9)               | 0 (0.0)               | 1(1.25)           | 3(1.4)    | 0.672   |
| <i>C. freundii</i>   | 0 (0.0)              | 2 (3.3)               | 1(1.25)           | 3(1.4)    | 0.173   |
| <i>E. tarda</i>      | 3 (4.3)              | 4(6.67)               | 3 (3.75)          | 10(4.8)   | 0.296   |
| <i>E. aerogenes</i>  | 1(1.43)              | 1 (1.67)              | 3 (3.75)          | 5(2.4)    | 0.394   |
| <i>E. cloacae</i>    | 2(2.9)               | 0 (0.0)               | 3 (3.75)          | 5(2.4)    | 0.098   |
| <i>E. hormaechei</i> | 3 (4.3)              | 0 (0.0)               | 4 (5.0)           | 7 (3.3)   | 0.431   |
| <i>E. coli</i>       | 5(7.1)               | 2(3.3)                | 5 (6.25)          | 12(5.7)   | 0.146   |

| Isolated bacteria       | Lake Hawassa<br>n=70 | Lake Langanoo<br>n=60 | Lake Zwai<br>n=80 | Total             | P-value            |
|-------------------------|----------------------|-----------------------|-------------------|-------------------|--------------------|
| <i>E. fergusonii</i>    | 0 (0.0)              | 0 (0.0)               | 3 (3.75)          | 3 (1.4)           | 0.042*             |
| <i>K. pneumoniae</i>    | 2 (2.9)              | 0 (0.0)               | 2 (2.5)           | 4 (1.9)           | 0.125              |
| <i>M. morgani</i>       | 3 (4.3)              | 3 (5.0)               | 6 (7.5)           | 12 (5.7)          | 0.293              |
| <i>P. carotovorum</i>   | 0 (0.0)              | 1 (1.67)              | 3 (3.75)          | 4 (1.9)           | 0.274              |
| <i>P. mirabilis</i>     | 3 (4.3)              | 3 (5.0)               | 4 (5.0)           | 10 (4.76)         | 0.742              |
| <i>P. alcalifaciens</i> | 2 (2.9)              | 3 (5.0)               | 4 (5.0)           | 9 (4.3)           | 0.547              |
| <i>P. rustigianii</i>   | 1 (1.43)             | 0 (0.0)               | 4 (5.0)           | 5 (2.4)           | 0.219              |
| <i>P. stuartii</i>      | 0 (0.0)              | 0 (0.0)               | 3 (3.75)          | 3 (1.4)           | 0.042*             |
| <i>P. entomophila</i>   | 2 (2.9)              | 3 (5.0)               | 3 (3.75)          | 8 (3.8)           | 0.479              |
| <i>P. fluorescens</i>   | 0 (0.0)              | 2 (3.3)               | 0 (0.0)           | 2 (0.95)          | 0.162              |
| <i>P. hunanensis</i>    | 0 (0.0)              | 1 (1.67)              | 2 (2.5)           | 3 (1.4)           | 0.562              |
| <i>P. mosselii</i>      | 1 (1.43)             | 0 (0.0)               | 3 (3.75)          | 4 (1.9)           | 0.427              |
| <i>P. putida</i>        | 2 (2.9)              | 1 (1.67)              | 4 (5.0)           | 7 (3.3)           | 0.274              |
| <i>Salmonella spp</i>   | 3 (4.3)              | 1 (1.67)              | 3 (3.75)          | 7 (3.3)           | 0.382              |
| <i>S. marcescens</i>    | 2 (2.9)              | 0 (0.0)               | 3 (3.75)          | 5 (2.4)           | 0.193              |
| <i>S. flexneri</i>      | 2 (2.9)              | 1 (1.7)               | 2 (2.5)           | 5 (2.4)           | 0.536              |
| <i>S. maltophilia</i>   | 3 (4.3)              | 4 (6.67)              | 5 (6.25)          | 12 (5.7)          | 0.391              |
| <b>Total</b>            | <b>56 (26.7)</b>     | <b>37 (17.62)</b>     | <b>99 (47.14)</b> | <b>192 (91.4)</b> | <b>&lt;0.0001*</b> |

### Bacteria distribution among naturally infected fishes

A total of 42 naturally infected fish samples were collected from Lakes Hawassa and Zwai. The diseased fish were 22 Nile tilapia (13 from Lake Hawassa and 9 from Lake Zwai) and 20 Common carp (9 from Lake Hawassa and 11 from Lake Zwai). Totally 147 (three from each) tissue samples were obtained from the naturally infected fish of which 33.33% were positive for gram-negative bacterial infection. Generally, 49 isolates were identified as gram-negative bacteria from diseased (naturally infected) fish (Nile tilapia and common carps) samples.

*E. tarda* was isolated from 5 Nile tilapia and 2 common carps with overall prevalence of 14.3% which significantly varied with the occurrence of any

other species among diseased fish from both Lakes ( $p = 0.042$ ). *A. veronii* was isolated from 6 Nile tilapia and 3 common carps with overall prevalence of 18.4% which was higher than the occurrence of any other species among diseased (naturally infected) fish from each Lake (Table 75).

**Table 67:** Number (percentage) of bacteria isolated from critically sick live caught fish from Lakes Hawassa, Langano and Zwai

| Isolated bacteria     | LH             |          |                  | LL       |          |               | LZ             |          |                 | Total          | P-value      |
|-----------------------|----------------|----------|------------------|----------|----------|---------------|----------------|----------|-----------------|----------------|--------------|
|                       | Carp           | Catfish  | Tilapia          | Carp     | Catfish  | Tilapia       | Carp           | Catfish  | Tilapia         |                |              |
| <i>A. hydrophila</i>  | -              | -        | 2(4.1)           | -        | -        | -             | 1(2.0)         | -        | 2(4.1)          | 5(10.2)        | 0.578        |
| <i>A. sobria</i>      | 2(4.1)         | -        | 1(2.0)           | -        | -        | -             | -              | -        | -               | 3(6.1)         | 0.154        |
| <i>A. veronii</i>     | 1(2.0)         | -        | 2(4.1)           | -        | -        | -             | 2(4.1)         | -        | 4(8.2)          | 9(18.4)        | 0.632        |
| <i>E. tarda</i>       | 2(4.1)         | -        | 5(10.2)          | -        | -        | -             | -              | -        | -               | 7(14.3)        | 0.042*       |
| <i>P. hunanensis</i>  | -              | -        | -                | -        | -        | -             | -              | -        | 3(6.1)          | 3(6.1)         | 0.106        |
| <i>P. putida</i>      | -              | -        | -                | -        | -        | -             | 3(6.1)         | -        | 1(2.0)          | 4(8.2)         | 0.102        |
| <i>P. mirabilis</i>   | 1(2.0)         | -        | 2(4.1)           | -        | -        | -             | 2(4.1)         | -        | 3(6.1)          | 8(16.3)        | 0.632        |
| <i>S. flexneri</i>    | 2(4.1)         | -        | 1(2.0)           | -        | -        | -             | 1(2.0)         | -        | 1(2.0)          | 5(10.2)        | 0.768        |
| <i>S. maltophilia</i> | -              | -        | 2(4.1)           | -        | -        | -             | -              | -        | 3(6.1)          | 5(10.2)        | 0.078        |
| <b>Total</b>          | <b>8(16.3)</b> | <b>-</b> | <b>16(32.65)</b> | <b>-</b> | <b>-</b> | <b>2(4.1)</b> | <b>9(16.3)</b> | <b>-</b> | <b>17(34.7)</b> | <b>49(100)</b> | <b>0.062</b> |

### Bacteria from water samples

The prevalence of bacteria in water samples from Lake Hawassa was 50%, Zwai 33.3% and Langanoo 16.7% with significant difference ( $p = 0.046$ ). *A. sobria*, *C. braakii*, *E. tarda*, *S. flexneri* and *salmonella* spp., were detected in Lake Hawassa. The only bacteria detected in Lake Langanoo and exclusive to it were *C. freundii* and *K. pneumoniae*. Similarly, from 4 species in Lake Zwai, 3 (*A. veronii*, *E. coli* and *P. mosselii*) were exclusive to it (Table 76). Not only in terms of prevalence but bacterial species diversity as well, Lake Hawassa was the most diverse and Langanoo the least.

**Table 68:** Distribution of bacteria from water samples of Lakes Hawassa, Langanoo and Zwai (N = 12)

| Bacteria species       | Lakes          |                 |                | Total, n (%)   | P-value       |
|------------------------|----------------|-----------------|----------------|----------------|---------------|
|                        | Hawassa, n (%) | Langanoo, n (%) | Zwai, n (%)    |                |               |
| <i>A. sobria</i>       | 1(8.3)         | -               | -              | 1(8.3)         | 0.064         |
| <i>A. veronii</i>      | -              | -               | 1(8.3)         | 1(5.3)         | 0.088         |
| <i>C. freundii</i>     | -              | 1(8.3)          | -              | 1(8.3)         | 0.087         |
| <i>C. braakii</i>      | 1(8.3)         | -               | -              | 1(8.3)         | 0.076         |
| <i>E. tarda</i>        | 1(8.3)         | -               | 1(8.3)         | 2(17)          | 0.108         |
| <i>E. coli</i>         | -              | -               | 1(8.3)         | 1(8.3)         | 0.066         |
| <i>K. pneumoniae</i>   | -              | 1(8.3)          | -              | 1(8.3)         | 0.102         |
| <i>P. mosselii</i>     | -              | -               | 1(8.3)         | 1(8.3)         | 0.072         |
| <i>Salmonella</i> spp. | 1(8.3)         | -               | -              | 1(8.3)         | 0.098         |
| <i>S. flexneri</i>     | 2(16.7)        | -               | -              | 2(16.7)        | 0.072         |
| <b>Total</b>           | <b>6(50)</b>   | <b>2(16.7)</b>  | <b>4(33.3)</b> | <b>12(100)</b> | <b>0.046*</b> |

### Bacteria distribution in live fish by sampling site

The majority of Lake Hawassa isolates were from S4 (30%) followed by S1 and S2 (17.1%). In Lake Langanoo, most isolates were from S2 (21.7%) and S3 (16.7%). Similarly, most of the isolates were from sampling points S3 (38.75%) and S1 (30%) of Lake Zwai. The distribution of *A. baumannii*, *A. baylyi*, *A. sobria*, *C.*

*freundii*, *E. cloacae*, *E. coli* and *P. fluorescens* varied significantly across live fish sampling sites of each Lake (Table 77).



**Table 69:** Number (percentage) of bacteria isolated from fish sampled from different sites of Lakes Hawassa, Langano and Zwai (S1 to S4 are sampling sites)

| Isolated bacteria       | Lake Hawassa n=70 |        |        |        | Lake Langano n=60 |        |        |        | Lake Zwai n=80 |        |        |        | Total n=210 | P-value |
|-------------------------|-------------------|--------|--------|--------|-------------------|--------|--------|--------|----------------|--------|--------|--------|-------------|---------|
|                         | S1                | S2     | S3     | S4     | S1                | S2     | S3     | S4     | S1             | S2     | S3     | S4     |             |         |
| <i>A. baumannii</i>     | -                 | 1(1.4) | -      | -      | -                 | -      | -      | -      | -              | 1(1.3) | 1(1.3) | -      | 3(1.4)      | 0.037 * |
| <i>A. baylyi</i>        | -                 | -      | -      | 1(1.4) | -                 | -      | -      | -      | 1(1.3)         | 1(1.3) | 2(2.5) | -      | 5(2.4)      | 0.042 * |
| <i>A. soli</i>          | -                 | -      | 2(2.9) | -      | -                 | -      | -      | -      | -              | 2(2.5) | 1(1.3) | 2(2.5) | 7(3.3)      | 0.063   |
| <i>A. hydrophila</i>    | 1(1.4)            | -      | 1(1.4) | 1(1.4) | 1(1.7)            | -      | -      | 1(1.7) | 1(1.3)         | -      | 1(1.3) | 2(2.5) | 9(4.3)      | 0.782   |
| <i>A. jandaei</i>       | -                 | -      | 1(1.4) | 1(1.4) | -                 | 1(1.7) | -      | -      | 2(2.5)         | 1(1.3) | -      | 1(1.3) | 7(3.3)      | 0.571   |
| <i>A. sobria</i>        | 1(1.4)            | -      | -      | 1(1.4) | -                 | -      | -      | -      | -              | -      | 1(1.3) | -      | 3(1.4)      | 0.001 * |
| <i>A. veronii</i>       | 1(1.4)            | 1(1.4) | 1(1.4) | -      | -                 | 1(1.7) | 1(1.7) | -      | 2(2.5)         | 1(1.3) | 1(1.3) | 1(1.3) | 10(4.8)     | 0.081   |
| <i>C. braakii</i>       | -                 | 1(1.4) | -      | 1(1.4) | -                 | -      | -      | -      | -              | 1(1.3) | -      | -      | 3(1.4)      | 0.078   |
| <i>C. freundii</i>      | -                 | -      | -      | -      | -                 | 2(3.3) | -      | -      | 1(1.3)         | -      | -      | -      | 3(1.4)      | 0.001 * |
| <i>E. tarda</i>         | 1(1.4)            | -      | -      | 2(2.9) | -                 | 2(3.3) | 1(1.7) | 1(1.7) | -              | -      | 2(2.5) | 1(1.3) | 10(4.8)     | 0.096   |
| <i>E. aerogenes</i>     | -                 | -      | -      | 1(1.4) | -                 | -      | 1(1.7) | -      | 1(1.3)         | 1(1.3) | -      | 1(1.3) | 5(2.4)      | 0.206   |
| <i>E. cloacae</i>       | 1(1.4)            | -      | 1(1.4) | -      | -                 | -      | -      | -      | 1(1.3)         | 1(1.3) | 1(1.2) | -      | 5(2.4)      | 0.003 * |
| <i>E. hormaechei</i>    | -                 | 1(1.4) | 1(1.4) | 1(1.4) | -                 | -      | -      | -      | 1(1.3)         | 1(1.3) | 1(1.3) | 1(1.3) | 7(3.3)      | 0.069   |
| <i>E. coli</i>          | 2(2.9)            | 1(1.4) | -      | 2(2.9) | 1(1.7)            | -      | -      | 1(1.7) | 2(2.5)         | -      | 1(1.3) | 2(2.5) | 12(5.7)     | 0.016 * |
| <i>E. fergusonii</i>    | -                 | -      | -      | -      | -                 | -      | -      | -      | -              | -      | 2(2.5) | 1(1.3) | 3(1.4)      | 0.329   |
| <i>K. pneumoniae</i>    | -                 | 1(1.4) | -      | 1(1.4) | -                 | -      | -      | -      | 1(1.3)         | -      | 1(1.3) | -      | 4(1.9)      | 0.153   |
| <i>M. morquarii</i>     | 1(1.4)            | -      | 1(1.4) | 1(1.4) | -                 | 1(1.7) | 2(3.3) | -      | 1(1.3)         | 2(2.5) | 2(2.5) | 1(1.3) | 12(5.7)     | 0.064   |
| <i>P. carotovorum</i>   | -                 | -      | -      | -      | -                 | -      | -      | 1(1.7) | -              | 2(2.5) | 1(1.3) | -      | 4(1.9)      | 0.057   |
| <i>P. mirabilis</i>     | 1(1.4)            | 1(1.4) | -      | 1(1.4) | 1(1.7)            | 2(3.3) | -      | -      | 1(1.3)         | 2(2.5) | 1(1.3) | -      | 10(4.8)     | 0.371   |
| <i>P. alcalifaciens</i> | 1(1.4)            | -      | -      | 1(1.4) | -                 | -      | 1(1.7) | 2(3.3) | 1(1.3)         | 2(2.5) | -      | 1(1.3) | 9(4.3)      | 0.244   |
| <i>P. rustigianii</i>   | -                 | -      | 1(1.4) | -      | -                 | -      | -      | -      | -              | 1(1.3) | 2(2.5) | 1(1.3) | 5(2.4)      | 0.152   |
| <i>P. stuartii</i>      | -                 | -      | -      | -      | -                 | -      | -      | -      | 1(1.3)         | -      | -      | 2(2.5) | 3(1.4)      | 0.332   |
| <i>P. entomophila</i>   | -                 | 1(1.4) | 1(1.4) | -      | 1(1.7)            | 1(1.7) | -      | 1(1.7) | -              | 1(1.3) | 1(1.3) | 1(1.3) | 8(3.8)      | 0.071   |
| <i>P. fluorescens</i>   | -                 | -      | -      | -      | -                 | -      | 2(3.3) | -      | -              | -      | -      | -      | 2(95)       | 0.042 * |
| <i>P. hunanensis</i>    | -                 | -      | -      | -      | -                 | -      | 1(1.7) | -      | -              | -      | 2(2.5) | -      | 3(1.4)      | 0.003 * |
| <i>P. mosselii</i>      | -                 | 1(1.4) | -      | -      | -                 | -      | -      | -      | 2(2.5)         | -      | 1(1.3) | -      | 4(1.9)      | 0.364   |
| <i>P. putida</i>        | -                 | 1(1.4) | -      | 1(1.4) | -                 | 1(1.7) | -      | -      | 1(1.3)         | 1(1.3) | -      | 2(2.5) | 7(3.3)      | 0.068   |

| Isolated<br>bacteria  | Lake Hawassa n=70 |                 |                 |               | Lake Langano n=60 |                 |                 |              | Lake Zwai n=80 |                  |                  |                 | Total<br>n=210   | P-<br>value  |
|-----------------------|-------------------|-----------------|-----------------|---------------|-------------------|-----------------|-----------------|--------------|----------------|------------------|------------------|-----------------|------------------|--------------|
|                       | S1                | S2              | S3              | S4            | S1                | S2              | S3              | S4           | S1             | S2               | S3               | S4              |                  |              |
| <i>Salmonella spp</i> | 1(1.4)            | -               | 1(1.4)          | 1(1.4)        | -                 | 1(1.7)          | -               | -            | 1(1.3)         | -                | 2(2.5)           | -               | 7(3.3)           | 0.413        |
| <i>S. marcescens</i>  | -                 | -               | -               | 2(2.9)        | -                 | -               | -               | -            | 1(1.3)         | -                | 2(2.5)           | -               | 5(2.4)           | 0.158        |
| <i>S. flexneri</i>    | 1(1.4)            | -               | -               | 1(1.4)        | -                 | -               | 1(1.7)          | -            | -              | 2(2.5)           | -                | -               | 5(2.4)           | 0.007<br>*   |
| <i>S. maltophilia</i> | -                 | 2(2.9)          | -               | 1(1.4)        | 1(1.7)            | 1(1.7)          | -               | 2(3.3)       | 2(2.5)         | -                | 2(2.5)           | 1(1.3)          | 12(5.7)          | 0.081        |
| <b>Total</b>          | <b>12(17.1)</b>   | <b>12(17.1)</b> | <b>11(15.7)</b> | <b>21(30)</b> | <b>5(8.3)</b>     | <b>13(21.7)</b> | <b>10(16.7)</b> | <b>9(15)</b> | <b>24(30)</b>  | <b>23(28.75)</b> | <b>31(38.75)</b> | <b>21(26.3)</b> | <b>192(39.1)</b> | <b>0.571</b> |

## Discussion

The mean values of all the measured physicochemical parameters in the three lakes were within the standard limit for fish health (Svobodová *et al.* 1993). In light of this, the lakes could be considered fitting for fish survival. Water quality factors such as DO, temperature, ammonia, phosphate, pH, alkalinity, hardness and clarity affect fish health in multiple ways. Each water quality factor interacts with and influences other parameters, sometimes in complex ways and what may be fatally toxic in one situation can be harmless in another. Nevertheless, we did not test many other parameters, which are important water quality factors for logistics reasons. The effect of sampling site, season and hour on the parameters is usually considerable. For instance, DO values significantly vary when the sampling site is surface water and along shorelines compared to deep water, or at the center. Our sampling was on surface water.

The oxygen requirements of fish also depend on a number of other factors including temperature, pH, and CO<sub>2</sub> level of the water, as aforementioned, and the metabolic rate of the fish. Therefore, changes in these physicochemical parameters in the aquatic environment are primary causes of fish stress (Stone *et al.* 2013) although the health impact of such stress may depend not only on the severity of the stress, but on its duration and the fish's overall physiological status.

The mean DO values of 6.27mg/l (Lake Hawassa), 5.10mg/l (Lake Langano) and 3.93mg/l (Lake Zwai) indicate relatively better aeration at lakes Hawassa and Langano than Zwai at least during the study period and sampling time. This might be attributable to variations in temperature and flow rate in the Lakes during the sampling season as lower temperature and good flow rate are associated with higher DOs (Adhikary *et al.* 2019). Most DO in ponds is produced during photosynthesis by aquatic plants and algae. For this reason, DO increases during daylight hours, declines during the night, and is lowest just before daybreak. DO concentrations

below 5mg/l may be harmful to fish and piping (gulping air at the surface) may be observed when DO falls below 2mg/l. Low levels of DO are most frequently associated with hot, cloudy weather, algae die-offs, or heavy thunderstorms (Adhikary *et al.* 2019). Overall, poor water quality is a key factor for low fish yields. In a pond study, whereas increase in temperature and OD was correlated with tilapia growth rate, increase in conductivity and pH showed the opposite (Makori *et al.* 2017). Different fish species have different requirements for water DO concentration (Stone *et al.* 2013), and water temperature may influence fish feeding, growth and overall behavior.

Similarly, the data showed insignificant pollution by nitrogenous wastes at the sampling time although ammonia is a pollutant frequently found in aquatic ecosystems. In fish, ammonia can cause physical damage, alter its behavior such as lower swimming activity and feeding behavior, and oxidative stress response, and even cause death. Exposure to ammonia also increases fish physiological stress and recent evidence suggested that once exposed, fish suffer from reduced antioxidant defenses and thus increased oxidative tissue damage even if water quality was improved (Soler *et al.* 2021).

The only exception was phosphate level in Lake Langano which was relatively high (2.34-4.48mg/l). The highest concentration of phosphate (4.48mg/l) recorded for Lake Langano O'etusite (S2) was higher than the standard limit although the mean value was normal. The mean value of phosphate for Langano was substantially higher than that of Hawassa, and that of Zwai was much lower. In the early 1990s, it was reported that Lakes Zwai and Hawassa (back then Aawassa) were phosphorus-limited, whereas Langano has surplus phosphorus (Kebede *et al.* 1994). It appeared that Lake Langano remained phosphate surplus. In the 1960s, however, increases in phosphorus in the lower Lakes raised considerable public concern (Gebremariam *et al.* 2002). The augment in phosphorus could be due to increased surface runoff from phosphate containing fertilizers and certain industrial wastes. Phosphate is an essential plant

nutrient. However, high phosphate level can lead to eutrophication boosting plant/algae growth. These plants/algae eventually decay and cause DO depletion in the water threatening certain species of fish favoring phosphate-pollution-tolerant organisms.

