ADDIS ABABA UNIVERSITY

AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT

Ecological and Socio-economic Impacts of Ecohydrological Interventions on the Wetlands along the Southeastern Shore of Lake Tana, Ethiopia

BY

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Addis Ababa, Ethiopia

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MSc Thesis

BY

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In Partial Fulfilment of the Requirements for the Degree of Master of Science in Water Management Specialization of Aquatic Ecosystem Management

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DECLARATION

I hereby declare that submission of my original thesis work with all sources of material used duly acknowledged and the work has not been presented for a degree in this or any other university**.**

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ADDIS ABABA UNIVERSITY AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT SCHOOL OF GRADUATE STUDIES

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BMP	Best Management Practice
IEP	Institute of Environmental Protection
IHP	International Hydrological Programme
IUCN	International Union for Conservation of Nature
IWM	Integrated Water Management
MEA	Millenium Ecosystem Assessment
SPSS	Statistical Software for Social Sciences
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USEPA	United States Environmental protection Agency
WBSR	Water and Biodiversity and Ecosystem Services for society and Resilience

ABSTRACT

Information regarding the ecological and socio-economic impacts of ecohydrology based intervention approach in the wetland ecosystem plays an indispensable role in increasing biodiversity, improve water quality and enhance ecosystem services. Although ecohydrological solutions have been proposed by various studies for immediate, nature based, management to prevent degradation from imminent developments, a comprehensive study on the impacts of ecohydrology intervention in relation to biological, physico-chemical and socio-economical aspects are limited. Such information is very important for the management of degraded shore wetlands of Lake Tana. Thus, the aim of this study was to investigate the impacts of ecohydrological intervention in relation to physical, chemical and biological attributes and assess the most common socio-economic benefits of the wetlands in Lake Tana shore. Ecological and socioeconomic impacts of ecohydrological intervention on the wetlands in the shore of Lake Tana were studied in November 2019 and April 2020. Physico-chemical data were measured on each sampling point. Sediment and water samples were measured and analyzed onsite and in the laboratory and most of the Physico-chemical parameters were significantly different ($p<0.05$) across the sampling sites. The quadrat/transect method was employed to collect macrophyte and macroinvertebrate data. Quantitative characteristics of macrophyte sampling were conducted using transect and quadrat method along vegetation and water depth gradients. A total of 24 quadrats of 1m×1 m size were employed using the species-area curve method for all sampling sites. A total of 12 major macrophytes species were recorded from all sampling sites. The abundance of macrophytes varied between sampling sites and season and this might be attributed to the differences in protection status, human disturbances, physico-chemical parameters and level of awareness of the community. Based on the Shannon diversity index ($H' = 0$), the Agid kirgna wetland could be grouped under the least diverse followed by Gedromesk wetland ($H' = 1.00$) and Gumetirs wetland ($H' = 1.24$). A total of 975 macroinvertebrate individuals belonging to 15 families were collected using a D-frame net from all sampling sites during the study period. Based on the biological indices, $H' = 2.39$ and $HFBI=4.68$, the Gumetirs wetland might be grouped under a good ecological condition. Both phytoplankton and zooplankton samples were collected using a 15µm mesh size plankton net. A total of 23 phytoplankton and 9 zooplankton taxa were collected. Numerical density and diversity of zooplankton and phytoplankton taxa varied along the sampling sites, habitats and seasons which could be linked with food availability, degree of disturbance and physico-chemical conditions. Qualitative and quantitative data were collected from 90 households head (HHDs) on several variables through structured questionnaire, interview and observation to assess the socio-economic benefits of the wetlands. Overall results of this study confirmed that biological, physico-chemical conditions and wetland benefits were associated with the intensive human activities carried out in and around the wetlands, and level of awareness of the local communities. Therefore, emphasis should be given to the factors which may lead to the degradation of wetland resources within and its catchment especially recession farming, overharvesting, overgrazing and invasion of water hyacinth. Immediate ecohydrology based intervention approaches should be implemented to conserve and minimize further degradation and ensure sustainable livelihoods of wetlands along the shore of Lake Tana.

Keywords: *Abundance; Biodiversity; Ecohydrology; Human disturbances; Lake Tana; Socio-economics; Wetland conditions; Wetland degradation.*

1. INTRODUCTION

1.1. Background of the study

Wetland is the most valuable and vulnerable ecosystem in the world aquatic ecosystem. Interfacing between land and water systems, wetlands are highly productive and biologically rich ecosystems, and are also the most endangered (Ramachandra, 2001).

Recently, there has been increasing concern over the continuing degradation of world's wetlands, particularly rivers and lakes. Aquatic ecosystems are especially vulnerable because human population density is on average higher near lakes, rivers and estuaries, and because water bodies accumulate the effects of developments in their catchment (Williamson *et al*., 2008). Biodiversity in freshwater ecosystems rivers, lakes and wetlands is undergoing rapid global decline and is expected to further decline (MEA, 2005; Revenga *et al*., 2005; CBD, 2014), possibly at even higher rates than in terrestrial and marine habitats (Loh and Wackernagel, 2012).

Information on wetland ecosystem services, drivers of change and subsequent impacts specific to regions or areas of concern is essential for ensuring wise use, conservation and sustainable development (Mopelwa and Blignaut, 2006; Ostrom *et al*., 2007 and Adekola and Mitchell, 2011).

Major drivers are land use change, eutrophication, hydrological disturbance, climate change, overexploitation and invasive species (Janse *et al*., 2015). One of the most prominent direct drivers contributing to the decline of aquatic biodiversity at a global scale is land use change which involves both the direct conversion of wetlands as well as indirect effects of land use in the catchment (Allan, 2004; Verhoeven *et al*., 2006) followed by hydrological disturbance resulting from water withdrawal (Revenga *et al*., 2005). More fundamentally, wetlands are lost or degraded because of their products, functions and attributes are not adequately appreciated or valued by human institutions and policies (Owuor *et al*., 2012).

Human activities, either within the wetland or in the catchment, in which they are situated, can alter the natural processes or accelerate the rate of change, threatening the wetland’s continued existence. Intensive agriculture with improper land use and exploitative resource management results in significant negative impacts including ecosystem deterioration in the form of water and land degradation, reduction in biological diversity, social and economic impacts, and so on (Ligdi *et al.*, 2010). Consequently, energy flow, nutrient cycle, water cycle, biological process and socio-economic aspects which are provided by the wetlands are greatly disturbed. The degradation of wetlands results in loss of important hydrological and ecological functions. The relevant challenge, therefore, is striking a critical beneficial uses of ecosystems for generating livelihoods for local communities without compromising environmental values and uses.

In Africa, particularly in Ethiopia, conservation and sustainable use of aquatic resources are a big challenge (Karunamoorthi, 2009). Ethiopia is one of the world most vulnerable biogeographic regions susceptible to land degradation. The major cause of land degradation in Ethiopia is deforestation (Tilahun Amede and Yitbarek Nigatu, 2001; Berry, 2003; Meqaunint Asres and Seleshi Awulachew, 2010; EPA, 2012) which together with unsustainable agricultural practices and intensive rain cause a progressive erosion (Dechasa Jiru, 2010). Such problems were observed in the case of Lake Tana (Ligdi *et al*., 2010; Ayalew Wondie, 2010).

The wetlands in the Lake Tana area are of major significance for the whole region. They provide a myriad of goods and services for humans and animals (ZurHeide, 2012). Lake Tana basin supports different economic activities, and agriculture is the major one. The basin has huge potential for socio-economic development and because of this it has been identified as a major 'economic corridor' (Stave *et al*., 2017). The Lake Tana watershed wetlands have critical functions of nutrient and sediment retention, biodiversity and hydrological functions of water storage and flood abatement. The wetlands support the livelihoods of hundreds of thousands of people in various ways (Stave *et al*., 2017). The wetlands support large biodiversity of plankton, fish, macrophytes, mammals and birds, and Lake Tana is migratory route for some overwintering birds such as the Pallid Harrier (EWNHS, 1996). Wetlands around Lake Tana and along the river banks are increasingly degrading and quickly disappearing and it brings a dramatic reduction of their buffering role in the ecosystem, the economic benefits, and the livelihoods they sustain(Ligdi *et al.*, 2010).

At the present level of human impacts on ecosystems, it is necessary to increase the opportunities for environmental restoration and wise management of water resources. This can be achieved by optimizing the absorbing capacity of ecosystems against human impacts. Such approach must be based on an understanding of the temporal and spatial patterns of water and biotic dynamics at the catchment scale. Therefore, wetlands provide a good scientific testing ground for the interdisciplinary fusion and development of ecohydrology theories. Hydrological and ecological factors are highly correlated in natural wetlands, although the quantitative studies of the interaction mechanisms between ecology and hydrology are insufficient in current wetland ecology or hydrology (Zhou *et al*., 2016).

There is now an increased recognition of the need to conserve the ‘natural capital’ that the environment provides. There are an increasing number of evidences in the scientific literature that hydrology and biological processes are strongly interconnected. This interdependence has been quantified and validated at various scales including the landscape (Ryszkowski, 2002), floodplains and wetlands (Junk *et al*., 1989), rivers (Zalewski and Naiman, 1985), lakes and reservoirs (Zalewski *et al*., 1990; Straskraba and Tundisi, 1999) and coastal zones (Chicharo *et al*., 2001).

Nowadays, the sustainable development of water bodies and the communities they sustain and improvement of quantity and quality of water calls for a shift from traditional engineering solutions to a holistic approach integrating hydrology and ecology, a new paradigm called ecohydrology (Zalewski *et al.* 1997; Zalewski, 2000; 2002). In order to reverse those forms of cumulative intermediate impacts, which often are major factors of degradation the ecological potential at catchments, profound understanding of the water - biota interplay is most important (Zalewski *et al.*, 2015). Urgent ecohydrology based intervention approach for the enhancement of water resources; biodiversity and ecosystem services for society and of the resilience (WBSR) to various forms of anthropogenic impacts is needed to reverse degradation of water resources and stop further decline in biodiversity (Zalweski *et al*., 2014). As a basis for sustainable integrated developmental activities for the improvement of the lake environment and upgrading of the livelihoods of the local community, trial studies and demonstration works on best management practices (BMP’s) of ecohydrology is necessary (Ligdi *et al*., 2010).

Hence, the ecohydrological concept solutions have been identified to tackle the existing problems (Ayalew Wondie and Ligidi *et al.*, 2010). The growing demand to provide evidence of successful implementation of ecohydrology solutions calls for a worldwide ecohydrology demonstration sites in order to validate and quantify the effectiveness of ecohydrological solutions (Zalewski *et al*., 2010). However, comprehensive studies about ecological and socio-economic impacts of ecohydrological intervention on the wetlands along the shore of Lake Tana are lacking. Therefore, this study was designed to quantify the impacts of ecohydrological interventions on the wetlands in the shore of Lake Tana in relation to biological and physico-chemical conditions as well as the socio-economic status and perception of local community. Additionally, this work is also expected to deliver useful recommendations for the management of wetlands along the shore of Lake Tana and other fresh water ecosystems to minimize any threats which may lead to the degradation of wetland and its benefits.

1.2. Statement of the problem

Due to lack of well planned and holistic watershed management along with poor knowledge and lack of awareness, a number of Ethiopian wetlands are shrinking or swelling over time. Inadequate hydrological knowledge and monitoring, insufficient consideration of highland-lowland interactions, and lack of watershed management results in successive degradation of water quality. Therefore, integrated management is a proactive approach towards sound water management (Ayalew Wondie, 2010).

Lake Tana ecosystem has undergone considerable changes. There is a continuous decline in biodiversity, degradation of water quality, high sediment loading and lack of vegetation cover and in general there is weakened self-purification potential in the wetlands in Lake Tana due to anthropogenic activities originated at the catchment of Lake Tana surrounding (Ayalew Wondie, 2010). According to Ayalew Wondie (2010) the most outstanding threats of shoreline and riparian wetland problems are agriculture, industrial pollution, drainage activities and overharvesting of wetland resources. He recommended that ecohydrology is a mandatory approach as a mitigation measure and to improving management of Lake Tana shore zones and riparian wetland ecosystems against human impacts. Sewmehon Demissie and Girma Tesfahun (2004) reviewed past studies and concluded that the trends in the management of the resources in and around the lake have been repeatedly indicated to be unsustainable and hardly controlled. Thus, Lake Tana deserves due attention so that this great deal of existing and potential ecosystem services can be sustainably used for current and future needs in supporting livelihoods and development .

The major issues which are identified by the Africa regional ecohyrology project in the demonstration sites in Lake Tana shore zone are encroachment of agriculture, land degradation , excessive presence of pollutants and nutrients, intensive land use, recession farming and loss of retention capacity of vegetation. In order to reverse negative trends on ecosystem, ecohydrology needs to be implemented and this must start with a transfer of knowledge of ecohydrology, not only on a theoretical level but also in practical applications (Zalewski, 2018). Ecohydrology principle based approach has been applied as a mitigation measure in the UNESCO demonstration site at Lake Tana shore zone since 2011 by Africa regional ecohydrology project.

Despite ecohydrological methodology has been implemented in the study site at the Lake shore, the ecological and socioeconomic impacts or effectivenessess of the intervention have not been assessed. Virtually, no studies have specifically addressed this research gaps. Information regarding the impact of ecohydrological intervention is very crucial to conserve biodiversity, improve water quality and enhance ecosystem services and also to address human impacts on aquatic resources. Therefore, it was found necessary to carry out a detailed investigation of ecological and socio-economic impacts of ecohydrological interventions at the shore of Lake Tana to recommend a harmonious and holistic management options to prevent ever-increasing degradation of the wetland. Thus, this study aimed to evaluate the ecohydrology interventions impacts related to the biological, physico-chemical, and socio-economic attributes of the wetland at the shore of Lake Tana.

1.3. Research questions

This study aims to answer the following questions

- Are there changes in physico-chemical variables, macrophytes, macroinvertebrates, plankton abundance and socio-economic conditions of wetlands across sampling sites along the shore of Lake Tana?
- Which sampling sites (wetlands) provide more benefits for the local community?
- Is there a significant difference across the sampling sites in biological, physico-chemical and socio-economic condition during wet and dry season?
- Does ecohydrological intervention measure and approach improve the ecological and socio-economic conditions of the wetland and livelihoods?
- How are ecohydrological intervention activities associated with wetland benefits and local people perceptions?

1.4. Objectives

1.4.1. General objective

The general objective of this study was to investigate the impacts of ecohydrological intervention in relation to physical, chemical and biological attributes and some of the socio-economic benefits of the wetland in Lake Tana shore intervention site.

1.4.2. Specific objectives

The specific objectives of the study were to:

- quantify the impacts of ecohydrological interventions on the ecological condition in relation to the physical, chemical and biological status of the wetlands along the southeastern shore of Lake Tana.

- assess and compare the wetland benefits and also the perception of the local people that benefited from the ecohydrological intervention activities.

1.5. The hypothesis of the problem

This study hypothesized that there is a significant variation in physico-chemical parameters, abundance and biodiversity of macrophytes, macroinvertebrates and plankton, wetland benefits and local people perceptions among sampling sites and better conditions exist at the intervention site.

1.6. Significance of the study

Basic information on the extent of human disturbances and level of awareness which were causes for less biodiversity, water quality and wetland benefits in both Agid kirgna and Gedromesk wetlands were generated from the study. These also suggested appropriate wetland management mitigation measures that should be implemented in these wetlands to conserve biodiversity, improve water quality, and enhance ecosystem services. The findings of this study at Gumetirs wetland also an insight into further strengthen the ecohydrological intervention activities for conservation and management of other wetlands with sustainable ways. Moreover, the study will motivate research and academic institutes to undertake further investigations on Lake Tana biodiversity, water quality and socio-economic status. Similarly, the research findings will be helpful as a baseline for researchers, decision makers and stake holders to understand the actual ecohydrology based intervention and its impact on water quality, biodiversity and ecosystem services and their sustainable conservation, utilization and restoration approach for the whole ecosystem health and functioning. Most notably, this study could also be used as a benchmark for future studies to investigate and apply ecohydrological approaches for sustainable wetland management and livelihoods sustainability so as to enhance, conserve, mitigate, and restore degraded wetland buffer zone along the shore of Lake Tana, as well as elsewhere.

1.7. Limitations of the study

The limitations of the present study are the fact that availability of turbidimetry to measure turbidity and phosphate analyzer, managing of sample size, limited time, financial constraints and conducting of in depth interviews for socio-economic survey.

2. LITERATURE REVIEW

2.1. General background

A wetland is a distinct ecosystem that is flooded by water, either permanently or seasonally, where oxygen-free processes prevail (Keddy, 2010). The primary factor that distinguishes wetlands from other landforms or water bodies is the characteristic vegetation of aquatic plants, adapted to the unique hydric soil (Butler, 2010). Wetlands form where water meets land surface that includes swamps, mangroves, peatlands and marshes, flooded forests, lakes and rivers, deltas, floodplains and, rice-fields as well as coral reefs. Whether any individual wetland performs different functions and the degree to which it performs them, depends on the characteristics of that wetland and the lands and waters near it (Dorney *et al*., 2018).

Many studies, including Shimelis Setegn (2008), point out that the land and water resources of the basin and the Lake Tana ecosystem are endangered among others by soil erosion, sediment transport and land degradation. According to Zinabu Gebremariam and Zerihun Desta (2002) many studies show that the rapid growth of human population, coupled with agricultural development and industrial activities are the main causes of water quality deterioration in Ethiopian lakes. Ecological properties of wetlands and riverine vegetation provide flow regulating function and play an important role in recharge filtration of ground and surface water bringing about attenuation of floods in open water bodies (Zalewski and Wagner, 2004). Thus, it is evident that the contributions attributable to adverse climatic effects and/or reduced regulatory function of the ecosystem (diminishing cover over the catchment and degradation of ecotones, wetlands and riverine vegetation) are not overemphasized (Ligdi *et al.*, 2010).

Human disturbances to wetlands are frequently the result of agricultural practices and urban development (Galatowitsch *et al.*, 2000) and their impacts can be divided into individual stressors that may have physical, chemical, and biological effects on wetlands. The ecological consequences of converting the floodplain areas to cropland and the development of flooding and erosion control infrastructure are closely connected with the removal of natural vegetation, which results in the degradation of wildlife ecosystems (Gaudi, 2005, Sudduth and Meyer, 2006; Florsheim *et al*., 2008).

Untreated effluents and encroachment for different purposes are negatively affecting the wetlands water quality and biodiversity (Negash Atnafu *et al*., 2011). The wetlands in the Bahir Dar city surroundind areas have faced several threats such as free grazing, chat production, water abstraction, urbanization, encroachment, settlement, drainage for agriculture, and wetland distribution to landless youths (Ayalew Wondie, 2108). The major challenges in Lake Tana watershed protection include: reducing pollution by silt load, water level fluctuation, eliminating overexploitation of resources, mitigation of conflicting interests in the use of water and land resources (deforestation, water logging, flooding, overgrazing, population pressure, and degradation). Sedimentation has now become a threat to the survival of the lake ecosystem (Ayalew Wondie, 2010). According to Zalewski and Wagner (2004) lack of a littoral zone as a consequence of water level changes is one of the limnological characteristics of reservoirs which make them especially susceptible to the processes of eutrophication. Wetlands in Lake Tana catchment are now threatened from sedimentation (silt load) as a result of the upper intensive agriculture activities and deforestation. The effects of non-point sources such as agriculture runoff are found to be greater than those of point sources of pollution. Above all, the surprising thing is a shift of farming practices. In the earlier centuries, farming occupied upland of the mountain areas following the long history of highland settlers of Ethiopia (Ayalew Wondie, 2010). In the last two decades with an increase of population pressure and limitation of resources (land and water) farming shifted to wetland including river banks channel banks and shore zones of lakes (Leykun Abunie, 2003).

The natural resource base in Ethiopia such as land, wild life and water are vital sources of domestic and national income. Such provide the basis for farming, fishing, energy production and tourism. However, these resources have been degraded due to high demand for agricultural land home energy use resulting from high population pressure. Hence environmental degradation will remain a major cause of low agricultural production. Generally, the major causes of biodiversity destruction are poor method of farming system which results in soil erosion, loss of mainland and soil fertility. This in return leads to low agricultural yield hence farmers become both agents and victims of environmental degradation (Yitaferu Birru *et al*., 2004).

An increasingly prominent focus on intervention perhaps indicates a progression in science from describing and attempting to understand ecosystem structure and dynamics to developing approaches that allow informed intervention in ecosystems (Pickett *et al*., 1994). Interventions are intended either to maintain a system in a current desirable state or to move a system away from a current undesirable state (Hobbs *et al*., 2011). An active intervention at the local scale is likely to form part of a reactive response to a broader degradation process. As Matthews and Turner (2009) pointed out humans have long undertaken ecological interventions, usually in response to particular environmental problems. Interventions can take the form of manipulating the biotic or abiotic

characteristics of the ecosystem and can vary in intensity from deliberate nonintervention through directed one-off interventions to ongoing, large scale interventions (Hobbs and Cramer, 2008).
Research indicates that the notion that water quality and biodiversity can be controlled by managing hydrologic parameters, as residence times or freshwater discharge volumes, or biological parameters, as the presence of riparian vegetation or filter feeders, and that integration with existing infrastructures can be made in a synergetic way, are novel approaches to water sciences (Chicharo *et al*., 2009). However, some research has suggested that since physical interventions are required to recover or create the hydrological conditions of degraded or new wetlands, and given the high cost (22–73%) of biological interventions (revegetation), the need for biological interventions is, in most cases, unclear(Moreno *et al*, 2015).

2.2. Ecohydrology approaches for water quality, biodiversity and ecosystem services

Ecological conditions and socio-economic issues have been widely associated with biodiversity, water quality, and ecosystem services particularly in wetlands. The relation between ecosystem and hydrology concerns is well established (Maltyby *et al*., 2011).