Although it appeared that the physicochemical parameters of the Lakes were normal, the proportion (20%) of fish with visible health problems is not a good sign. Alternatively, it may be plausibly argued that encountering relatively lesser number of clinically diseased fish with visible pathological changes might be attributed to the good water quality of the Lakes during the study period notwithstanding the seasonal fluctuations in water quality (Garg *et al.* 2010 and Rottmann *et al.* 1992). At least during the study season, majority of the fish caught were less stressed. The effect of stress on freshwater fish may be a factor of the severity of the stress, its duration and the overall physiological state of the fish (Rottmann *et al.* 1992).

The proportion of bacterial isolates from the intestine of live-caught fish (41.43%) was significantly higher than that of the liver (24.3%) or kidneys (25.7%). But, there were slight variations with respect to the individual bacteria species. For instance, the number of isolates from live-caught fish intestines was equal to those of the livers concerning *E. coli* which was the most prevalent bacterium isolated. The second most prevalent in this study, *E. tarda*, was similarly isolated from the intestines and livers in equal proportion. *E. tarda* is a cause of rare but fatal food-/waterborne infection in man (Hirai *et al.* 2015). Contrastingly, *A. veronii* was most frequently isolated from the kidney. A study on marine fish found significantly higher potential pathogenic bacteria in kidneys than in liver samples and variation was found between the fish species (Meron 2020). The authors reported significant differences were observed between fish species, organs and sites, indicating the importance of the environmental conditions on the fish microbiome. Although we did not investigate bacteria in different portions of the fish gut, it appears that microenvironment dynamics along the gut of various fish species may

influence the composition and abundance of the bacterial flora (Bereded et al. 2020).

In African catfish, higher bacterial load was recovered from the intestine than other organs like skin and gills (Uwem and Nathaniel 2019). There is evidence that dense microbial populations occur within the intestinal contents, with numbers of bacteria much higher than those in the surrounding water, like the current finding, indicating that the intestines provide favorable ecological niches for these organisms (Austin and Austin 1987). However, the method of intestinal bacteria sampling varied in different surveys. Some used anal swabs, others only the intestinal contents, while still in others intestinal tract and contents were homogenized and used for culturing (Cahill 1988). Austin and Al-Zahrani (1988) distinguished between the flora of the gut contents and that intimately associated with the wall of the gastrointestinal tract, and noted that scanning electron microscopy showed only sparse microbial colonization of the wall. Although the genera present in the gut generally seem to be those from the environment or diet which can survive and multiply in the intestinal tract, there is evidence for a distinct intestinal microflora in some species (Cahill 1988). This same author reviewed the progressive decline in the numbers of aerobic heterotrophic bacteria along the digestive tract. Anaerobes were detected only in the upper intestine and in the intestinal contents.

However, other investigators (Trust and Sparrow 1976) found that numbers of bacteria in freshwater Salmonids increased between the stomach and the posterior portion of the intestine. The authors suggested that these numbers must represent active multiplication in the tract, as they could not be accounted for by ingestion. The numbers detected in this survey were probably an artificially low estimate since the methods used did not allow for the isolation and growth of strict anaerobes, species sensitive to oxygen, nutritionally fastidious species, or those requiring low growth temperatures (<20°C). In addition, the counts obtained were based on the total tissue weight in each sample, while the bacteria actually

populate only the epithelial surface of the tract, and the rest of the tissue sterile. There was no significant difference in the bacterial flora of fish of different species, sex, breeding status, weight, or geographical source. But, microenvironment characteristics at various locations through the gastrointestinal tract of fish influence the composition and abundance of gut bacteria (Wu *et al.* 2012) and bacterial counts significantly differed between species, sources and feeding habits of examined fishes (Alikunhi *et al.* 2017).

Fish internal organs such as the spleen, liver, and kidneys are expected to be sterile (Nieto *et al.* 1984). Nonetheless, evidence accumulates for bacteria from internal organs of apparently healthy fish (Frerichs and Hendrie 1985) in agreement with the current study. Possible fish immune compromise may explain such observations. Immune defect could happen due to stress. Fish stress could be associated with poor water quality, temperature changes, nutritional deficiencies, overcrowding, trauma, parasitism, primary viral infections (Raman *et al.* 2013, Lindsay 1986 and Ellis 1982), among others. For instance, fish immunity was found significantly affected by lower temperatures (Wang *et al.* 2017) making them susceptible to obligate or facultative pathogenic bacteria such as *A. hydrophila*.

The bacterial flora of the gut of two marine fish has been investigated in an attempt to clarify the relationship between these bacteria and the bacterial flora of their diets, and to determine the effect of the degree of specialization of the digestive tracts on their floras (Sera and Ishida 1972). Bacterial flora of fish with relatively undeveloped digestive tracts reflected that of the fishes' food, whereas fish with more specialized tracts have a distinctive gut microflora. In the red sea bream, the composition of the bacterial floras of the stomach and intestine changed with time after feeding. Half an hour after ingestion, most of the bacteria isolated from the stomachs resembled those of the fish meat diet, but after 6 hours, vibrio's resistant to bile and low pH predominated. Further work comparing representative strains of these indigenous vibrio's from the red sea bream

with other isolates from the stomach and intestine showed that the vibrio's were able to survive in the presence of gastric juice at pH 4, and were able to grow, although at a reduced rate, at pH 5, while most of the other isolates were inhibited by these conditions (Sera *et al.* 1972).

In this study, the water samples were positive for *A. sobria*, *A. veronii*, *Citrobacter* spp., *E. tarda*, *E. coli*, *K. pneumoniae*, *P. mosselii*, *Salmonella* spp., and *S. flexneri*. Detection of these and other related bacteria both in marine and freshwater habitats and fish has been widely recorded (Rani *et al.* 2016, Egerton *et al.* 2018, marinho-Neto *et al.* 2019, Shafi *et al.* 2020). *Aeromonas* is associated with a range of human opportunistic infections including enteritis and septicemia (Daiy *et al.* 1981, Gracey and Burke 1986 and Lami and kodjo 2009) and is one of the most common pathogens in tropical fish (Wahli *et al.* 2005). Fecal coliforms such as *E. coli* and non-fecal coliforms such as *Citrobacter*, *Klebsiella* and *Enterobacter* are indicators of contamination of aquatic environments and food. *E. coli* were the most frequently detected bacterium in processed and live-caught fish samples. Detection of *E. coli* in processed fish samples could be due to unhygienic handling during processing and indicate recent fecal contamination of fish products.

Moreover, the fact that most of *E. coli* isolated during this study was from fish intestine reflects warm-blooded animal pollution level of the water. *E. coli* can have a long-term survival and can multiply depending on fish and water temperatures (Flint 1987, Sampson *et al.* 2006, Blaestein 2013 and Pachepsky *et al.* 2014). It is known that fish possess distinct intestinal microbiota, but nutritional status or feeding habits, trophic level, species (attribute to complexity of the fish digestive system) and the environmental conditions (salinity of the habitats and the bacterial load in the water) are the most influential factors which change the intestinal microbiota composition and abundance (Egerton *et al.* 2018). This may explain the observed differences in the distribution of bacteria from fish samples in the three Lakes. While bacteria in water can influence the microbial flora associated with fish, the reverse is also worth consideration.



*Shigella* spp. and *Salmonella* spp. are pathogenic bacteria found in animal, human or environmental reservoir. Although contamination of fish products with these bacteria is commonly from the environment, their incidence in ready-to-eat fish product due to unhygienic handling cannot be ruled out (Jajere 2019). *Citrobacter*, *Enterobacter* and *Klebsiella* are indigenous to general environment and frequently present in fish but most of these bacteria are considered non-pathogenic environmental strains. The bacterial species isolated from processed fish (*E. coli*, *K. pneumonia* and *Salmonella* spp.) were also recovered from the lake water samples.

The variation in the number of isolates and bacterial species between sampling sites of the study Lakes might be attributed to the relative distance and degree of exposure to the nearby point source pollution around the study area. Disruption of the environmental microbiome after an earthquake followed by seasonal variation in the water quality was noted although restoration of these microbial communities as a function of time and sanitation practices occurred in Nepal (Uprety et al. 2017).

All positive live fish samples were positive for at least one isolate of all the 31 bacteria species recovered. This shows the highest bacteria species diversity encountered in a single fish was 22, namely: *A. baumannii*, *A. baylyi*, *A. soli*, *A. hydrophila*, *A. jandaei*, *E. aerogenes*, *E. cloacae*, *E. hormaechei*, *E. fergusonii*, *M. morgani*, *P. carotovorum*, *P. mirabilis*, *P. alcalifaciens*, *P. rustigianii*, *P. stuartii*, *P. entomophila*, *P. fluorescens*, *P. hunanensis*, *P. putida*, *S. marcescens*, *S. maltophilia* and *S. typhi*. This finding suggests that the bacteria detected in fish internal tissues indicate that the fishes in the three study lakes are exposed to highly contaminate aquatic environment, which very likely has also contaminated their food sources and the lake water they engulf. Such dynamics in the aquatic ecosystem may explain particularly the absence of human urinary and respiratory tracts pathogens *E. aerogenes* and *E. cloacae* (Buckle 2015) in water samples and their detection in fish. Another surprising finding is the

absence of human urinary and respiratory tract pathogens, such as, *E. aerogenes* and *E. cloacae* (Janda *et al.* 2016) in the fish and water samples was highly unexpected given that there is no household and hospital waste treatment systems in the watersheds of all the three study lakes. This suggestion is based on the fact that the common environmental reservoirs for these organisms include freshwater ecosystems and estuaries and inhabitants of these aquatic environs, and a series of food-borne enteritis outbreaks have been solely or partially attributable to *P. fluorescens* (Liu 2018).

Detection of the common total coliforms (*E. coli*, *K. pneumonia*, *E. aerogenes*) and *Salmonella* spp., in all of the sample types especially in processed fish, signals the danger of passage of these pathogens and their toxins to man via infected and contaminated fish products. *Salmonella* spp. and fecal coliforms were detected in 42% of water samples and 64% of processed fish samples in this study. *Shigella* spp. and *Salmonella* spp. are pathogenic bacteria found in animal or human reservoir and contamination of fish products by these bacteria is almost always due to poor hygiene.

Except *A. sobria*, all the others species were detected from Nile tilapia in different frequencies. Similarly, all bacteria species were also detected from the African catfish with the exception of *A. baumannii*, *A. jandaei*, *C. braakii*, *E. fergusonii*, *P. carotovorum*, *P. fluorescen*, *P. hunanensis*, *P. mosselii*, *Salmonella* spp., and *S. flexneri*. However, *C. freundii*, *P. stuartii*, *P. fluorescens* and *P. hunanensis* were not isolated from the common carps. Even though it seemed that some bacteria species tended to be specifically associated with a particular fish species, the association was not statistically significant, indicating that each fish species were susceptible against those pathogens. Different studies reported the occurrence and antimicrobial resistance of *A. sobria*, *E. tarda*, *P. shigelloides*, *P. aeruginosa*, *Citrobacter* spp. and *Klebsiella* spp. from Nile tilapia and catfish (Wamala *et al.* 2018, Chandrarathna *et al.* 2018, gufe *et al.* 2019 and Hossain *et al.* 2019).

During the study period, differences were observed in the bacterial prevalence and frequency across the sampling sites of each Lake. This may be attributed to the relative distance and degree of exposure to a nearby pollution source around.

Although the report on fish bacteria and their occurrence in humans is limited in Ethiopia, there were some efforts. Among the bacteria found in this study, *E. coli*, *Klebsiella* spp., *Enterobacter* spp., *Citrobacter* spp., and *Aeromonas* spp. which are enterotoxin-producing were detected in stools of Ethiopian children with diarrhoeal disease in the late 1970s (Wadstrom *et al.* 1976). *E. tarda* was isolated from the liver of a tilapia from Lake Zwai for the first time for the Lake (Yimer 2000). The other bacteria detected in this same study were *E. coli*, *Klebsiella oxytoca*, *Citrobacter* spp. and *Yersinia enterocolitica*. Another investigator (Nuru 2007) isolated *Aeromonas* spp., including *A. sobria*, *E. tarda*, *Vibrio* spp., *E. aerogenes*, *P. shigelloides*, *E. coli*, *K. pneumoniae*, *Shigella* spp., *Citrobacter* spp. from fish of Lake Tana. The author also reported that all the bacterial species, which were isolated from the water samples, were also recovered from fish in the Lake. Moreover, an outbreak of *A. hydrophila* associated with a certain parasite in pond of African catfish fingerlings at Sebeta, central Ethiopia, was reported (Almaw *et al.* 2014). *Vibrio* spp., *Salmonella*, *Shigella* and *E. coli* were detected from surface water and sediment samples of Lake Zwai and drinking water system of Batu (former Zwai) town, Ethiopia (Mekonnen *et al.* 2014).

From the total 410 fish samples examined, six were found contaminated with Shiga toxin-producing *Escherichia coli* strain in Ethiopia (Assefa *et al.* 2019). The isolates were resistant to ampicillin and streptomycin disks. However, ciprofloxacin, gentamicin and nalidixic acid were found effective in inhibiting the growth of all of the isolates. *Vibrio*, *Escherichia*, *Aeromonas*, *Pseudomonas*, *Salmonella* and *Streptococcus* were detected from Nile tilapia in Hawassa with the bacterial population significantly

higher in the intestine than in the liver (Bekele *et al.* 2019). A short review on bacterial pathogens of fish presented pathogenic and zoonotic bacteria such as *Edwardsiella*, *Salmonella*, *Escherichia*, *Staphylococcus*, *Vibrio* and *Aeromonas* recovered from fish from various parts of Ethiopia (Sorsa *et al.* 2019). A more recent molecular study that analyzed the diversity of microbiota in different sections of tilapia gut found more diversity in Lake Chamo than Lake Hawassa (Beredet, *et al.* 2020).

In some countries like Poland (Kozłńska *et al.* 2015) and Malaysia (Marcel *et al.* 2013), the emergence of hitherto unreported pathogenic fish bacteria is becoming evident. Thus, fish bacteria detection methods in Ethiopia must take into account less known and unreported ones as well. Moreover, exploring possible reciprocal transmission of potential pathogenic bacteria from wild fish to aquaculture, and domestic animals or humans is essential. This will contribute towards microbial-source-detection investigations.

This work will serve as an initial step to establish a baseline dataset of microbial communities associated with wild freshwater fish in Ethiopia. But, it has certain notable limitations. It neither quantified the detected bacteria, nor molecularly identified them, and no antibiotic susceptibility test was done. The results would have been more robust if samples from fish skin and gills which are gateway routes of transient or resident microbiota and/or potential pathogenic bacteria have been included. Moreover, the study did not assess seasonal patterns of both water quality and fish microbiota.

## Conclusion

Despite the fact that the physicochemical parameters of the water samples were within normal range at which most freshwater fish are non-stressed; the 20% prevalence of clinically sick fish is a source of concern. Moreover, the bacteria identified from water, live fish and processed fish samples are potential pathogens of fish and man, spoilage agents and indicators of environmental contamination. In processed fish particularly,

hygiene indicator bacteria occurred at higher level suggesting that fresh processed fish available in fish markets of Batu town likely act as a reservoir of pathogenic bacteria. Moreover, the identified bacteria species are zoonotic and associated with food-borne illnesses. This has implications for the fish market and consumer health. Therefore, consistent adherence to simple hygienic steps is advisable. Further, establishing a practice of regular inspection of fish products and source aquatic habitats, including fish processing channels for pathogenic bacteria and environmental sanitation is indispensable.

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## Chapter 15

### Prevalence and effects of fish parasites in commercially important fish species of Lake Zwai

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#### Abstract

*Oreochromis niloticus*, *Clarias gariepinus*, *Carassius carassius*, and *Cyprinus carpio* are the most commercially important fish species in Lake Zwai. The purpose of this study was to look into the prevalence of major fish parasites in four of the most commercially important fish species in Lake Zwai, and their effects on the commercial values of host fishes and health of fish consumers. From May to July 2019, the study was carried out by parasitological examination from live fishes and administering a research questionnaire to various stakeholders. 240 specimens from the four species were examined in the Batu Fish and Other Aquatic Life Research Center laboratory. The obtained data were analyzed using SPSS software. A total of 210 (87.5%) examined fishes were found to be infested with 64.2% (trematodes), 42.5% (nematodes), 40% (crustaceans), 17.1% (cestodes) and 1.3% (*Acantocephala*). The examined fishes were

found to be heavily infested with zoonotic *Clinostomum*, *Contraceacum*, and *Capillaria* species. The parasitic prevalence difference among the studied fish species was statistically significant ( $P = 0.00$ ), but it was not statistically significant between sexes ( $P = 0.60$ ). Lake Zwai's commercially important fish species were heavily infested with various types of external and internal parasites, which have both health and economic consequences.

**Key Words:** Infestation, Parasites, Prevalence, Zoonotic disease

## Introduction

Fish resources are vital to support human well-being and economic development. More than 17% of animal protein for the global population is obtained from fish (FAO, 2018). In addition, fish also serve as an important source of energy and a range of essential nutrients such as fatty acids, iodine, vitamin D, and calcium (Pal *et al.*, 2018; Khalili Tilami and Sampels, 2018). Hence, fish represents a very important source of protein-rich food and a reasonably important supplementary source of income through fishing, processing, transporting, and retailing, particularly in developing countries where other options are often limited (Lynch *et al.*, 2016).

In natural situations, small proportions of fish larvae reach the adult stages, while the majority are preyed upon by predators or die out due to several restrictive agents (Abowei *et al.*, 2011). Among these restrictive agents, fish parasites are considered as one of the major factors that limit human wellbeing through production losses from high fish mortality, morbidity, growth rate and weight reduction, and rejection of fish as well as causes of human diseases (Marcogliese, 2004; Kayis *et al.*, 2009). In terms of these constraints, the annual global cost of parasites in finfish aquaculture is estimated to be \$1.05 to \$9.58 billion with losses ranging from 1% to 10% of harvest size (Shinn *et al.*, 2015; FAO, 2018). In general, the presence of pathogenic parasites in fish is one of the most significant constraints limiting fish

production and productivity. As a result, a better understanding of the various effects of fish parasites on their hosts and fish consumers is critical to the global development and maintenance of fisheries (Barber *et al.*, 2000).

During their parasitic phase, almost all fish species are hosts to at least a few parasitic species, which are small, short-lived, and are usually found hiding on or within organs of their hosts (Marcogliese, 2004). Parasitic organisms, on the other hand, are frequently overlooked in the management and conservation of biological resources and ecosystems (Marcogliese, 2004; Sitja-Bobadilla and Oidtmann, 2017). As a result, information on the parasite fauna, particularly in/on freshwater fishes of sub-Saharan African regions, is limited due to a lack of experienced personnel in fish parasitology (Aloo, 2002) and poor aquaculture production practices.

The most commercially important fish species in Ethiopian lakes, including Lake Zwai, have been found to carry variety of pathogenic parasites from nematodes, cestodes, trematodes, crustaceans, and protozoan families (Hailekiros Gebreegziabher and Assefa Kebede, 2017). However, existing studies on fish parasites in Ethiopia in general, and Lake Zwai in particular, have primarily focused on simple epidemiology rather than parasitic effects. For instance, the study conducted by Eshetu Yimer (2000), Lemma Abera (2013), and Jossy Bekele and Daniel Hussien (2015) in Lake Zwai documented the presence of some nematodes, trematodes, and larval Cestodes from *Oreochromis niloticus* and *Clarias gariepinus*, but not their impacts. These two fish species were the largest stock in the lake and the largest catch size in fishermen nets during their study period.

Cyprinid fishes such as *Carassius carassius* and *Cyprinus carpio* have recently dominated the Lake Zwai fish production and marketing system. However, there has been little or no reporting on the level of parasitism in these species in the country. Furthermore, Lake Zwai is



polluted (Haya lDesta and Brook Lemma, 2017), which may promote the growth of parasites and have a negative impact on people's health because some people enjoy eating raw or undercooked fish meat (Lemma Abera, 2013). Consuming raw or poorly done fish may result in the transmission of zoonotic parasites to consumers. As a result, the information obtained from this study is intended to provide some supportive knowledge to all interested bodies that have direct or indirect contact with fishery products and the health of fish consumers.

This study hypothesized that commercially important fish species in Lake Zwai are infested with myriads of internal and external parasites. As a result, the specific objective of the study was to look into the prevalence of the major parasites in four commercially important fish species in Lake Zwai, as well as their effects on the market values of the host fishes and the health of the people consuming fish in the study area.

## **Materials and methods**

### **Description of the study area**

Lake Zwai is found in the Central Ethiopian Rift Valley (CERV), 165 km South of Addis Ababa at an altitude of 1636 m above sea-level, with latitude ranging from 7°51' N to 8°07' N and longitude ranging from 38°43' E to 38°57' E (Fig. 86). It is a shallow natural freshwater lake with a surface area of approximately 434 km<sup>2</sup> and maximum and mean depths of 9 m and 2.4 m, respectively (Lemma Abera, 2016). It is 25 km long and 20 km wide, with a margin of macrophyte vegetation and marshy grassland all around it. The lake is fed by the Meki River, which flows from the North-West Gurague Mountains and River Kattar (Qatar), which flows from the North-East Chilalo Mountain. Its water drains into Lake Abijata in the South via the Bulbula River (Abebe Getahun, 2017; Hayal Desta and Brook Lemma, 2017). The lake watershed has a semi-arid to sub-humid climate and two rainy seasons, with the main rainy season lasting from June to the end of

September and the short rainy season lasting from March to May. Lake Zwai's average annual rainfall and temperature are 650 mm and 25 °C, respectively (Lemma Abera *et al.*, 2014).