The timing and onset of human activities and how these have modified aquatic ecosystems in the past are becoming of increasing scientific and management concern (Dearing *et al*., 2006; Gell *et al*., 2007; Saulnier-Talbot, 2016) especially as global aquatic ecosystems shift towards alternative anthropocene states (Kopf *et al*., 2015). Despite massive ecological protection measures carried out by developing countries, the future health and sustainability of many protected natural wetlands remains questionable due to poor implementation of policies and ineffective legislative measures (Luan and Zhou, 2013).

The interplay between water, ecosystems and society becomes increasingly complex as humanity approaches the limits of the carrying capacity of the bio-geosphere, and as a result of drastic modification of ecological cycles, degradation of ecosystems, emission of pollutants and over-engineering of the environment. Tropic regions are perhaps the most rapidly changing terrestrial ecosystems of the anthropocene (Hansen *et al*., 2013), allowing for opportunities to investigate ecohydrological responses to land use and climate change.

Despite wetlands significant role in maintaining the healthy ecosystem and contribution to the local livelihoods of the people, wetlands are under threat due to degradation of catchments and water diversion leading to changes in water regimes. The increasing human population and degradation of biological integrity of ecosystems has been expressed, to a great extent, as a decline in water resources, the most critical factor to achieve sustainable development. This is because overexploitation and degradation of the biotic structure alters ecosystem processes to the point at which the ecosystem ability to provide desired resources is seriously diminished (Zalewski, 2002).

It is now well understood that decline of environmental resources is occurring on a global scale, severely reducing the biodiversity and ecosystem services of water basins for ever growing societies (Meybeck, 2003; Millennium Ecosystem Assessment, 2005). This in many cases reduces the socio-economic potential of countries, especially in the "Developing World" (Zalewski *et al*., 2009).

Ramachandra *et al*.(2011) found that anthropogenic activities impact physical, biological, and chemical processes of wetlands, which impair the ecosystem functioning causing decline and degradation of ecosystem services and also economic value of wetlands. Wetlands are constantly adjusting to disturbances occurring within (direct impact) them and within (indirect impact) the surrounding landscape. It is important to recognize to what extent various disturbances affect wetlands when assessing disturbance and impact, and when considering wetland protection options (Clearwater *et al*., 1998). Human activities have produced extensive and rapid perturbations of natural ecosystems, resulting in what is now recognized as the ''anthropogenic era''. Considering the relationship between landscape and the dynamic nature of wetlands is essential to the assessment of wetland functions and values.

Large scale deforestation, urbanization and infrastructure development resulting from rapid population growth, and aspirations of the people, have generalized major impacts on aquatic ecosystems (Zalewski, 1992, 1995), often beyond the buffering capacity of the environment.

In particular, development has come through squeezing the physical spaces of various natural ecosystems, for example through land use and land cover change such as that caused by mass urbanization, and the associated direct or indirect accelerated rapid destruction of biotic habitats (Luan and Zhou, 2013). Due to major factors such as siltation, pollution, drainage and deforestation of wetland species, wetlands are among the most vulnerable habitats (Rewati, 2012).

This is the result of cumulative synergetic effects on global (climate changes) and regional (example. acid rains) processes with various local impacts (pollution, excessive water extraction). These various form of environmental perturbations affect quality and acceptable quantity of inland waters by increasing runoff, erosion, sedimentation and pollution. In parallel, modifications of land use affect the residence time and partitioning into which precipitation is transformed: surface runoff, soil moisture, evaporation and ground water. The channelization of rivers, reduction of floodplain areas and wetland drainage cause serious modifications in patterns of water flow, nutrients, sediments and pollutants. These processes reduce the biodiversity and biotic integrity, water quality and ecosystem services of many freshwater ecosystems.

These phenomena are of increasing concern because they are likely to inflict irreversible damage on the sustainable use of freshwater resources in many regions. Naiman *et al*. (1995) state that there are still a lack of integrated conservation strategy that considers entire freshwater resources management are too often taken without sufficient scientific and empirical background, addressing only short term and single goals, and ignoring the complexity of processes in aquatic ecosystems. Consequently, low environmental and economic efficiency of activities have usually been observed. Moreover, there are seven major threats to lakes of the world includes: accelerated eutrophication, invasive species, toxic contamination, overfishing, water diversion, acidification, and climate change.

Major threats to wetlands in Ethiopia, include conversion to agriculture by draining, overharvesting of the resources, and appearance of invasive species, introduction of perennial vegetation and overgrazing. Moreover, lack of clear awareness in general public, decision and policy makers coupled with the absence of clear policy and direction on wetlands issues are contributing to the problems mentioned before (Afework Hailu, 2005). A study by Ayalew Wondie (2010) found that the most outstanding threats of the shoreline and riparian wetlands stability are agriculture, industrial pollution, drainage activities and overharvesting of wetland resources. Similarly, Shewit Gebremedhin *et al*. (2018) also found that rapid population growth and the economic transformation are the main driving forces leading to various pressures such as water quality and wetlands degradation as well as declining fish community, which is detrimental to the socio-economic state and health of the local inhabitants.They also further notice that the major anthropogenic threats in the Lake Tana catchment are illegal fishing, agriculture, dam construction, waste water discharge, water hyacinth invasion and sand mining. Invasion of aquatic habitats by non-native species is also a global environmental challenge with serious ecological, social and economic consequences (Williamson, 1999). Similarly, Eshete Dejene *et al*. (2017) conclude that the decline of three commercially important fish taxa in the lake is linked to recruitment overfishing and increased recession farming.

In the Lake Tana sub basin, majority of the wetlands distributed along the tributaries and around the lake shores and estimated to cover 2.14% of its total surface area (Ibrahim Mohammed *et al*., 2019). They also further noticed that development activities in Lake Sub-basin very rarely consider the ecological and socio-economic values of wetlands and wetland destruction and conversion for the purpose of recession agriculture is still seen as advanced mode of development.

Ayalew Wondie (2018) recommended that regulation of biota by altering hydrology and vice versa (the ecohydrology principle of dual regulation of wetland ecosystems) is a mandatory approach for the wetlands in the Lake Tana area of Ethiopia, as well as elsewhere. Ligdi *et al*. (2010) also found that source of pollutions from urban waste and rural agriculture and degradation of biota in the catchment are the two main environmental threats for the Lake Tana ecosystem. They also further stress that land and ecological degradation is one of the major constraints of agricultural and rural development in Ethiopia. Intensive agriculture with improper land use and exploitative resource management results in significant negative impacts including ecosystem deterioration in the form of water and land degradation, reduction in biological diversity, social and economic impacts, and so on. They also further points out that degradation of wetlands results in loss of important hydrological and ecological functions.

Unsustainable and exploitative use of inland water bodies (rivers and lakes) for different purposes can greatly threaten the aquatic ecosystem and their diverse values. Misuse of water and biota (wetlands) affects hydrology in the basin. It reduces the resilience of the ecosystem and may intensify pollution, eutrophication and sedimentation from human activities, which may place these important systems at risk (Ligdi *et al*., 2010).

Humbert and Dorigo (2005) reviewed that important significant impacts that were causing extensive damage to the water resources and the loss of aquatic biodiversity are deforestation, use of pesticides in agriculture and water for irrigation purpose, rise in urban and industrial sector, regulation of water for dam and hydroelectricity production, mineral and petroleum extraction, solid wastes dumps, bottom dredging and water flow channelization, fishing and aquarium market (Humbert and Dorigo, 2005). They conclude that the major causes for aquatic biodiversity depletion are overexploitation of species, habitat modification and organic pollutants.

Ecohydrology and ecosystem services

The concept of ecosystem services is becoming influential in environmental research and policy (Chaudhary *et al*., 2015 and Bastian *et al*., 2014). Applied from coastal (Brown *et al*., 2008) to mountain ecosystems (Gret-Regamey, 2012; Van Oort *et al*., 2015 and Bhatta *et al*., 2015), ecosystem services are now prioritized for conservation (Baral *et al*., 2013 and Paudyal *et al*., 2015), landscape level planning and management (Baral *et al*., 2013; Wu, 2013 and Baral *et al*., 2014) and decision-making (Daily *et al*., 2009). Ecosystem services are widely evaluated for wetlands, showing people's dependency on ecosystem services, the value of wetlands, and the drivers of change affecting wetland functions (Costanza, 2006). However, assessing and mapping of community perceptions of ecosystem services has only recently emerged (Malinga *et al*., 2013; Paudyal *et al*., 2015 and van Oort *et al*., 2015). Millennium Ecosystem Assessment (2005) demonstrated the strong links between ecosystem services and the livelihoods of people and how the decline of ecosystem services across biomes has resulted in changes to peoples' livelihoods.

Wetland ecosystems around the world, provide a variety of goods and services such as land for cultivation, water for productive purposes (crops, livestock and construction) and non-productive purposes (washing, bathing and consumption), grazing pastures, fuel-wood, reeds and building materials and other indirect benefits (recreation, flood attenuation, storm buffering) (Schuyt and Brander 2004). Ecosystem services, the goods and services that ecosystems provide for human well-being (Alcamo *et al*., 2003; Millennium Ecosystem Assessment Program, 2005) are increasingly used as a framework worldwide for the purposes of ecological restoration and conservation (Wei *et al*., 2017), watershed management (Falkenmark *et al*., 2004), and sustainable development policy making (Asbjornsen, 2015). Among the myriad of services provided by ecosystems, hydrological services such as water purification and water supply are considered the key to realizing other ecological services such as drinking water, recreation, and human health (Brauman *et al*., 2007; Keeler *et al*., 2012). Indeed, water is the most fundamental driver for ecological processes (Chapin *et al*., 2002) and is essential to all forms of life on Earth and human civilization (Gleick, 2003). It is critical to understand how human dominated ecosystems work in order to properly define and evaluate ecosystem services from both ecological and economical points of view (Boyd and Banzhaf, 2007). Wetlands are also important for human society (Mitsch and Gosselink, 2000; Ricaurte *et al*., 2014) as they provide a diverse range of ecosystem services (Ramsar Convention Secretariat, 2007). In particular, the provision of food, water and livelihood security to the people living in and around them is widely recognized (Schuyt, 2005; Rebelo, 2010 and Ricaurte *et al*., 2014). Their global economic values were calculated to be about USD 70 billion per year (Schuyt, 2004).

One of the factors that affect wetland ecosystem services is the household characteristics for environmental resource utilization. A lot of studies that have explored resource use behavior by households have asserted that the extent of resource utilization is largely affected and influenced by household asset endowments in the form of physical assets (land, equipment and tools) and non-physical assets (social, human, natural, and financial capital), demographic factors (age, size, and composition of the household) and geographic factors (location of household relative to natural resource) (Adhikari, 2002; Coomes *et al.* 2004; Solomon Mulugeta, 2004).

However, wetlands are under constant degradation in many countries (Mitsch, 2007; Wei, 2015) despite increased understanding of their values (Millennium Ecosystem Assessment, 2005). Global loss of wetlands has been estimated to be about 50% since 1900 (IUCN, 1992), resulting in significant impacts on ecosystem services, biodiversity and livelihoods of people (Ecosystem Change and Human Well-being, 2008). In Asia alone, about 5,000 square kilometers of wetlands are lost annually (Mcallister, 2001). Unfortunately, ecosystem services are under serious threats and rapidly diminishing as a whole in the anthropocene in many watersheds around the world (Falkenmark, 2003; Jackson *et al*., 2001). Increasing demands on ecosystem services such as clean water (Caldwell *et al*., 2012), fiber, bioenergy (Sun and Vose, 2016), and recreational use of wildlands stress natural ecosystems and contribute directly to the decline of watershed hydrological services (Brauman *et al*., 2007; Vorosmarty, 2002).

Information on individual wetlands and their exploitation at the local level is very limited (Gopal *et al*., 2008). Precise information about the values and drivers of changes is required for the conservation and sustainable use of wetlands (Balmford *et al*., 2011). Assessment of wetland ecosystems on a temporal scale and particularly at the local level helps with monitoring changes, providing vital information for natural resource planning and management (Prasad *et al*., 2002).

Perceived declining trends in the availability or supply of ecosystem services threaten the livelihoods of local communities (Bhatta *et al*., 2015). Further decline of ecosystem services could negatively impact the livelihoods of wetland dependent communities as they have limited alternative options for livelihood diversification. For conservation planning and management, there is a clear need for a more detailed understanding of the ecosystem services provided by wetlands, and of the threats they are exposed to (Millennium Ecosystem Assessment, 2005). An integrated and holistic management plan with alternative livelihood options could be effective in mitigating degradation of the wetlands while maintaining the supply of ecosystem services.

2.3. Ecohydrological approaches for wetland degradation and ecosystem services

In the face of increasing pressure on freshwater resources, there remains an urgent need for new practical tools to achieve their sustainable management. Such management must improve the coexistence of man and nature. Reversing the degradation of the water ecosystems requires solutions based on integrative problem solving science, such as ecological engineering and ecohydrology (Zalewski, 2010; 2011). Zalewski (1996) proposes solutions to solve complex environmental problems, such as sustainable use of freshwater resources, it is necessary to apply a new multidimensional approach. This can be achieved by optimizing the absorbing capacity of ecosystems against human impacts. Such an approach must be based on an understanding of the temporal and spatial patterns of water and biotic dynamics at the catchment scale.

Zalewski *et al*. (2010) states that ecohydrology is a new scientific approach to water management and conservation of aquatic systems that based on the integration of hydrologic and biological processes, seeks the understanding of ecosystem processes and functioning to increase the carrying capacity of ecosystems and their natural resilience to support anthropogenic impacts, as a basis for the development of ecological integrated low costs solutions to mitigate or restore degraded aquatic ecosystems. It has to be based on a multidimensional goal integrated in the following areas: water resources, biodiversity, ecosystem services, resilience (Zalewski, 2014), and cultural heritage. Throughout the world ecohydrology has lately been discovered as a scientific discipline. Several authors have stressed its importance to the progress of hydrology and ecology (Eagleson 2005; Grootjans *et al*., 1996; Nuttle, 2002; Rodriguez-Iturbe, 2000) but there appears to be a wide range of ideas on the topics ecohydrology is supposed to include.

Zalewski *et al*.(1997) define ecohydrology as the study of the functional interrelations between hydrology and biota at catchment scale and a new approach to achieve sustainable management of water. The ecohydrology concept suggests that this can be done by two types of actions: reduction of energy and material use per capita expressed by the UNEP concept of ecoefficiency or "factor four" (von Weizsacker *et al*,. 2014) and enhancing the absorbing capacity of ecosystems.

Ecohydrology as an interdisciplinary science aims at understanding the interactions between hydrology and ecosystems. It is clear that humans are one of the important components of human-dominated ecosystem in the twenty-first century (Zalewski, 2015). As a result, human activities have shaped almost all aspects of natural ecosystems and present increasing challenges to the integrity of ecosystems that people depend on.

The new paradigm proposed by ecohydrology expands the scope and perspectives of environmental management from protection and conservation towards active regulation of ecological processes especially in “novel ecosystems” (Hobbs *et al*., 2006) and “engineering harmony“ between society and ecosystems (Zalewski, 2005).

Ecohydrology is a new scientific approach to water management and conservation of aquatic systems that, based on the integration of hydrologic and biological processes, seeks the understanding of ecosystem processes and functioning to increase the carrying capacity of ecosystems and their natural resilience to support anthropogenic impacts, as a basis for the development of ecological integrated low costs solutions to mitigate or restore degraded aquatic ecosystems. Moreover, it represents a new approach to a sustainable management and provides an additional tool to manage the degradation of ecological and water processes in the landscape.

According to Wolanski *et al.* (2004) enhancement of carrying capacity of ecosystems will improve ecosystem services and enable the creation of a positive socioeconomic feedback between environmental quality and society.

Within the integrated water resource management (IWRM) concept, ecohydrology also aims at harmonizing society needs with enhanced ecosystem potential through increasing carrying capacity of ecosystems; it therefore expands the concept of balancing social economic needs by harmonization of the same with enhanced ecosystem potential. Ecohydrology also calls for maintaining notions of conservation for pristine ecosystems and expands efforts for regulation of ecohydrological processes at novel ecosystems (man modified) in order to increase their ecological potential in terms of water resources, biodiversity, ecosystem services and resilience to global change and anthropogenic stress (WBSR, for Water, Biodiversity, Services and Resilience). As such ecohydrology is compliant with the IWRM concept but also provides novel potent tools to achieve sustainability (Zalewski, 2015).

Recent studies have shown that, by regulating hydrological processes, the biological dynamics of systems (and consequently the quality of water resources) can be controlled and vice versa (e.g. Zalewski *et al.*, 1990, 1998; Mitsch, 1993; Jorgensen, 1996; Staskraba and Tundisi, 1999). According to Zalewski (2002), ecohydrological solutions will work towards reducing the stochastic variation of water dynamics and their consequences, Example, erosion and accelerated nutrient transfer across landscape gradients. This can be done by using biota-land cover, ecotones, in-stream processes, wetlands, and manipulation of nutrient allocations between trophic levels (bio-manipulation).

Land/water (riparian) ecotones play a dual role. One is the filtering of nutrients and pollutant transfer along catchment gradients with conversion into organic matter and the second is flood plain trapping of organic matter, nutrients and pollutants transported along a river continuum with in-stream/river channel processes such as acceleration of self-purification (Naiman and Decamps, 1990; Zalewski *et al*., 1998; Zalewski and Harper, 2001; Zalewski and Wagner, 1998). Reservoir/lake ecosystems are important foci where the sedimentation of minerals and the retention and conversion of transported nutrients and organic mineral matter can largely be controlled by the regulation of biota by hydrological processes (Zalewski *et al*., 1990; Staskraba and Tundisi, 1999).

Wetland ecohydrology is an effective scientific tool to address such concerns in this anthropogenic era, by measuring the response characteristics of wetlands to anthropogenic stress, and providing scientific strategies with practical value for carrying out wetland restoration and protection. Thus, wetland ecohydrology has attracted widespread attention (Zhou *et al.*, 2016).

Particular and isolated actions may provide solutions for water quality degradation. However, a synergetic harmonization of several ecohydrology solutions can provide more long term sustainable solutions and maximize the results of the top-down and bottom-up control approaches mentioned above (Chicharo *et al*., 2009).

The multi-dimensional goal of sustainability science proposed by Zalewski (2015) initially covered only four elements, i.e. water, biodiversity, ecosystem services for society and resilience to climate change and human impact. However, the implicit challenge of such an approach has been the steadily increasing demand for declining ecosystem services amplified by the decline of the biosphere potential, due to habitat degradation, emission of pollutants and even more importantly, a degradation of ecological cycles especially those of water, carbon, nitrogen and phosphorus. That is why the fundamental assumption of ecohydrology’s theory is that the enhancement of ecosystem potential of human modified ‘‘novel’’ ecosystems is an essential condition for sustainability of the planet (Zalewski, 2000, 2014).

Ecohydrology implementation and ecological engineering solutions

In the initial stage of the development of the concept, the need for the integration of existing fragmented knowledge on hydrological and biological processes at the basin scale into a holistic framework was underlined (Zalewski *et al.,* 1997). Technical water management in the 20th Century has been focused upon mitigation of hazards such as pollution, floods and droughts. Ecohydrological principles and system solutions formulated to address the following major issues especially at the ecohydrological demonstration sites such as pollutants and nutrients, intensive land use, water over abstraction, floods, invasive species, droughts, habitat loss and loss of retention capacity of vegetation. Successful strategies however, involve two directions of action, which are elimination of threats, while at the same time, amplification of opportunities.

Implementation of the ecohydrology approach for integrated water resource management (IWRM) encompasses activities related to the atmospheric/terrestrial and aquatic phases of the hydrological water cycle (Zalewski, 2009). In the terrestrial phase, diverse biota plays a role in moderating water quantity and quality (Rodriguez-Iturbe, 2000 and Eagelson, 2005). Here, land-use and management, especially control of vegetation cover, play an important role in shaping the water cycle (Ryszkowski, 2002). In the aquatic phase, biotic processes are strongly controlled by hydrology, which is a key factor in aquatic vegetation performance and related water quality outcomes. Example, Eutrophication leading to toxic cyanobacterial blooms (Zalewski, 1999; Traczynska *et al*., 2002). The important steps were also made through studying constructed wetlands (Mitsh and Gosselink, 2007). One of the key concepts which strengthen the application of ecohydrology is phytotechnology, described as application of science and engineering to examine problems and provide solutions involving plants (UNEP, 2003). Phytotechnology contributes not only to the water cycle regulation, but also to water quality improvement (phytoremediation), bioenergy production and others. Borre *et al*. (2001) states the institutions and institutional arrangements for addressing these issues and for implementation a watershed approach is just beginning to emerge on lakes around the world.

Ecohydrology engineering solutions

Ecohydrology is about engineering a harmony between environment and society, i.e. it is a problem-solving science. It proposes low-cost, nature-based solutions (Zalewski *et al*., 2010). Rapid progress in science and engineering has resulted in great improvements in productivity and global living standards.

Ecological engineering is defined as the design, restoration, or creation of ecosystems, with a strong emphasis on ecosystem self design and self organization. When using ecological engineering to restore a system, often less effort is needed, or desired, to begin ecosystem recovery due to the self-designing qualities of this approach. This method integrates the hydrological framework and ecological targets to improve water quality and ecosystem services, using engineering methods such as levees, biomanipulation, reforestation, and other management strategies. Moreover; ecological engineering incorporates contemporary environmental engineering practices with ecological principles to attain ecologically driven goals (Murdock, 2008).