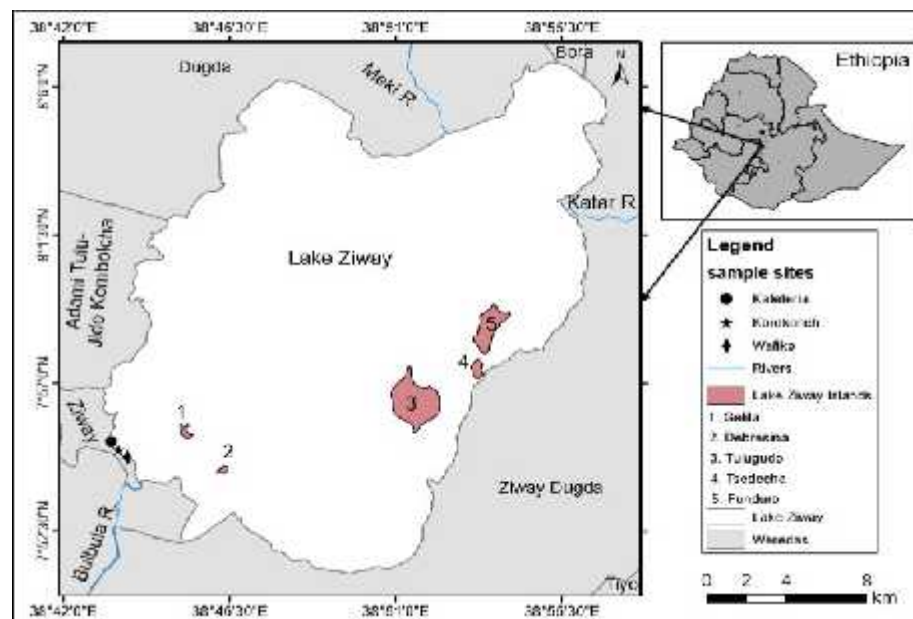


**Figure 84:** Map of Lake Zwai with the locations of the sampling sites numbered 1 to 5

### Study design and sample size determination

Standing from our experience in the study area and reports of previous studies listed above, our study was designed to investigate the prevalence of major fish parasites, their effects on host fish market values, and clinical incidences on residents. To do so, primary data were gathered through parasitological examination and questionnaires, and secondary data were gathered from parasitological disease result reports of Batu hospital. The study was conducted from May 2019 – July 2019. The study's target species were *O. niloticus*, *C. gariepinus*, *C. carassius*, and *C. carpio* (Plate 87). Sample size was determined using Ossiander and Wedemeyer (1973) sample size determination table for fish disease assessment and study to take approximately equal samples

of each species for comparison of parasitic prevalence in the four fish species of the lake. Accordingly, 20 specimens per week were examined from one commercially important fish species, with the sampled fish species changing at weekly intervals. Within three months, 60 specimens from each species and 240 specimens from the four species were examined.



**Figure 85:** Commercially important fish species collected from Lake Zwai (a) *O. niloticus*, (b) *C. gariepinus*, (c) *C. carassius* and (d) *C. carpio*

### Field sample collection

Three landing sites namely, Wafiko, Korokonch and Kafeteria, were chosen for fish sampling based on accessibility, volume of catch, and classification of fishermen by Batu Fishermen Cooperative based on the government guidelines for natural fish stock harvesting. Live fishes were purchased early in the morning with random sizes between 6:00 to 7:30 a.m. from local fishermen who used wooden boats to access the lake and fish with hook-and-lines and beach sein net. The collected live fishes were kept in a 40-liter bucket filled with oxygenated lake water (Justine *et al.*, 2010) and transported to Batu Fish and Other

Aquatic Life Research Center laboratory on L. Zwai shore, which was very close to the fish landing.

### **Parasitological examinations**

The lake water in the bucket containing the sampled fish specimens was aerated in the laboratory using BB.34BA aquarium air pump to keep the fish alive until the closer examinations were done (Justine *et al.*, 2010). The sexes of the specimens were then determined visually by inspecting their genitals and gonads. The external bodies of the specimens, such as fins and skin, were scraped off with scalpels and visually examined for ectoparasites in Petri dishes (Cribb and Bray, 2010). A scalpel, forceps, and scissors were used to remove the eyeballs and gill arches (Justine *et al.*, 2010). Following that, a scissor was used to open the abdominal wall along the ventral middle line. Another incision was made from the anus to the lateral line, and then from the lateral line to the gill cover (Justine *et al.*, 2010; Calhoun *et al.*, 2018). The heart, liver, spleen, gallbladder, intestine, kidneys, muscles, and brains of the specimen were all carefully examined. Swimming bladders from two carps and a Nile tilapia were collected separately for endoparasite recovery.

Drops of 0.85% physiological NaCl solution were applied to each examined organ, and the parasites released were collected in wet Petri dishes to avoid drying (Cribb and Bray, 2010; Khalil *et al.*, 2014). Each organ was thoroughly examined with the naked eye for the presence of cysts, larval and adult parasites internally and externally, as well as under a 40x binocular microscope (Mohammed Reshid *et al.*, 2015). The collected parasites were counted and identified morphologically to the genus level using the identification guidelines of Paperna (1996), Florio *et al.* (2009), and Shehata *et al.* (2018). As directed by Oros *et al.* (2010), some representative samples of the collected parasites were preserved in 4% neutral formalin for further identification. After one to two weeks, the preserved parasites were transformed into 70% ethanol

according to procedures by Oros *et al.* (2010) and Khalil *et al.* (2014) to prevent the parasites' bodies from becoming hard and fragile as a result of long-time preservation with formalin. Finally, the ethanol-preserved parasites were transported to Sebeta, National Fisheries and Aquatic Life Research Center fishery laboratory for further identification.

### Questionnaire development

A research questionnaire was developed, validated, and distributed to members of the local communities, including fishermen and fish traders or middlemen, fishery experts in Zonal Agricultural Offices, restaurants serving fish dishes, and public health professionals at Batu Hospital, who have direct or indirect contact with Lake Zwai fish and fish products. This was done to assess stakeholders' perceptions of the types of common fish parasites found in commercially important fish species in Lake Zwai, as well as their effects on the marketability of the fishes. Secondary data were also gathered from Batu Hospital in order to learn about clinical incidences in the surrounding community.

### Statistical tools

Prevalence describes the presence or absence of parasites in the examined samples. To arrive at the percentage of infected individuals, the number of infected hosts at least by one parasite is divided by the total number of examined hosts and multiplied by 100 (Bush *et al.*, 1997).

$$\text{Prevalence (P\%)} = \frac{\text{Total number of infected fish}}{\text{Total number of examined fish}} * 100$$

### Statistical data analysis

All the data obtained during the study period were recorded in Microsoft Excel sheet and differences in the parasitic prevalence among the four fish species, and between sexes were analyzed using SPSS software, version-21. P-values less than 0.05 were considered as

statistically significant at 95% confidence interval.

## Results

### Prevalence of parasitic infestations

About 87.5% of the 240 fish specimens examined were found to be infested with at least one internal or external parasite. *Clarias gariepinus* had the highest level of parasite infestation (100.0%), followed by *O. niloticus* (90.0%), and *C. carassius* (85%). *Cyprinus carpio* had the lowest proportion of parasite infestation (75%) (Table 70). The differences in parasite infestations of the different fish species were statistically significant ( $P = 0.00$ ,  $\chi^2 = 17.83$ ,  $df = 3$ ). During the study period, 94 (86.2%) of the 109 male fishes examined were infected with at least one external or internal parasite, while 116 (88.6%) of the 131 female fishes examined were infected by parasites, but the difference in parasitic prevalence between the sexes was not statistically significant ( $P = 0.592$ ,  $df = 238$ ,  $SE = 0.098$ ).

**Table 70:** Fish species sampled and the prevalence of parasites in the four commercially important fish species of Lake Zwai (N = 240)

| Sampled fish species        | No. of infected fish | Parasitic prevalence (%) |
|-----------------------------|----------------------|--------------------------|
| <i>O. niloticus</i> (n=60)  | 54                   | 90                       |
| <i>C. gariepinus</i> (n=60) | 60                   | 100                      |
| <i>C. carassius</i> (n=60)  | 51                   | 85                       |
| <i>C. carpio</i> (n=60)     | 45                   | 75                       |
| <b>Total (n=240)</b>        | <b>210</b>           | <b>87.5</b>              |

### Types of parasites and their prevalence

A total of 22,909 parasite specimens grouped under fourteen genera were identified (Table 71). Out of the 240 fishes examined during the study period, 154 (64.2%) fishes were infected by trematodes, 102 (42.5%) were infected by nematodes, 96 (40%) by crustaceans, 41 (17.1%) by cestodes, and five (1.3%) were harboring *Acantocephala* species.

**Table 71:** Organs of infestation, prevalence and intensity of parasites collected from the four commercially important fish species of Lake Zwai (N = 240). NOTE: B. cavity is for brachial cavity, C. cavity is for cranial cavity and P. cavity is for pericardial cavity

| Taxonomy of parasites  |                             | Infected fish organs               | Number of infected fish |                         |                        |                     | No. of<br>Detected<br>parasites | P (%) |
|------------------------|-----------------------------|------------------------------------|-------------------------|-------------------------|------------------------|---------------------|---------------------------------|-------|
|                        |                             |                                    | O.<br><i>niloticus</i>  | C.<br><i>gariepinus</i> | C.<br><i>carassius</i> | C.<br><i>carpio</i> |                                 |       |
| Crustacean             | <i>Argulus</i> spp.         | Gill, Skin, Mouth                  | 1                       | 8                       | 5                      | 14                  | 55                              | 11.67 |
|                        | Copepodite                  | Gill, Skin                         | 12                      | 2                       | 37                     | 27                  | 358                             | 32.50 |
| Monogenean             | <i>Gyrodactylus</i> spp.    | Skin                               | 0                       | 15                      | 0                      | 0                   | 27                              | 6.25  |
|                        | <i>Cichlidogyrus</i> spp.   | Gill                               | 3                       | 0                       | 0                      | 0                   | 5                               | 1.25  |
|                        | <i>Tylodelphys</i> spp.     | C. cavity, Eye                     | 36                      | 59                      | 29                     | 25                  | 20,002                          | 62.08 |
| Digenean<br>Trematodes | <i>Clinostomum</i> spp.     | Gill, Muscle, B. cavity, Eye orbit | 20                      | 11                      | 0                      | 0                   | 144                             | 12.92 |
|                        | <i>Clinostomum</i> cyst     | Muscle                             | 0                       | 44                      | 0                      | 0                   | 936                             | 18.33 |
|                        | <i>Neascus</i> spp.         | Muscle                             | 3                       | 0                       | 0                      | 0                   | 4                               | 1.25  |
|                        | Unidentified trematode      | Intestine                          | 0                       | 11                      | 0                      | 0                   | 42                              | 4.58  |
|                        | <i>Contracaecum</i> spp.    | Mesentery, P. cavity               | 13                      | 50                      | 7                      | 3                   | 855                             | 30.42 |
| Nematodes              | <i>Capillaria</i> spp.      | Intestine                          | 30                      | 8                       | 0                      | 0                   | 161                             | 15.83 |
|                        | <i>Procamallanus</i> spp.   | Intestine                          | 0                       | 19                      | 0                      | 0                   | 84                              | 7.92  |
| Cestodes               | <i>Bothriocephalus</i> spp. | Intestine                          | 0                       | 31                      | 0                      | 0                   | 173                             | 12.92 |
|                        | Unidentified cestode        | Intestine                          | 10                      | 0                       | 0                      | 0                   | 55                              | 4.17  |
| Acantocephalans        | <i>Acantocephala</i> spp.   | Intestine                          | 5                       | 0                       | 0                      | 0                   | 8                               | 2.08  |
| Total                  |                             |                                    |                         |                         |                        |                     | 22,909                          |       |

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### Demography of the respondents

The study was supported by information generated from different group of people involved in the fishing activities of Lake Zwai, fish and fishery experts, and health professionals in Batu Hospital. These were: fishermen (30), fish traders (20), fish house owners (10), fish and fishery experts (6) from the Oromia Agricultural Research Institute, Batu livestock bureau and (4) from Oromia Agricultural Research Institute Batu Fish and Aquatic Life Research Center, Medical doctors (7) and laboratory technologists (4) from Oromia Health Bureau Batu Hospital. Their ages ranged from 20 to 50 years. Of the interviewed participants 73 (90.12%) were males and 8 (9.88%) were females. 81 respondents with different status participated in throughout the study.

### Stakeholders' perspectives on various types of fish parasites and their commercial implications

Parasites affected the commercially important fish species in Lake Zwai, according to respondents. All respondents (100%) including fishermen, fish traders, fish restaurant owners, and fish and fishery experts agreed that parasites have a significant impact on the commercially important fish species, particularly African catfish. *Contracaecum* spp, also known as "Wesfat" or "Maga," and *Clinostomum* spp., also known as "Koso," are the two well-known fish parasites. *Tyloodelphys* spp. are also common in the cranial cavity of African catfish and occasionally in the eyes of Cyprinid fish species in Lake Zwai, according to the four (40%) fish and fishery experts (Fig. 88). The presence of too many parasites causes fish losses, according to 22 (73.3%) fishermen, 16 (80%) fish traders, 10 (100%) fish restaurant owners, and 4 (40%) fish and fishery experts. *Clinostomum* spp. were the most common parasite in the muscles of African catfish, causing a significant loss of the fish in the market. According to the interviewees' responses, up to ten fish per box (one box may contain 25-50 fish depending on the fish size) may be lost in some cases, costing 2 to 15



Ethiopian Birr per fish (equivalent to 0.05\$ to 0.34 USD per fish at the current exchange rate).



**Figure 86:** Most prevalent fish parasites at Lake Zwai with commonly known ones: (a) *Contracaecum* spp., (b) *Clinostomum* spp. and (c) *Tyloodelphys* spp.

### Stakeholders' responses to clinical incidences of fish parasites

All respondents in the research questionnaires among the health professionals of Oromia Health Bureau Batu Hospital stated that they had not experienced any zoonotic human diseases caused by consuming parasite-infected fish such as those described above. However, because of the local people's tradition of eating raw fish and poorly prepared fish, there have been reports of the presence of zoonotic fish parasitic diseases. Although no active cases were observed during this study, oral narratives of helminth diseases contracted from fish have been heard on several occasions. According to Batu Hospital health professionals, up to 90 people per month are infected with helminth parasitic diseases. When asked which parasites were present, the health workers were unable to

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identify the type and severity of the infections. According to reports, all patients were treated with broad-spectrum antihelminthic drugs.

## Discussion

The higher parasitic prevalence observed in the current study could be attributed to a variety of natural and anthropogenic factors that provide favorable conditions for the parasite's increased magnitude. For example, the shore area of Lake Zwai is covered by several macrophytes (Hayal Destaa and Brook Lemma, 2017), that may be suitable for the propagation of the parasites' first intermediate hosts (Crotti, 2013). Furthermore, a variety of water birds visit the lake, which may serve as the final hosts for several helminth larval parasites lodged in or on the fish that birds eat. Furthermore, almost all fish caught by fishermen are eviscerated at the lake's shore, washed, and the offal (guts, heads, scales, and so on) other fish carrion are disposed there at the spot of the operation. The fish carrion is likely to contain parasites at various stages of development. When the carrion is eaten by flesh-eating birds such as storks, hammer-cops, and some dogs, the parasites in some cases continue their life cycles in these secondary or tertiary hosts (Lemma Abera, 2013).

In comparison, the overall parasitic prevalence (87.5%) in this study was higher than the total parasitic prevalence of 63.7% in Armand River, Iran (Raissy and Ansari, 2012), 50% in the Ase River Catchment, Delta State, Nigeria (Ito, 2017), 65.8% in upper Tana Basin, Kenya (Mathenge, 2010), 47.8% in Lake Hayq (Abadi Amare *et al.*, 2014), 66.3% in Koka Reservoir (Yewubdar Gulelat *et al.*, 2013) and 24.6% and 20.8% in Lake Zwai by Eshetu Yimer (2000) and Jossy Bekele and Daniel Hussien (2015), respectively. The higher parasites prevalence in the present study might be attributed to the fact that, the sample size of this study was high as it involved four different fish species with various models of feeding habits, which may have apparently increased the probability of parasite richness (Ito, 2007). Furthermore, the present study was conducted in the rainy season in the study area (May, 2019 to July, 2019) that may have increased the occurrence of parasites, because of the proliferation of high number of

first intermediate hosts such as molluscs, oligochaetes, and zooplankton (Bichi and Dawaki, 2010).

This study also revealed the prevalence rate for *O. niloticus*, *C. gariepinus*, *C. carassius* and *C. carpio* were 90%, 100%, 85%, and 75%, respectively. These results are also consistent with previous prevalence rates of 100% reported for *C. griepinus* by Gumpinger (2016) in Lake Baringo. However, the results of this study revealed a higher rate of prevalence of fish parasites than those found previously by other researchers, specifically, 22.6% for *C. gariepinus* (Carp, 2007), 74.5% for *C. gariepinus*, 63.8% for *O. niloticus*, and 51.2% for *C. carpio* (Shehata *et al.*, 2018), 76.1% for *O. niloticus* (Brian *et al.*, 2018), 42.47% for *O. niloticus* (Yewubdar Gulelat *et al.*, 2013). The parasitic prevalence in the current study, on the other hand, was lower than the prevalence of 98.4% reported for *O. niloticus* from Gigel Gibe-I Dam in Ethiopia (MarshetAdugna *et al.*, 2018). This variation of parasitic infection from location to location suggest that the occurrence of fish parasites is influenced by a variety of factors, including differences in physical and chemical parameters of the water, climatic conditions of the areas and season that stress fish hosts and predispose for parasite infection (Edema *et al.*, 2008; Abadi Amare *et al.*, 2014).

*Clarias gariepinus* had the highest prevalence of parasitic infestation, followed by *O. niloticus*, *C. crassius*, and *C. carpio*, and the difference in parasitic prevalence among the studied fish species was significant. The higher prevalence of total parasitic infection in *C. gariepinus* could be attributed to the presence of *Tylodelphys* spp. and *Contracaecum* spp., which have prevalence rates of 98.3 % and 88.3 %, respectively. *C. gariepinus* has the highest infestation rate due to its ability to live and feed near the bottom as well as in midwaters or near the surface of freshwater bodies which is termed as benthopelagic feeding behavior (Abebe Getahun, 2017). This aids in the transmission of many internal parasites by feeding on aquatic animals that harbor the infective stages of these parasites. Furthermore, *C. gariepinus* is a "scaleless" fish whose skin may

be easily penetrated by the infective stages of parasites. It is also possible that *C. gariepinus* is highly susceptible to infections as a result of its diverse feeding habits, which take it into a variety of micro-habitats and expose it to multiple and severe parasitic infestations (Shehata *et al.*, 2018). *C. carpio* and *C. carassius*, on the other hand, were the fourth and third least infected fishes in the current study, respectively. This could be attributed to carps' hardiness (Copp *et al.*, 2008), which could serve as a non-specific defense mechanism to trap and inhibit the growth of parasitic organisms (Rasouli *et al.*, 2012). This could also be due to the fact that carps are newcomers to the lake, having been introduced by some fishery experts. Furthermore, the detection of lower parasitic prevalence rates in *O. niloticus* and the two carps than in *C. gariepinus* could be due to the fact that *O. niloticus* and carps are fast growers, reaching marketable size in a short period of time, reducing their period of exposure to parasitic infestations (Shehata *et al.*, 2018).

There was no any significant difference in parasitic prevalence between the sexes. However, female fish had a slightly higher parasitic prevalence (88.6 %) than male fish (86.2%). This could be attributed to the fact that females, particularly gravid females, are physiologically more vulnerable to parasitic infestations (Simkova *et al.*, 2005). This observation is consistent with the findings of Shehata *et al.* (2018) in Egyptian freshwater aquaculture, Brian *et al.* (2018) in Lake Baringo, Kenya, and Abadi Amare *et al.* (2014) in Lake Hayk, Ethiopia.

During the study period, 22,909 parasites from 12 identified and 2 unidentified different taxa were collected from 210 (87.5 %) infected fishes. This value was higher than the findings of Gumpinger (2016), who found 2598 parasites from ten different taxa in 101 fishes from four commercially important fish species in Lake Baringo, Kenya. It was also higher than the findings of Brian *et al.* (2018), who discovered 6027 parasites from six taxa in 447 *O. niloticus* fish species at River Molo Inlet in Lake Baringo, Kenya. The differences in the geo-climatic conditions of

the study areas, variations in the host-parasite relationships, and differences in the quality of the environments where the Lake Zwai study has become so conducive to the propagation of parasitic agents could all be reasons for this (Ito, 2017). The latter case is exemplified further by the fact that the parasite load per fish (109) in this study is significantly higher than that found in both Kenyan studies (26 and 14 parasites per fish, respectively).

Only three of the fourteen different parasite genera identified in this study, namely *Clinostomum* spp., *Contraceacum* spp., and *Bothriocephalus* spp., were previously reported from Lake Zwai fishes by EshetuYimer (2000), Lemma Abera (2013), Jossy Bekele and Daniel Hussien (2015), and Temesgen Bihonegn and Getachew Tilahun (2017), while the remaining (11genera) are new reports of this study. This might be attributed to pollution (eutrophication) of Lake Zwai from time to time that may have created a conducive environment for propagation and proliferation of valuablefish parasites. Inaddition, it could be due to the research method such that we used live fish samples for the parasitological examination that may have enhanced the chance to find existing parasites compared to the use of long time stored dead host (Justine *et al.*, 2010).

The classes of parasitic prevalence revealed that trematodes made up 64.2%, nematodes 42.5%, crustaceans 40.0%, cestodes 17.1%, and *Acantocephala* spp 1.3%. The findings of this study contradicts those of Kiprono (2017), who found 34.5% nematodes, 26.5% trematodes, 15% cestodes, 11.3% crustaceans, and 3.8% *Acantocephala* spp., most likely belonging to Class *Eoacanthocephala*. These findings are also not comparable to Mathenge's (2010) work, which reported 45.3% nematodes, 41.5% trematodes, 13.9% *Acantocephala*, and 2.5% cestodes. In the current study, the most common parasitic trematode class was *Tylodelphysspp.*, which was the most common parasite affecting 201 fish specimens from the four examined fish species that were positive for one or more parasitic species. This could be because Lake Zwai is surrounded

by a margin of macrophyte vegetation and marsh (Abebe Getahun, 2017; Hayal Desta and Brook Lemma, 2017), which provides important habitat for the propagation of mollusks, which are the first intermediate hosts of this parasite (Crotti, 2013). The trematodes colonize the mouths and pharynxes of piscivorous birds such as egrets, herons, darters, cormorants, storks, and pelicans (Paperna, 1996). Furthermore, the presence of *Tylodelphys* spp. in all examined fish species suggests that this parasite is adaptable in its host selection, ensuring its survival in a diverse range of hosts (Rasouli *et al.*, 2012).

The questionnaire survey was designed primarily to gather stakeholders' perspectives on Lake Zwai's commercially important fish parasites and their effects on fish market value and health of the residents. As a result, 100 percent of the respondents agreed on the presence of fish parasites, which continue to be a nuisance in the processing and marketing of Lake Zwai fish harvests. This concurrent response in this study was higher than the findings of Haftom Abay (2018), who reported that 41.6 percent of respondents were from people living near Lake Ashenge. According to the respondents' responses, the most common parasites of commercially important fish species in Lake Zwai were *Contracaecum* spp. (locally known as "wesfat" or "Maga"), *Clinostomum* spp. (locally known as "Cosotil"), and *Tylodelphys* spp. (has no local name).

Respondents confirmed that *Clinostomum* spp., particularly those that lodge in the muscles of *C. gariepinus*, have a significant economic impact, rendering the fish flesh unappealing or repulsive to consumers (see also the reports of Brian *et al.*, 2018). Furthermore, even though all health professionals responded that there had been no reports of zoonotic disease thus far, the patients' profiles recorded at Batu Hospital revealed a higher occurrence of helminth disease. According to Amer (2014), parasites such as *Contracaecum* spp., *Capillaria* spp., and *Clinostomum* spp. are zoonotic and can be transmitted from fish to humans when raw flesh is consumed. It is therefore unlikely that, with such a high abundance of these parasites in

Lake Zwai fish and the raw fish consumption habits of the people in Zwai, some of the zoonotic diseases have gone unnoticed.

## Conclusion

The results of this study have demonstrated that various types of external and internal parasites seriously affect commercially important fish species in Lake Zwai. It was found that 87.5% of the fish catches examined were found to be infested with 64.2% trematodes, 42.5% nematodes, 40% crustaceans, 17.1% cestodes, and 1.3% Acantocephala as well as infected with zoonotic *Clinostomum*, *Contraceacum*, and *Capillaria* species. Fishers are losing some of their catches due to parasitic effect, especially due to unattractive muscle of *C. gariepinus* infected by numerous *Clinostomum* cyst. These parasites, which have a significant impact on the fish market, have gone unnoticed so far in the study area. What is more, the local inhabitants eat raw fish and have no awareness about the dangers it poses to their health. To avert the dangers of suffering from internal parasites and concomitant zoonotic disease, people living on fish as food should be made aware of the problem and discouraged from eating rawfish and encouraged to take appropriate sanitary measures. Research should be done in the future focused on fish ecology with the participation of biologists, parasitologists, public health experts, and aquatic ecologists. This can help to generate more reliable data in improving the quality of the aquatic environment, decreasing fish parasites, and protecting the public from fish-borne internal parasites and zoonotic diseases.

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## Chapter 16

### Changes in the patterns of land and water use in Lake Zwai watershed

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#### Abstract

The degradations of land and water resources in Lake Zwai watershed are serious problems. The increase in human population and the subsequent changes in land use and land cover (LULC) patterns and water demand for various uses have been increasing in this watershed since 1970s. These changes have significant influences on the lake watershed hydrological processes and the lake itself. Recognizing these facts, LULC change detections for the periods 1973, 1989 and 2014 were analyzed using Landsat Satellite image series. Estimations were also made for the lake evaporation, and sediment yields at the lake sub-watershed levels using Soil and Water Assessment Tool (SWAT) model. The general objective of this paper was to examine the patterns of land and water use changes in Lake Zwai and its watershed, quantify the changes that took place, and suggest management options. The LULC change pattern analysis showed that the dominant land use type in the lake watershed is cultivation, being expanded at the expense of other land use types. The results of SWAT model showed an increase in evapotranspiration and sediment load in both Meki and Qatar Sub-watersheds. This study showed that human impacts

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are the main drivers for the degradation of Lake Zwai and its watershed resources. Water abstractions and sedimentation were the main impacts for the lake water level reduction. The study suggested planning recommendations to improve the future sustainable utilization and management alternatives towards Lake Zwai and its watershed resources' conservation.

**Keywords:** Lake Zwai, Watershed, Human impacts, land-use land-cover, LULC, sediment yield

## Introduction

Land and water resources are the main source of peoples' livelihoods. However, the degradations of these resources are among the many critical environmental problems. The adverse impacts on these resources, especially in developing countries, have happened by human pressures associated with the ever increasing of population being aggravated by the impacts of poverty. In East Africa countries including Ethiopia, the increase in human population has quickly increased since the 1950s, which is manifested by the expansion of mixed crop-livestock systems into the grazing land and intensification of agriculture (Olson and Maitima, 2006).

Currently the most severe threats to water resources are also related to the increase in human population. Globally significant portions of the Earth's land surface have been transformed by humans into different land use types (Vitousek *et al.*, 1997). Vitousek (1994) noted that land-use land-cover (LULC) change is one of the well-documented global factors for the degradation of natural environments. Human land-use and related change activities have significant influences on watershedsof lakesand their associated physical, biological, and chemical processes (Brooks *et al.*, 1997). Roth *et al.* (1996) and Tomer and Schilling (2009) asserted that these changes are important drivers in altering watershed hydrology, decreasing the availability of different products and ecological services (Moshen, 1999). Moreover, lakes are harmed by direct uncontrolled abstraction of water, fishery resources, woods, grasses and other materials.



In general, water resources have now increasingly become one of the scarce resources due to rapid population increasing, fast economic development, and mismanagement (Huang and Cai, 2009). Recognizing these facts, sustainable land and water resource management has become one of the priority agenda in many countries of the world. Xiaomei and Ronqing (1999) noted that information about LULC changes is therefore necessary for the management of natural resources such as land and water and considerable concern for humans (Cohen *et al.*, 1996; Lambin *et al.*, 2001).

The Ethiopian Central Rift Valley (CRV) is massively degraded by human activities (Feoli and Zerihun Woldu, 2000; Jansen *et al.*, 2007), with key problems being irrigation agriculture and large-scale floriculture industries (Hengsdijk and Jansen, 2006). Lake Zwai (also referred to as Zwai or Zeway in the literature) is the largest freshwater lake in the CRV. The lake and its watershed have significant contributions in supporting the livelihoods of many people in the watershed. However, the sustainable use and management of Lake Zwai and its watershed are being under threat by multifaceted factors the cause of which is mainly associated with the on-going livelihoods activities and large-scale agricultural development activities. Intensification of multiple land use changes along with increasing demand for water in the watershed have greatly affected the hydrologic dynamics of the lake and its watershed. Water extraction for irrigated land uses from the lake and its feeder rivers is very high (Tenalem Ayenew, 2004; Scholten, 2007). Jansen *et al.* (2007) pointed out that high population pressures have resulted in a clear decrease of the level of Lake Zwai. Besides, feeder-rivers, namely, Meki and Qatar Rivers inject considerable loads of sediments into Lake Zwai from the Gurage Highlands in the west and Arsi Highlands in the east, respectively. Thus, the water withdrawal, land use changes, and irrigated farming activities in the upstream areas of the watershed are affecting the lake ecology and in turn the livelihoods of local people who depend on the lake (Hengsdijk and Jansen, 2006).

Accordingly, the land and water resources on which the great majority of people in the watershed depend on for their livelihoods need comprehensive actions for the sake of these resources' sustainability. Therefore, a scientific study in land and water use management is necessary on Lake Zwai watershed and the lake itself in order to overcome the impacts and maintain the wise use and sustainable management of the resources. In this regard, this study was intended to provide evidence-based recommendations to the efforts being undertaken by the Federal Government of Ethiopia Ministry of Water, Irrigation and Electricity, Environment, Forestry and Climate Change Commission, Ministry of Agriculture, Agricultural and Environmental Protection Bureaus of the Oromia National Regional State and Southern Nations and Nationalities People Regional and to wisely use Lake Zwai and its watershed. Therefore, the general objective of this paper was to examine the past and present forms of land and water uses in Lake Zwai and its watershed, quantify the changes that took place in the watershed and on Lake Zwai and suggest management options.

### Materials and methods

**Description of the study area:** Lake Zwai watershed covers an area of 7,032.3 km<sup>2</sup> (703,228.5ha), falling between gradients 7°15'N to 8°30'N latitude and 38°E to 39°30'E longitude (Fig.89). The watershed has two sub-watersheds, namely Meki Sub-watershed in the northwestern part and Qatar Sub-watershed in the southeastern part of the Lake Zwai with mountain peaks reaching 2,049.3 and 3,337.7 km<sup>2</sup> respectively. The remaining part of the watershed covers the Lake Zwai surrounding plains. Qatar Sub-watershed is entirely located within Oromia National Regional State (ONRS) while Meki Sub-watershed is scattered over two Administrative regions, i.e. ONRS and Sothern Nation Nationalities and People regions (SNNPR). The Meki River watershed covers parts or all of eight Woredas (one of the Administrative Structures in Ethiopia that represents 'Districts'), namely *Meskan*, *Mareko*, *Soddo*, *Siltie*, *Dalocha*,

*Lanfaro, Adami-Tulu, Jido-Kombolcha and Dugda Bora*. All except the last two are located in SNNPRS. The Qatar River watershed covers Zwai Dugda, *Degeluna Tijo, Hitosa, Tiyo, Munesa and Bekoji*. In general, 73.6% of the whole Lake Zwai watershed is located with the ONRS and the remaining in SNNPR.

The climatic conditions are not uniform throughout the year, both dry (locally named as *Bega*) and rainy (locally named as *Kiremt*) seasons are distinguished. The Qatar and Meki Sub-watersheds have respectively a mean wet season precipitation of 464mm (116mm per month) and 456mm (114mm per month) and temperature of 15°C and 18°C.

Lake Zwai watershed stretches from the edges of the Gurage Mountains in the west and the edges of the Arsi Mountains in the eastern escarpment, rising over 3000 m above sea level (masl). The lake has important ecosystem services. It is the source of drinking and domestic water uses for Zwai (Batu) and Meki Towns, source of water for open farm irrigation, food, and serves as home of a wide range of biological diversities that include various forms of invertebrates and non-vascular plants to the higher vertebrates such as fishes, birds, mammals e.g. hippopotamus, and various forms of vascular plants. Many people make their livelihoods in and around the lake. Besides the economic values, the lake has also recreational and religious values. According to Vuik (2008), the lake and its watershed support unique ecological and hydrological characteristics. The marshes around the lake, for example, support several bird species, and roosts for several thousands of cranes, heron, ducks, geese, etc. (Spliethoff *et al.*, 2009). About 2 million human populations (CSA, 2013) and about 1.9 million livestock (Derege Tsegaye *et al.*, 2012) inhabit the Lake Zwai watershed. Agriculture is the most dominant land use system contributing to the livelihoods of the majority of the watershed population.

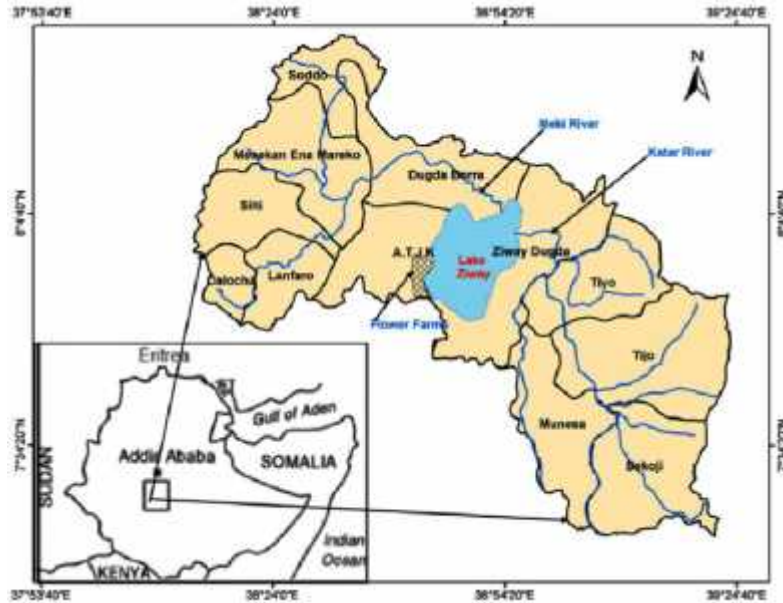


Figure 87: Location of Lake Zwai and its watershed

### Methods of data collection and data analysis

**Land-use land-cover (LULC) Change detections:** Satellite images [Landsat Multispectral Scanner (MSS) of 1973, Landsat Thematic Mapper (TM) of 1989 and Enhanced Landsat Thematic Mapper Plus (ETM+) of 2014] were used for LULC change detections. To minimize discrepancies in reflectance, the images were used from the same month of the year, i.e., January, as the seasonal moisture content and percent cloud cover are lowest in this month of the year in the watershed.

For verification of the image classification procedures, the coordinates of the actual ground truthing points for each LULC types were collected using the GPS both during data collection periods. These were supported by additional information from elderly local people based on the prior knowledge of the study area, previous researches and Goggle Earth images. The final LULC classes are classified for the three distinct years (1973, 1989 and 2014) and their LULC types were mapped in eight categories

(Table 80). The classification scheme for the study area was developed after modification as shown in Table 1. An accuracy assessment was done to determine the quality of the information derived from the images. Erdas Imagine Software Version 13 and ArcGIS Software Version 10.2 were used to examine LULC change pattern detections.

**Table 72:** Brief explanations of the major LULC patterns of Lake Zwai Watershed (after Dagnachew Legesse *et al.* 2003)

| Land use/cover categories | Brief description                                        |
|---------------------------|----------------------------------------------------------|
| Woodlands                 | Degraded Acacia land with cultivation/grazing            |
| Wetlands                  | Non-forested wetlands                                    |
| Water bodies              | Permanent open water (lakes and reservoirs)              |
| Plantation                | Planted eucalyptus trees                                 |
| Afro-alpine               | Afro-alpine bushland, shrubs, and grasses                |
| Cultivation               | Intensively rain fed and irrigated cultivated lands      |
| Agroforestry              | Cultivated lands with vegetation/ tree stands in between |
| Settlement                | Build-up areas                                           |

**Soil and water assessment:** Soil and Water Assessment Tool (SWAT) is used to assess the watershed hydrology (Arnold *et al.*, 1998, and Jha, 2011). Digital Elevation Models (DEM), LULC data, FAO digital soil map of Ethiopia (FAO-UNESCO 1976), Climate data for the period from 1984 to 2014 and Meki and Qatar Rivers' Daily discharge data were used for SWAT model calibration and validation.

**Sediment yield Estimation:** A watershed sediment yield refers to the amount of sediment exported from a watershed over a given period of time, and also the amount which will enter a receiving water body (a reservoir/lake) located at the downstream limit of the watershed (Oeurng *et al.*, 2011). It is calculated in SWAT using the Modified Universal Soil Loss Equation (Williams, 1975).

**Assessment of water abstraction:** Data to estimate water abstraction from Lake Zwai was collected from three districts bordering the lake, assuming six working hours per day using the Equation below:

$$A = P * C * H$$

Where:

*A* is water abstraction (liter/day),

*P* is number of pumps being used,

*C* is abstraction capacity of the pumps (liter per second),  
and

*H* is abstraction hours per day.

## Results

**Land use land cover change detections:** On the basis of the temporal and spatial datasets acquired, LULC maps of Lake Zwai watershed were prepared for 1973, 1989 and 2014 (Fig. 90). The results showed that eight land-cover classes were identified in Lake Zwai watershed, namely agroforestry, cultivation, afro-alpine, plantation, settlement, water bodies, wetlands and woodlands, and their overall units are shown in Fig. 91 for the year 1973, 1989 and 2014. LULC types were classified and details of their statistics of the study area were derived from the maps for the same years, and the LULC change of Lake Zwai watershed is shown in Table 80. The Fig. s in Table 81 represented the statistic area of each LULC category for the three study periods. Plantation, settlement, and wetlands occupy the least class with just below 2% of the total classes in each study years.

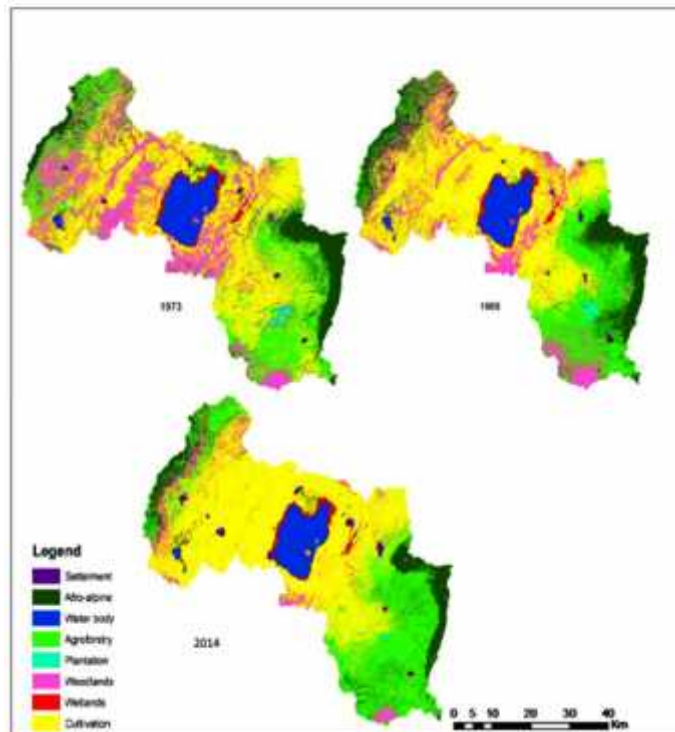


**Figure 88:** LULC in the study area between 1973 and 2014 (Legend top-down: Settlements, afro-alpines, water body, agro-forestry, plantations, woodlands, wetlands and cultivated lands)

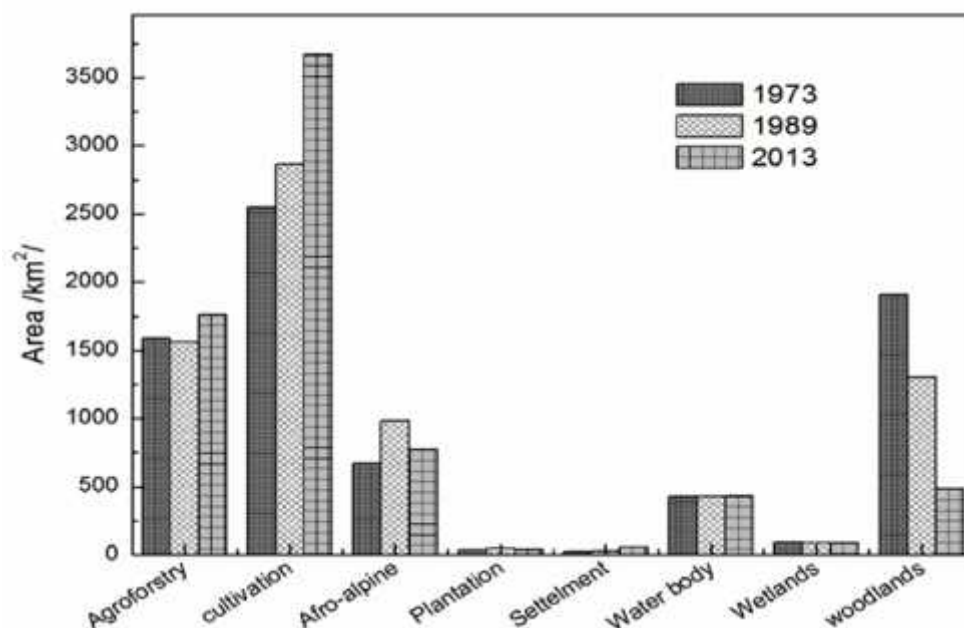


**Figure 89:** LULC classes by 1973, 1989 and 2014

**Table 73:** Statistical distribution of LULC class areas in Lake Zwai Watershed by 1973, 1989 and 2014

| Land cover class | 1973                  |            | 1989                  |            | 2014                  |            |
|------------------|-----------------------|------------|-----------------------|------------|-----------------------|------------|
|                  | Area, km <sup>2</sup> | %          | Area, km <sup>2</sup> | %          | Area, km <sup>2</sup> | %          |
| Agroforestry     | 1590                  | 21.78      | 1560                  | 21.37      | 1759                  | 24.1       |
| Cultivation      | 2547                  | 34.89      | 2863                  | 39.22      | 3667                  | 50.23      |
| Afro-alpine      | 672                   | 9.21       | 984                   | 13.48      | 773                   | 10.59      |
| Plantation       | 37                    | 0.51       | 49                    | 0.67       | 40                    | 0.55       |
| Settlement       | 25                    | 0.34       | 28                    | 0.38       | 59                    | 0.81       |
| Water bodies     | 427                   | 5.85       | 426                   | 5.84       | 430                   | 5.89       |
| Wetlands         | 92                    | 1.26       | 88                    | 1.21       | 88                    | 1.21       |
| Woodlands        | 1910                  | 26.16      | 1302                  | 17.84      | 484                   | 6.63       |
| <b>Total</b>     | <b>7300</b>           | <b>100</b> | <b>7300</b>           | <b>100</b> | <b>7300</b>           | <b>100</b> |

In 1973 the highest proportion was covered by cultivation (34.9%). About one fourth of the study area was covered by woodlands which later became



the third largest cover in 1989 (26%). Settlements and wetlands are the smallest areas throughout the study period in LULC classes of Lake Zwai watershed.

Cultivation and settlement showed increasing trends throughout the study periods. Cultivation was estimated 35% in 1973 and increased by 4% in 1989. In 2014, however, the cultivation has increased by 11% from its 1989 coverage. Agroforestry was also estimated at about 22% in 1973 and remained the same in 1989. In 2014, however, the agroforestry has increased by about 3% from its 1989 area. In general, in this LULC analysis, it was found out that agricultural land coverage (agroforestry and cultivation) showed about 55% increase since the last 40 years (1973 to 2014). In 1973, the area under these land covers was about 57 % of the total, which was an increase of about 61% by 1989 and 74.3% by 2014.