Efforts to compensate for anthropogenic modifications of the water cycle, resulting from catchment cover modification, urbanization, agriculture, overexploitation and pollution, for example, have not been successful (Kundzewicz, 1999). Second, solutions applied in developed countries up to now, based on civil engineering methods, are unsustainable because of financial and energy constraints (e.g. Somlyody *et al,* 2001; Wagner *et al.,* 2002). Moreover, Ecohydrology should also be considered a development of the idea of ecological engineering (Mitsch, 1996), incorporating eco-technologies from the 1970s, such as constructed wetlands, bio-manipulation, and ecotone management. There are four groups of ecohydrology engineering solutions that were developed and used as ecohydrological methods, tools and measures implemented on the demonstration site. These are: ecohydrological infrastructure, faunatechnology, phytotechnology and hydrological flow. Among these, the ecological engineering solution is a part of ecohydrological infrastructure (Capobianco and Stive, 2000; Zalewski, 2015). They further explained that it is based on ecohydrology and ecological engineering methodologies (Example, management of wetlands for water purification from excessive nutrient loads based on ecological theory and mathematical modelling). This engineering solution includes four measures such as dual regulation, biotechnologies, self- design and ecosystem conservation: (the ecological engineer depends on species and ecosystems). It follows managing of biota to control hydrological processes and vice versa (ecological engineering) as ecohydrological implementation principle.

There has been a continuing debate about the appropriate application of the term ‘ecosystem engineer’, in part to avoid broad overgeneralizations (Jones *et al*., 1994; Power *et al*., 1996; Wright and Jones, 2006).

Various studies have advocated that spatial and temporal scales are important in assessing the true impacts of engineered landscapes on both biotic and abiotic processes (Berkenbusch and Rowden, 2003; Pringle, 2008; Wright, 2009). Typically, analyses of specific ecosystem engineers in aquatic systems have linked the influence of an engineer to the particular physical feature that it engineers

Moreover, Ecohydrology should also be considered a development of the idea of ecological engineering (Mitsch, 1996), incorporating eco-technologies from the 1970s, such as constructed wetlands, bio-manipulation, and ecotone management. All these, integrated for synergy based on the ecohydrological principles, may be referred to as "low cost and high technology" solutions for sustainable river management, to minimize threats for human health and biodiversity, to maximize water availability and ecosystem services for society.

2.4. Ecohydrology demonstration sites in the world

Ecohydrology is about engineering a harmony between environment and society and it is a problem solving science. It proposes low cost, nature-based solutions. It often starts with the creation of demonstration sites (Zalewski *et al*., 2010). The selection of the demonstration projects addresses a variety of water-related issues along a theoretical river continuum in a catchment and proposes ecohydrological solutions to these issues. They relate to landscape processes, water issues in cities, rivers, floodplains, wetlands, reservoirs and coastal areas.

Zalewski *et al*. (2009) states that each demonstration site aims to show an application of ecohydrology to deal with issues such as nutrients concentrations, water purification, diverse aquatic habitats like wetlands, marshes, mangroves, cyanobacterial blooms, among others, in order to find long-term solutions integrating social components. The demonstration sites integrate the concept of enhanced ecosystem potential with ecohydrological strategies to achieve sustainability of ecosystems closely related with water to improve integrated water resource management on specific areas. This is termed WBSR (w-water, b-biodiversity, s-ecosystem services, and r-resilience) containing the four elements that should be taken into consideration while trying to improve the ecosystems potential. Through the dissemination of this initiative, it is expected to contribute to the development of research and knowledge-sharing of ecohydrology.

Pilica River, Poland: Application of ecohydrology and phytotechnology for eutrophication control and sustainable development (Wagner *et al.*, 2009)

The project develops an ecohydrological approach to mitigate toxic algal blooms in a lowland reservoir recreational area and an additional drinking water supply for more than 1 000 000 inhabitants. Understanding the relationships between hydrological patterns of the reservoir's tributaries and nutrient transport is a basis for the cost efficient reduction of nutrient loads. Optimization of floodplain hydraulics maximizes nutrient retention by both physical sedimentation and conversion into biomass that can be used as bioenergy, providing alternative income for local communities.

Amazon River Floodplain, Brazil: Sustainable timber production and management of Central Amazonian white-water floodplains (Wittmann *et al.*, 2009)

The conservation of biodiversity and genetic resources of tropical forests remains one of the most important ecological challenges today. This project elaborates an innovative concept for economically efficient management of fast-growing plantations as an alternative for tropical forest overexploitation. Understanding the effects of flooding on tree growth will enhance plantation productivity.

Guadiana Estuary, Portugal: Sustainable estuarine zone management for control of eutrophication, toxic blooms, invasive species and conservation of biodiversity (Chicharo *et al.*, 2009)

Construction of the Alqueva Dam across the upper Guadiana River affected nutrient ratios and sediment loads transported to the estuary, resulting in eutrophication, toxic algal blooms, decreased biodiversity and marshland degradation. These processes can be mitigated by developing guidelines for optimizing pulse-patterns of water discharge from the reservoir. Maintenance of good water quality and biodiversity will positively influence fisheries and tourism development in the area.

Danube River, Lobau floodplain, Austria: Hydrological regime optimization to maintain biodiversity in the Lobau Biosphere Reserve and flood protection for Vienna (Barta *et al.*, 2009)

The goal is the optimization of the river's hydrological regime to maintain biodiversity. Potential conflicts are foreseen with the planned hydrological flood protection that may increase sedimentation and reduce biodiversity in the floodplain. Solutions include strengthening ecosystem services by providing alternative habitats for the abundant and diversified macrophyte vegetation.

Lake Naivasha, Kenya: Re-creation of artificial *Cyperus papyrus* wetlands surrounding the lake and at inflowing river delta using phytotechnological methods for restoration (Morrison and Harper, 2009)

The major stressors for the lake are increased sediment and nutrient inputs, biodiversity loss and habitat degradation. The mechanisms of loss of the important buffering capacity of the ecotone have been identified and ecohydrological solutions proposed utilizing this understanding. At basin scale, they include mitigation of further pollution by catchment reforestation, re-creation of a papyrus buffering zone around the lake's shoreline, and trapping nutrients and sediments from rivers using sequential wetlands during different discharge regimes and hydrographic stages.

Parana Floodplain, Brazil: Creation of a biosphere reserve to prevent decline in the unique subtropical river floodplain biodiversity (Agostinho *et al.*, 2009)

Creation of 26 large reservoirs in the basin altered the hydrological regime of the river, resulting in modified ecosystem structure and functioning and decreased biodiversity. Adjustment of operational procedures for water outflow from the Porto Primavera Dam to ecological cycles can restore these processes without significant hydroenergy production loss. Maintaining biodiversity and ecosystem services will create income for local populations (e.g. fisheries and tourism) and led to the creation of a biosphere reserve.

Mara River and Serengeti Plain, Kenya and Tanzania: Water deficit and inter-basin transfer of water resources for large mammals migrating to Serengeti (UNESCO World Heritage Site and MAB Biosphere Reserve) (Gereta *et al.*, 2009)

The Mara River Catchment is a dry weather refuge for more than one million migrating wildebeest *Connochaetes taurinus* (Burchell) and zebra of the Serengeti ecosystem. In Kenya, deforestation, water diversion and hydropower development have distressed the river's hydrological pattern, connectedness with the plain and biodiversity, and thus have impacted the economic base of communities. Reforestation, forest conservation and use of existing and new wetlands are proposed to restore the hydrological stability of the region.

Lacar Lake, Huahum River Basin, Patagonia, Argentina: Reduction of erosion in a catchment using ecohydrology and phytotechnology (Sarandon *et al.* 2009)

The project is designed to contribute to the mitigation of floods in urban areas of San Martin de los Andes and improvement of ecosystem services (water quality and the landscape aesthetic values). These can be achieved by regulation of surface hydrology in the catchment through vegetation cover management (phytotechnology), sedimentation and runoff control. Policies based on sound science will improve the management of land and water resources and reduce institutional and management conflicts.

City of Lodz, Poland: Urban ecohydrology as a basis for the sustainable city strategic planning

Advancement of the ecohydrology concept and experiences gained within the demonstration projects implementation, have also allowed for expansion of the concept application in heavily impacted urban systems. An excellent opportunity to create a new dimension - urban ecohydrology- and achieve substantial advancements in this fields have been provided by the European Project SWITCH - "Sustainable Water management Improves Tomorrow's Cities' Health" (EU PF6, GOCE 018530) and its implementation in the city of Lodz, Poland (Maksimovic, 2005; Zalewski, Wagner, 2005; Wagner *et al.,* 2008; Wagner, Zalewski, 2009).

2.5. Ecohydrology demonstration sites and approaches in Ethiopia

Rib catchment

Rib watershed is one area of ecohydrology demonstration site under UNESCO which is located in Lake Tana Sub Basin, northwest part of Ethiopia, in Amhara Regional State. Rib watershed has a total drainage area of 1790 km² and the main Rib River is about 129.7 km long, flowing towards the west until it reaches Lake Tana. The watershed demonstrates severe land degradation. The problem has been long aged and deep rooted, as the watershed is one of the aged agricultural areas. The long aged agricultural activities resulted in progressive depletion on resources through haphazard deforestation, overgrazing and over cultivation and hence sever soil erosion and land degradation (Yohannes Zerihun, 2016).

Lake Tana shore Ethiopia

The objective of ecohydrological methodology implementation is to reduce encroachment of agriculture to Lake Tana shore (Yohannes Zerihun, 2019 in press). This ecohydrological measure mainly focuses on maintaining nutrient cycle. Apparently, the business as usual agricultural practices exposes the lake to external inputs: agricultural nutrients, organic matters, minerals, sediments etc changing ecology of the lake and disrupting the healthy ecosystem processes ,creating favourable condition for invasive alien species like water hyacinth. Therefore, this recession farming has been replaced by systemic solution comprising: rehabilitation of papyrus, fish pond integrated with horticulture enhancment of wetland (between the fish pond and the papyrus), small irrigated vegetable farm.

Burkitu reservoir

Restoration of the Burkitu reservoir as an alternative source for water supply in Assela city, Ethiopia (Zalewski *et al*., 2012). The main cause of Burkitu's reservoir is water quality problems due to soil erosion, and thus siltation, resulting from deforestation, land overgrazing and overload of pollutants coming from livestock and Asella Water Treatment Plant. Regarding the high siltation and contamination of the Burkitu Reservoir by dioxins (Zalewski *et al.*, 2010) and nutrients, with higher concentrations in the inlet and smaller concentrations at the outlet of the reservoir, the construction of the sequential biofiltration system was proposed in order to mitigate the pollutants accumulation in the reservoir's ecosystem (Zalewski *et al.,* 2010). To solve the above problems, the reduction of organic and mineral matter input as well as contamination with pollutants in the upper part of the river catchment was needed. This was achieved by the implementation of the Asella Sequential Biofiltration System (Zalewski *et al.,* 2010)

Sequential sedimentation bio-filtration system for coffee waste water treatment in Jimma, Ethiopia

The recent ecohydrological intervention is sequential sedimentation bio-filtration systemic solution developed by Yohannes Zerihun (2019 in press) for coffee wastewater treatment in southwest Ethiopia. The results showed that the efficiency of SSBFS-solution was found to be slightly efficient for removal of TDS (48.96), TSS (49.6), TP (40.5), TN (51), ortho-P (25.69), NH_4^+N (43.75), NO_3^-N (80.28) percent's and pH neutralization from 4 to 5.7, for acidic CPWW. As a results of removal efficiency the SSBFS-solution CPWW treatment plant might be functional consideration as nature based treatment option.

3. MATERIALS AND METHODS

3.1. General description of Lake Tana area

Geographically, Lake Tana is located in the range of 10°58' -12°47 ' N and 36°45' - 38°14' E . It is a source of Blue Nile River and has a total of around 15,000km^2 drainage areas, of which the lake covers around 3,000km^2. The basin drains into the shallow freshwater Lake Tana (Ligdi *et al.*, 2010). The sub basin can be divided into four distinct physiographic units comprising: the lake water body (including the islands); lower catchments (shorelines and surrounding wetlands); middle catchments (flood plains and gentle hill slopes and upper catchments (low plateau plains, ridges and mountains) (Ligdi *et al*., 2010).

The lake is a shallow lake with average depth less than 9m and maximum depth about of 14 m. About 65% of the catchment is seasonally flooded extensive wetland. Land uses of the catchment area include natural landscape with vegetation, agricultural land (crop field and pasture land) and residential area. The catchment area of the lake has a dendritic type of drainage network.

The mean annual rainfall of the catchment area is about 1280 mm. The mean annual rainfall over the catchment is estimated to be 1326 mm with slightly more rain falling in the south and south-east than in the north of the catchment (SMEC, 2008).The annual mean actual evapotranspiration and water yield of the catchment area is estimated to be 773 mm and 392 mm, respectively (Shimelis Setegn, 2008). Average annual evaporation over the lake surface is approximately 1675 mm (SMEC, 2008). It is characterized by two rainfall seasons: a major rainy season, which extends from June to September and a minor rainfall season, which occurs in April and May. The climate of the region is “tropical highland monsoon”. The air temperature shows large diurnal but small seasonal changes with an annual average of 20°C. The Lake and its watershed is the country’s largest water body. With its large area of wetlands it has high biodiversity and many endemic species (Ligdi *et al*., 2010). Under natural conditions, discharge from the lake is closely linked to rainfall and there is considerable seasonal and inter-annual variability (Seifu Kebede *et al*., 2006)

Five major permanent rivers, Gelgel Abbay (Small Blue Nile), Gumara, Rib, Megech and Dirma, as well as more than 30 seasonal streams feed the lake, whereas the Blue Nile River is the only outflow from Lake Tana (Ayalew Wondie, 2006). According to Seifu Kebede *et al*. (2006) these four major rivers contribute 93% of the inflow and only 7% of the lake inflow is from ungauged catchments. A study during 1990/2000, reported that the average retention time of the lake water was 6.5 years (Tesfaye Wudneh, 1998).

The climate of Lake Tana is characterized by a main-rainy season with heavy rains during July-September, a dry season during December-April, and two minor rainy seasons during May-June (pre-rainy season) and October-November (post rainy season) (Tesfaye Wudneh, 1998). The complex pattern of water losses (Example, hydropower generation) and inputs (seasonal rains) can cause large daily and seasonal water level fluctuations. Sometimes during the dry season, water level decreases by up to 2m (Ayalew Wondie, 2006). Generally, the southern part of the Lake Tana basin is wetter than the western and the northern parts (Seifu Kebede *et al*., 2006).

The lake is much exposed to wind. Wind speed is generally low in the morning and high in the afternoon, which invariably causes mixing of the whole water column (Hakanson, 1981). About 55 % of the total land surface area of the Lake Tana watershed (~ 15.000 km^2) is under cultivation, 21.06 % is water area, 10.38 % is grassland, 1.6 % is wetland/swampy area and 0.39 % is natural forest (IFAD, 2007). Cultivated land and water bodies cover about 69% and 20% of the Lake Tana basin, respectively (Hanibal Lemma *et al*., 2017). Cereals dominate more than 70% of the rain fed crop production, whereas rice and other recession agriculture are practiced in the low lying flood plains. Lake Tana catchment is also characterized by severe land degradation driven by the combination of erosion rains, steep topography, deforestation and land mismanagement that leads to high sediment loads and wetland loss (Nyssen *et al*., 2004; Shimelis Setegn *et al*., 2009 and Nyssen *et al*.,2015).

Wetlands are also threatened from sedimentation as a result of upstream agriculture and deforestation (Ayalew Wondie, 2010). Deforestation and recession agriculture coupled with erosion from the catchments resulted in high sediment deposition (Shimelis Setegn *et al*., 2009). The northern and eastern shore of Lake Tana is occupied by large sediment, where most inflowing rivers originate and flood the lake during the rainy season (Gasse, 1987). Apart from drainage, wetland hydrology has been modified by the construction of channels, dams, and ditches to achieve irrigation, transportation, and industrial activity. The wetlands in Lake Tana area have been suffered by several threats such as free grazing, chat production, water abstraction, urbanization, encroachment, settlement, drainage for agriculture, and wetland distribution to landless youths. Wetland destruction and conversion for the purpose of recession agriculture is still seen as advanced mode of development (Ibrahim Mohammed and Minwyelet Mengist, 2018).

Overall, the major threats to wetlands in the Lake Tana Sub-basin attributed to anthropogenic activities such as recession agriculture, unplanned urbanization, rapid population growth, indiscriminate industrial and development activities, disposal of domestic and industrial toxic wastes and free grazing (Shewit Gebremedhin, 2017; Shewit Gebremedhin *et al*., 2018).

3.2. Sampling sites and sampling procedures

The study was conducted in November as a wet and April as a dry seasons of 2019–2020 at three sampling sites on the wetlands along the southeastern shore of Lake Tana. These sampling sites were specifically selected based on their disturbance extent by anthropogenic activities and to compare the general ecological status and socio-economic aspects among the study sites along the shore of the lake based on the reconnaissance field survey. Additionally, sites were selected based on their intervention extent, impact, accessibility, and availability. The quantitative and qualitative studies were carried out in all sampling sites. Sampling points (stations) were selected according to vegetation gradient. Sampling sites were designated and abbreviated as Gt, Gm, Ak for Gumetirs, Gedromesk and Agid kirgna wetlands, respectively (Figure 1). Both Gedromesk and Agid kirgna wetlands were selected as reference sites to compare the biological, physical and chemical and the socio-economic aspects with the intervened site at Gumetirs wetland at the lake shore. Overall, the sampling procedure employed using quadrats along transects to quantify physiochemical and biological parameters.

Each transect was following the main ecological gradient of water depth and vegetation structure and growth form which starting from the lakeshore and ending at the open water. The number of transects and quadrats were mostly followed methods for evaluating wetland condition in the United States Environmental Protection Agency (USEPA, 2002).

Transects with quadrats were laid following systematic sampling techniques. Transects were laid from the shore to open water at two segments of the wetland. Quadrats were employed for each transect at fixed distances. The baseline of the wetland was estimated to be 120 m, with a maximal width of 100 m. At each quadrat macrophytes, macroinvertebrates, sediment, and water samples were collected and analyzed. Collected samples of each quadrat from the sampling site were pooled to represent each sampling site. Zooplankton and phytoplankton samples were also collected from shore area at fixed stations. Identification and enumeration of samples were carried out in Addis Ababa University Zoology laboratory and Horticoop Ethiopia private limited company for soil and water analysis.

Gumetirs

This wetland is located about 5km away from Bahir Dar city at Zenzelima Kebele in the southeast direction which is above the outlet of Abbay River (Blue Nile River). Geographically, it is located at 037°24'41.6" E and 11°37'33.4" N with an altitude of 1790 m. a. s. l. It has an area of less than 5 hectares. This wetland is surrounded by cultivated crops and local residents. It is mainly dominated by *Echinochola* and *Cyprus papyrus* plant species.

Lake Tana has earlier been identified and selected by UNESCO as a representative area to investigate the ecohydrological issues in Ethiopia’s Nile basin. Lake Tana demonstration site which is established under UNESCO has focused on finding solutions to water quality, biodiversity, ecosystem services degradation and resilience (WBSR) issues in Lake Tana, particularly those affected by anthropogenic activities in the lakeshore area. Gumetirs site was established as one of the ecohydrology demonstration site in 2010 by UNESCO African regional ecohydrology center in Lake Tana shore area.

The ecohydrological system solution demonstration site comprising the integrated activities includes implementation of ecohydrology at the buffer zone of the lake for reducing point and non- point sources of pollution, recovery of degraded ecosystems and soils and optimization of fish-based aquaculture in the Lake Tana shore zone as ecohydrological measures (system solutions).

Gedromesk

It is located adjacent to Gumetirs study site. This site is mainly surrounded by farmlands and cultivated crops. It is located at $37^0$25'24.04" E and $11^0$38'47.7" N. This wetland is used for grazing and farming land purposes mainly during the dry season. It is mainly covered by *Echinochola* grass species.

Agid kirgna

This wetland is surrounded by extended farmlands. It is located in the northeastern direction of Lake Tana at the way of Bahirdar to Gonder road in Libo Kemkem district. It is geographically located at $37^0$37'17.1" E and $12^0$06'5.7" N. It is situated between Rib and Arno Garno rivers. This lakeshore is completely covered by water hyacinth. This site is characterized by impacts from agriculture and overgrazing pressure.