Afro-alpine and plantation showed similar change trends. The result in this study showed that there was an increase of plantation, and afro-alpine bushland and shrub lands in the watershed from 1973 to 1989. However, this change was entirely reversed for both land covers from 1989 - 2014. The Afro-alpine was estimated at 9% in 1973 and increased by 4% in 1989. However, it has decreased by 3% from its 1989 area. Similarly, plantation was estimated at 0.5% in 1973 and increased in 1989 by 0.16%, and has decreased to what its area was in 2014. There was however 15% and 8% increase for afro-alpine and plantation land covers respectively since the last 40 years (1973 to 2014).

Similarly, settlement was estimated 0.34% in 1973 and increased by 0.38% in 1989 and by 0.43% in 2014 from its 1989 area. The result in this study showed that settlements showed increasing coverage similar to agricultural lands. There was an increase of 136% settlement area in the watershed from the year 1973 to 2014. However, this change was more pronounced from 1989 to 2014. In 1973, the area under settlement was 0.34% of the total watershed, which increased to 0.38 by 1989 to 0.81% by 2014 of the total area.

Water bodies in Lake Zwai watershed include two rivers (Meki and Qatar) and Lake Zwai that are indicated on satellite imagery by black and dark blue colors. The changing rate of this LULC type was also showing increasing trends since 1989. However, water bodies and wetlands did not show significant changes in the three time periods.

Unlike cultivation and settlements, woodlands the most important part of land cover in the watershed showed decreasing trends so that it was estimated at about 26% in 1973 and decreased by 8% by 1989 and 11% by 2014. Woodlands showed a negative change, decreasing year after year. As per the results of observation gained through the image analysis, it is understood that the watershed of Lake Zwai was predominantly covered by woodlands. However, there was about 32% and 63% decrease of this land cover from 1973 to 1989 and from 1989 to 2014, respectively, with an overall decrease of about 75% from the total watershed in the last 40 years. In 1973, the area under woodland was about 26% of the total watershed, which decreased to about 18% and 7% by 1989 and 2014, respectively.

### **Soil and water assessment**

**Watershed characterization:** Qatar Sub-watershed is found to have a total area of 3337.7km<sup>2</sup> while Meki 2049.3km<sup>2</sup>. Thus, runoff from each sub-basin is routed through the Qatar and Meki Rivers' network to the main watershed outlets to Lake Zwai. The spatial distributions of elevation in Lake Zwai watershed range from 1601 to 4213 m above sea level (m.a.s.l). The elevation of the Qatar Sub-watershed was found ranging from 1604 to 4213 m.a.s.l., and from 1601 to 3612m.a.s.l. for Meki Sub-watershed. Areas with higher elevation are located along the southeastern and northwestern ridge of the watershed, in Arsi and Gurage mountains whereas areas with lower elevation are located in the central portion of the watershed, all along the rift valley at both Sub-watersheds' outlets (Fig. 4).

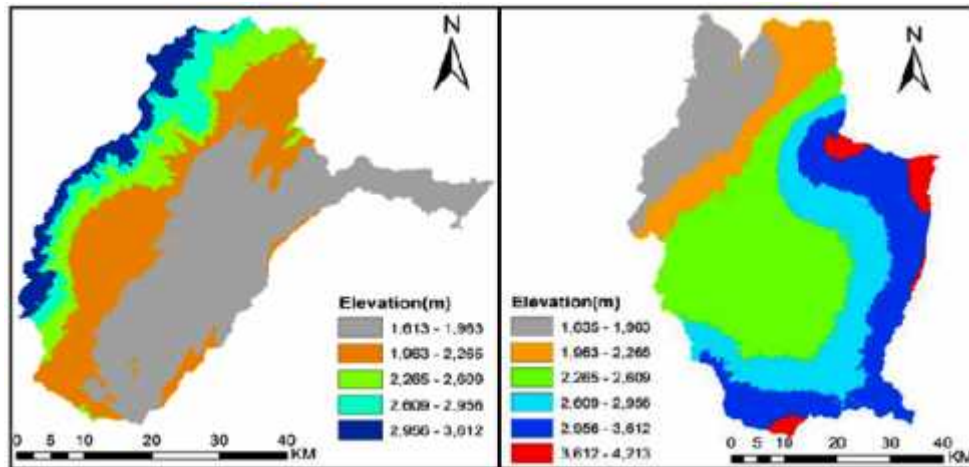


**Figure 90:** Elevation in the Lake Zwai subwatershed: LEFT-River Meki Subwatershed and RIGHT-River Qatar Subwatershed

**Table 74:** Slope percent coverage in the whole Lake Zwai Watershed

| Sub-watersheds        | 0 – 30%<br>(Level to moderately steep) | 30 – 60 %<br>(Steep hills and mountains) | >60 %<br>(Very steep hills and mountains) | Area, km <sup>2</sup> |
|-----------------------|----------------------------------------|------------------------------------------|-------------------------------------------|-----------------------|
| Meki                  | 1921.09 (85.3%)                        | 271.45 (12.1%)                           | 59.43(2.6%)                               | 2251.97               |
| Qatar                 | 2754.28(88.2%)                         | 353.27(11.3%)                            | 14.35 (0.5%)                              | 3121.90               |
| Lake Zwai surrounding | 1630.65                                | 26.87                                    | 0.91                                      | 1658.43               |
| <b>Toral</b>          | <b>6306.02</b>                         | <b>651.59</b>                            | <b>74.69</b>                              | <b>7032.30</b>        |

Slopes generated from DEM (Fig. 93) showed the different slope classes in the whole of Lake Zwai watershed (Table 82). Of the total Lake Zwai watershed, 89% is found within the slope range of 0-30%, and 11% has more than 30% of slopes of which 9% of it is within the range of 30% to 60%, and 2% is > 60% (Table 82).

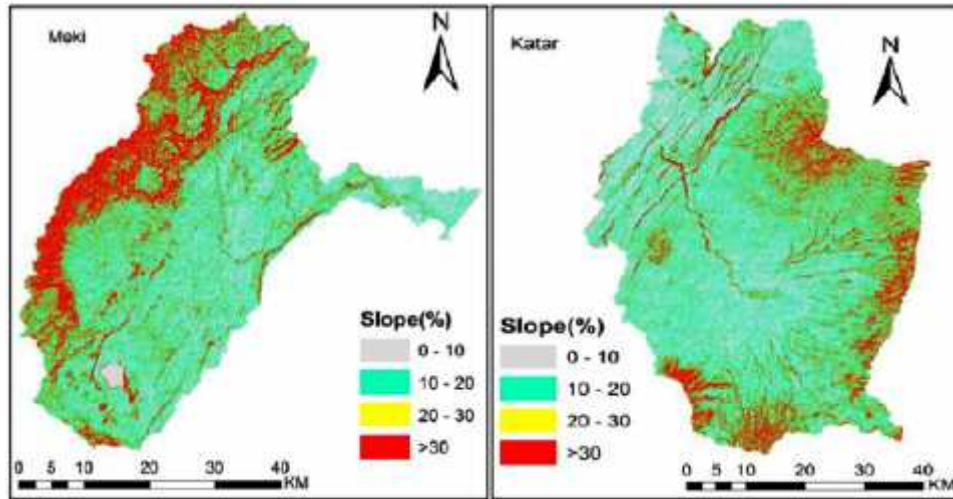


**Figure 91:** Topography in Lake Zwai Subwatershed: LEFT - River Meki Sunwatershed and RIGHT - River Qatar Subwatershed

**Watershed evapotranspiration:** The temporal dynamics of the mean annual precipitation and potential evapotranspiration as simulated in SWAT are consistent with the general trend in the two sub-watersheds of the Lake Zwai watershed. Precipitation in the two sub-watersheds has a bimodal pattern and peaks in July and August (Fig. 94a and b). Actual evapotranspiration (AET) is the amount of water released to the atmosphere through a combination of evaporation from soil and water bodies and transpiration from vegetation. Thus, it constitutes water flow. In this study as modeled by SWAT, the potential evapotranspiration (PET) is high throughout the year except in July and August, but the maximum values are recorded in March in both sub-watersheds. evapotranspiration is higher in Meki than Qatar Sub-watershed. Generally, in both sub-watersheds the mean monthly PET exceeds the mean monthly rainfall in 10 of the 12 months.

The Lake Zwai watershed average annual evapotranspiration amounted to 675mm, and thus to 70% of the average annual precipitation in the watershed. However, the long term (26 years) average annual actual

evapotranspiration predicted for Lake Zwai by the SWAT model is 1920mm (Table 83).

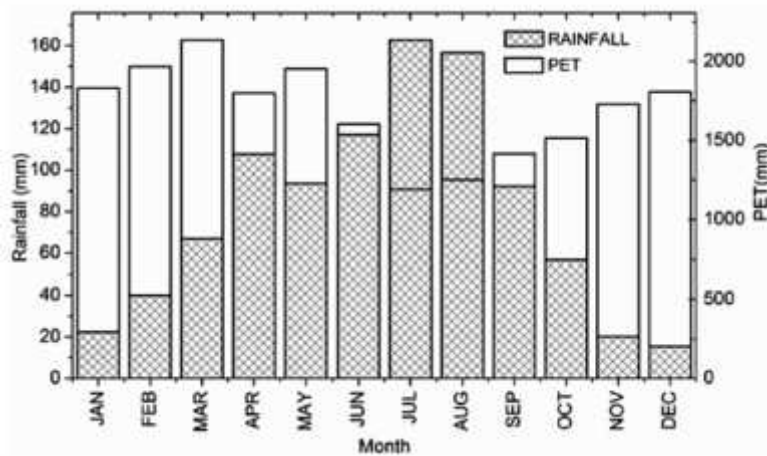


**Figure 92:** Temporal dynamics of mean rainfall and potential evapotranspiration (PET) in the Qatar Subwatershed (from SWAT Model: 1988-2013)

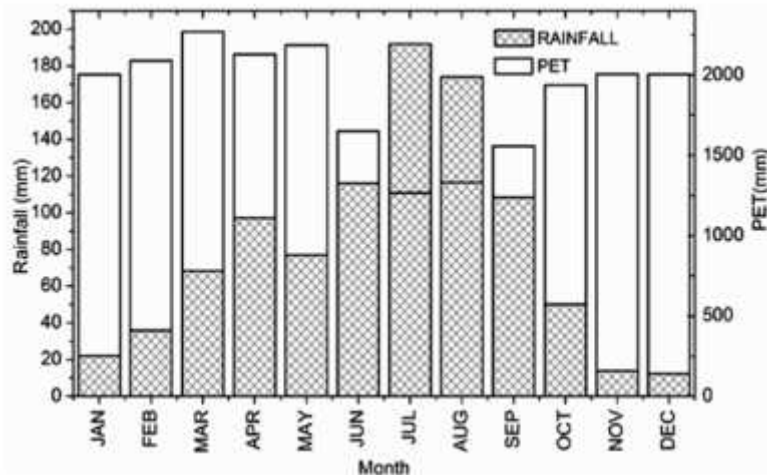


**Figure 93:** Temporal dynamics of mean rainfall and potential evapotranspiration (PET) in the Meki subwatershed (from SWAT Model: 1988-2013)

**Table 75:** Temporal dynamics of mean rainfall and potential evapotranspiration (PET) in the Meki Subwatershed

| Month            | Solar Radiation<br>(MJ/m <sup>2</sup> ) | ET, mm      |
|------------------|-----------------------------------------|-------------|
| January          | 23.9                                    | 167         |
| February         | 26.3                                    | 169         |
| March            | 25.8                                    | 185         |
| April            | 25.0                                    | 173         |
| May              | 25.0                                    | 178         |
| June             | 20.9                                    | 144         |
| July             | 18.1                                    | 126         |
| August           | 19.4                                    | 135         |
| September        | 21.4                                    | 145         |
| October          | 23.0                                    | 161         |
| November         | 25.1                                    | 169         |
| December         | 24.3                                    | 168         |
| <b>Annual ET</b> |                                         | <b>1920</b> |

From the period 1987 to 2013, the result showed that ET increased by 30 mm (4.5%) to an average of annual 666.9 mm of ET. In contrast, the water yield decreased by 75mm (30%) to an average of annual 268.5 mm.

**Surface runoff distribution and discharge of rivers:** The results recorded in this study showed that about 18% and 24% of the rains falling in the Meki and Qatar Sub-watershed, respectively, end up in Lake Zwai as total discharge. The temporal variability of the mean annual runoff is higher than the temporal variability of the mean annual rainfall in both Sub-watersheds (Table 84). The temporal variability of the mean annual runoff coefficient is higher in Qatar than Meki Sub-watershed (Table 84). However, the long-term mean annual runoff showed a decreasing trend in both Meki and Qatar Sub-watersheds. Comparing the two Sub-watersheds with respect to discharge and water yield, Qatar Sub-watershed also

showed higher discharge and water yield than Meki Sub-watershed (Fig. 96).

**Table 76:** Rainfall and runoff of Lake Zwai Watershed for the period of 1984-2013

| Parameters                                    | Sub-watershed |       |
|-----------------------------------------------|---------------|-------|
|                                               | Qatar         | Meki  |
| Mean annual rainfall (mm)                     | 966.6         | 951.7 |
| Coefficient of variation (Rainfall)           | 12.8          | 13.1  |
| Mean annual runoff (mm)                       | 122.4         | 126.7 |
| Coefficient of variation (Runoff)             | 34.8          | 29.3  |
| Mean annual runoff coefficient (mm)           | 0.1           | 0.1   |
| Coefficient of variation (runoff coefficient) | 22.4          | 21.3  |

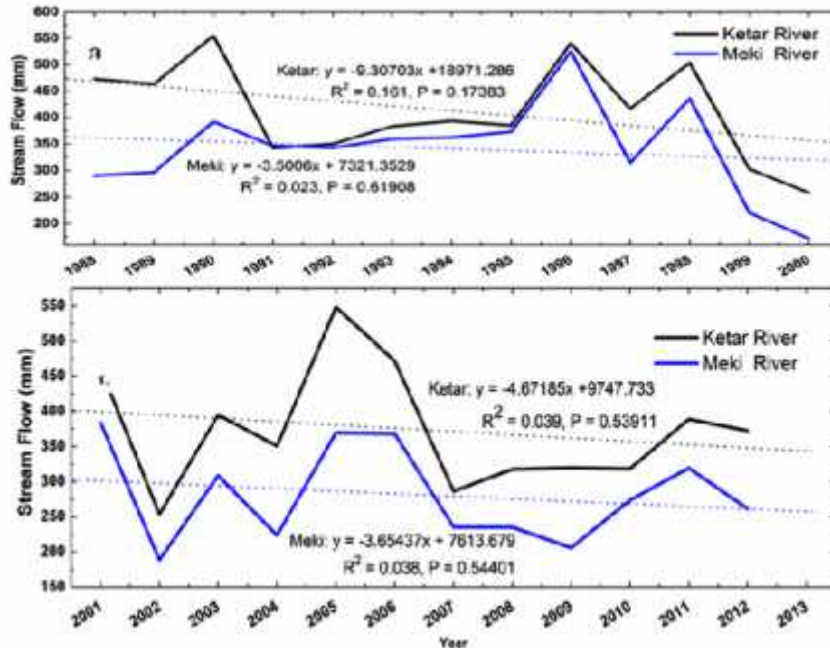


**Figure 94:** Long-term mean annual discharge of Meki and Katar rivers; (a) calibrated and (b) validation periods

**Watershed sediment yield:** The lowest sediment yields were estimated in the sub-basins along the lower reaches of Meki and Katar Rivers near to the rift floor (Fig. 97). The amount of the mean annual estimated sediment yield in Meki Sub-watershed is 4.44t/ha/yr, and 4.42 t/ha/yr for Katar Sub-watershed. The long term (i.e. 26 years) model simulation was used to estimate total sediment yield and long-term sediment yield rate for both Sub-watersheds. The long term predicted total sediment yield and annual sediment yield rate for Meki Sub-watershed by SWAT model is 23,657,385t and 909,899.4t/yr (0.91Mt/year) respectively whereas the long-term predicted total sediment yield and annual sediment yield rate for Katar Sub-watershed by SWAT model is 38,356,745t and 1,475,259t/yr (1.48Mt/year), respectively.



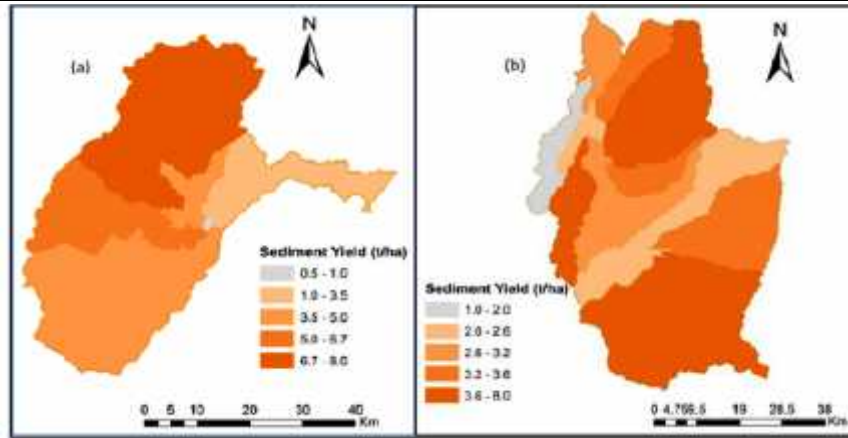


**Figure 95:** Average annual sediment yield in (a) Meki and (b) Qatar subwatersheds

## Discussions

**Patterns of LULC changes and their drivers:** Any changes in land use and land cover (LULC) reflect the impacts of human activities on the environment (e.g. Serneels and Lambin, 2001). Likewise, the LULC change analysis in this study has shown changes in the magnitude and pattern within Lake Zwai watershed since 1973. Makin *et al.* (1975) and Coulomb *et al.* (2001) strengthened the fact that such changes in LULC of the study area have commenced since the early 1970s. A shift trend towards agricultural lands and settlements was observed at the expense of other land use types such as woodlands and wetlands (See Fig. 98). Agricultural lands and settlements have shown increasing trends since 1973 whereas woodlands, wetlands and Afro-alpine bush-lands are decreasing. These results are in agreement with the previous studies by Mohammed and Bonnefille (1991), Henze (1977), Friis (1986), and McCann (1995), confirming that most of Lake Zwai watershed were dominantly covered by dense acacia woodlands up until 1975. Along with such shifts in LULC types, changes in land use policies (e.g. Proclamation No. 31/1975)

(PMAC, 1975) have continued to the present with additional modifications (e.g. Proclamation No. 1/1995) (FDRE, 1995).



**Figure 96:** Conversion of wetlands to cultivated lands around Lake Zwai

Informal discussions with elders of the surroundings also reiterated the reduction in vegetation cover and expansion of agricultural lands which have again become highly apparent after the policy changes since the beginning of the 1990. These views of the elders agree with Temesgen Habtamu *et al.* (2013). According to Ethiopia's Climate-Resilient Green Economy Strategy (FDRE, 2012), reduction in vegetation cover is mostly caused by the conversion of forested areas to agricultural land with fuel wood consumption becoming the major driver as population growth almost increased by 50% in the watershed over the past 40 years (CSA, 2013).

The growing population of the study area requires more fuel-wood and more agricultural production, in turn creating needs for new farmland; both of which accelerate deforestation and forest degradation. As a result, conversion of natural public resources (forests, land, water, etc.) into cultivated land, settlement and industrial areas continued to take place by the local communities and investors without sustainable budgeting and planning (see Table 2). Such expansions of agricultural lands by decreasing vegetation cover increased soil erosion and siltation to Lake Zwai (see also Badege Bishaw 2001; Aklilu Amsalu *et al.* 2007; and Derege Tsegaye *et al.* 2012). Simultaneously, absence of alternative energy resources could place additional burden to the existing land-cover especially to woodlands and bush-lands which are constantly converted to fuel wood and charcoal.

According to the Ethiopian Green Economy Strategy (2012), fuel-wood accounts for more than 80% of households' energy supply particularly in rural Ethiopia. Rural people in the watershed still depend on fuel-wood, cow dung and charcoal as their major source of energy. Currently, some vegetation cover is limited in the less-accessible areas of the watershed like the steep slopes of the Gurage Mountains in the west and the Chilalo Mountains in the east (Fig. 90).

It is generally known that wetlands serve as refuge areas for livestock and wildlife during the dry season. However, the results of this study revealed that wetland areas have been decreasing in the watershed since 1973. The general drivers for LULC change patterns regarding the increase in cultivated lands and settlement areas at the expense of decreasing woodlands, wetlands and afro-alpine bush-lands in Lake Zwai watershed could be attributed to human actions and natural causes. In this study it appears that the majority of changes at contemporary time are however induced by human actions. Such drivers could be: (i) the pressures exerted by a rapid rural population growth (Henze, 1977; Zerihun Woldu and Mesfin Tadesse, 1990; McCann, 1995; Aklilu Amsalu *et al.*, 2007; Assefa Admassie *et al.*, 2008; FDRE, 2012), and livestock population increase (Jansen *et al.*, 2007; Hengsdijk *et al.*, 2008; Derege Tsegaye *et al.*, 2012), (ii) land policy changes that came along with changes in governments and hence lack of consistent sustainable plan on LULC scenarios, (iii) poverty (Temesgen Habtamu *et al.*, 2013) associated with the dependence of about 85% of the country's Ethiopian population on traditional agricultural production system that is incompatible with changes in population growth, climate related factors and lack of efficiency in production systems, (iv) economic development heavily dependent on agriculture (47% of the country's gross national product and >80% of exports) (FDRE, 2012) and the need for natural resources as inputs for development, and (v) land demand for settlement expansion. It should be realized that such changes as mentioned above will continue to exist, if the current trends in development directions and population growth continues which is in the order of 3% per

annum without family planning and development plans remain to undermine sustainable use of natural resources. However, the expansion of agricultural lands and the increase in livestock appears to continue in the face of growing population, thereby creating extra pressure on the land resource (Tekalign Mamo and Gezahegn Ayele (2003), and on the hydrologic system (Dagnachew Legesse *et al.*, 2003). The subtle actions of climate variables in terms of increasing air temperature and rainfall variables exacerbate the situation (Serneels and Lambin, 2001; Lijalem Zeray *et al.*, 2006; Assefa Admassie *et al.*, 2008).