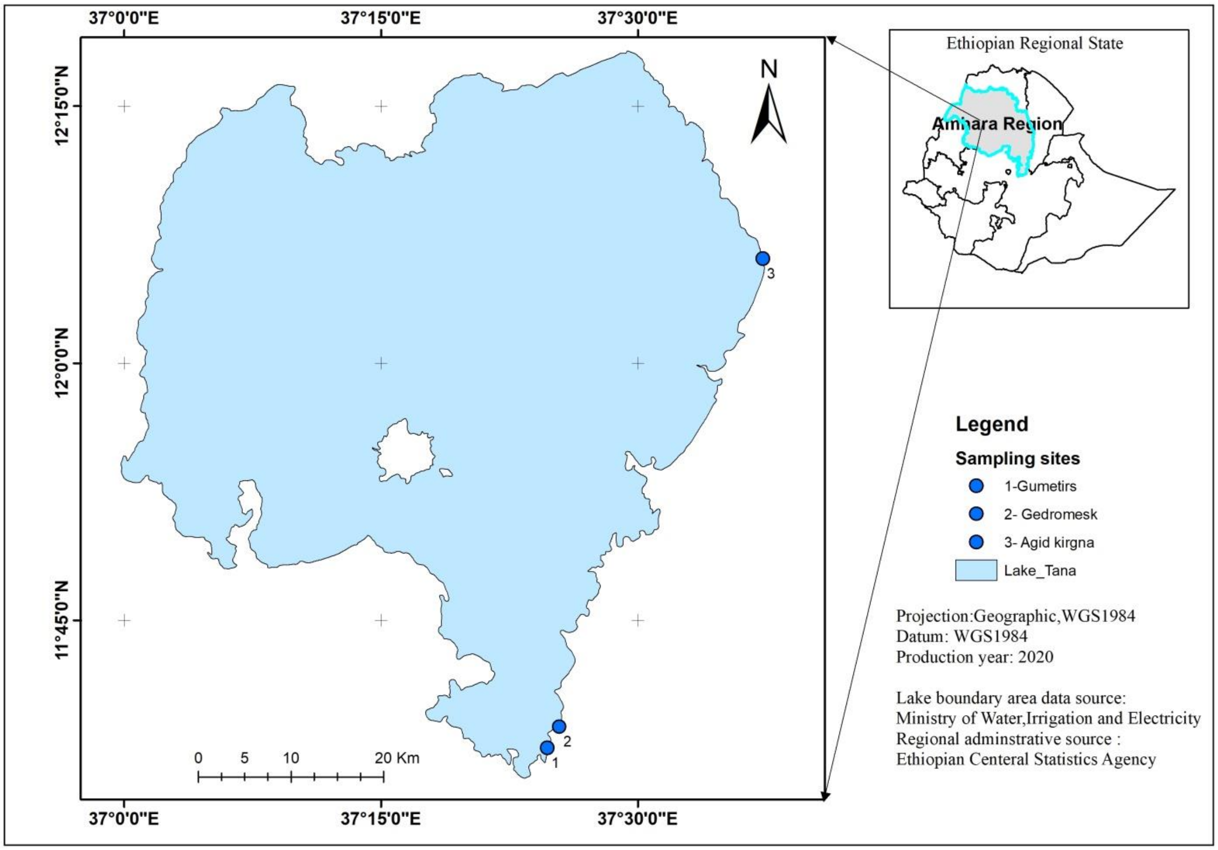


Figure 1: Map of the study area showing sampling sites

Sampling design and data collection

Quantitative and qualitative methods were carried out to collect parameters of biological, physico-chemical and socio-economic aspects in all sampling sites of the wetland along the shore of Lake Tana during the study period. Three sampling sites, namely Gumetirs (Gt), Gedromesk (Gm) and Agid kirgna (Ak**)** were purposively selected on the wetlands along the shore of Lake Tana. Generally, to collect and analyze biological and physico-chemical data, a belt transect with quadrats method was employed as recommended by IEP (2009). Two 100 m transects were laid from the shore towards the open water of the lake following Burlakoti and Karmacharya (2004). Transects were laid based on the vegetation gradients of the wetland. Four quadrats at every 25m distance (Gaudet and Muthuri, 1981) were laid at each transect. A total of 24 quadrats of 1m x1m size were taken following the suggestion of Sutherland (1996) in all sampling sites. Alternatively, the number of quadrats was determined by the species-area curve method as mentioned by Cain (1938). The species-area curve method ascertained by graphing the cumulative number of species recorded as a function of the number of quadrats examined. Samples were collected and analyzed for two consecutive seasons in the wet and dry season in November and April in order to accommodate seasonal differences during the study period of September 2019 to May 2020.

3.3. Physico-chemical parameters

Physico-chemical parameters of water and sediment were carried out at each sampling point and analyzed by using water and soil examination standards for all sampling sites. For water and sediment samples, a composite integrated sample technique was employed for each collected sample. Sediment samples were collected by using soil corer from 20cm depth soil layer. The sediment samples collected from each sampling point were mixed properly, air-dried and passed through a 2mm mesh sieve to remove large particles. Total nitrogen (TN), total phosphorus (TP), organic carbon (OC), and available phosphorus (AP) were analyzed in sediment samples using ES ISO 11261:2015 (Kjeldahl), Strong acid digestion, Walkely and Black and ES ISO 11263: 2015 (Olsens) methods, respectively.

Parameters such as water temperature (T^{o}), dissolved oxygen (DO), total dissolved solids (TDS), PH, and electric conductivity (EC) were measured onsite using YSI model 556 multi-probe system.

One litter composite water sample was collected approximately 10cm depth from each study site to analyze nutrients. Nutrients such as ammonium-nitrogen (NH_4^+-N), nitrate –nitrogen (NO_3^--N), and bicarbonate (HCO_3^-) were analyzed in water samples using ES ISO 7150-1:2005, ES ISO 7890-3:2001, and ISO 9963-2 methods respectively in the laboratory. The physico-chemical parameters were measured and taken between 9.30 am and 12.30 am to adjust variation in light and temperature. Transparency of the water was measured by lowering a 20cm diameter circular Secchi disc into the water column. Physiochemical parameters were compared with the standard desirable limit of that parameter in the lake as prescribed by different agencies such as Ethiopia fresh water physico-chemical condition, USEPA and WHO.

3.4. Macrophyte sampling

Macrophytes were collected manually across the three sampling sites for two sampling seasons. Macrophyte samples were pressed and transported to the National Herbarium at Addis Ababa University for further identification at the genus and species level using Ethiopian flora and previous collected samples in the National Herbarium.

Quantitative sampling was carried out based on the standard method as described by Curtis (1959), Misra (1968), and EPA (2002). Quantitative characteristics of macrophytes comprised relative frequency, density, abundance and importance value index (IVI). Macrophytes were collected manually using a belt transect method. In order to collect macrophyte samples in the lakeshore, two transects with 100m length were laid from the shore towards the open water direction. Four quadrats were placed at each transect with 25m distance interval. A total of 24 quadrats were employed for all sampling sites. The distance between quadrats was determined by adding all transects length and divided by the number of quadrats sampled. All the species occurred in each quadrat was noted and their numerical count was carried out.

3.5. Macroinvertebrate sampling

Quantitative sampling was conducted based on the standard operating procedures protocols for sampling aquatic macroinvertebrates in freshwater wetlands (Difranco, 2006). Moreover, standard operating procedures for benthic macroinvertebrate sampling and processing were adopted (USEPA, 2002). Macroinvertebrate samples were taken from areas of emergent vegetation zones in the water-column along each transect and quadrat using a standard D-frame dip net with 500 micrometers mesh size. Samples were collected from each quadrat by submerging the net and sweeping through the water for a distance of one meter. The net was pumped against the bottom substrate three times to dislodge and collect organisms from the bottom of the vegetation and water column. Sweeping was done in a vigorous action for about 5minutes at each site to dislodge macroinvertebrates attached to any substrates present (Baldwin *et al*., 2005). All samples collected in the field were sieved and put into collection bottles. Samples collected from each quadrat were pooled in order to obtain a single sample from each sample site. Samples were sorted and preserved using 70% ethanol for further laboratory analysis and counting. Samples were counted and identified at the family level using guides to the freshwater invertebrates of Southern Africa.

3.6. Phytoplankton and zooplankton sampling

Quantitative sampling was carried out in the wet and dry seasons in November 2019 and April 2020. The samples of planktons were collected with a 15 micrometer mesh size plankton net. Both zooplankton and phytoplankton samples were collected by deeping the plankton net approximately 5cm below the water surface. Within each sampling site two stations were fixed in the shore area based on vegetation zones. 100ml concentrated sample was collected and transferred into each sampling bottle which are labeled for each plankton species. Soon after sampling and transferring, zooplankton and phytoplankton samples were preserved with 4% formalin and 5%lugols iodine solution respectively for further laboratory analysis and counting. In the laboratory, the samples were subsampled to 20ml after thorough homogenization. In order to estimate and calculate the abundance or density of each taxon, 1ml of the sample was poured into a griddle slide by using a pipette to observe and count under a microscope by adjusting appropriate magnification power. Specimens were arranged (sorted) into species and counted under a microscope (40x) which were helpful to enumerate taxa by using gridded glass counting chambers. Counting procedure was carried out by following the transect counting method. Species found in 80 grids were counted up out of 1000 grids. Identification of planktons was carried out using the freshwater manual key of plankton species up to family and species level.

The abundance of phytoplankton and zooplankton population was estimated as individual m^3 following Edmondson and Winberg (1971).

$$V = \pi r^2 h$$

Where, V is the volume of the water filtered,

r is the radius of the net, and

h is the length of the course of the net through the water

The total number counted (N) in the subsample was multiplied by the sub sample factor (SSF) and divided by the total volume (V) of water strained, (N×SSF)/V, to determine the density in numbers per cubic meter (m^3). Sub sample factor (SSF) was computed by dividing the volume of the total sample by the sub sample. Based on this, the number of organisms per m^3 of the sampling site was computed and the number of each type of plankton species of the wetland was described as number per m^3.

Numerical density was computed as individual per liter, following Tesfaye Wudneh (1998) and Wetzel and Likens (2000). Numerical density was computed as an individuals per liter and all calculations were averages of 3 replicates taken at each station.

$$Nw = Na * 1000/V$$

Where:

Nw= number of organisms of each species per liter of lake water.

Na= number of organisms in a concentrated (filtered) sample

V=volume of water filtered in ml. and

The density of concentrated sample was calculated as:

$$Na = Nc/Ng * NG$$

Where: Nc= Number of organisms in grids counted

Ng = Number of grids counted

NG= Number of grids in the counting chamber

3.7. Socio-economic sampling design and data collection

Questionnaire design and survey method

The household survey questionnaire was designed to measure: (I) the benefits obtained from the wetlands, and (II) perception of the local community about wetland benefits and ecohydrological intervention impacts on their livelihood opportunities on the wetland. The questionnaire contain several questions including socio-economic benefits and perception aspects.

The household survey developed to provide information on a range of socio-economic aspects, generated quantitative and qualitative information on patterns of individual and household use of the wetlands and to assess community perception of ecohydrological intervention impacts on livelihood opportunities. The interviews were conducted in the area of wetland with determined groups of communities that are benefiting or affecting the ecosystem services. The interview was mainly focused on each household socio-economic characteristic and their understanding of the importance of each wetland benefits and their attitude toward the wetland's degradation, the number of people depend on the wetland, trends of benefits, the overall concern of local people regarding wetland bio-diversity, sustainable use of wetland resources and protection status and management strategies of the wetlands.

Perceptions of the local community about ecohydrological intervention activity impacts were assessed. Each question has different possible options to choose. The questionnaire was developed, based on the researches made previously and based on Cochran (1977). More than 30 questions with different options were presented. The questionnaire was structured in six sections; the first captured demographic and socio-economic characteristics of the household heads; and then their sources of livelihood, knowledge of the wetland, status and perception of the wetland with reference to sustainable use and conservation monitoring, socio-economic benefits of the wetlands and the major direct drivers of the changes in the wetland. Questionnaires were translated into the local language and some rearrangements were slightly performed prior to use.

Data collection and sampling method

For this study, both qualitative and quantitative approach were used to quantify the socio-economic aspects and assess local people perception about the impacts of ecohydrological intervention activity on the livelihood opportunities along the shore of Lake Tana. The primary data were collected through a household survey by using structured questionnaire, interview and observation. The interviewer sometimes tried to use an indirect approach to address some of the wetland ecosystem benefits and intervention activities to generate qualitative and quantitative data from the respondents. Data were collected on a number of variables including household characteristics, sources of livelihood for the local community, major benefits of the household in the wetland, wetland contribution to the local economy, and drivers of the change in the wetland.

The survey was undertaken systematically by selecting groups of households living around the lakeshore. Households were selected based on proximity and distance to the lakeshore. The study sites (*kebeles*) were purposively selected since they are located in the southeastern shore of Lake Tana and have a different degree of human disturbance and benefits at each wetland. A total of 90 respondents were involved in the survey which accounted for 30 respondents from each sampling site (kebele). Cross-sectional interviews of households head (HHDs) and key informants were conducted in November 2019 using clustered sampling in the community living within a 3-km radius of each wetland (Turyahabwe *et al*., 2013; Abebe Tariku *et al*., 2014). This method was used due to the heterogeneity of the communities in terms of their levels of benefits from and impacts on the wetlands in relation to their location.

3.8. Data analysis

For all data analyses, SPSS version 20.0 was used. Differences in spatial and temporal variations of physico-chemical variables, macrophytes, macroinvertebrates, and phytoplankton and zooplankton were tested and compared using analysis of variance (ANOVA) in each sampling site. Since the counts were not normally distributed, they were log-transformed. Each parameter was analyzed for differences among sites and between seasons. Kruskal-Wallis test was performed to evaluate the significant differences in physico-chemical data. Mann Whitney U-test was also used to analyze seasonal differences.

In order to quantify the diversity of macrophytes, macroinvertebrate, phytoplankton and zooplankton, the Shannon-Weiner diversity index following Shannon and Weiner (1963) (H') that incorporates richness and evenness was computed. H' was calculated as follows:

$$H' = -\sum_{i=1}^{s} pi \times \ln pi \qquad J' = H'/Hmax \qquad (1)$$

Where:

H' = index of species diversity, pi = the proportion of the i^{th} species, ln = the natural logarithm of pi, S = the number of species, Σ = sum from species 1 to species S and J' = evenness; Hmax = the maximum diversity of a sample. The index values range between 0 and 5, where higher index values demonstrate higher diversity, while low index values are considered to indicate lower diversity or sometimes indicate pollution. Species diversity index can be used in order to show relative differences from one sampling site to other sites with the same aquatic system or at the same site over the time period (Kratzer and Batzer, 2007).

The importance value index (IVI) was also employed for macrophytes data. It is an important parameter that reveals the ecological significance of species in a given ecosystem (Lamprecht,1989). Species with high IVI 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 *et al*., 2002). Species with high IVI value need less priority for conservation effort while those with low IVI value need high conservation effort. It provides the overall picture of density, frequency and cover of a species in relation to the community.

Spearman bivariate correlation analysis was also used for relating the structure of macroinvertebrate families as a whole with physico-chemical variables. Moreover, the Hilsenhoff Family-level Biotic Index (HFBI) was calculated for macroinvertebrate families by multiplying the number of individuals of each family by an assigned tolerance value for that family. Assigned tolerance values range from 0 to 10 for families and increase as water quality decreases (Hilsenhoff, 1988; Bode *et al*., 2002). This index was calculated as follows:

$$HFBI = \Sigma\, (TVi)\, (ni) / (N), \qquad (2)$$

Where: TVi is a tolerance value for family i, ni is the number of individuals in family i and N is the total number of individuals in the sample collection. High HFBI community values are an indication of organic pollution, whereas low values indicate good water quality.

Similarly, SPSS version 20.0 software was also employed to analyze the socio-economic data collected through structured questionnaires. The data were analyzed using descriptive statistics (mean, percentage, and frequency distribution) and chi-square test .

4. RESULTS

4.1. Physico-chemical parameters

The spatial and seasonal variations of physico-chemical water quality parameters and sediment nutrients studied are summarized in table 1. There were some variations observed in the mean values of physico-chemical parameters such as pH, EC, and DO, TDS, temperature and Secchi depth in water and sediment samples among sampling sites.

The average value of dissolved oxygen (DO) ranged from 5.71mg/l to 6.87 mg/l with the highest value recorded at the Gumetirs (Gt) site and the lowest value at the Agid kirgna (Ak) site. The mean value of dissolved oxygen showed a significant difference across sampling sites and between seasons ($p < 0.05$). On the other hand, the highest value of pH was measured in Gedromesk sampling site with a mean value of 7.12 while the lowest was recorded in Agid kirgna site (6.85). There was no significant variation in the pH range among sampling sites ($p>0.05$). The mean value of water temperature ranged from 18.5^0C at Ak site to 22.5^0C at Gedromesk site. The highest and lowest value was measured at Gedromesk and Agid kirgna sites, respectively. However, there was no significant difference in temperature among sampling sites ($p>0.05$).

The electric conductivity (EC) of Gumetirs, Gedromesk and Agid kirgna was 0.14mS/cm, 0.18mS/cm and 0.38mS/cm, respectively. There was a significant difference in electric conductivity across different sampling sites ($p < 0.05$), the value at Ak site being significantly higher than at Gt and Gm sites. The mean Secchi depth (transparency) ranged from 0.22 - 0.32m, with the highest and lowest values measured at Gt and Ak sites, respectively. Statistical difference in Secchi depth measurement was observed among sampling sites ($p<0.05$). The mean value of total dissolved solids (TDS) along the study sites ranged from 153.0 -383.6 mg/l. The highest value was recorded at Ak and the lowest at Gt site.

Total dissolved solid value at Ak was significantly higher than the values at Gt and Gm sites ($p<0.05$).

The mean values of nutrients in sediment samples ranged from 1040.36 -2704.85mg/Kg for TP with the highest attained at Gm and lowest at Gt, 0.15-0.98% for TN with the highest in Gt and the lowest in Ak, 2.61-11.83% for organic carbon (OC) with higher value at Gt and lower value at Ak sites. There was a significant variation in TN and OC among different sampling sites ($p<0.05$) but significant difference not observed in TP concentration ($p>0.05$).

Similarly, the highest and lowest values of available phosphorus (AP) were recorded at Gm (27.05±1.53ppm) and Gt (11.01±1.57ppm) sites, respectively. Available phosphorus did not differ significantly among sampling sites ($p>0.05$).

The values of nutrients in water ranged between 0.30-0.64, 3.99-4.61 and 138.64-251.86mg/l for NH_4^+-N, NO_3^- -N and HCO_3^-, respectively. Both ammonium and bicarbonate ions were the highest concentration at Agid kirgna site. However, the highest concentration of Nitrate (NO_3^--N) was recorded at Gedromesk site with a value of 4.61mg/l. There was no statistically significant difference in the concentration of $NH4^+$-N and NO_3^--N but a significant difference was observed in HCO_3^- concentration among sampling sites($P<0.05$).

During the dry season, TP concentration was highest at the shore and open water at Ak site (1334.28 mg kg^{-1} and1317.05 mg kg^{-1}) followed by Gm site (1124.30 mg kg^{-1} and 1300.2 mg kg^{-1}) but least at Gt site (680.71 mg $kg^{-1}$and 1269 mg kg^{-1}), respectively. However, on average, a higher concentration of TP was recorded at Gm site in both shore and open (2704.85±912.53 and 1210.05±97.09) followed by Ak site (1849.84±297.66 and 1325.66±101.32), respectively across sites. However, during the wet season, the highest concentration of TP was measured at Gm site in both shore and open water areas followed by Ak site. On average, more TP was recorded in the wet (2683.33±848.0) than dry season (1046.43±192.77).

There was more available phosphorus (AP) concentration at Gm site in both shore and open areas even though higher value recorded in open water followed by Ak site. On average of the three sites, higher concentration of available phosphorus was recorded at Gm site followed by Ak site.

Similarly, there was a similar trend during the dry season in the concentration of nitrate in the water samples with the highest value at Ak and lowest at Gm sites in both shore and open water. There was a higher concentration measured during the wet season (6.15±0.64) as compared to dry season (2.36±0.80). However, on average across sites, there was higher concentration of nitrate (NO_3^-) was recorded at Gm site (4.61±0.66) and the least at Gt site (3.99±2.25).

The total dissolved solids (TDSs) also slightly increase during the dry season than the wet season along the three sites but still the highest value recorded at Ak site in both seasons.

On the other hand, the mean values of dissolved oxygen, pH, temperature, electric conductivity, secchi depth, TDSs, TN, HCO_3^- , organic carbon(OC), and available phosphorus in the wet and dry seasons were not significantly different across sampling sites ($p>0.05$). However, there was a significant difference in concentration of nitrate (NO_3^- -N), total phosphorus(TP) and ammonium ion

($NH4^+$-N) in the wet and dry seasons across sampling sites($p<0.05$). Overall, all water and sediment nutrient measured mean values were decreased from shore to open water areas along the sampling sites except Secchi depth and available phosphorus.

Table 1: Physico-chemical characteristics of the water quality of wetlands along the southeastern shore of Lake Tana at three sampling sites in November 2019 and April 2020 (Mean ± S.E) (N=24)

		Sampling sites			**Season**	
Parameters	Unit	**Gt**	**Gm**	**Ak**	**Wet**	**Dry**
DO	mg/l	6.87 ±0.02	5.81 ±0.02	5.71 ±0.79	6.16 ±0.78	5.81 ±0.14
pH	range	7.05 ±0.00	7.12 ±0.06	6.85 ±0.05	7.00 ±0.02	7.01 ±0.10
Temp.	$^{\circ}C$	22.18 ±0.09	22.50 ±0.28	18.50 ±0.92	20.50 ±1.10	21.96 ±0.53
EC	mS/cm	0.14 ±0.01	0.18 ±0.01	0.38 ±0.06	0.19 ±0.03	0.28 ±0.07
Sec. depth	m	0.32 ±0.01	0.25 ±0.01	0.22 ±0.01	0.28 ±0.03	0.26 ±0.02
TDS	mg/l	153.0 ±1.15	159.1 ±2.83	383.6 ±62.93	196.53 ±27.73	267.26 ±79.67
TP	mg/kg	1040.36±207.64	2704.85±912.53	1849.84±297.66	2683.33±848.0	1046.43±192.77
TN	%	0.98±0.01	0.48±0.07	0.15±0.05	0.53±0.17	0.54±0.18
NH_4^+-N	mg/l	0.46±0.07	0.30±0.05	0.64±0.29	0.23±0.04	0.71±0.16
NO_3^- -N	mg/l	3.99±2.25	4.61±0.66	4.16±0.38	6.15±0.64	2.36±0.80
HCO_3^-	mg/l	138.64±11.19	207.55±13.44	251.86±18.75	189.82±25.06	208.88±27.21
OC	%	11.83±1.64	5.98±0.98	2.61±1.01	5.87±1.10	7.74±2.82
AP(sed.)	ppm	11.01±1.57	27.05±1.53	16.58±4.01	15.87±4.90	20.55±2.42

(**Abbreviations**: DO-dissolved oxygen; Temp.-Temperature; EC-Electric conductivity; TDS- Total dissolved solids; TP-Total phosphorus; TN-Total nitrogen; OC-Organic carbon; AP(sed.)-Available phosphorus in sediment, and Gt-Gumetirs; Gt-Gedromesk; Ak-Agid kirgna

4.2. Macrophytes diversity, relative abundance, density, frequency and important value index

Generally, a total of 12 different macrophyte species were identified from the three sampling sites (Table 2). Out of 12 macrophytes, 8 species were identified from Gumetirs site and 7 species from Gedromesk site but only one species was identified from Agid kirgna wetland.

Diversity of macrophytes

The diversity of macrophytes in Gumetirs (Gt), Gedromesk (Gm) and Agid kirgna(Ak) wetlands are given in figure 3. The Shannon diversity index was 1.24 for Gumetirs, 1 for Gedromesk and 0 for

Agid kirgna wetland. The evenness value was 0.67 for Gumetirs, 0.62 for Gedromesk and 0 for Agid kirgna wetland. The site which has a larger number of species (Gumetirs, 8 species) has a greater diversity index and evenness value than the site with lower number of species (Gedromesk, 7) and (Agid kirgna, 1) species.