**Soil and water resources existing scenarios:** Enactments of FDRE (2005), ONRS (2007) and SNNPR (2007) on the management of rural lands state that (i) cultivation of annual crops on rural lands having a slope gradient of 30-60% are allowed only by making the necessary terracing such as bench terraces; and (ii) the rural land with a slope gradient of > 60% shall not be used for crop production and free grazing, but limited for plantation of trees. However, it is found out in this study that in Lake Zwai watershed, practically against the enactments, areas with slopes between 30-60% [about 239 km<sup>2</sup> (54%)] and > 60% [50km<sup>2</sup> (about 34%)] are generally being used for crop production; neglecting the fact that such landscapes could easily be affected by land degradation impacts (e.g. runoff and wind erosions) (Fig. 99). This is an indication that cultivated lands are expanding in the upslope areas of the watershed whose natural land covers have been removed and the top soil exposed for all sorts of erosion forms.



**Figure 97:** Images showing severe land degradations in some parts of Lake Zwai Watershed

**Estimation of Lake Zwai evapotranspiration (ET):** The magnitude of ET could affect water budget (Lentersa *et al.*, 2005). Monthly and annual average Lake Zwai evapotranspiration have also been estimated by different authors (Coulomb *et al.*, 2001; Tenalem Ayenew, 2003; Assefa Melesse *et al.*, 2009) (Table 83). In this study, ET is therefore estimated for Lake Zwai using the Penman–Monteith method (PMM) and SWAT model. The mean monthly and mean annual evapotranspiration of Lake Zwai for the study period is presented in Table 83. Monthly evaporation is low during the rainy seasons from June to September and increase thereafter. Table 6 shows the estimated monthly Lake Zwai evapotranspiration as compared to the estimates made by other methods.

**Table 77:** Comparison of Lake Zwai evapotranspiration by months of the year calculated using various models, where EM stands for Energy balance Method, PMM for Penman-Montheith Method, CRLE for Complementary Relationship Lke Evaporation Method, PM for Pan Method, RM for Radiation Method; SAM for Simple/Abitew Method; and those used in this study, SRM for Solar Radiation; and SWATM for Soil and Water Assessment Tool Method (see also Coulomb *et al.* 2001; TenalemAyenew 2003; and Assefa Melesse *et al.* 2009)

| Months        | EBM<br>(mm) | PMM<br>(mm) | CRLEM<br>(mm) | PM<br>(mm)  | RM<br>(mm)  | PM<br>(mm)  | SAM<br>(mm) | SRM<br>(mj/m <sup>2</sup> ) | SWATM<br>(mm) |
|---------------|-------------|-------------|---------------|-------------|-------------|-------------|-------------|-----------------------------|---------------|
| Jan.          | 143         | 154         | 132           | 150         | 135         | 159         | 142         | 23.9                        | 167           |
| Feb.          | 149         | 162         | 135           | 128         | 120         | 144         | 131         | 26.3                        | 169           |
| Mar.          | 152         | 166         | 149           | 148         | 142         | 192         | 144         | 25.8                        | 185           |
| Apr.          | 156         | 166         | 155           | 188         | 138         | 142         | 141         | 25.0                        | 173           |
| May           | 163         | 170         | 160           | 188         | 138         | 156         | 150         | 25.0                        | 178           |
| Jun.          | 147         | 168         | 155           | 135         | 107         | 137         | 136         | 20.9                        | 144           |
| Jul.          | 128         | 136         | 146           | 139         | 115         | 126         | 121         | 18.1                        | 126           |
| Aug.          | 136         | 137         | 136           | 135         | 115         | 123         | 127         | 19.4                        | 135           |
| Sep.          | 141         | 136         | 137           | 164         | 124         | 112         | 126         | 21.4                        | 145           |
| Oct.          | 159         | 162         | 141           | 200         | 151         | 170         | 151         | 23.0                        | 161           |
| Nov.          | 160         | 161         | 144           | 223         | 157         | 178         | 147         | 25.1                        | 169           |
| Dec.          | 143         | 157         | 139           | 225         | 157         | 130         | 145         | 24.3                        | 168           |
| <b>Annual</b> | <b>1777</b> | <b>1875</b> | <b>1728</b>   | <b>2023</b> | <b>1599</b> | <b>1799</b> | <b>1662</b> | <b>278.2</b>                | <b>1920</b>   |

In this study, the annual evapotranspiration for Lake Zwai was calculated as 1920 mm (Table 85) which consumed nearly about 2.4 times the yearly contribution of rainfall to the lake water budget. The level in this study is therefore found between the highest estimates by Penman methods for Coulomb *et al.* (2001) and the lowest that of Tenalem Ayenew (2003); with differences of 148 mm, which is 7.3% and 7.9% of the two extreme values, respectively. However, the estimate in this study is 5.4% lower than the Penman method estimate by Tenalem Ayenew (2003) and 2.4% higher than the Penman method estimates by Coulomb *et al.* (2001). The monthly lake evapotranspiration estimates in this study fitted more to Penman estimate by Coulomb *et al.* (2001) than others (Table 85). The increment in evaporation rate ultimately resulted in the declining of the lake level.

**4.2.3. Rivers discharge in Qatar and Meki Sub-watersheds:** Qatar Sub-watershed is 1.4 times larger than the Meki Sub-watershed (Table 83). These sub-watersheds are the main water sources of Lake Zwai. The annual rainfall amount in Qatar Sub-watershed is found greater than the Meki Sub-watershed. This led to the differences in the amount of water contribution from these Sub-watersheds to Lake Zwai. Surface runoffs from un-gauged sub-watershed areas surrounding the lake (1658 km<sup>2</sup>) also contribute water to the lake during the rainy season. The findings in this study are consistent with Tenalem Ayenew (2008) in that Qatar and Meki rivers have, though their similar highland origins, different flow regimes and large temporal variability. This variation might be caused by the different distribution of rainfall in the Sub-watersheds. In general, the hydrology of Lake Zwai depends largely on the flow of these rivers. Thus, the volume of Lake Zwai starts increasing at its maximum in August and September since the monthly flows of the Meki and Qatar rivers' discharge reach peak levels during these months while the volume of water flowing in these rivers becomes at its lowest levels during the dry season (January - March). Actually, every year in the dry seasons River Meki completely dries up. Moreover, the study by JICA (2002) also demonstrated that Meki Sub-watershed has relatively lower storage capacity and fast response to rainfall than Qatar Sub-watershed due to the differences in geology, geomorphology, plant cover surface area and rainfall volumes.

Another approach of the water volume contributions of the two sub-watersheds to Lake Zwai is the analysis of their runoff coefficient (total runoff/total rainfall). In this study, the runoff coefficient is higher in Qatar than Meki Sub-watershed (Table 84), while the long-term mean annual runoff coefficient shows consistently decreasing trends in both Meki and Qatar Sub-watersheds. As discussed in the sections above, this is likely to be due to the changes in LULC and climate patterns in the watershed that occurred over the years. Similar accounts have also been reported by Merz and Blöschl, (2009), Zhang *et al.* (2009), Sriwongsitanon and Taesombat (2011) and Wang *et al.* (2014).

Based on the results collected in this study (Fig. 95) and the LULC change patterns continue as is, it can be suggested that Meki River is likely to cease to exist after 67 years, and Qatar River after 70 years. According to this scenario, within seven decades Lake Zwai may dry out, keeping other causes of lake volume reduction such as global warming, water abstraction, etc. constant and assuming that factors such as groundwater inflow into Lake Zwai will not be sufficient to maintain the lake as is. Such a phenomenon may be comparable to what happened to Lake Haramaya (Alemaya) of Eastern Ethiopia (Brook Lemma, 2002 and 2003). Further, the contribution of surface water to downstream system of Abijata-Shalla System from Lake Zwai also seizes jeopardizing that part of the ecosystem.

**Sediment yield in Qatar and Meki Sub-watersheds:** As estimated in this study, Meki and Qatar Sub-watersheds have on average exported  $\approx 0.91 \times 10^6$  tons year<sup>-1</sup> (4.44 tons hectare<sup>-1</sup> year<sup>-1</sup>) and  $\approx 1.48 \times 10^6$  t/year (4.42 tons hectare<sup>-1</sup> year<sup>-1</sup>) of sediment yield respectively. The result for Meki Sub-watershed is however lower than the one reported by MoW (2008) (6.1 tons hectare<sup>-1</sup> year<sup>-1</sup>). The difference can be attributed to the levels of degradation, land use types, soil types and slope classes. The land use changes mainly due to deforestation in the past have contributed to severe soil erosion, and massive soil loss to this country (Tekalign Mamo and Gezahegn Ayele, 2003).

In Lake Zwai watershed, high amount of sediment loads is transported to the lowest flat reaches of the watershed (here represented by Lake Zwai), facilitated by feeder rivers (Meki and Qatar) particularly at flow peak rainy seasons and finally deposited to Lake Zwai with increasing sediments as shown in Fig. 100, below.





**Figure 98:** Image showing sediment depositions in Lake Zwai

The parts of the watershed that produce the most sediment yield are higher elevation areas with high percentage of slopes and degradation impacts as the Gurage and Chilao Mountains and at the same time where there are high rainfall distributions that easily result rapid runoffs.

The sediment load of Lake Zwai can be attributed to (i) the expansion of crop fields up to the shores of the rivers and Lake Zwai at the expense of loss of other land uses (see also MoW, 2008), (ii) The absence of implementing soil conservation policies of the government, Proclamation No. 456/2005 (FDRE, 2005) (iii) the need for grazing land for livestock whose population is increasing (see also Derege Tsegaye *et al.*, 2012), (iv) Sedimentation of Lake Zwaican also be associated with nutrient load that may impact its water quality, leading into eutrophication (Lenhart *et al.*, 2005; Girum Tamire and Seyoum Mengistou, 2012 ) and (v) the data thus collected suggest that the above mentioned factors may contribute to the deceasing of the lake volume due to siltation, and enhancing evapotranspiration.

**4.2.5. Water abstraction:** Excessive water abstraction from Lake Zwai has recently become a common practice (Fig. 101). Irrigation using water

abstraction from feeder rivers is also being expanded in both the lower and upper Sub-watershed areas. This has happened due to the fact that all water resources are common property of the people and the state that leads to free access to anyone (FDRE, 2000). Direct water abstraction mainly for irrigation from the lake and its feeder-rivers could therefore be one of the reasons that can contribute to the reduction in the level of Lake Zwai, the view also shared in other earlier studies (Zinabu Gebemariam and Elias Delebo, 1989; Tenalem Ayenew, 2001, 2004; Tamiru Alemayehu *et al.*, 2006). For example, the current water level abstraction from Lake Zwai reaches about  $612 \times 10^6$  l/day as calculated in this study (Table 86), mainly to be used for water inefficient furrow type of irrigation and municipal water supply.

**Table 78:** Water abstraction from Lake Zwai: \* indicates electric powered pumps

| Districts       | No. of Pumps | Pump Capacity (L/s) | Abstraction (in '000) |
|-----------------|--------------|---------------------|-----------------------|
| Zwai Dugda      | 542          | 18                  | 210,729.6             |
| Dugda Borra     | 367          | 18                  | 142,689.6             |
|                 | 2*           | 764                 | 33,004.8              |
| Adami Tulu-Jido | 283          | 18                  | 110,030.4             |
| Kombolcha       | 7*           | 764                 | 115,516.8             |
| <b>Total</b>    | <b>1201</b>  |                     | <b>611,971.2</b>      |



**Figure 99:** Images showing different types of pumps being used for abstracting water from Lake Zwai

The recent agricultural developments being undertaken around Lake Zwai and the urban population increase in Batu (Zwai) town aggravated the pressure on water abstraction for irrigation and municipal water use, which are based on unlimited free-access to water for all users. This could lead to the further negative impacts on the water budget imbalance of the lake (see Table 101). It is very difficult to assume that local, regional or state level administrators do not know the risks that would follow as a result of the unlimited free-access to the waters of L. Zwai, because evidence-based knowledge is widely available today. If business continues at usual following present trends, the first and most affected will be those operations (e.g. irrigated agriculture) and the people that are completely dependant of the existence of excess water in L. Zwai.

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**Conclusions and recommendations**

The results of this study showed that Lake Zwai watershed has undergone extensive LULC changes over the last 40 years. The driving forces of such changes have originated from different sources. Rapid human and livestock population growths may be regarded as the major driving forces. Agricultural development and the demand for cultivated land, fuel-wood and charcoal productions have been rapidly increasing along with population growth. In general, there will be negative repercussions on land and water resources if the present trends of LULC changes continue to exist.

Lake Zwai and its feeder rivers are faced with a number of challenges. The major ones are siltation, and unlimited and free-access water abstraction. Severe erosion is also a major problem in the watershed and a source of siltation to the lake. When factors like climatic variability are added to the human impacts, the future scenario of Lake Zwai and its watershed seems grim unless the current use practices are sustainably managed, and appropriate measures are timely taken.

Considering the existing impacts, integrated watershed management strategy encompassing the full participation of all stakeholders, scientific communities and local communities regardless of their age, gender, and educational level with government programs should be implemented using bottom-up approach for the sustainable management of both the lake and its watershed resources. Policy-makers should then optimize the knowledge and experiences from these groups of the society. With the framework of setting such integrated watershed management strategy, environmental awareness programs should also be developed to build a conservation-oriented community at the lower level in the whole Lake Zwai watershed. Besides, the short-term profit gains from investment activities should also consider the longer-term 'environmental costs' in the watershed. In general, it is necessary to warn not alarm all concerned public offices, private enterprises and communities about the consequences that may follow on

future generations because of the actions people take today in Lake Zwai watershed.

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## Chapter 17

### ***Concluding reflections: Sustainable development with water quality and biodiversity: A hit or a myth?***

Brook Lemma, Aquatic Science stream, Addis Ababa University

#### **Abstract**

Considerable years have passed since the World has embarked on sustainable development. The formal beginning goes back to 1983 when the United Nations formulated a 22-country Commission headed by Mrs. G. H. Brundtland of Norway to head the Commission. By 1987, the *Brundtland Report* was published by the UN using the term sustainable development for the first time. Since then, more than seven international conferences and summits have been conducted with the most popular ones being the Rio Summit in 2012 and the Paris Agreement of 2015. Since then, many projects have been developed and implemented at various levels of effectively. At present after almost 40 years, the World is still faced with the challenges of environmental degradation, the central ones being natural resources especially biodiversity and water quality. Recent researches and literature surveys indicate that business has continued as usual, despite the efforts made to replace natural resource uses by safe alternative technologies. Watersheds are on being degraded, biodiversity lost, waters are polluted and climate impacts are pushing ecosystems to the limits of collapse. This presentation therefore makes survey of the works done so far by way of examining the causes of the damage to biodiversity and water quality deterioration and revisit where the World stands today as exemplified by the situation in the Ethiopian Rift Valley lakes and their watershed.

## Introduction

Since the industrial revolution which is generally referred to have started in 1850, the world witnessed unprecedented natural resources use and environmental degradation. Over the years that followed, development and use of natural resources have increasingly shown clear correlations. As economic development intensified reinforced with the advancement of technology of production, use of natural resources became unstoppable. The desires of humans for more consumables became insatiable. This trend of economic growth was eventually realized to be incompatible to the finite natural resources available in the World. This prompted into the formulation of a global action in the name of sustainable development (SD) (Guercio 2015, Chancel 2020).

As a consequence, the global effort to make production sustainable within the finite resources, a number of international agreements and / or conventions were proclaimed.

Some of them are listed below.

1983: UN Global agenda for change: Mandated Mrs. G. H. Brundtland, Norway, Secretariat in Geneva,

1987: The *Bundtland* Report, 1<sup>st</sup> used the term sustainable development (SD)

1992: The Rio Summit!

2011: The UN Environmental Program!

2012: The Rio Conference on the Environment!

2015: The UN Sustainable Development Goals (17)

2015: The Paris Agreement on Climate Change

2016: Cancun, Mexico, Conference of Parties to the Convention on Biological Diversity (CBD)

Following these conventions millions of dollars were spent to conserve nature, including ameliorating the problems of water quality and biodiversity conservation. These funds trickled down to universities and research institutes around the World into research projects, research findings were published repeatedly indicating the trend of production, consumption and the pollutants that were released into the environment were unsustainable to the level of challenging the very existence of human wellbeing.

In other words, all of these “agreements” or conventions cascaded to low income countries as conditions for loan and release of development aids. Projects have been developed with universities, environment and water ministries. Universities developed dissertations, publications and the ministries sent out outreach experts into rural areas to conduct on conservation projects. Local people may have gained trickling daily subsistence payments, which were latter came to be called the ‘trickling effect’. However, development remained business as usual.

This trend in turn prompted into raising the questions such as: Is the global vision for sustainable development progressing as planned? Is sustainable development with water quality and biodiversity progressing as anticipated? Or is it a hit that the World is going in the direction of saving itself from destruction rather by taking a short cut or is it just a myth that things are slowly slipping out of the control of man and nature is taking its course action?

I then proceeded to examine some of the facts by way of conducting desktop studies into the literature by keeping in mind the research outcomes I published with my PhD students and fellow colleagues in the university where I belong. There are actually four main challenges to the sustainable development with water quality and biodiversity that are facing the World today. These challenges were identified to be (i) Land use land cover changes (LULC), (ii) Climate change (iii) Invasive species and (iv)

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Natural events in the form of Earth movements in the watersheds of wetlands (Brook Lemma 2002, 2003 and 2011, Yemane Gebreegziabeher 2004, Kalliset *al.* 2012, Herath 2016, Seddonet *al.* 2016, Bassem, 2020, Otero *et al.* 2020 and others).

The above four main challenges were then reflected to the currently existing scenarios of the water quality and biodiversity of the Ethiopian Rift Valley lakes and their respective watersheds.

#### **CHALLENGE I: Land use land cover changes (LULC)**

With regard to this first challenge of LULC changes situation, as it exists today. It is revisited both from my own research experiences and from the data reported in various scientific publications. Let us then see the situation found in the lakes and their respective watersheds of the Ethiopian Rift valley.



### Lakes Abaya and Chamo and their respective watersheds

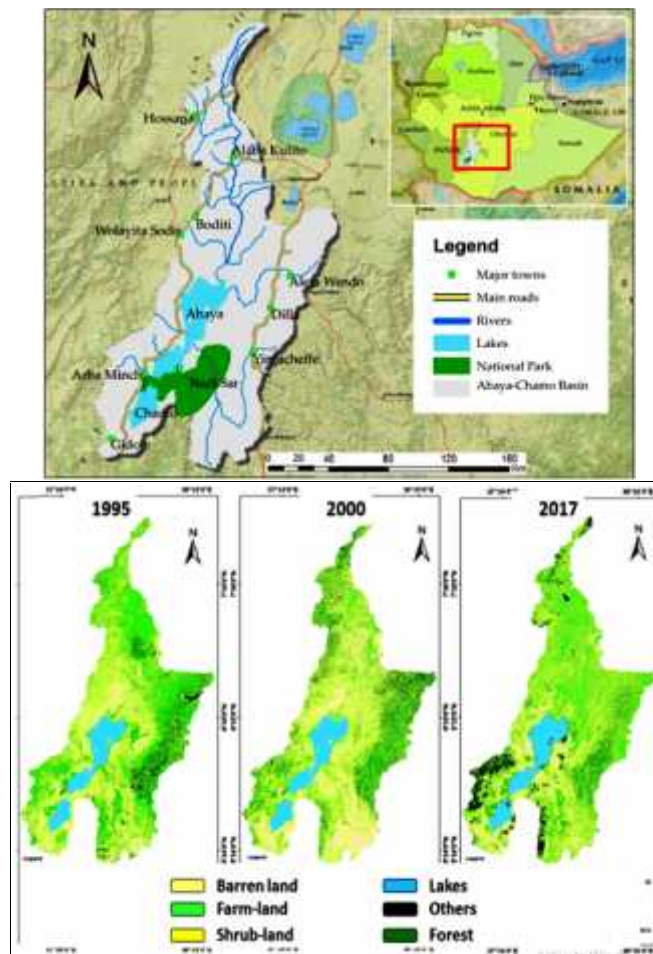


**Figure 100:** UPPER: Lakes Abaya and Chamo with their feeder-rivers and watershed areas with Abaya having a much wider watershed than Chamo and the latter with high population and development activities. LOWER: The LULC changes in the watersheds (1995-2017) show tremendous increase in farm-land expansion at the expense of degraded and disappearing forests, shrubs and bare lands that were used for grazing livestock (from Ayele Elias Gebeyehu *et al.* 2019).



**Figure 101:** Soil erosion and land degradation in (a) Wolayita and Kembata tembarro and (b) some zones of River Blattee catchment, ACB (Ayele Elias Gebeyehuet *al.* 2019).



**Figure 102:** Eventually the sediments and passibly the nutreint laods of River Blattee enters Lake Abaya and LOWR: The waters of lake Abaya appear extremely turbid with very shallow light penetration (Secchi Depth of less than 20 cm) (Photos: Brook Lemma, 2012).

The water quality of Lakes Abaya and Chamo and the biodiversity in and outside the lakes in the watersheds are severely affected by land use changes that include expansion of cultivated land, settlements, uncontrolled use of fertilizers and pesticides and generally the impacts of population growth in the watersheds. These impacts are more pronounced on Lake Abaya than on Chamo as the former lake has a much wider watershed with high population and a lot of development activities underway (see also Ashebir Wolde Yohannes *et al.* 2018, Fasil E. Teffera *et al.* 2018 and Ayele Elias Gebeyehu *et al.* 2019).

### Lake Hawassa and its watershed

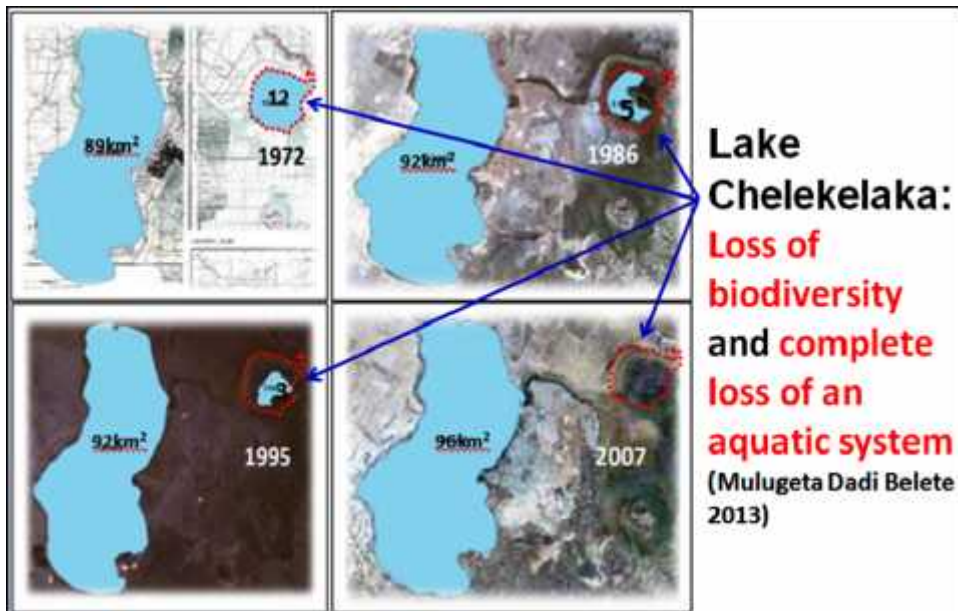


**Figure 103:** The gradual disappearance of Lake Cheleklaka (1972 - 2007), a wetland north-west of Lake Hawassa (Mulugeta Dadi Belete 2013, Mulugeta Dadi Belete *et al.* 2015).

The above scenario is an exemplary indicative of the impact of LULC changes in the Lake Hawassa watershed. Further changes that show the overall changes are given in the following figures.

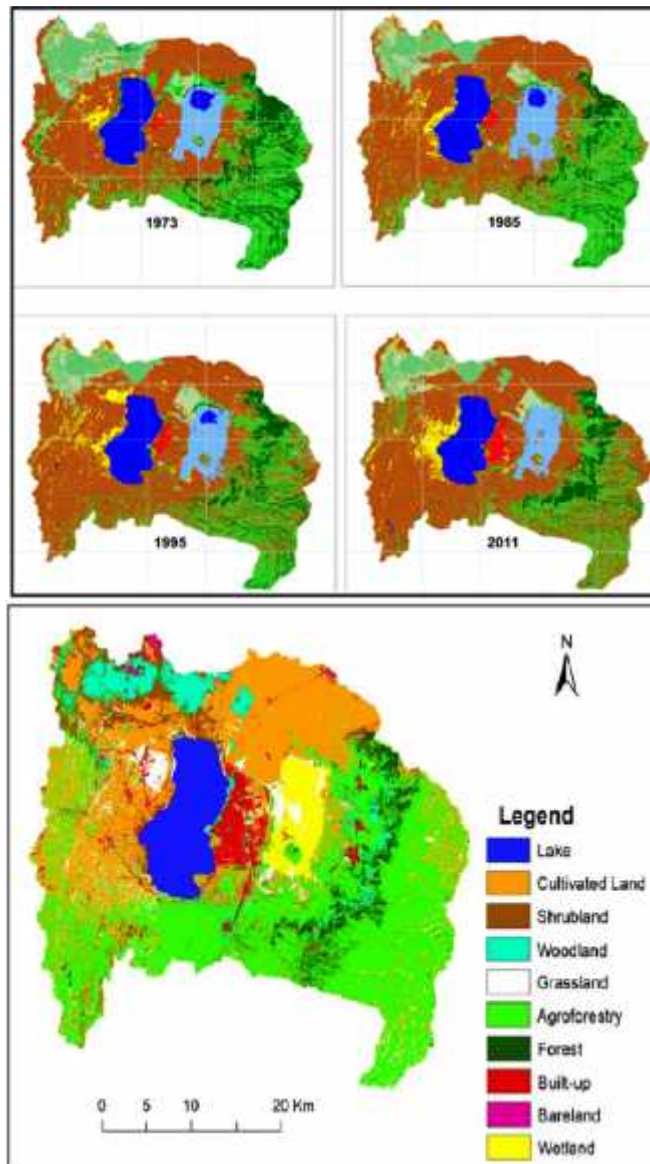


**Figure 104:** ABOVE - LULC of Lake Hawassa Watershed 1973-2011 and BELOW - LULC changes in 2019(Arega Degefe *et al.* 2019).

In summary, the expansion of cultivated land and settlements (built-up areas) took over the forests, shrubs, grasslands and led to the shrinking of wetlands around Lake Hawassa. This is associated with population increase, demand for clean water and natural resources that led to the degradation of the area in association with pollution that emanates from increased consumption of products of agriculture and industry that were produced at the expense of the use natural resources (see also Yemane Gebreegziabeher 2004, Mulugeta Dadi Belete 2013, Mulugeta Dadi Belete et al. 2015, Nigatu Wondrade Tedo 2015 and Arega Degefe et al. 2019).

### **Lake Koka and its watershed**

Lake Koka is a reservoir constructed by Emperor Haile Selassie to supply power to Addis Ababa and the growing industries in and around it. Before the Koka Dam, Addis Ababa was receiving power from Aba Samuel Dam (Lake Aba Samuel) built by the Italians during their five-year occupation of the country. This eventually proved insufficient for the expanding population and industries of the city. In other words, the watershed of Lake Koka extends all the way into the watersheds of the city of Addis Ababa. This metropolitan center of the country has a population of 5,006,000 by 2020 with an increase of 4.42% over the previous year (UN World Population Prospects 2019). In recent years, the rate of development of the city and its entire watershed happens to be one of the fastest in the World with the expansion of built-up areas, industries and a whole lot of infrastructure that are converting the natural environments with distinct fingerprints of human impacts. The consumption of these resources has polluted the rivers that come out of it (River Akaki and its branches crossing Addis Ababa) to the level that one does not need to do any chemical tests as the smell and color of the water contaminated with uncontrolled release of household, toilet, industrial and other wastes give the systems away. All of these eventually find their way into Lake Koka via River Akaki and Lake Aba Samuel (see Dagnachew Adugna and Brook Lemma 2018). Along Mojo River, another feeder-river to Lake Koka, there

are many leather, flower and other industries that dump their wastes loaded with organic and heavy metalwastess in these rivers to finally enter into the lake.

Further, Lake Koka is also included in the River Awash watershed which is a wider, probably the most populated area in the country with intensively cultivated agriculture, settlements and industrialization. At present, Lake Koka is probably the leading polluted lake in the country as a result of the fast LULC changes taking place in the watershed. Below are some images showing the impacts that are currently experienced with this lake.



**Figure 105:** Lake Koka and its relations to the Addis Ababa subwatershed (Google Map)



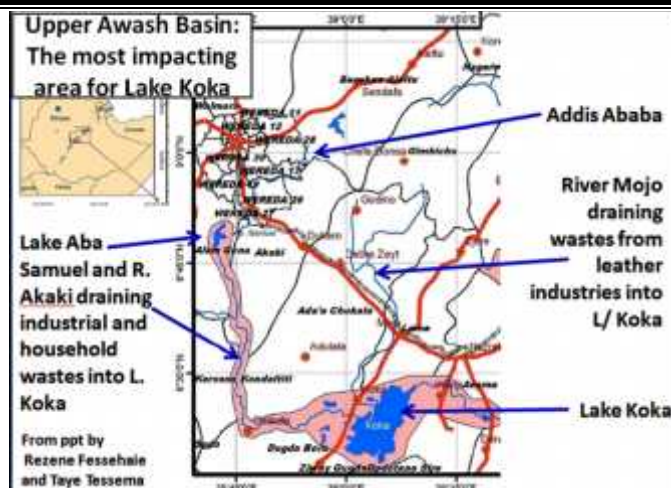


**Figure 106:** The Akaki-Mojo Rivers complex bringing into Lake Koka heavy loads of pollutants from household, cultivated lands, industries and silt from highly degraded and deforested areas of the watershed (from the power point presentation of WakshumShiferawet *al.* 2018).

The overall LULC changes of Lake Koka watershed is captured by Samuel KassaBeyeneet *al.* (2018) as shown in Fig. 109, below.

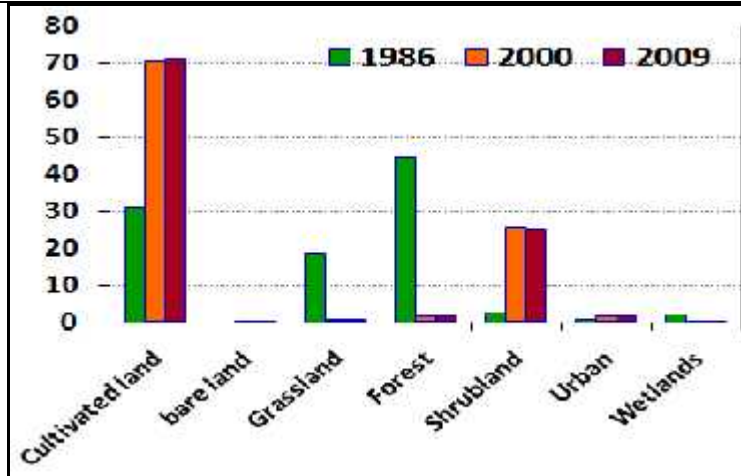


**Figure 107:** LULC of Upper Awash River Basin 1986 – 2009 (modified from Samuel KassaBeyene *et al.* (2018))



**Figure 108:** In the wet seasons Lake Koka inundates as shown by the salt deposits on the barks of the acacia trees and in the dry seasons farmers follow the regressing water and plow the fertile alluvial soil, thereby creating excessive erosion and pollution of the lake with excess agricultural inputs (Photo by Brook Lemma, 2016).

### Lake Zwai and its watershed

Probably, Lake Zwai is the most studied lake of all the Ethiopian Rift Valley lakes. The watershed of Lake Zwai extends from the Chilalo



Mountains (about 4036 m above sea-level, asl.) in the east to the Gurage Mountains (about 3719 m asl) in the west, both having a thin margin of Afro-alpine forests. From these two elevations, River Meki originates from the Gurage Mountains and River Qatar (Qatar) from the Chilalo Mountains and both flow into Lake Zwai. River Qatar is by far larger than River Meki, and it feeds the lake throughout the year, while the later, in recent years, dries up in the dry seasons as its waters are diverted for irrigation purposes upstream. Both rivers, like all the previous rivers we saw above, contain highly turbid waters with complex agricultural inputs followed by deterioration of the water quality of Lake Zwai as reported by many authors (e.g., Dessie Ayele *et al.* 2018, 2020a and 2020b). The satellite images and ground-truthing of Lake Zwai watershed was conducted by Hayal Desta and Brook Lemma in a research conducted from 2012 to 2017 (Jansen *et al.* 2007, Hayal Desta 2016, Hayal Desta and Brook Lemma 2015, 2017a and 2017b)

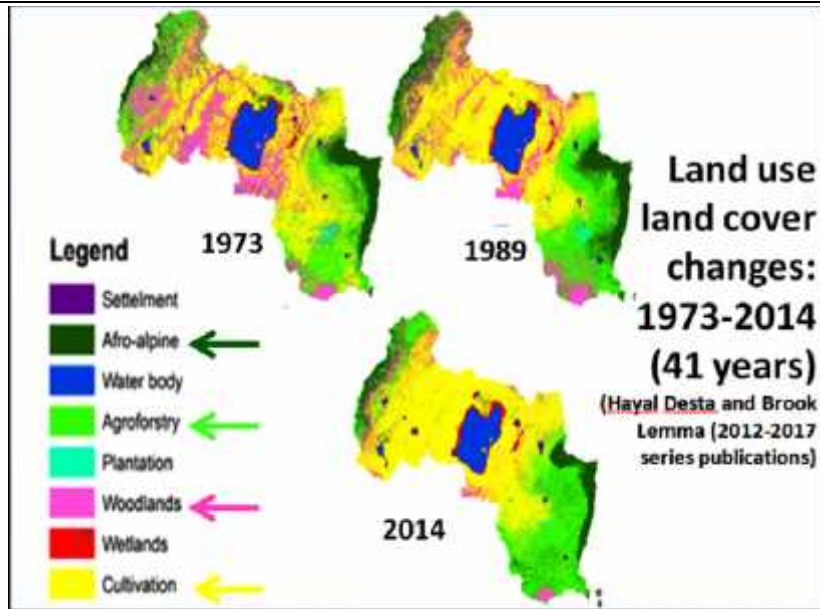


**Figure 109:** LULC changes of Lake Zwai watershed as captured from satellite images and ground-truthing (Hayal Desta 2016, Hayal Desta and Brook Lemma 2015, 2017a and 2017b)

In a span of 41 years (1973-2014), the cultivated land increased by 44% and settlements (built-up areas) by 136%, while woodlands declined by -74% (Hayal Desta 2016). The primary and secondary data collected on the ground indicated that consumption of agricultural and industrial inputs, human and livestock populations are continuously increasing in Lake Zwai watershed, while for instance fish catch continuously declined. The sizes of the individual fishes collected from the wild in Lake Zwai have continuously declined. There is also clear evidence that the previously dominating and highly marketable fishes like *Oreochromis niloticus* (Nile tilapia) are being replaced by carps which have very flexible feeding habits and that have better survival capacities in turbid and qualitatively poor waters. These are indications of overfishing and degradation of the aquatic system in Lake Zwai. Similarly, tests conducted on the availability and abundance of pathogenic bacteria in Lake Zwai have shown that *Salmonella* spp., *Shigella* spp., *Vibrio* spp. Such as *V. cholera* and *Pseudomonas*

*aeruginosa* have been detected (Mekuria Mekonnen *et al.* 2014). Similarly, grazing domestic animals in the wetlands along the shores of Lake Zwai are burdened with heavy infections of helminth parasites by such blood sucking parasites as *Hemonchus contortus* and many others (Ayalew Sisay and Brook Lemma 2021, in write up).

Among all of the factors in LULC changes, increase in human population is probably the most important deserving considerable attention. According to Scott (2017) the growth of the human population on Earth showed a trend of increase that is explainable in the context of development and the impacts thereof. The last two hundred years deserve special emphasis as they are correlated to the human population growth in Ethiopia and this increase is associated with the start of the industrial revolution and the improvements in human wellbeing such as improved health, increasing birth rates and low death rates or longevity of life expectancy. This is summarized in the Fig. 112, below.

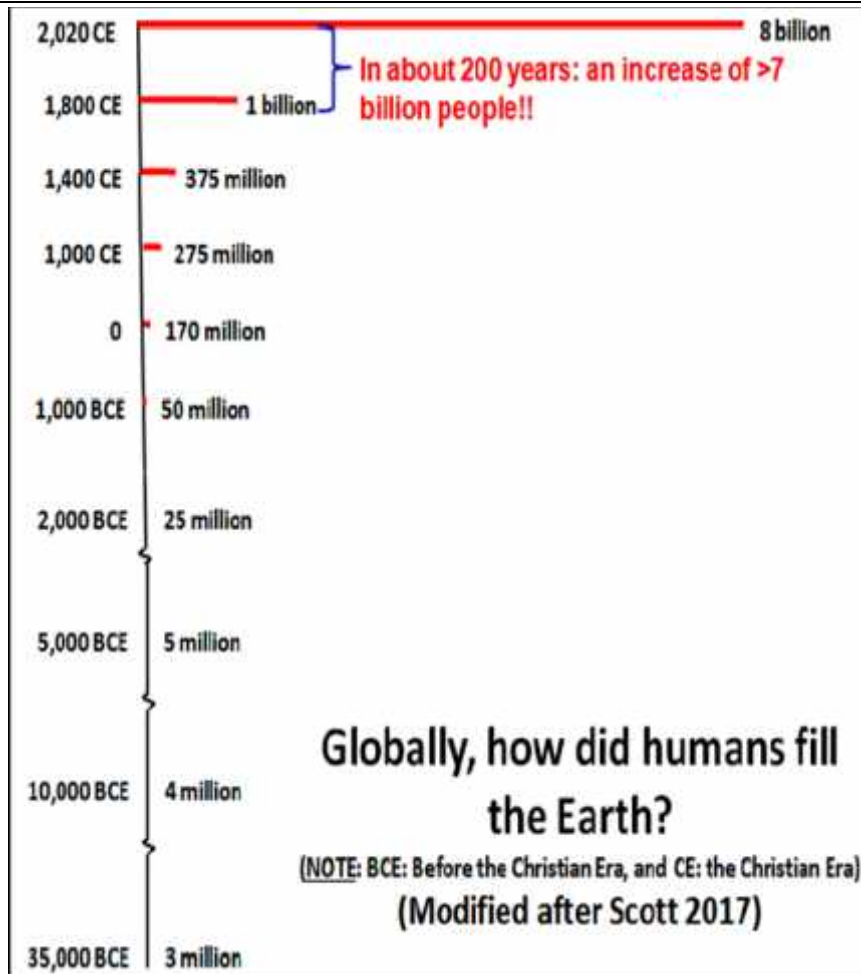


**Figure 110:** The trends of human population growth with particular actuation of the growth in the last 200 years, namely, the onset of the industrial revolution (modified after Scott 2017).

The situation in Ethiopia and the watershed of Lake Zwai is no different from this.

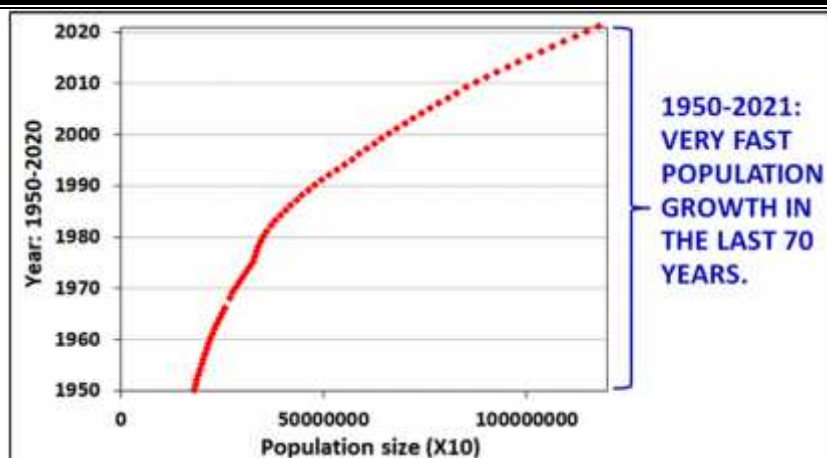


**Figure 111:** Growth of the Ethiopian population (after Central Statistics Office, Addis Ababa)

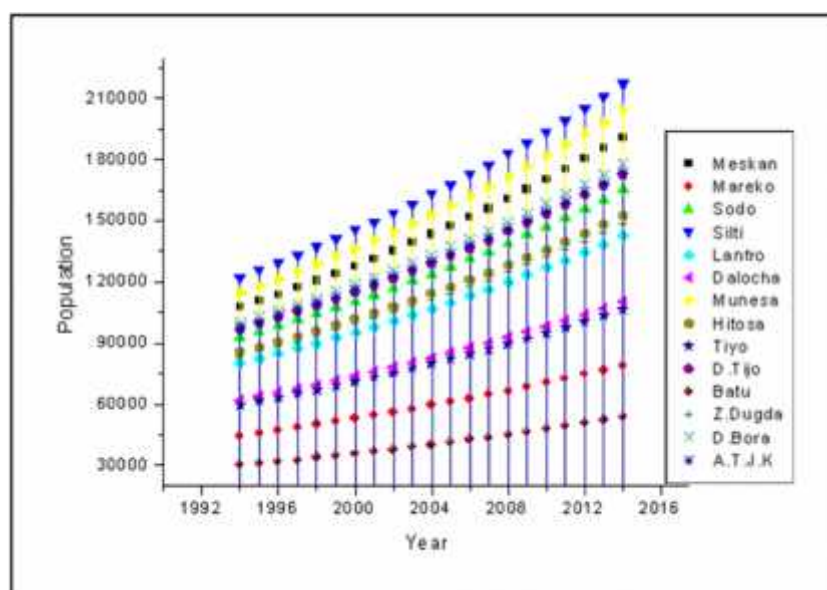


**Figure 112:** Growth trends of human population in the Zwai Watershed (1972-2014) segregated by *Woredas* (districts). This growth trend complements the global and national situations (Hayal Desta 2016)

The human impact expressed in increased need of natural resources (loss of biodiversity) in Lake Zwai watershed resulted in increasing production and

consumption with the consequent release of uncontrolled solid and liquid wastes from the expanding farmlands, settlements and industries into the water system (water quality deterioration). This is currently happening in all the above watersheds discussed so far and other systems of the Ethiopian Rift valley that are not mentioned here.



**Figure113:** Two contrasting images representing the outflow from Lake Zwai through River Bulbula feeding Lake Abujata in 2012 (*UPPER*) and in 2020 (*BELOW*) The water quality deterioration and the loss of the biodiversity in just eight years is extraordinarily unprecedented (Photos by Brook Lemma)

## **CHALLENGE II: Climate change**

Climate change has always been there with the Earth. The Earth, once a hot ball of gas and dust, kept condensing and cooling down. So, climate of the

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time was changing. Later, the Earth's atmosphere came into being and the Earth was behaving as an immense greenhouse. That too was changing the climate of the Earth (see also Berger 2012 and others).

Each time major events happened, they were interspaced by millions of years with substantial climate changes. There were hotter and cooler or drier and flooded periods, e.g., as in the ice age. Each time, climate was changing. Nature accommodated the new changes and sustained the continuity of living things. In other words, climate has been changing in the past; but, it changed very slowly but continuously; as the changes took millions and millions of years to bring about substantive and qualitative changes. We call those periods today as geologic times measured in millions and millions of years and during which period living things had the time to use their genetic plasticity to modify and change themselves to fit into the changing ecosystem. Darwin's outlook of survival of the fittest was at work given the millions of years of geologic time.

In other words, in the process organisms perished or adapted to it using their biological genetic potentials (changing physically and physiologically). In the worst scenarios, those living organisms that could, survived by changing and adapting themselves to the changing environmental and climatic conditions or challenges, while those that couldn't change themselves using their genetic plasticity, unfortunately died out due to the unforgiving pressure of changes of nature. Thereby, nature was correcting itself and continuing. The last such major change happened in the Mesozoic Era some sixty five million years ago and as a consequence, back then the Dinosaurs (reptiles) disappeared to be replaced by the dominance of the vertebrates and the ferns plants were replaced by the broad-leaf plants, such as in the Amazon, Equatorial Africa and Asia forests.

Now, we say climate is changing as we see it by the year. It is changing much more rapidly in unprecedented way than in the past or in a way nature has never experienced it before. One does not have to go far or



investigate geological records to witness the changes. It is enough to turn the pages of the vast literature using the Internet by just sitting luxuriously in one's living room. I did the same from my office to examine what happened in the past less than 150 years or so, i.e., particularly since the Industrial Revolution (1850).