The seasonal macrophyte species diversity also showed certain variations. A total of ten species were identified in the wet season but eight species in the dry season. However, during the dry season there were higher diversity index and evenness value compared to the wet season.

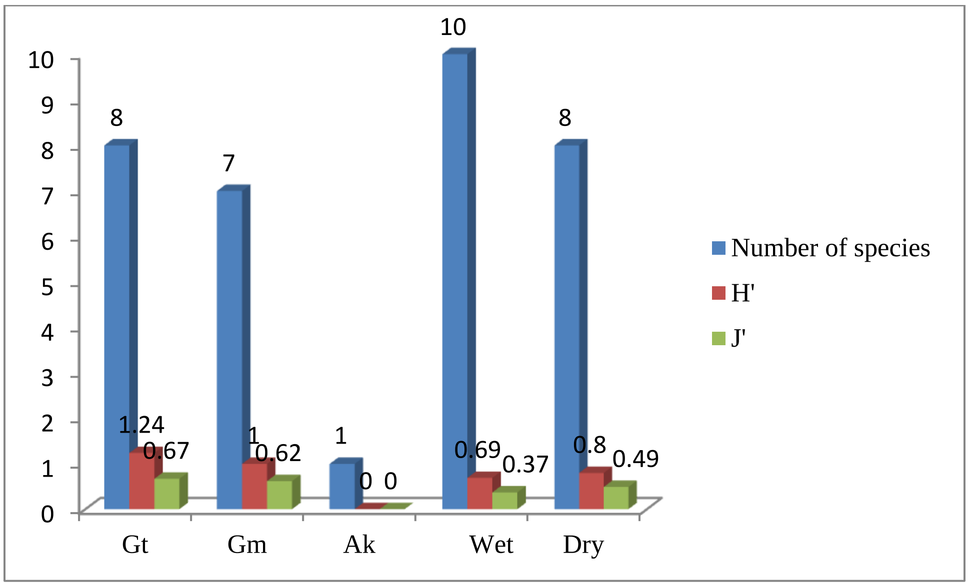


Figure 2: Shannon -Weiner diversity index (H') and evenness value (J') of macrophytes at three sampling sites along the shore of Lake Tana

Relative abundance

The result shows that both Gumetirs and Gedromesk sites were dominated by *Echinochola* species that attained the highest relative abundance of 36.1% and 37%, respectively. Similarly, *Cyprus papyrus* species was dominant following by *Echinochola* species which accounted for 32.7% and 20.1%, respectively. On the other hand, *Eichhornia crassipes* (Water hyacinth) was the prominent macrophytes species only found in the Agid kirgna site which accounted for 100% coverage of abundance. The remaining species accounted for less than 13.6% of relative abundance across sampling sites. The mean relative abundance of sampling sites was ranging from 1.8 to 100.

Moreover, twelve macrophytes were recorded in the wet season as compared to dry season which were eight species from the three sampling sites. Comparatively, more macrophytes species were recorded in the wet season than dry season. On average, *Eichhornia crassipes* (33%), *Echinochloa* species (25.3%), *Cyprus papyrus* (19.9%) of and *Ipomoea aquatica* (4.3%) were the major macrophytes found in the wet season at the three sampling sites. On the other hand, on average, *Eichhorina crassipes* (33%), *Echinochola* species (24.0%), *Cyprus papyrus* (15.4%) of and *Polygonum* species (6.8%) were the four dominant species in the dry season at the three wetlands.

Based on the result determined by one-way ANOVA, there was a significant difference in relative abundance across the sites ($p<0.05$) but no significant difference was observed between seasons ($P>0.05$).

Relative Frequency

The result revealed that the highest frequency occurrence of macrophytes in Gumetirs and Gedromesk was recorded by *Echinochola* (35.0% and 37.5%), *Cyprus papyrus* (23.4% and 12.5%) and *Ipomoea aquatica* (11.7% and 18.7%), respectively. However, in Agid kirgna wetland *Eichhornia crassipes had* a 100% frequency of occurrence. The remaining species accounted for less than 15% frequency of occurrence.

The seasonal difference in the number of species frequency of occurrence, there were ten species were identified during the wet season in all sampling sites. Among the list of macrophytes, *Echinochloa sp.*(21.6%), *Cyprus papyrus* (10.2%), *Eichhornia crassipes* (33.3%) and *Ipomoea aquatic* (11.4%) were the dominant species occurred in wet season. Similarly, in the dry season the highest frequency of occurrence was recorded by *Echinochola sp.* (26.8%), *Cyprus papyrus* (13.7%), *Eichhornia crassipes* (33.3%) and *Scirpus pallidus* (8.3%) followed by *Ipomoea aquatica* (8.9%). The remaining species accounted for less than 4.8% frequency of occurrence.

However, there was a significant difference in the relative frequency of occurrence among the sites ($p<0.05$) and but there was no statistically significant difference in sampling seasons ($P>0.05$).

Relative density

The maximum value of relative density was recorded by *Echinochola sp.* with values ranging from 51.7% to 58.3% in Gumetirs and Gedromesk sites (Table 2). The second highest density was recorded by *Cyprus papyrus* with values ranging from 10.3% to 31.9% plants m^2 in Gedromesk and Gumetirs wetland, respectively. On the other side, the maximum relative density was recorded by *Eichhornia crassipes* with values 100% in Agid kirgna wetland.

The result indicated that *Cyprus papyrus* (15.6% and 12.6%), *Echinochloa* species (37.9% 35.4%) and *Eichhornia crassipes* (33.3%) attained the highest density values in both wet and dry season respectively. Comparatively, more macrophytes species were recorded in the wet season than the dry season. The remaining species accounted for less than a 5% relative density in both seasons. Based on the result determined by one-way ANOVA, there was a significant difference in relative density across the sites ($p<0.05$) but no significant difference was observed between seasons ($P>0.05$).

Relative importance value index (IVI)

The value of important value index (IVI) ranged from 8.4% to 300 but *Eichhornia crassipes* was the peak important value index recorded in Agid kirgna wetland which accounted for among the three sampling sites. Macrophytes species such as *Echinochloa* species (121.8), *Cyprus papyrus* (89.4) and *Polygonum*(32.0) were the major ecologically important species in Gumetirs out of 300. The remaining species accounted for less than 16 (Table 2). Likewise, *Echinochloa* species (133.6), *Cyprus papyrus* (42.9) and *Ipomoea aquatica* (34.4) were the dominant species in the important value index (IVI) value in Gedromesk site.

Based on the result determined by one-way ANOVA, there was a significant difference in importance value index across the sites ($p< 0.05$).

Table 2: Macrophytes relative abundance, frequency, density and importance value index at three sampling sites along the shore of Lake Tana in November 2019 and April 2020

Macrophytes	Relative abundance			Relative Frequency			Relative density			Importance value index		
	Gt	Gm	Ak	Gt	Gm	Ak	Gt	Gm	Ak	Gt	Gm	Ak
Cyprus papyrus	32.7	20.1	-	23.4	12.5	-	33	21.1	-	89.1	53.7	-
Echinochloa sp.	36.1	37.8	-	35.1	37.1	-	51.7	58.3	-	122.9	133.2	-
Eichhornia crassipes	-	-	100	-	-	100	-	-	100	-	-	300
Hydrocotyle sp.	2.6	-	-	4.5	-	-	1.3	-	-	8.4	-	-
Hydrophila sp.	7.6	-	-	4.6	-	-	3.7	-	-	16	-	-
Hydrophila Spinosa	-	6.1	-	-	6.2	-	-	2.2	-	-	14.5	-
Ipomoea aquatica	2.9	12.4	-	11.7	18.7	-	1.4	6.8	-	16	38	-
Pistia stratiotes	1.8	-	-	4.5	-	-	0.9	-	-	7.2	-	-
Polygonum sp.	13.6	-	-	11.7	-	-	6.7	-	-	32	-	-
Sespania sp.	2.6	4.1	-	4.5	6.2	-	1.3	1.5	-	8.4	11.8	-
Ludwigia abysinica	-	7.8	-	-	6.3	-	-	2.5	-	-	16.6	-
Scirpus pallidus	-	11.8	-	-	13	-	-	7.6	-	-	32.4	-

(**Abbreviations**: Gt=Gumetirs site; Gm=Gedromesk site; Ak=Agid kirgna site)

4. 3. Macroinvertebrate diversity and abundance

Diversity and biotic indices of macroinvertebrate

The number of species ranged from 6 to 14 at the three sampling sites. The values of H' ranged from 1.45 at Ak to 2.39 at Gt (Table 4). The H' value showed variation among sampling sites, the value being higher at Gt than Gm and Ak. On the other hand, Gumetirs and Agid kirgna wetland had a different number of macroinvertebrate families. As a result, the value H' and J' of Gedromesk was greater than Agid kirgna wetland. There were 14 and 7 macroinvertebrate recorded in the wet and dry season, respectively. There was a difference in the value of diversity index and evenness value between seasons, the value H' and J' of wet season was greater than the dry season. Based on the study findings, there was greater diversity in Gumetirs wetland than Gedromesk wetland. However, there was less diversity found in Agid kirgna wetland. The value of the Hilsenhoff Family-level Biotic Index (HFBI) was 4.68 for Gt, 5.89 for Gm and 6.77 for Ak site. The lowest value was recorded at Gt and the highest was at Gm and Ak site (Table 4). There was a significant difference in H' and HFBI indices across sampling sites ($p<0.05$)

Table 3: Spatial and seasonal diversity index (H'), evenness (J') and Hilsenhoff Family- level Biotic Index (HFBI) of major macroinvertebrates of the wetlands along the shore of Lake Tana in November 2019 and April 2020

Parameter	Sample sites			Season	
	Gt	Gm	Ak	Wet	Dry
Number of species	14	9	6	14	7
H'	2.39	1.96	1.45	2.27	1.64
Hmax	2.64	2.20	1.79	2.64	1.95
J'(evenness)	0.91	0.89	0.81	0.86	0.84
HFBI	4.68	5.89	6.77	5.70	6.53

Abundance of macroinvertebrates

A total of 975 macroinvertebrate individuals belonging to 15 families were collected from three sites during the study period (Table 3). The total number of individuals present at each site ranged from 150 at Ak to 508 at Gt, and 335 to 640 during dry and wet seasons, respectively. Hydrophilidae was the most abundant family (192 individuals), followed by Physidae (138 individuals), Coenagrionidae (132 individuals), Dytiscidae (114 individuals) and Notonectidae (108 individuals). The remaining families accounted for less than 69 individuals of abundance in each study site.

The highest number of individual macroinvertebrate was recorded in Gumetirs (Gt) wetland (514 individuals) which accounted for nearly 50%. Among those macroinvertebrates, Hydrophilidae (84 individuals), Coenagrionidae (84 individuals), Notonectidae (66 individuals) and Belostomatidae (48 individuals) were the dominant families in Gumetirs wetland. The remaining families accounted for less than 46 individual macroinvertebrates. Taxa diversity and richness at Gt site significantly different from Gm and Ak sites ($P<0.05$).

Similarly, in Gedromesk (Gm) wetland, Physidae (90 individuals) especially in the dry season, Hydrophilidae (60 individuals), Coenagrionidae (48 individuals) and Dytiscidae (30 individuals) were the four dominant families out of 317 total individuals found in the wetland.

On the other side, the lowest individual macroinvertebrate was recorded in Agid kirgna (Ak) wetland (168 individuals). Dytiscidae (60 individuals) and Hydrophilidae (48 individuals) were the two dominant macroinvertebrate families recorded in Agid kirgna wetland. The remaining families accounted for less than 18 individual macroinvertebrates. More macroinvertebrate families were lacking in Gedromesk and Agid kirgna wetlands. The distribution of relative abundance of macroinvertebrates was not the same, there were statistically significant differences across sampling sites ($P<0.05$).

Higher number of macroinvertebrate families was recorded in the wet season than the dry season. However, on average, there was no significant difference observed between seasons ($p > 0.05$)

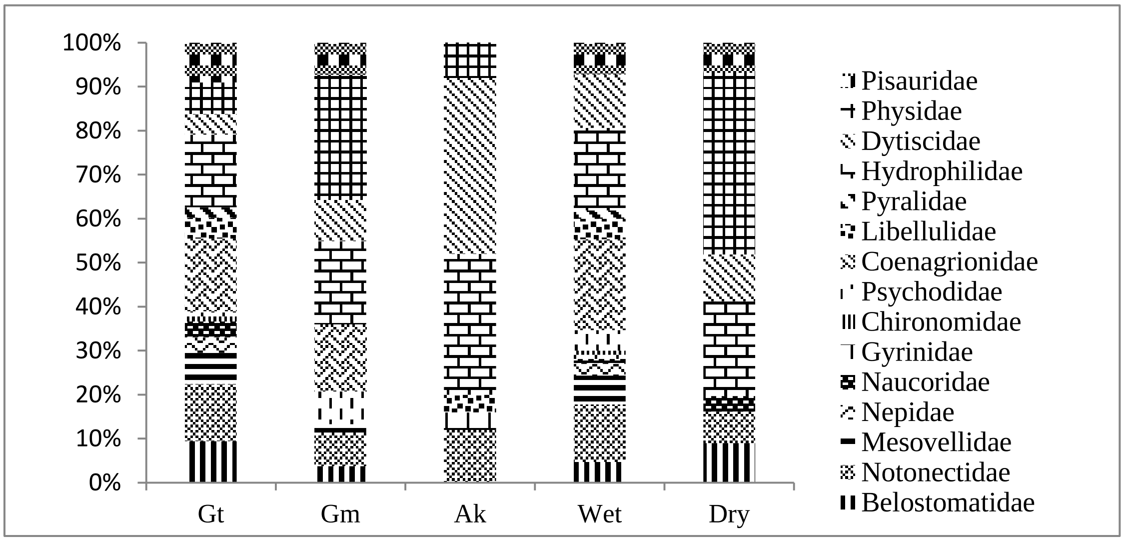


Figure 3: Spatial and seasonal relative abundance of the main taxonomic groups of macroinvertebrates at each sampling site and season in November 2019 and April 2020

Table 4: Total number of macroinvertebrates in each sampling site and season on the wetlands along the shore of Lake Tana in November 2019 and April 2020 (N=24)

Family	Sampling sites			Season		
	Gt	Gm	Ak	Wet	Dry	Total/m^2
Belostomatidae	48	12	-	30	30	60
Notonectidae	66	24	18	84	24	108
Mesoveliidae	36	6	-	42	-	42
Nepidae	18	-	-	18	-	18
Naucoridae	18	-	-	6	12	18
Gyrinidae	-	-	6	6	-	6
Chironomidae	6	-	-	6	-	6
Psychodidae	6	24	-	30	-	30
Coenagrionidae	84	48	-	132	-	132
Libellulidae	24	-	6	30	-	30
Pyralidae	12	-	-	12	-	12
Hydrophilidae	84	60	48	120	72	192
Dytiscidae	24	30	60	78	36	114
Physidae	36	90	12	-	138	138
Pisauridae	46	23	-	46	23	69
Total individuals	**508**	**317**	**150**	**640**	**335**	**975**

(Abbreviations: Gt=Gumetirs site; Gm=Gedromesk site; Ak=Agid kirgna site)

Correlation between Physico-chemical parameters and macroinvertebrate abundance

Spearman's correlation coefficients between physico- chemical parameters and macro-invertebrate are presented in Table 5. Therefore, Belostomatidae showed a strong positive correlation with Temperature and organic carbon ($p<0.05$) but it also showed a strong negative correlation with TDS and HCO_3- ($P<0.05$). Similarly, Notonectidae showed a strong positive correlation with temperature and organic carbon ($p<0.01$) but it also showed a strong negative correlation with TDS and HCO_3^- ($p<0.01$). Furthermore, Mesovelidae showed a strong positive correlation with temperature and organic carbon but it also showed a strong negative correlation with total dissolved solid and bicarbonate ($p<0.01$). Nepidae showed a strong positive correlation with organic carbon but it also showed a strong correlation with total dissolved solid, available phosphorus, total phosphorus and bicarbonate ($p<0.01$). On the other side, Naucoridae showed a strong positive correlation with OC but strongly negative correlated with TDS, AP, TP, and HCO_3^-($p<0.01$). Gyrinidae showed weak positive correlation with DO and strong with TDS and HCO_3^- but strong negatively correlated with temperature and organic carbon ($p<0.01$). Chironomidae showed a strong positive correlation with OC and strong negatively correlated with TDS, AP, TP and HCO_3^-($p<0.01$). Psychodidae showed a strong positive correlation with temperature but slightly negative correlation with TDS, TP, OC, HCO_3^- and AP ($p<0.01$). Coenagrionidae showed a medium positive correlation with temperature but a strong and weak correlation with TDS, HCO_3^-, OC and TP, AP respectively ($p<0.01$). Libellulidae showed a weak and strong positive and negative correlation with OC and TDS, HCO_3^- respectively but it also showed a strong negative correlation with TP and AP($p<0.01$). Pyralidae showed only a strong negative correlation with TDS, TP, HCO_3^-, OC and AP ($p<0.01$). Hydrophilidae showed a strong positive correlation with OC and temperature and a strong and weak negative correlation with TDS, HCO_3^-, OC and Secchi depth, TN respectively ($p<0.01$). Dytiscidae showed a very positive correlation with TDS and HCO_3^-, and a weak positive correlation with DO, EC, TP and AP but it showed a strong negative correlation with OC ($p<0.01$). Physidae showed a weak positive correlation with PH, Temperature, TP, OC and AP but a strong positive correlation with temperature ($p<0.01$). Pisauridae showed a strong positive correlation with OC and temperature and weak correlation with light transparency and TN but highly negatively correlated with TDS and HCO_3^- ($p<0.01$).

Table 5: Correlation between physico-chemical parameters and macroinvertebrate density

					Taxa/family											
Parameters		Belostomatidae	Notonectidae	Mesoveliidae	Nepidae	Naucoridae	Gyrinidae	Chironomidae	Psychodidae	Coenagrionidae	Libellulidae	Pyralidae	Hydrophilidae	Dytiscidae	Physidae	Pisauridae
DO	R	-0.171	-0.081	-0.204	-0.159	-0.159	0.577	-0.159	-0.365	-0.265	0.181	-0.159	-0.174	0.526	-0.271	-0.159
	p-value	0.425	0.708	0.338	0.459	0.459	0.003	0.459	0.08	0.21	0.398	0.459	0.417	0.008	0.2	0.458
PH	R	0.303	0.404	0.268	-0.005	-0.005	-0.048	-0.005	0.304	0.204	0.004	-0.005	0.306	0.111	0.404	0.316
	p-value	0.150	0.05	0.205	0.983	0.983	0.823	0.983	0.149	0.339	0.984	0.983	0.145	0.607	0.05	0.133
Temp	R	.755**	.782**	.733**	0.298	0.298	-.732**	0.298	.792**	.688**	-0.064	0.298	.716**	-.494*	.817**	.764**
	p-value	0.001	0.001	0.002	0.157	0.157	0.002	0.157	0.001	0.001	0.767	0.157	0.001	0.014	0.002	0.001
EC	R	0.004	0.11	-0.031	-0.182	-0.182	0.301	-0.182	0.003	-0.097	0.003	-0.182	0.011	0.403	0.109	0.017
	p-value	0.985	0.609	0.886	0.396	0.396	0.153	0.396	0.99	0.652	0.99	0.396	0.96	0.051	0.613	0.938
Secc. depth	R	0.404	.503*	0.368	0.172	0.172	-0.048	0.172	0.206	0.305	0.206	0.172	.406*	0.014	0.308	.415*
	p-value	0.05	0.012	0.076	0.421	0.421	0.823	0.421	0.335	0.147	0.335	0.421	0.049	0.947	0.143	0.044
TDS	R	-.842**	-.791**	-.855**	-.801**	-.801**	.840**	-.801**	-.421*	-.877**	-.421*	-.801**	-.826**	.965**	-0.378	-.838**
	p-value	0.001	0.001	0.001	0.002	0.002	0.001	0.003	0.04	0.002	0.04	0.001	0.001	0.001	0.069	0.002
TP	R	-0.387	-0.345	-0.399	-.801**	-.801**	0.042	-.801**	.490*	-.421*	-.877**	-.801**	-0.378	.517**	.517**	-0.383
	p-value	0.062	0.099	0.053	0.002	0.004	0.845	0.005	0.015	0.04	0.00	0.01	0.069	0.01	0.01	0.065
TN	R	0.404	.503*	0.368	0.172	0.172	-0.048	0.172	0.206	0.305	0.206	0.172	.406*	0.014	0.308	.415*
	p-value	0.05	0.012	0.076	0.421	0.421	0.823	0.421	0.335	0.147	0.335	0.421	0.049	0.947	0.143	0.044
NH_4^+	R	0.104	0.209	0.069	-0.005	-0.005	0.301	-0.005	-0.095	0.004	0.204	-0.005	0.111	0.306	0.013	0.116
	p-value	0.627	0.328	0.748	0.983	0.983	0.153	0.983	0.658	0.984	0.339	0.983	0.607	0.145	0.953	0.588
NO_3^-	R	0.104	0.208	0.069	-0.182	-0.182	0.126	-0.182	0.202	0.003	-0.097	-0.182	0.109	0.305	0.305	0.116
	p-value	0.63	0.33	0.75	0.396	0.396	0.557	0.396	0.344	0.99	0.652	0.396	0.613	0.148	0.148	0.588
HCO_3^-	R	-.842**	-.791**	-.855**	-.801**	-.801**	.840**	-.801**	-.421*	-.877**	-.421*	-.801**	-.826**	.965**	-0.378	-.838**
	p-value	0.001	0.001	0.001	0.001	0.002	0.000	0.000	0.04	0.003	0.04	0.003	0.002	0.00	0.069	0.000
OC	R	.974**	.995**	.963**	.798**	.798**	-.740**	.798**	.479*	.942**	.501*	.798**	.964**	-.813**	.509*	.978**
	p-value	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.018	0	0.013	0.0	0.0	0.0	0.011	0.0
AP	R	-0.387	-0.345	-0.399	-.801**	-.801**	0.042	-.801**	.490*	-.421*	-.877**	-.801**	-0.378	.517**	.517**	-0.383
	p-value	0.062	0.099	0.053	0	0	0.845	0	0.015	0.04	0	0	0.069	0.01	0.01	0.065
P (water)	R	0.054	0.16	0.019	-0.183	-0.183	0.215	-0.183	0.103	-0.047	-0.047	-0.183	0.06	0.356	0.208	0.067
	p-value	0.802	0.456	0.93	0.393	0.393	0.314	0.393	0.632	0.826	0.826	0.393	0.78	0.088	0.33	0.756

**Correlation is significant at the 0.01 level (2-tailed).

(**Abbreviations**: DO-dissolved oxygen; Temp.-Temperature; EC-Electric conductivity; TDS- Total dissolved solids; TP-Total phosphorus; TN-Total nitrogen; OC-Organic carbon; AP-Available phosphorus in sediment; P(water) – phosphorus in water ; Secc. depth –Secchi disk depth

4.4. Phytoplankton diversity and abundance

Diversity of Phytoplankton

From the three sampling sites in the wetland, a total of 23 different genus/species were identified that consisting of 23 from Gumetirs (Gt), 18 from Gedromesk (Gm) and 13 from Agid kirgna (Ak) (Table 7). The highest number of species was recorded in Gumetirs wetland followed by Gedromesk. However, few phytoplankton genus/species were found in Agid kirgna wetland. Gumetirs wetland was rich in phytoplankton genus/species as a result of it, there was a maximum value of diversity index (H'=2.38; J'=0.83) and evenness (J') than Gedromesk wetland (H'=2.11, J'=0.80) but the less species diversity and evenness recorded in Agid kirgna wetland (H=1.41, J'=0.69) (Table 7).