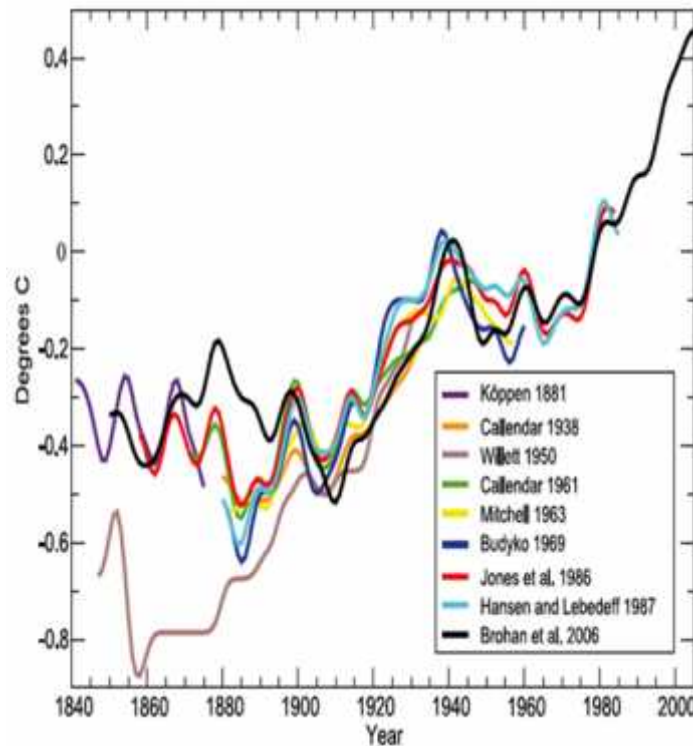


**Figure 114:** Analogous results of global surface air temperature changes (1840 - 2000) by renowned authors as indicated in the inset (after Le Treut *et al.* 2007).

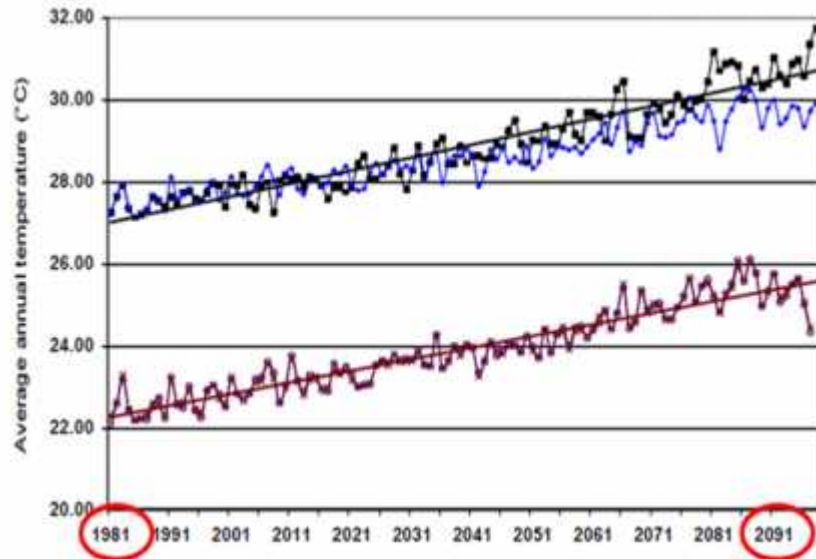


**Figure115:** Air temperature data on Lake Zwai Watershed with projections from 1881 to 2091, in which case this area in the Ethiopian Central Rift Valley was and is undergoing substantive changes and that is projected to continue, if it is not mitigated in time (Lijalem Zeray *et al.* 2006).

More recently, Hayal Desta and Brook Lemma in a series of publication from 2012 to 2017 recorded the following data (Fig. 117).

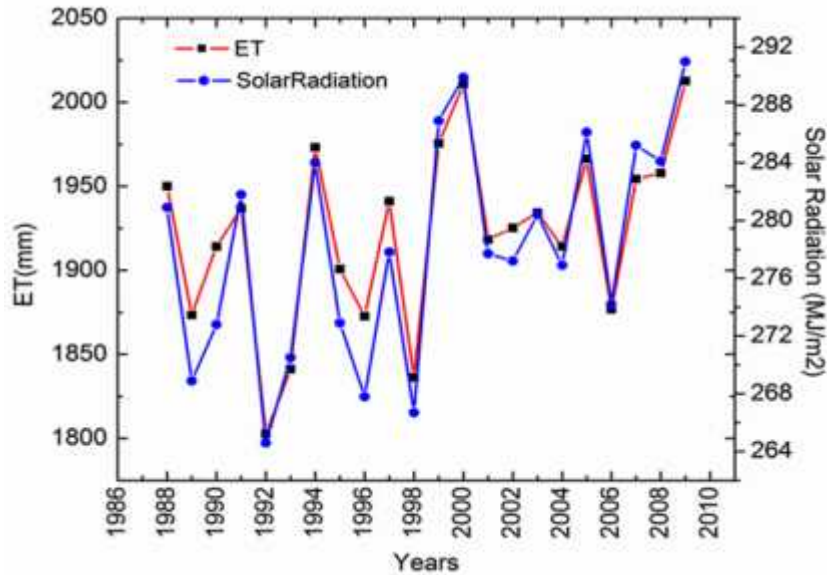


**Figure 57:** Mean annual evapo-transpiration versus solar radiation of Lake Zwai Watershed (1986-2010) (Hayal Desta 2016).

These changes in the climate of the Earth are taking place in completely unprecedentedly short times. The biodiversity in the watersheds of the Ethiopian Rift Valley are changing in the most undesirable ways before our own eyes. There is no talking about geologic time. It is all happening in one or utmost two generations of human society. Before I go into the third main factor that is driving the degradation of water quality and biodiversity on Earth and for that matter in the Ethiopian Rift valley, I must mention that one must realize that the effects of climate change are likely to act in synergy with the effects of land-use land-cover changes (Otero *et al.* 2020).

### CHALLENGE III: Invasive species

Following the expansion of agriculture and settlements at the expense of forests, shrub and grasslands; invasive species started to undermine biodiversity both in aquatic and terrestrial systems. In waters of the world, particularly tropical regions, such invasive species as water hyacinth

(*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), Cyanobacteria and others have replaced more important and ecologically diverse species of micro and macro plants of the water. On land, invasive plants such as Weyanezaf (*Prosopis juliflora*), *Parthenium hysterophorus*, (local name: yewef Qollo) (*Lantana* spp.), *Striga hermonthica*, *Orobanchecrenata*, *Cuscuta campestris*, wild tobacco (*Nicotia naglauca*), and others (Wakshum Shiferaw *et al.* 2018) are replacing the natural vegetation of many watersheds in the Ethiopian Rift Valley. I am here mentioning just those common invasive plant species. There are many more animals, especially, insects, rodents and other animals that associate themselves to the life of man as scavengers and becoming complacent to human management system and get preference over other wild animals (exemplified by the hyenas in Hararie and parts of Eastern Oromia, Ethiopia) and those that have just become invasive acting as opportunistic species filling up the niches of the natural species that are overrun by man-made degradations of the environment.



**Figure 117:** RIGHT - Water hyacinth, MIDDLE - water lettuce in Lake Zwai and LEFT - dense Cyanobacteria in Lake Koka, which happen to produce toxins that affect people and domestic animals that drink the water (Photos by Brook Lemma).

But there are even more important and more devastating invasive species than the above. The leading and the most devastating species is the *Homo sapien* (humans) followed by the domesticated animals and plants that have left the Earth filled by fields of monoculture crops, domesticated animals

and grazing fields. Just imagine if there is any place on Earth that man has not covered. It is very difficult to name one. I just think of the most hostile spots on Earth, name them, the Sahara Desert, Antarctica, the deepest point in the oceans, the highest peaks of mountains, and so on. Humans have been there for the search of natural resources. Who is next, the Moon, Mars or what?

The crops replaced the immense biological diversity (forests, grasslands, aquatic biota, etc.) and converted them into monoculture crop systems. Domesticated animals replaced wild animals and changed forests to grazing lands filled with a few selected grass species. All of these domesticated species are incompetent if let alone to compete with the natural biodiversity. We, humans, developed technologies to give domesticated species the advantages or the upper hand over biodiversity. You may ask; how did we do that? We developed fertilizers, pesticides, farm management techniques, irrigation schemes, drugs against diseases of the domesticated species, and so on and considered any other plant or animal that appeared among our favored species as weeds and destroyed them one after the other. Who else could be much worse than this? (See Scott 2017). All of these phenomena are happening to the waters of the Ethiopian Rift valley and their watersheds in the name of job creation and development.

#### **CHALLENGE IV: Natural events**

The literature is rich that recorded the seismic and volcanic activities in the Great African Rift Valley extending along the Red Sea into the Afar Depression, all the way down to Mozambique. These activities are expressed to the commons in terms of the hot springs that flow into the Rift Valley lakes and the thermal energy that gashes out of the ground and converted to electric power in many countries, including in Ethiopia at a place called Aluto Langano in the Central Ethiopian Rift Valley and in the Afar Depression at Tendaho Alalobeda, TendahoDubti, Corbetti and many others in the same region with untapped pockets (Khan and Singh 2017 and

official reports of the Ministry of Water, Irrigation and Energy, Addis Ababa).

It is not unusual to feel some rumblings and cracking of the ground surface in the Ethiopian Rift Valley systems. The most recent ones are those that happened in Lakes Hawassa and Zwai watersheds (Fig. 120, below).



**Figure 118:** RIGHT - Cracks in Lake Zwai Watershed in late 1990s and LEFT - Lake Hawassa Watershed at Mulati between 1996 and 1998 (from Yemane Gebreegziabeher 2004).

Once again, It is important that I reiterate that the Ethiopian Rift Valley lakes are sitting on active volcanoes and seismicity all along the length of the rift north to south as vindicated by the hot springs that flow into the lakes, the numerous geothermal outlets and most of all the data consistently reported by Ethiopian and international scientists (Keir, *et al.* 2006, Sisay Alemayehu Angere 2011, Atalay Ayele *et al.* 2015). Such events do affect water quality and the very survival of biodiversity to the extent of complete disappearance of the water bodies and the local/global extinction of species.

### **Drawing the parallels: Lessons learnt from the discussed watersheds in the Ethiopia Rift Valley**

Based on the four main challenges that I discussed above on the watersheds and water bodies of the Ethiopian Rift Valley, the following points that appeared across the board (parallels) can be summarized.

1. All the watersheds are experiencing expanding agriculture, including irrigation (diversion of feeder-rivers, lake water abstraction), followed by recession agriculture in the dry seasons. This is a clear indication that there is scarcity of fertile land and since in Ethiopia land is public property without planned management agreements at local levels, it is difficult to control expansions.
2. Domesticated animals and plants replaced biodiversity protected by sophisticated farm management technologies.
3. All the watersheds are loaded with high amounts of imported agricultural inputs (fertilizers, pesticides, herbicides, etc.), adding to water pollution and eutrophication; making the aquatic and terrestrial systems conducive to opportunistic invasive species.
4. All the watersheds are challenged by growing human population and expanding settlements (built-up infrastructures and industries) that regularly need excessive quality water, and thereby releasing wastes, including heavy metals, drugs, hormones, micro-plastics, etc.
5. All the watersheds are exposed to climate change impacts that lead to increasing water temperatures and sustained stratifications separating the nutrient rich bottom waters from the food producing phytoplankton in the illuminated upper waters and other ecological consequences. Currently, these watersheds are not receiving the benefits of any mitigation measures.
6. In all cases, because the land covers have been changed in favor of agriculture and built-up areas, top soils are exposed to extensive erosion by wind and runoffs whereby the inflows are loaded with silt, nutrients,

heavy metals, pesticides, macro and micro-plastics, etc., adding to the pollution of the water systems.

7. As a consequence, the rift valley lakes in Ethiopia have brown waters (silt), reduced light penetration, resulting in poor plant growth, including phytoplankton; with growth of undesirable algae such as toxic Cyanobacteria and aquatic invasive species that are well adapted to such degraded situations.

## Conclusions

Following the discussions and summary given above I came to learn that all the watersheds of the lakes of the Ethiopian Rift Valley are subject to similar degradations in the effort to enhance economic growth (development) for the growing population. In all cases, maximum effort is being done by all actors to create jobs and work extensively (in space and time) for the sake of social development whereby increase in production with agricultural and industrial inputs using natural resources to deliver products for consumption. This has over time shown increased transform of natural resources to human uses, followed by excessive release of pollutants into water, soil and air, that we call environmental degradation.

At the end of each production year, success of the growth economy (development) is measured by the contribution of the watersheds of the Ethiopian rift Valley lakes to the national gross domestic production (GDP). In other words, each *woreda* (district) reports contain the number and types of jobs created, quintals of harvested crops of various types, number of heads of animals slaughtered, etc. In those reports, one does not find number of hectares of forests lost, grasslands, shrubs or the soils and amount and levels of waters polluted.

In the final analysis, the development of the *weredas* are then measured or judged by their contributions to the growth economy (GE) or GDP of the country, which is defined as an increase in production, consumption and



investment in the pursuit of surplus products, inevitably leading to increased use of natural resources, energy and land (Anon. 2010).

It is important here to examine that the GE operates against a number of backdrops, namely, that (i) it is completely dependent on the transformation of natural resources for human use which comes in the name of products (production) (ii) The utilization of these products are oriented into insatiable consumption of humans and (iii) Natural resources are not valued as costs or they are extremely undervalued (Kalliset *al.* 2011, Kalliset *al.* 2012, 2018, Herath 2016, Seddon 2016, Simons and Federici 2019, Bassem 2020, Klimaszyk and Goldyn 2020, and Otero *et al.* 2020).

This drive for fetish growth produces wastes that result in environmental pollution (water, soil, etc.) and air with increasing and uncontrolled greenhouse gas (GHG) emissions and the consequent impacts of global warming. While this keeps on going, one must realize that the growth economy works for 1% of the adult global population that controls 40% of the world's wealth (Guercio 2015). Further, it can be stated that the degradation of the environment continues to satisfy the needs these same 1% adult population of found in the Western World (Kalliset *al.* 2012, 2018, Herath 2016, Seddon 2016, Simons and Federici 2019, Bassem 2020).

The end result I learned from my survey is that the poorest nations, the majority, who are the most dependants on natural resources, suffer from droughts, floods desertifications or total environmental degradations and dumping of toxic wastes, while the rich have the resilience to mitigate climate damages. At the same time, the rich countries have reached the optimum points of operating their economies and hence they export their production systems to the poor countries where natural resources are intact at least for now and environmental control measures are weak or non-existent. When this is reflected to the bigger picture of the global economic situation, this will eventually lead to uneconomic growth (Guercio 2015: a

report submitted to the UN). The 1% adult population continues to get richer consumes more products, release more wastes (e.g. a family with more than one car) and the rest of the low income countries get poorer and eventually the World has become and continues to become a place where there is rampant unsustainable inequality (Global Wealth Report, 2018, Chancel 2020). All of this happens because the overall operation of the growth economy is led by the nonstop drive of GDP Growth, which is still presupposes or focuses the future of the World is GDP growth at the expense of natural resources (Kallis 2012, Herath 2016, Seddon 2016, Simons and Federici 2019, Otero *et al.* 2020 and Chancel 2020).

But, then it begs the questions: “What should sustainability then mean if the end result is inequality?” In the true sense, sustainability should mean social inclusion (avoiding inequality), rational use of natural resources and yet continue to bring about social wellbeing (happiness or satisfaction of all in balanced natural and production systems) (Guercio 2015). The following and most obvious question is that is this then what is happening now despite all the talk and conventions on sustainability? What should be the way out?

There are two schools of debate. There are: (i) Decoupling of the growth economy and (ii) formulate a new economic order referred to as the degrowth economy.

The debate in the decoupling of the growth economy group goes in the direction that the use of natural resources is decoupled from the economic growth system or make as good valuation of them and include their costs into the growth economy. To meet such direction of development the developed countries decouple their economy by importing natural resources from poor undeveloped nations or outsource their companies to poor undeveloped nations, as mentioned above where resources are plenty, cheap and uncontrolled. In terms of energy supply they make shift from use of fossil fuels to clean energy (Simons and Federici 2019 and Otero *et al.* 2020). Or, shifting from animal proteins to plant proteins, for instance, to

make burgers, which automatically removes the question of deforestation or GHG emissions from livestock husbandry. In other words, there will not be or only limited and controlled conventional agriculture, replaced by, for instance, by vertical farming. All would have been well if the measuring stick is not again the GDP, which always focuses on growth of the economy and profits to the 1% adult World population that would eventually end up in increased inequality (Simons and Federici 2019, Otero *et al.* 2020, Chancel 2020 and others).

This brings us into the second debate of degrowth economy (DE). It is defined as an equitable downscaling of production and consumption that increases human wellbeing and enhances ecological conditions at the local and global levels (Kershner 2010, Kallis 2012, Kallis *et al.* 2013 and 2018). Such a new stride into changing the global economic system must have some background thinking and research. Its brief history goes back to its first initiation in 1968 to find its 1<sup>st</sup> International Conference in 2008 in Paris and later it found its UN platform in 2015. This conference examined its prones and cons and ended up without endorsing to any level of consideration (Anon. 2010).

Degrowth economy holds that, firstly, growth economy has reached or bypassed its limits of natural resources (excessive environmental degradations and wars on resources) and named it as an ecological overshoot. Secondly, the transformation of ecosystems by the growth economy for human use led to loss of the wilderness, biotic homogenization (mono-cultured crops and animals), rapid erosion of species, etc. Thirdly, the growth economy must replace the fixation on fetish GDP increase, as this cannot continue indefinitely with limited global natural resources and fourthly and in short, the growth economy is like sitting in the wrong train in which case to get to the desired destination it is not enough to slow or stop the train but climb down and jump into the right next train going in the correct direction to get to the desired destination (Kallis *et al.* 2012, Herath 2016, Seddon *et al.* 2016, Parrique, 2020, Simons

and Federici 2019 and others). This argument is captured in the following figures (Fig. 121 and 122).

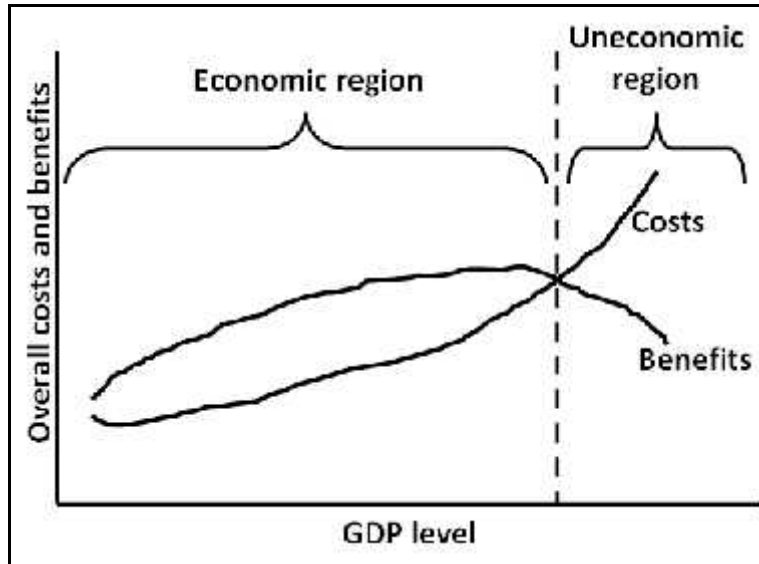


**Figure119:** GDP versus overall costs and benefits (modified after Herath 2016)

In place of the above model of the costs and benefits of the growth economy, the debate of degrowth economy is presented in Fig. 122, below.

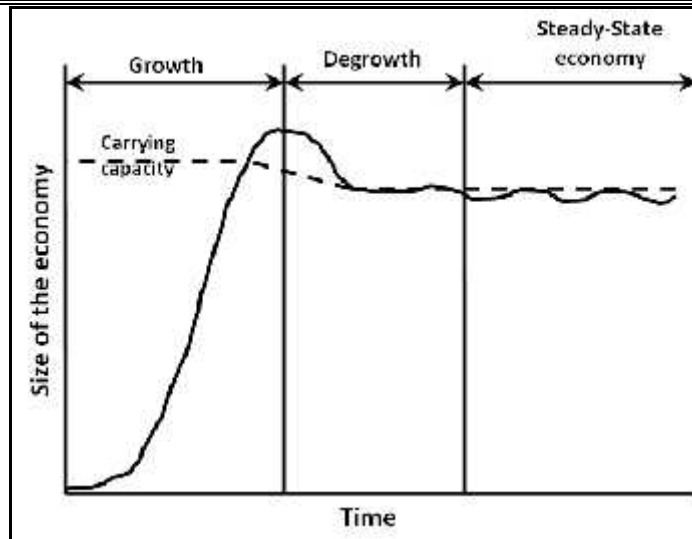


**Figure 120:** Degrowth transition to a steady-state economy and sustainability in the use and conservation of natural resources of the World (after O'Neil, 2012 and Herath 2016)

Then, what does this mean to the ecosystem and humans? In contrast, degrowth economy debates that production should be downscaled to fit to sustainable use of natural resources. Similarly, consumption should be downscaled not to overburden the ecological sink with excess and poisonous liquid, solid and gaseous wastes (e.g., GHGs). Working hours should be reduced and add more of them to leisure and quality family time, use less cars and more public transport, work online, produce safe energy, make less and less of conventional agriculture and so on to promote human wellbeing and sustainability of natural resources. However, degrowth economy the continuity of controlled production and consumption in low income countries for a limited time such that wealth could be redistributed to level off the inequality in rich and poor countries (Kallis 2011, Kallis *et al.* 2012 Seddon 2016, Simons and Federici 2019 and Parrique 2020 and others).

After having come all the way up to here the overriding question remains. That is: Is sustainable development with water quality and biodiversity then a hit or a myth despite all the rhetoric of the international community with its conventions and agreements? Millions of dollars' worth of resources has been spent in low income countries in the name of development, improving human wellbeing and conservation of resources. Numerous projects are running in watershed management, mitigation of climate change impacts and improving the resilience of the poor developing countries. Universities conduct numerous researches and produce PhD graduates in the same, who would go out and work on sustainable development. Are we there where sustainability is being achieved, natural resources are being used accountably, are inequalities being narrowed approaching to even out? I question myself if we are at the hit or still languishing in a myth.

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