Seasonally, there was a high diversity index and evenness in wet season (H'=2.26, J=0.85) as compared to the dry season (H'=1.67, J'=0.70). Similarly, even though no difference in species evenness between habitats, there was a difference in diversity. The greater phytoplankton genus/ species diversity was recorded at the shore habitat (H'=2.81, J'=0.91) as compared to open water habitat (H'= 1.89, J'=0.91 (Figure 5).

Table 6: Spatial and seasonal diversity index (H') and evenness (J') of major phytoplankton taxa in the sampling sites on the wetlands along the shore of Lake Tana in November 2019 and April 2020

	Sample site			Season	
Parameter	Gt	Gm	Ak	Wet	Dry
Number of species	23	18	13	20	15
H'	2.38	2.11	1.41	2.26	1.67
J' (evenness)	0.83	0.80	0.69	0.85	0.70

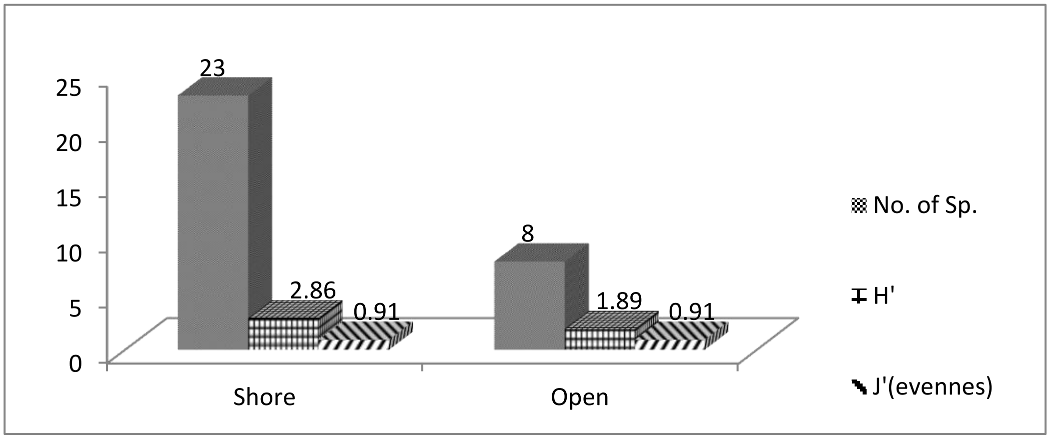


Figure 4: Habitat diversity index (H') and evenness (J') of major phytoplankton of the wetlands along the shore of Lake Tana in November 2019 and April 2020

Abundance of major phytoplankton

The list of phytoplankton species recorded at the three sampling sites along the shore of Lake Tana during the study period is presented in table 6 below. A total of 23 species of phytoplankton were identified over the study period. The number of genus/species present at each site ranged from 13 at Agid kirgna site (Ak) to 23 at Gumetirs (Gt) site. The numbers of phytoplankton cells, colonies and filaments are given in counts per ml. The number of cells ranged from 70 cells per milliliter in the dry season to a high of 1051 cells per milliliter in the wet season. Similarly, the number of cells ranged from 11cells/ml at Agid kirgna wetland to 1026 cells/ml at Gumetirs wetland.

The highest density and type of phytoplankton genus/species was recorded in Gumetirs (Gt) sampling site which accounted for more than 50% of all the sample sites. Phytoplankton cells/ml ranged from 20cells/ml for *Staurastrum* species to 1026 cells/ml for *Navicula* species. The four phytoplankton species, *Navicula* sp., *Planktothrix sp, Osilatoria sp., and Aulacoseira sp.* were dominant in the number of cells they represented > 40% of the total sum of phytoplankton followed by *Psedoanaebena* and *Flagillaria* species.

The second highest number of individual cells/ml and type was identified in Gedromesk (Gm) sampling site followed by Agid kirgna wetland (Ak). *Navicula* species, *Planktothrix* and *Melosira* species were the three major dominant species which accounted for greater than 30% of the total count of phytoplankton followed by *Oscilatoria* species in Gedromesk wetland. The number of phytoplankton cells ranged from 11cells/ml for *Scenedesmus* species to 591cells/ml for *Navicula* and 453cells/ml for *Melosira* species.

The minimum density and types of phytoplankton were found in Agid kirgna site which was 15 species out of 23 phytoplankton. Phytoplankton such as *Aulacoseira* species (343 cells/ml), *Melosira* species (179 cells/ml) and *Navicula* species (128 cells/ml) were recorded the highest number of cells/ml which accounted for 60% followed by *Synedra* species (88cells/ml), *Pediastrum* species (80 cells/ml) and *Cyclotella* species (70 cells/ml) among the other species found in Agid kirgna wetland.

Along with the study sites in Lake Tana, the phytoplankton showed some variations between seasons. The total phytoplankton density ranged from 4876cells/ml during the dry season to 9705cell/ml during the wet season (Table 6). A high types and densities of phytoplankton species were recorded in the wet season.

The total phytoplankton species was ranged from 73cells/ml to 1051cells/ml. The types of Phytoplankton/genus/ species were 15 and 20 during the dry and wet season respectively. During the dry season characterized by low phytoplankton density as a result of some fluctuation in other phytoplankton species but *Pseduanabena* species, *Aulacoseira* species and *Planktothrix* species dominated the phytoplankton community.

Moreover, a high density of individuals per milliliter and types of phytoplankton were recorded in the shore area compared with open water habitats. The most abundant genus/species were located at Gumetirs wetland (Gt) shore area. There was a significant difference in the average number of individual/ml of phytoplankton among sampling sites and between habitats ($P<0.05$) as determined by one-way ANOVA. However, there was no significant difference observed in the density of phytoplankton between seasons ($P>0.05$).

Table 7: Spatial and seasonal abundance of major phytoplankton genus/species (Number of individuals per milliliter, No./ml) recorded at three sampling sites along the shore of Lake Tana in November 2019 and April 2020

Phytoplankton genus/species	Sampling sites			Season	
	Gt	Gm	Ak	Wet	Dry
Aulacosera sp.	564	345	343	779	473
Cocous sp.	378	280	-	658	-
Cosmarium sp.	140	-	-	140	-
Cyclotella sp.	327	280	70	677	-
Cymbella sp.	284	151	-	352	82
Flagillaria sp.	502	280	-	597	185
Gomphonema sp.	54	18	4	-	75
Mallomonas sp.	70	-	-	70	-
Melosira sp.	463	453	179	716	378
Microcysts sp.	490	350	56	896	-
Mougetia sp.	401	141	-	356	186
Navicula sp.	1026	591	128	1051	693
Nitzschia sp.	579	88	-	438	229
Osilatoria sp.	619	423	18	717	342
Pediastrum sp.	70	70	80	220	-
Phacus sp.	70	-	-	70	-
Pinnularia major	362	318	19	537	163
Planktothrix sp.	963	546	11	867	652
Pseudoanabaena sp.	514	262	-	-	776
Scenedesmus sp.	169	11	14	126	68
Spirogyra sp.	421	-	-	-	421
Staurastrum sp.	20	-	53	73	-
Synedra sp.	280	151	88	366	152

(**Abbreviations**: Gt=Gumetirs site; Gm=Gedromesk site; Ak=Agid kirgna site)

4.5. Diversity and abundance of major zooplankton taxa

Diversity of Zooplankton

The total number of species found in Gumetirs (Gt), Gedromesk (Gm), and Agid kirgna (Ak) were 9, 7 and 5, respectively. The values of H' at sampling sites ranged from 1.54 at Ak to 2.12 at Gt (Table 9). The H' value showed a difference among sampling sites from 1.54 to 2.12 the value was greater in Gt and lowest in Ak and moderate in Gm site. The difference between seasons also showed difference in diversity index and species evenness. Even though less species evenness was observed, the wet season had greater diversity (H'=1.82, J= 0.95) than dry season (H'=1.73, J= 0.96)

On the other hand, habitats supported a different number of species, 9 species preferred the shore area and 8 for open water. Though similar species evenness occurred, shore area habitat exemplified higher diversity (H'= 2.06) as compared to open water areas (H'=1.95) (Figure 7).

Table 8: Spatial and seasonal diversity index (H') and evenness (J') major phytoplankton species of the wetlands along the shore of Lake Tana in November 2019 and April 2020

Parameter	Sampling sites			Season	
	Gt	Gm	Ak	Wet	Dry
Number of species	9	7	5	9	9
H'	2.12	1.67	1.54	1.82	1.73
J'	0.97	0.94	0.96	0.95	0.96

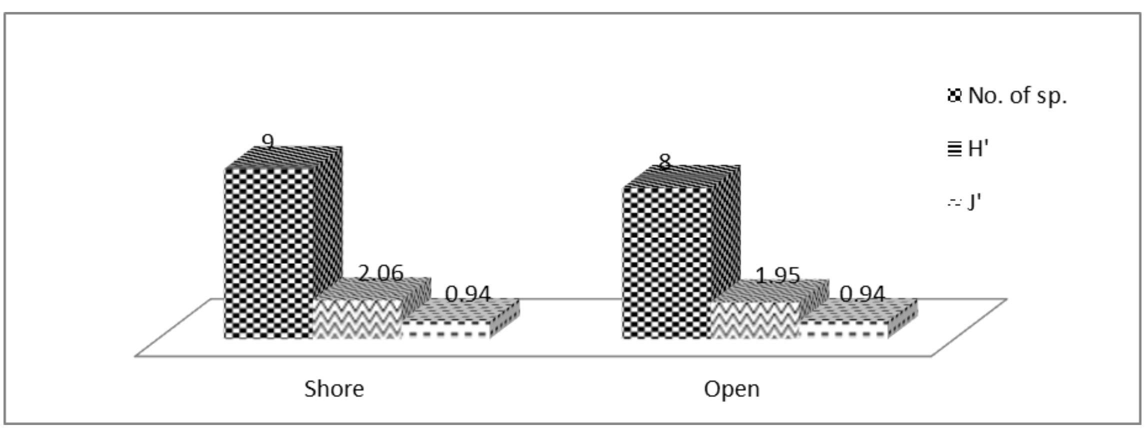


Figure 5: Number of species, diversity index (H') and evenness (J') of major zooplankton taxa at shore and open water habitats of the different sampling sites along the shore of Lake Tana in November 2019 and April 2020

Abundance of zooplankton species

A total of 9 zooplankton species which included four rotifers, three copepods, and two cladocerans species were recorded during the sampling periods (Table 8).

Numerically *Lecane* species were higher by more than 50% from other rotifer species. The mean density was 4.83 (range 7-12 ind /l) for *Lecane* species, 3.50 (range 5.0-9 ind/l) for *T.galebi*, 3.17 (range 3.0-9.0 ind /l) for *Daphnia species*, 2.83 (range 3.0-10.0 ind/l) for *Bosmina* species and 2.15(range 0-7.0 ind/l). The remaining zooplankton species mean density accounted for less than 1.50. The highest density values were observed in the Gumetirs wetland followed by Gedromesk and Agid kirgna wetland for *Lecane* species and *T.galebi*. Numerical density peaks occurred in Gumetirs (Gt) wetland. The highest density peaks were observed and occurred in Gumetirs site followed by Gedromesk and Agid kirgna site for *Lecane* species.

In general, *Lecane* sp. was both dominant and most frequently recorded species compared to other zooplankton species followed by *T. galebi* and *Daphinia* species in all study sites along the lake shore. The density of zooplankton was decreased from dry to wet season.

There was no difference in the type of species even though the highest density was recorded in the wet season compared to the dry season. In terms of habitat distribution of zooplankton, the highest density was recorded in the shore habitat as compared with open water in all sampling sites (Figure 6).

There was a significant difference in the density of zooplankton across sampling sites and habitats ($P<0.05$). But, on average, there was no significant difference observed in the density of zooplankton between seasons ($P>0.05$).

Table 9: Spatial distribution of zooplankton genus/species (Number of individuals per liter, No./l) among sampling sites along the shore of Lake Tana. (± SE represents Standard Errors of Mean)

Zooplankton genus/species	Sampling site			
	Gt	Gm	Ak	Total
	No./L ± SE	No./L ± SE	No./L ± SE	No./L ± SE
Keretella sp.	3.5±0.8	1.0±0.2	-	9±2.1
Lecane sp.	6.0±1.4	5.0±1.1	3.5±0.8	29±6.6
Daphnia sp.	4.5±1.0	3.5±0.8	1.5±0.3	19±4.3
Testudinella sp.	3.0±0.7	-	-	6±1.4
Thermodiaptomus galebi	4.5±1.0	3.5±0.8	2.5±0.6	21±4.8
Bosmina sp.	5.0±1.1	1.5±0.3	2.0±0.5	17±3.9
Ceriodaphina sp.	3.0±0.7	3.5±0.8	-	13±3.0
Brachionus sp.	2.5±0.6	-	1.5±0.3	8±1.8
Diaphanosoma sp.	2.0±0.5	0.5±0.1	-	5±1.1

(**Abbreviations**: Gt=Gumetirs site; Gm=Gedromesk site; Ak=Agid kirgna site)

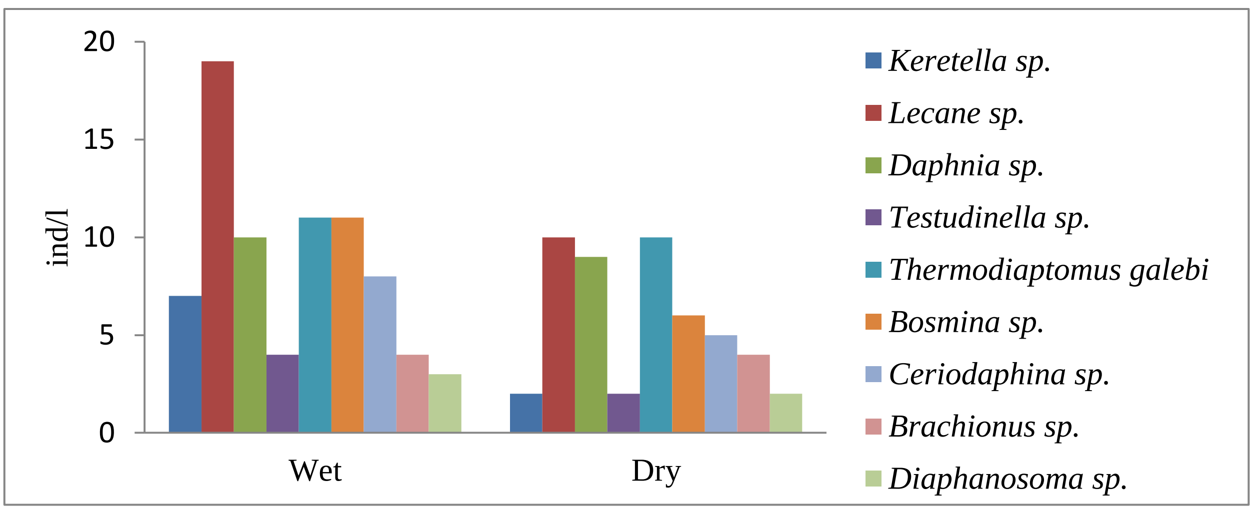


Figure 6: Seasonal difference in density of major zooplankton species/genus at three sampling sites along the shore of Lake Tana in November 2019 and April 2020

4.6. Socio-economic benefits and status of wetlands among sampling sites

Demographic characteristics of sampled household (respondents)

The structured questionaire was conducted to a total of 90 household heads. The findings of the study indicate that majority of the respondents who participated in the study were male-headed that accounted for 65.6%, while the female-headed accounted for 34.4% (Table 10). This shows that males were more involved compared to female respondents in the surveyed study area. On the other hand, the mean respondent age was 40 with a minimum of 25 and a maximum of 61 years old. Regarding to level of education, the result showed that 58.9% of the respondents which accounted for half of the participants did not follow formal education but few of them can write and read only their names through experience. On the other hand, almost three fourth of the respondents (84.4%) got married and the mean family size of the respondents was five per each family. 92% of the respondents were farmers compared to government employed and self-employed respondents.

Table 10: Socio-economic characteristics of the sampled household

Socioeconomic characteristics	Description
Gender	Male: 65.6% and Female: 34.4%
Age	Mean: 40 and Range: 25-61
Level of education	No education or basic education: 58.9% Primary education: 35.6 % Secondary education: 4.4% College or University:1.1%
Social status	Single:14.4% ; Married: 84.4% ; Divorced:1.1%
Occupation	Government employed:1.1% Self-employed: 6.7% Farmer: 92.2%
Family size	Mean : 5 and Range: 1-8

Sources of livelihood of sampled household in selected kebeles

Five major sources of livelihood were identified (Table 11). On average, crop was the mainstay of livelihoods for the majority of the households which accounted for 48.9% of total respondents of the three sampling sites (*kebeles*). It is followed by crop, livestock (21.1%) and fodder, fruit and vegetable sales (21.1%), which are the other sources of livelihood for the local people. However, the smallest source of livelihood was rent land, which only accounted for 1.1% among the other sources of livelihoods. As a result of the inferential statistics test, there was a statistically significant difference in sources of livelihood across the sites as determined by the chi-square test, X^2 (12, N = 90) = 34.304, p = 0.001.

Table 11: Sources of livelihood of the sampled household heads

Sources of livelihood	Sample sites			Mean	Std. Error	Frequency	Percent (%)	Sig.
	Gt	Gm	Ak					
Crop	9	12	23	14.7	4.3	44	48.9	0.001
Forestry	1	2	0	1	0.6	3	3.4	
Livestock	4	9	6	6.3	1.5	19	21.1	
Rent land	0	1	0	0.3	0.3	1	1.1	
Agricultural wage	0	1	1	0.7	0.3	2	2.2	
Fodder, fruits and vegetable sales	14	5	0	6.3	4.1	19	21.1	
Small scale business	2	0	0	0.7	0.7	2	2.2	

(**Abrevations**: Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kiregna)

Number of people that depends on the wetland resources and degree of dependency

The results revealed that 72.2% of 1 up to 5 family sizes of the respondents were depending on the wetland resources. On the other hand, most participants' degree of dependency were partial and they accounted for 58.9% and fully dependent and accounted for 36.7% of the wetland resources (Table 12). There was no significant difference in the number of dependent families and degree of dependency on the wetlands, X^2 (2, N = 90) = 1.440, p = 0.487 and, X^2 (4, N = 90) = 2.853, p = 0.583, respectively.

Table 12: Number of dependents and degree of dependency of the sampled household heads

Number of families dependent on the wetland	Sample sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
1-5	20	24	21	21.7	1.2	65	72.2	0.487
5-10	10	6	9	8.3	1.2	25	27.8	
Degree of dependency								
Fully dependent	8	14	11	11	1.73	33	36.7	0.583
Partial dependent	20	15	18	17.7	1.45	53	58.9	
Independent	2	1	1	1.3	0.33	4	4.4	

Abrevations: Gt=Gumetirs; Gm=Gedromesk; Ak=Agid Kiregna

Overall trends of benefits and concern of biodiversity in the wetlands

The respondents were asked their opinion on the overall trend of benefits in the last five years and their concern about wetland biodiversity and their contribution in maintaining the healthy functioning of the ecosystem. The respondents were asked their opinion and awareness of wetland degradation. Among the three study sites, the overall trends of benefits from the wetland of Gumetirs site increased compared to Gedromesk and Agid kirgna in the last five years. Despite the overall trends of wetland benefits increased in Gumetirs site, 62.3% of the respondent stated that wetland benefits across the site were decreased. On the other side, the overall concern of the community about biodiversity was moderate (64.4%). However, the trends of benefits provided by the Agid kirgna wetland were completely decreased in the last five years (Table 13). Additionally, the respondents were asked their attitude towards wetland degradation and its cause and consequence. As a result, half (51%) of the respondents had moderate awareness about wetland degradation. The majority of the respondents in Gumetirs site had good awareness compared to the other two wetland sites. Statistically, there was a significant difference in the overall trends of benefits, X^2 (4, N =90) = 46.542, p = 0.001, and concerns of biodiversity, X^2 (4, N =90) = 23.203, p = 0.002 and awareness of wetland degradation, X^2 (4, N =90) = 27.952, p = 0.003 among the sampling sites.

Table 13: Overall trends, awareness and concerns of wetland benefits, degradation and biodiversity of the sampled households

	Sample sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Overall trends of benefits in the last five years								0.001
No change	10	2	0	4	3.06	12	13.3	
Decreased	5	21	30	18.7	7.31	56	62.3	
Increased	15	7	0	7.3	4.33	22	24.4	
Overall concern of local people for biodiversity								0.002
Highly concerned	14	6	2	7.3	3.53	22	24.4	
Moderately concerned	14	24	20	19.3	2.91	58	64.4	
Unconcerned	2	0	8	3.3	2.4	10	11.1	
Awareness of local people about wetland degradation								0.003
Largely aware	15	7	0	7.33	4.33	22	24.4	
Moderately aware	15	13	23	17	3.06	51	56.7	
Largely unaware	0	10	7	5.67	2.96	17	18.9	

(**Abbreviations:** Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna)

Protection status of wetlands

This section asses the protection extent of the wetlands. The finding revealed that the majority of the respondents (25.6%) agreed to the fact that overgrazing, free grazing and pollution are not prohibit in the wetland (Table 14). This is especially observed in the Agid kirgna site which accounted for 56.5% compared to the remaining sites. Generally, Gumetirs site was protected properly than the other two wetlands in which farming and hunting practices are not allowed in the wetland. There was a significant difference in the protection status of the wetlands across the sampling sites, X^2 (16, N =90) = 90.723, p = 0.003

Table 14: Protection status of wetlands of the sampled households

Protection status of the wetland	Sample sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Fishing prohibited or regulated	2	1	0	1	0.58	3	3.3	0.003
Biosphere reserve	1	0	0	0.3	0.33	1	1.1	
Farming is prohibited	10	0	0	3.3	3.33	10	11.1	
Hunting prohibited	3	0	0	1	1	3	3.3	
Over grazing, free grazing and pollution prohibited	14	0	0	4.7	4.67	14	15.6	
Not yet protected	0	5	6	3.7	1.86	11	12.2	
Over grazing, free grazing and pollution are not prohibited	0	10	13	7.7	3.93	23	25.6	
Farming is not prohibited	0	7	8	5	2.52	15	16.7	
Fishing is not prohibited	0	7	3	3.33	2.03	10	11.1	

(**Abbreviations:** Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna)

Major uses, anthropogenic activities and use of vegetation cover of wetlands

This part of the survey basically assesses the major uses provided by each wetland to the local people and the impacts of anthropogenic activities in and around the wetlands area. Additionally, the respondents were asked their opinion on the use of vegetation cover. The findings revealed that the majority of the respondents agreed that grazing or fodder for livestock and water supply for irrigation purpose were the two major uses of the wetland across the sampling sites (Table 15). Moreover, cultivation of crops including vegetables and fruits were the third major use of wetland for the sampled households.

Among the study sites, Agid kirgna site was highly exposed to overgrazing. About 50% of the respondents understood those anthropogenic activities and their negative impacts on the normal functioning of the ecosystem. Conversely, half of the respondents (50%) were not aware of anthropogenic activities and their negative impacts on the normal functioning of the ecosystem health. On the other side, 48.9% the respondents understood the importance of vegetation cover for both ecosystem health but more than half (51.1%) of the respondents were not aware on the use of vegetation cover for ecosystem health. There was a significant difference in the major uses of wetland across the wetlands, X^2 (12, N =90) = 34.648, p = 0.001 and awareness of anthropogenic activities and its impact, X^2 (2, N =90) = 17.867, p = 0.003. However, there was no significant difference among the sampled sites in the use of vegetation cover for ecosystem health, X^2 (2, N =90) = 2.223, p = 0.329.

Table 15: Major uses, anthropogenic activities and uses of vegetation cover of the wetland of the sampled households

	Sampling site			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Major uses of the wetland to the local people								
Grazing or fodder for livestock	10	11	12	11	0.58	33	36.7	0.001
Reed gathering	2	3	0	1.67	0.88	5	5.6	
Cultivation of crops including vegetables and fruits	6	2	1	3	1.53	9	10	
Water supply for irrigation	10	11	3	8	2.52	24	26.7	
Fishing and culturing	2	3	3	2.67	0.33	8	8.9	
Sand mining	0	0	3	1	1	3	3.3	
Source of drinking water	0	0	8	2.67	2.67	8	8.9	
Anthropogenic activities and impacts								0.003
Yes	24	15	12	17	3.61	45	50	
No	6	15	18	13	3.61	45	50	
Uses of vegetation cover for lake health								0.329
Know	18	13	13	14.67	1.67	44	48.9	
Do not know	12	17	17	15.33	1.67	46	51.1	

(**Abbreviations:** Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna)

Income contribution of wetlands for the sampled households

This part of the survey emphasize mainly on the types of income utilized by the community directly or indirectly from the wetlands **(**Table 16). Livelihood sources such as fish, grass, fruits and vegetables, Cyprus papyrus reed, milk, biogas, fattening and compost were the direct and indirect ecosystem services provided by the wetland. The result showed that the majority of the respondents (31.1%) gained 1-10kg fish product per year. Comparatively, more fish products were obtained in Gumetirs site compared to Gedromesk and Agid kirgna. However, 48.9% of the respondents did not get fish throughout the year from the wetland. There was a significant difference across the site in fish products, X^2 (8, N =90) = 28.829, p = 0.002. Similarly, a wetland in Gumetirs site provided more grass production than the other two reference sites. There was a significant difference, X^2 (10, N =90) = 65.524, p = 0.001 in grass production among the sampling sites. On the other hand, results showed that wetlands were valued as major cultivation site of vegetables and fruits even though more yield was obtained in both Gumetirs and Gedromesk sites with an amount of between 1500-2500kg per year. However, fruit and vegetable productions not much produced in Gedromesk site but nothing in Agid kirgna sampling site. Statistically, there was a significant difference, X^2 (8, N =90) = 84.586, p = 0.001 in fruits and vegetation production among sampling sites.

The majority of households obtained *Cyprus papyrus* reed mainly from Gumetirs site by either selling raw papyrus materials or after value addition through mat making. More production was obtained from the Gumetirs wetland which totally accounted for 38.9% by many households. Despite more respondents have got papyrus from Gumetirs wetland and Gedromesk wetland, there was nothing obtained papyrus reed products in Agid kirgna wetland which accounted for 61.1%. There was a significant difference, X^2 (10, N =90) = 73.382, p = 0.002 in *Cyprus papyrus* production across the study sites. Similarly, products such as milk, biogas, fattening and compost were mainly obtained from Gumetirs wetland which accounted for nearly 90% of all product types compared to other sites. According to the result from chi-square test, there was a strong evidence of significant difference in milk products, X^2 (8, N =90) = 56.919, p = 0.003; biogas, X^2 (8, N =90) = 28.300, p = 0.002; fattening, X^2 (8, N =90) = 50.122, p = 0.001 and compost, X^2 (6, N =90) = 44.893, p = 0.004 products across the sample sites.

Table 16: Types of income gained by the sampled household heads per year

	Sample site			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Products obtained from the wetlands per year								0.002
Fish 1-10kg	17	9	2	9.33	4.33	28	31.1	
10-20kg	3	5	1	3	1.15	9	10	
20-30kg	4	2	2	2.67	0.67	8	8.9	
30-400kg	0	0	1	0.33	0.33	1	1.1	
nothing	6	14	24	14.67	5.21	44	48.9	
Grass 100-150tone	3	0	0	1	1	3	3.3	0.001
150-250tone	7	0	0	2.33	2.33	7	7.7	
250-300tone	4	2	0	2	1.15	6	6.6	
300-350tone	7	9	0	5.33	2.73	16	17.8	
350- 400tone	7	6	0	4.33	2.19	13	14.4	
nothing	2	13	30	15	8.14	45	50	
Fruits and vegetables								0.001
Below 500kg	3	9	0	4	4.33	12	13.3	
500-1500kg	3	10	0	4.33	1	13	14.4	
1500- 2500kg	12	3	0	5	3.84	15	16.7	
above 2500kg	11	3	0	4.67	3.38	14	15.6	
nothing	1	5	30	12	8.39	36	40.0	
Cyprus papyrus reed								0.002
50-100tone	3	7	0	3.33	2.03	10	11.1	
100-150tone	3	0	0	1	1	3	3.3	
150-200tone	5	1	0	2	1.53	6	6.7	
200-250tone	9	0	0	3	3	9	10	
above 250tone	7	0	0	2.33	2.33	7	7.8	
nothing	3	22	30	18.33	8.01	55	61.1	
Milk 500L	1	2	13	5.33	3.84	16	17.8	0.003
500L-1000L	1	3	0	1.33	0.88	4	4.4	
1000L-1500L	1	8	0	3	2.52	9	10	
above 1500L	16	3	0	6.33	4.91	19	21.1	
nothing	11	14	17	14	1.73	42	46.7	0.002

Biogas								
1000-2000 birr saving	6	1	0	2.33	1.86	7	7.8	
2000-3000 birr saving	3	0	0	1	1	3	3.3	
3000-5000 birr saving	4	2	0	2	1.15	6	6.7	
above 5000 birr saving	3	1	0	1.33	0.88	4	4.4	
nothing	14	26	30	23.33	4.81	70	77.8	
Fattening								0.001
1500-2500 birr	0	2	0	0.67	0.67	5	5.6	
2500-3500 birr	1	4	0	1.67	1.2	2	2.2	
500-1500 birr	2	0	0	0.67	0.67	2		
more than 4500 birr	20	8	0	9.33	5.81	28	31.1	
nothing	7	16	30	17.67	6.69	53	58.9	
Compost								0.004
500-1000birr	3	1	0	1.33	0.88	4	4.4	
1000-2000birr	1	2	0	1	0.58	3	3.3	
more than 2000birr	21	10	0	10.33	6.06	31	34.4	
nothing	5	17	30	17.33	7.22	52	57.8	

(Abbreviations: Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna)

Changes in area, water regime, and quality, exploitation, alien species and management strategies of the wetlands

Among the alternative questions under the changes in the wetland area, 66.67% of the respondents answered the prominent cause of change in wetland area was recession farming and conversion to agricultural land especially in Gedromesk site and Agid kirgna site (Table 17). Moreover, there was a significant difference, X^2 (4, N =90) = 73.257, p = 0.001 in changes in wetland area across sample sites. On the other side, the majority of the respondents also answered that the cause of change in water regime was the building of a dam (48.9%) and change in land use (41.11%), respectively. There was a significant difference in change in water regime, X^2 (4, N =90) = 13.518, p = 0.003 and water quality, X^2 (6, N =90) = 86.514, p = 0.002. Nearly, 60% of the respondents answered that exploitation was mainly observed in Gedromesk site and Agid kirgna sites due to overgrazing of the wetland vegetation in and around the wetland area. On the other hand, 33.33% of the respondents agreed that the main alien species was water hyacinth weed, especially in Agid kirgna. Moreover, there was a significant difference, X^2 (4, N =90) = 61.181, p = 0.003 in the invasion of alien species across sampling sites in the wetlands.

The respondents were asked their opinion on which management strategies they agree with. Vegetation management, the prohibition of free grazing, and recession farming and restoration of vegetation were selected by those respondents across the study sites especially for Gedromesk and Agid kirgna sites. 22.22% of the respondents agreed that prohibition of free grazing and recession farming as a management strategy but they emphasized the other alternative ways. There was a significant difference, X^2 (8, N =90) = 60.238, p = 0.001 in the management strategies which were recommended by sampled respondents for each study site.

Table 17: Changes in area, water regime and quality, exploitation, alien species, and management strategies of the wetlands.

	Sampling sites			Mean	Std. Error	Freq.	Percent (%)	Sig.
	Gt	Gm	Ak					
Changes in wetland area								
Land conversion to urban areas	2	0	0	0.67	0.67	2	2.22	0.001
Conversion into agricultural land (recession farming)	2	28	30	20.00	9.02	60	66.67	
No change	26	2	0	9.33	8.35	28	31.11	
Land conversion to industrial area	0	0	0	0	0	0	0	
Changes in the water regime								
Dam	16	14	12	14	1.15	44	48.9	0.003
Drainage	0	0	6	2.00	2.00	6	6.66	
Irrigation	13	15	12	13.33	0.88	40	44.44	
Change in water quality								0.002
Nutrient enrichment	0	1	0	0.33	0.33	1	1.11	
Fertilizer/Pesticide/Herbicide runoff	2	8	14	8.00	3.46	24	26.67	
Changes in land use	0	21	16	12.33	6.33	37	41.11	
No change	28	0	0	9.33	9.33	28	31.11	
Exploitation								0.001
Over fishing	13	10	0	7.67	3.93	23	25.56	
Over hunting	14	0	0	4.67	4.67	14	15.56	
Over grazing	3	20	30	17.67	7.88	53	58.89	
Alien species								0.003
Water hyacinth	0	0	30	10.00	10.00	30	33.33	
Other invasive weeds	2	9	0	3.67	2.73	11	12.22	
No alien species	28	21	0	16.33	8.41	49	54.44	

Management strategies								
Vegetation restoration	4	5	10	6.33	1.86	19	21.11	0.001
Management of hunting	13	3	0	5.33	3.93	16	17.78	
Management of fishing	13	2	0	5.00	4.04	15	16.67	
Do not allow free grazing	0	10	10	6.67	3.33	20	22.22	
Prohibit recession farming	0	10	10	6.67	3.33	20	22.22	

(**Abbreviations:** Gt=Gumetirs; Gm=Gedromesk; Ak=Agid kirgna)

5. DISCUSSIONS

5.1. Physico-chemical parameters

Dissolved oxygen levels ranged between 5.71mg/l to 6.87 mg/l along the sampling sites which are generally considered favorable for most aquatic organisms (USEPA, 2002). This finding is somewhat in agreement with Eshete Dejen (2003) which reported a range of 5.9-7.3 mg/l, and Yezibe Kassa (2016) from 5.19 -7.54. However, better dissolved oxygen concentration was measured at Gumetirs site as compared to Gedromesk and Agid kirgna sites. This is due to the presence of less amount of organic matter from the nearby farmlands which demand more oxygen for the decomposition process. The catchment and buffer zone of Gumetirs wetland is relatively well protected and covered by vegetations which easily uptake nutrients that come from the upper catchment before reach the lake. The lowest dissolved oxygen level was measured at Agid kirgna sampling site followed by Gedromesk wetland. This result indicated that the depleted dissolved oxygen leads to unfavorable conditions for an aquatic healthy life. This is most probably due to pollutants inflow which demanding more oxygen for decomposition which come from nearby farmlands with intensive fertilizers at different non-point source and animal wastes while grazing. Dissolved oxygen is usually low in water where there is high organic input due to microbial respiration (Wetzel, 2001). On the other hand, water bodies infested by water hyacinth are characterized by higher turbidity, a higher level of chlorophyll a, higher level of chemical oxygen demand (COD), lower dissolved oxygen (DO), lower pH, and lower nitrates than no infested areas (Brendonck *et al*., 2003; Masifwa *et al*., 2001; Rommens *et al*., 2003). On the other hand, the decline in dissolved oxygen level at Gedromesk wetland is most probably due to the increased organic matter and their decomposition which come from animal wastes during grazing in the wetland.

Dissolved oxygen level is higher in the wet season as compared to the dry season. This might be attributed to the differences in temperature and the high flux of oxygen. However, during the dry season, the level of dissolved oxygen is low. This is also probably due to the presence of high decomposition of organic matter accompanied by high temperature in the water and nutrient that come from the surrounding areas and agricultural fields. The other reason may be during the dry season the oxygen demand of most aquatic organisms is high.

The pH range showed variation across sites and seasons, and values are within the permissible range for natural waters (USEPA, 2002). Moreover, in all sites pH values varied within narrow limits (range 6.85 -7.12), this meets the quality standards for surface water of Ethiopia (range: 6.0 - 9.0)

(Ethiopia EPA, 2003). However, the water sample in Agid kirgna wetland is slightly acidic which is probably due to the high load of organic nutrients come from nearby agricultural areas.

The temperature was varying within a small range across the wetlands and seasons though the lowest temperature was recorded in both Gumetirs and Gedromesk wetlands. However, the slight increase in temperature at Agid kirgna site is a result of the dense mats of water hyacinth over the water surface which blocks the exchange of heat between the lake surface and the atmosphere. These findings suggest that water hyacinth mats may have a strong influence on the temperature fluctuations. The mean water temperature of the infested area was slightly higher than that of the open area and the other two wetlands without water hyacinth. Mehra *et al.* (1999) have also shown that floating water hyacinth mats may have a profound influence on the diurnal temperature fluctuation. The water hyacinth also has been found to stabilize pH levels and temperature in experimental lagoons thereby preventing stratification and increasing mixing within the water column (Giraldo and Garzon, 2002).

Lake Tana is a shallow tropical lake with relatively low water temperatures, varying only within small limits (Eshete Dejen *et al*., 2004). The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter (UNESCO/WHO/UNEP, 1996). The higher temperature in the dry season was probably due to the increased load of suspended solids, soil particles and decomposed organic matter in the lake; because they absorb more heat (Phul, 2016).

The observed electric conductivity (EC) and total dissolved solids (TDSs) markedly similar trends along the wetlands. The highest values were recorded at Agid kirgna site followed by Gedromesk and Gumetirs wetlands. This shows that a high organic load may have existed or entered into the wetlands. However, low electric conductivity was measured at the Gumetirs wetland which assured that flow or deposition of dissolved ions might not occured due to the regulation of influx of wastes or nutrients at the wetland as a result of biotic and abiotic intervention activities. It is generally known that organic loading including domestic and industrial wastes, fertilizers and pesticides increase the lake water ionic concentrations and subsequently conductivity (Deepa *et al*., 2016).

Moreover, during the dry season, both EC and TDS increased. This is probably due to the high decomposition rate of pollutants and nutrients accompined by high temperature but low values in the wet season which may be because of the extent of dilution. A related low value of EC and TDS measurement during the main rainy season was recorded by Ayalew Wondie *et al*. (2007).

The highest and lowest transparency was observed in Gumetirs site and Agid kirgna site, respectively. This is probably due to the extent of TDSs concentration and turbidity at each site. There was less water transparency measured in the shore zone during the dry season. This is most likely due to wind induced resuspension of bottom sediments which in turn reduces the depth of light penetration despite high nutrient availability (Kimmel, *et al.*, 1990). Similar findings were also reported by Ayalew Wondie *et al*. (2007) and Goraw Goshu (2010).

Nutrients in the sediments such as total phosphorus (TP), total nitrogen (TN), and nitrate (NO_3^-) concentrations in the water varied across sites and seasons. The mean concentrations of TP in all the sampling sites were higher than the maximum limit (0.05 mg/l) recommended by USEPA (1986) for streams discharged into reservoirs. The highest value of TP was recorded at Gedromesk wetland mostly in the wet season. This is probably due to the grazing pressure and animal wastes and agricultural nutrient runoff. The probable reason for the highest concentration of available phosphorus (AP) in the sediment in Gedromesk wetland is due to the increment of temperature and pH in the dry season but lowest in Gumetirs wetland. The study findings of total nitrogen and available phosphorus concentrations in the sediment are higher than the findings of Yirga Kebede and Hassen Muhabaw (2015) which obtained 0.54% and 52.3mg/kg, respectively.

Similarly, the nitrate concentration showed similar trends to total phosphorus across sites and seasons, which is highest at Gedromesk wetland followed by Agid kirgna wetland but very less in Gumetirs wetland. This may be due to inputs from the catchment during the rainy season and later settlement during the dry season. The other probable reason for the nitrate addition might be from the excess availability of ammonia that can be readily converted to nitrate in the sediment and also through agricultural nutrients surplus which could be rich in nitrate concentration. Although the trophic status of Lake Tana is meso-oligotrophic (Ayalew Wondie and Seyoum Mengistu, 2014; Eshete Dejen *et al*., 2003), there is an increasing trend in the concentration of nitrate and phosphorous, especially at shore areas and river mouths, that would eventually lead to eutrophication and infestation and expansion of invasive weeds. The lowest amount was observed at Agid kirgna wetland which is highly infested by water hyacinth weed. Rommens *et al.* (2003) found that littoral sites with water hyacinth in Lake Chivero, Zimbabwe, had significantly less ammonium, nitrate, and dissolved oxygen than limnetic sites or than littoral sites without water hyacinth. The seasonal variation of nitrate concentration shows a high significant difference. The concentration of nitrate is much higher in the wet season than the dry season. This study is in agreement with Sisay Misganaw

(2018). This might be due to fertilizer runoff from farmlands and wastewater release. The major anthropogenic sources of nitrate in aquatic ecosystems are sewage, fertilizers, and waste from farmlands and domesticated animals (ANZECC, 1992). Therefore, nitrate concentrations above and below the limit of 5 mg/l which both would become unfavorable for aquatic organisms health (Chapman, 1996).

The spatial and seasonal differences of nitrate and total phosphorus mean concentrations were significantly greater at littoral sites as compared to the open water areas but higher nitrate concentrations were measured than results reported by Rzoska (1976) and Ayalew Wondie *et al*. (2007). The increasing trend in nitrate is probably because of nutrient influxes of the shore zone of the lake from anthropogenic sources in the catchment area.

Total nitrogen was also with considerably higher concentration at Gumetirs site. This could be due to the nitrogen cycling taking place in the wetland, where nutrients are produced by the decaying organic matter. However, the least value was recorded in Agid kirgna site. Also, the nutrients trapped in plant parts dissolve in the water or are deposited as sediment contributing to more nutrients in the wetland (Mugisha *et al*., 2007). A high total nitrogen concentration in the wetland can also be because of biological nitrogen fixation and surface run-off from agricultural lands. However, there was no significant seasonal variation was observed during the study period. There was a high ammonium ion (NH_4^+-N) concentration in the Agid kirgna site as compared to other sites. This is probably due to the preference of phytoplankton and macrophytes over nitrate to maintain energy to breakdown and used up easily. The other reason could be nitrogen- containing fertilizer and other nutrient runoff from the catchment. Moreover, the other reason might be the higher reduction rate of nitrate into ammonium ion. Similarly, a high concentration of bicarbonate ion (HCO_3^{-1}) was measured at Agid kirgna wetland. The highest percentage of organic carbon (OC) was recorded at the Gumetirs wetland especially in the dry season. This finding is in agreement with Wetzel (2001) which states that high concentrations of dissolved organic carbon can emanate from macrophytes. The wetland is covered by dense vegetation and protected from free grazing and other human activities.

Generally, the physico-chemical parameters were recorded mostly within an acceptable range of WHO standards that can support healthy aquatic life. This physico-chemical ranges mostly observed at Gumetirs sampling sites. This may be due to the presence of less amount of organic matters emanated from agricultural lands and the extent of grazing pressure. This mostly indicates that such improvements maybe come from the intervention activities performed at the shore and catchment area of the lake. However, high concentration of nutrients in both water and sediment samples at Gedromesk and Agid kirgna sampling sites are becoming above the permissible range. This mostly associated with the intensive human activities carried out in and around these wetlands. Based on the research findings, Gumetirs wetland was found in good water quality as compared to Gedromesk and Agid kirgna wetlands. The physical and chemical parameters have been used as water quality indicators for many years in many countries (Valentina *et al*., 2011).

Some differences in physico-chemical parameters were observed during the dry season compared to the wet season. During the dry season, Gumetirs wetland was found in good ecological conditions interms water quality as compared to Gedromesk and Agid kirgna wetlands. Mostly, the physical and chemical variable findings confirmed that ecohydrology based intervention activities improved the physico-chemical conditions of the wetland.

5.2. Macrophyte diversity, relative abundance, density, frequency, and importance value index

The quantitative characters which comprise relative abundance, relative density, relative frequency and importance value index vary along sites and seasons. The abundance and diversity of macrophytes are better at Gumetirs wetland. This is because in this wetland anthropogenic activities are very less and wetland resources are well protected and utilized wisely and sustainably by the local people throughout the year. The most dominant macrophytes are *Echinochloa* sp. and *Cyprus papyrus* species in Gumetirs and Gedromesk wetlands. However, the abundance of *Cyprus papyrus* was very less in Gedromesk wetland. These macrophytes in the wetlands are currently under severe degradation by the local inhabitants especially the area covered by papyrus reed. This is probably due to the existence of human interference in the wetland. The loss of *Cyprus papyrus* reduces the wetland's anti-pollution services because of the effectiveness of this species in reducing nitrogen and phosphorus level in water (Abe *et al*., 1999).

These macrophyte species were more abundant in both seasons followed by *Polygonum* species compared to other macrophytes species at the Gumetirs wetland. However, in Gedromesk wetland *Echinochloa* and *Cyprus papyrus* species are the dominant species followed by *Ipomea aquatica* but compared to Gumetirs site, the abundance of both macrophytes were very less during the dry season.

Macrophytes attained the highest relative abundance, frequency and density in all wetlands during the wet season. Similarly, the highest diversity of species was observed during the wet season.

The lake has its highest volume of water during the post rainy season when water from all its tributaries rich in nutrients reaches the lake (Ayalew Wondie *et al*., 2007). The study by Ayalew Wondie (2006) also described as macrophytes are more common in the post rainy season because of the absence in human interference due to the high volume of water and flood conditions. The lake has its highest volume of water during the post rainy season when water from all its tributaries rich in nutrients reaches the lake (Ayalew Wondie *et al*., 2007). However, during the dry season, the abundance and density of *Echinochloa* sp. and *Cyprus papyrus* species were very less in Gedromesk sites as compared with Gumetirs wetland. This wetland is degraded by overgrazing and agriculture and as a result, the abundance and density of *Echinochloa* species meadow is poor. The conversion into farming land by burning, ploughing and overgrazing are the main threats for this wetland during the dry season. Ayalew Wondie (2010) states that the intensification of farming and the shift of farming practices are among the main problems in Lake Tana. Besides that, the reeds are threatened as a result of over-harvesting for handcraft and building purpose (Mundt, 2012).

There were high physical differences observed across the sampling sites. The most reasonable in this case is the difference in the protection status of the wetlands. Gumetirs wetland is more protected and free from free grazing and recession farming activities even though there is harvesting of meadows and reeds during the dry season. On the other hand, in the dry season, Gedromesk and Agid kirgna wetlands were used as grazing areas (own observations). During the dry season, those meadows fall completely dry and are immediately converted into farming land as the water is receding (own observation). However, during the wet season (rainy season) there was no significant difference in both Gumetirs and Gedromesk wetland. This is because of both wetlands had similar water level and protected by the water that make it unavailable for harvesting. As a result, there were similar trends of abundance, density and frequency of both species during the wet season.

Echinochloa species in both Gumetirs and Gedromesk, and *Eichhornia crassipes* in Agid kirgna wetland are ecologically importance macrophytes followed by *Cyprus papyrus* as the results determined by importance value index (IVI) value. The remaining macrophytes species in the wetlands require a conservation effort. The importance value index is an important parameter that reveals the ecological significance of species in a given ecosystem (Lamprecht, 1989).

Species with high IVI are considered more ecologically important than those with low IVI. On the other hand, values of IVI can be used for prioritizing species for conservation (Simon, 2002).

The main ecological gradients influencing the composition of the vegetation of the wetlands are water depth and the impact of human activities. The main ecological gradient on which the vegetation of the wetlands at Lake Tana depends primarily is the water depth and associated with seasonal fluctuations of the water level. The second important factor influencing the vegetation cover is the impact of human utilization which is gaining more and more importance within recent years (Mundt, 2012).

On the other hand, *Eichhorina crassipes* (Water hyacinth) was the only dominant rooted-floating macrophytes species in Agid kirgna wetland. This finding is in agreement with Yezbie Kassa (2016) that mentioned *Eichhornia crassipes* as the dominant macrophyte in most of the sampling sites that attained the highest relative frequency and density in the eastern littoral zone of Lake Tana.

The study conducted by Ayalew Wondie (2007) and Mundt (2012) also reported there were many other macrophytes species in the area but currently the area is completely occupied by *Eichhornia crassipes.* This could be due to human activities causing the increase in nutrient input into the lake and the aggressive nature of the invasive weed along with climate factors. Most of the natural vegetation were destroyed for farmland expansion (recession farming), settlement and intensive grazing area. Besides, Agid kirgna is an example of degradation of shores and wetlands due to sand mining practices (Mundt, 2011).

The highest level of species diversity, evenness and richness was found and confirmed by the Shannon diversity index at Gumetirs site compared to the other two wetlands. This maybe due to the protection status and degree of human disturbance. Different levels of disturbance have different effects on diversity. Macrophytes are more evenly distributed in Gumetirs wetland in which the J' value is closer to 1. Magurran (1988) explained that evenness (J') ranges normally between 0 to 1, where 1 represents a situation in which all the species are equally abundant. The Shannon diversity index normally varies between 1.5 and 3.5 and rarely exceeds 4.5 (Magurran, 1988). A higher number indicates high diversity and evenness. It is influenced by the number of species and their evenness among each other. In natural habitats where human interference is relatively small, the diversity and abundance of species are greater than in fragmented habitats where intensive farming is carried out (Shimelis Aynalem and Afework Bekele, 2008).

The abundance and diversity of macrophytes were very less in the Agid kirgna wetland which is highly disturbed and covered by water hyacinth weed. This study is in agreement with the study by Bedilu Bekele *et al.*(2017) entitled with the invasion of water hyacinth is associated with the decline in macrophytes biodiversity in an Ethiopia Rift valley Lake, Abaya. They conclude that water hyacinth affects macrophytes community composition, abundance and diversity negatively. Similarly, Firehun *et al*. (2014), showed a positive relationship between human impacts and the exotic species abundance in the lake ecosystem. Furthermore, this study corroborated the study of Lolis *et al.* (2020) on the negative correlations between native macrophytes diversity and water hyacinth abundance. The authors found a negative correlation between macrophytes richness and cover and *Eichhornia crassipes* biomass. The cumulative number of species decreased at a higher extent in plots dominated by *Eichhornia crassipes* in China. They also suggested that the reduction of all diversity attributes related to *Eichhornia crassipes* probably results from its engineering species role which decreases littoral region habitat heterogeneity and affects rare species in the introduced (Lolis *et al.,* 2020).

5.3. Macroinvertebrate diversity and abundance

The macroinvertebrate communities were mainly dominated by Belostomatidae, Notonectidae, Coenagrionidae and Hydrophilidae in Gumetirs wetland. There was a high abundance and diversity of macroinvertebrate families at Gumetirs wetland. This may be due to the presence of different vegetation zones, physico-chemical conditions and nutrient availability. This result mainly showed that macroinvertebrate families are associated with the composition and structure of vegetation as well as the physical and chemical properties of water and sediment. This might be mostly linked with the extent of protection and physico-chemical characteristics of the wetland. Moreover, the higher number of macroinvertebrate found at the Gumetirs wetland may be reflective of less anthropogenic stress, presence of different habitats, nutrient availability and moderate physico-chemical conditions improvement through the implementation of intervention activities at Gumetirs site. However, there was less in abundance and diversity status observed at Gedromesk wetland even though Dytiscidae, Hydrophilidae, and Coenagrionidae were the dominant macroinvertebrate families recorded in both seasons but Physidae mainly during the dry season. There was a shift in species abundance in the dry season, all families of macroinvertebrates number decreased in all wetlands. However, Physidae was the dominant macroinvertebrate family during the dry season, especially at Gedromesk wetland. This could be due to seasonal variation of elevated physico-chemical characteristics, less nutrient fluxes, high human disturbance extent, high water level fluctuation and less feeding relationship among macroinvertebrates. Gastropoda population will increase to sizes that will suppress the populations of other invertebrates (Batzer *et al*., 2000). Mollusca was lacking during the wet season. Gastropoda populations, specifically physidae, are suppressed in the presence of fish (Batzer *et al*., 2000). This indicates that the abundance of Physidae depends on the presence and absence of predators, high temperature and water level.

According to Gencer and Nilgun (2010) most values measured using the Shannon diversity index range from 1.5 to 3.5, rarely exceeding 4.5. values above 3.0 indicate that habitat structure is stable and values under 1.0 indicate the presence of pollution and degradation of habitat structure. Based on this criterion, diversity index of Gumetirs wetland is nearly 1.5 which indicates the wetland condition at Gumetirs site is better. However, the Shannon diversity indices of the other sampling site were below one. This further indicates that the presence of high levels of pollution and degradation of habitat structure.

Generally, the abundance and diversity of macroinvertebrate species decreased at Gedromesk and Agid kirgna wetlands which are highly impacted by anthropogenic activities through overgrazing and agricultural activities. This finding is in agreement with Ayenew Gezie *et al*. (2017), human activities in and around the wetlands such as farming, overgrazing by domestic livestock, eucalyptus plantation, vegetation clearance, water abstraction, drainage, leather tanning, and effluent discharge from domestic and industrial plants were contributed to the degradation of water quality and decrease in the richness and diversity of macroinvertebrate taxa. Similarly, macroinvertebrates are greatly affected by local changes due to intensive agricultural practices, cattle grazing, waste discharge, and draining of water for controlling vector mosquitoes and other flies (Kratzer and Batzer, 2007). The abundance and diversity of macroinvertebrate species are linked with the abundance and diversity of macrophytes species and nutrient availability.

Moreover, macroinvertebrate species abundance and diversity are directly related to protection status, habitat condition (structure), degree of disturbance of the wetland, and physico-chemical conditions of water and sediment. Moreover, the correlations observed among elevated physico-chemical parameters indicate the presence of anthropogenic causes of pollution. In this regard, most of the physico-chemical parameters were noticed to be correlating significantly with the macroinvertebrates abundance and diversity which is an indication that the physico-chemical conditions of the wetland noticeably affected the macroinvertebrate community.

Overall, the abundance and diversity of aquatic invertebrates generally increase in response to increased habitat heterogeneity and structural complexity provided by water hyacinth but decrease due to decreased phytoplankton (food) availability (Villamagna, 2010). Macroinvertebrate had higher abundance and diversity at the edge of water hyacinth mats, compared with open water or areas of emergent plant (*Cyprus papyrus*) (Masifwa *et al*., 2001). However, invertebrate abundance and diversity were not only affected by the water hyacinth roots but also by temperature, dissolved oxygen, turbidity, and salinity in the water column (Rocha-Ramirez *et al*., 2007).

5.4. Phytoplankton diversity and abundance

The results showed that the diversity and abundance of phytoplankton varied across sampling sites along the shore of Lake Tana. Differences in the abundance and diversity of phytoplankton along the wetland are probably related to the vegetation type and abundance, habitat condition and physico-chemical conditions of the wetlands. The structure of a macrophyte assemblage plays a large role in determining the composition of phytoplankton, zooplankton, fish, and birds in freshwater ecosystems (Meerhoff *et al*., 2006). The highest cell abundance of phytoplankton was observed in Gumetirs wetland. This is mostly associated with the presence of less internal and external nutrient loading (pollution) and better physico-chemical conditions (dissolved oxygen concentration or extent of turbidity) that play an important role in phytoplankton abundance and diversity as a result of intervention activities. But the lowest abundance and diversity of biological components are identified at Agid kirgna wetland. This maybe due to the impact of the water hyacinth shading effect. The abundance and diversity of phytoplankton are highly depend on the degree of human disturbance. This is more likely related to human activities that disrupt natural patterns and processes of aquatic ecosystems thereby species cannot adapt to the rapid environmental changes.

Additionally, the high abundance and diversity of species indicate the high productivity of this wetland. The productivity of an aquatic environment is directly correlated with the density of phytoplankton (Narasimha, 2013) as they play an important role as primary producers and thus can affect higher trophic levels by providing nutritional bases for zooplankton and subsequently to other invertebrates, shellfish and finfish (Emmanuel and Onyema, 2007). Jackhar (2013) found that diversity and abundance of phytoplankton and zooplankton were well correlated with the abiotic factors (temperature, pH, TDS, DO, BOD, nitrate, phosphate, hardness, alkalinity) of the aquatic environment. There were only some differences in phytoplankton abundance between Gumetirs and Gedromesk wetlands. This is because of their closeness/distance; as a result, both wetlands share some physico-chemical characteristics especially during the wet season. But there are still some differences between the wetlands. It is mostly due to the protection status or degree of disturbance of the wetland. Both wetlands are mainly dominated by *Bacillariophyta* (Diatoms) groups followed by *Cyanophyta* as compared to Agid kirgna wetland. These groups of phytoplankton had the highest density. This may be due to the capability that possesses a wide range of environmental variables. This finding is in line with Ayalew Wondie (2007). However, this is somewhat deviated from Dilnessa Gashaye (2016) study, who reported the dominance of Chlorophyceae in the Southern gulf of Lake Tana. On the other hand, in Agid kirgna wetland, there was a clear difference in the abundance and diversity of phytoplankton. The lowest number of phytoplankton cells were recorded in Agid kirgna wetland. This maybe due to the water hyacinth nutrient competition and shading effect to make photosynthesis by phytoplankton. Water hyacinth floats and grows on water surface and absorbs dissolved nitrogen and phosphorus from water, which leaves less nutrients available for phytoplankton to perform adequate photosynthesis in the process of growth and development, thus leading to depletion in numbers or even dying out of phytoplankton communities (McVea and Boyd, 1975). The *Aulacosera* and *Melosira* species were the dominant phytoplankton species in Agid kirgna wetland which are higher in the wet season and lower during the dry season. This may be due to the extent of TDS and water hyacinth shedding effect. Their growth and diversity may, besides other factors, be controlled by seasonal temperature changes and increasing water temperatures (Schabhuttl, 2013).

A significant increase was observed in phytoplankton cell density during the wet season. This may be due to the wet season favored phytoplankton populations with its maximum water level and high amount of nutrients. There was a sharp decline in both abundance and diversity of phytoplankton just immediately after the wet season. According to Ayalew Wondie (2007) among the four periods of the seasonal cycle of the phytoplankton community in Lake Tana, diatoms dominate in the wet, post rainy and post dry seasons. That is why diatoms play a major role in both tropical and oligotrophic lakes (Kalff, 2002). Phytoplankton populations were often low during the dry season and developed to the second increase in the wet season. The correlations between the observed decline of the phytoplankton with diminishing nutrient concentrations and increase temperature during the early dry season indicate that the relationship appears to be predominantly causal (Ayalew

Wondie, 2007). There was a shift in dominance of abundance from Bacillariophyceae to Cyanophyta. Although many other external factors, some biological and hydrological influence phytoplankton seasonality, periodic changes in the hydrographic structure of the water column often appear to dominate in large and deep African lakes. In such waters, the hydrological (water input/output) influence is typically diminished by longer retention times (Lewis, 1987). Some temporal changes in the hydrographic structure were recognized in several investigations in Lake Victoria (Fish, 1957; Talling, 1966, 1986), Tanganyika (Coulter, 1963, Mareau *et al.*, 1993) and Malawi (Hecky and Kling, 1981). Observations by Harding (1963) on Lake Malawi showed seasonal variability in net phytoplankton, highest quantities generally corresponding with cooling, and the lowest to periods of prolonged high surface temperature and more pronounced thermal stratification. Generally, the high density (aggregation) of phytoplankton at the shore zone is most likely linked with nutrients availability, wind turbulence, and water current (wave action).

5.5. Zooplankton diversity and abundance

The abundance and diversity of zooplankton species almost follow similar trends as phytoplankton. Their abundance and community structure are usually used as indices of aquatic ecosystem health (Chen *et al*., 2012). Generally, the abundance and diversity of the zooplankton community at the three sampling sites along the shore of Lake Tana are poor. Such low taxa numbers, however, appear to be a typical feature of tropical water bodies (Irvine and Waya, 1999; Kurki *et al*., 1999; Seyoum Mengistou and Fernando, 1991). Numerical density and variety of zooplankton vary along the sampling wetlands depending on the abundance of phytoplankton, habitat condition, predation and degree of disturbance and physico-chemical conditions of the wetlands. Analogous to phytoplankton abundance and diversity, the highest abundance and diversity of zooplankton is noted at Gumetirs wetland. This might be linked with the abundance of phytoplankton species as a source of food and due to the presence of less organic matters, and lack of invasive species due to the conservation and protection effort carried out in Gumetirs wetland. The diversity and density of zooplankton depend upon the nutrient condition of the water body, abiotic factors, dissolved oxygen, food chain, soil-water chemistry and stated that to monitor the aquatic ecosystems and integrity of water the zooplankton has been used as bioindicators (Dhembare, 2011).

Rotifers were more abundant and dominant taxa followed by Copepod which constituted more than 50% of the total zooplankton density at the three wetlands. Numerically, *Lecane* species are the prevalent species of rotifers followed by *Thermodiaptomus galebi* of Copepods along the sampling sites. However, the high abundance of rotifers can be attributed to the high abundance of phytoplankton in the wetlands.

The minimum zooplankton density was found in the most agricultural impacted wetland, Agid kirgna. This may be linked with the degree of disturbance, lower phytoplankton abundance, predation pressure, density of water hyacinth and high TDS concentration that affect the density of zooplankton directly or indirectly. A decrease in phytoplankton abundance may have adverse effects on zooplankton (Wang, 2017). Zooplanktons are preferable bio-indicators for the detection of dispersal patterns of anthropogenic contamination and for understanding the incorporation and movement of waste nitrogen into pelagic and benthic food chains (Xu and Zhang, 2012). According to Trivedy and Goel (1984), an excess amount of TDS in water tends to disturb the ecological balance due to suffocation in aquatic fauna even in presence of a fair amount of DO. On the other hand, TDS is positively correlated with abundance of zooplankton. According to the study by Mustapha (2010) total zooplankton is positively correlated with phosphate, nitrate, DO, conductivity and TDS, whereas a negative correlation was observed between total zooplankton with carbon dioxide, transparency, temperature and total alkalinity. The distribution of zooplankton is affected by many factors, including water transparency, light, temperature, dissolved oxygen, phytoplankton and food resources (Villamagna and Murphy, 2010). The growth of water hyacinth could change the above mentioned factors to alter the abundance and diversity of zooplankton communities even though the well-developed fibrous root system of water hyacinth could provide a suitable ecological niche for zooplankton, especially with the mat's "edge effect. It drastically affects the physical and chemical properties of the water by reducing the temperature, pH, biological oxygen demand and nutrient level (Bedilu Bekele Mengistu *et al*., 2017).

Additionally, zooplankton abundance and composition can be structured by resources (bottom-up), competition and/or predation pressure (top-down control) (Lampert and Sommer, 1997). Moreover, invertebrate abundance and diversity were not only affected by the water hyacinth roots, but also by temperature, dissolved oxygen, turbidity and salinity in the water column (Rocha-Ramirez *et al*., 2007).

Zooplankton density was higher during the wet season (post rainy season). This maybe due to the availability of phytoplankton as a source of food and physico-chemical properties of the water. Moreover, seasonal variation of food availability may be expected to influence zooplankton abundance. Maximum zooplanktons were observed in winter probably due to low temperature, high content of dissolved oxygen and low velocity (Khanna *et al*., 2000; Khanna and Bhutiani, 2003; Purushothama *et al*., 2011). Despite the overall zooplankton density is poor, rotifers are still dominant in the Agid kirgna wetland. According to Kumar *et al*. (2011) rotifers are nutrient tolerant species which, in total number as well as diversity are seen to be typical for high productivity and eutrophic wetland.

Copepods are the second abundant and diversified groups of zooplankton across the sampling sites in this study. The reason may be due to nutritional constraints and predation pressure to dominate the system. This is consistent with the findings of several other authors reported the dominance of copepods in tropical and subtropical lakes and reservoirs (Amarasinghe *et al*., 1997, Burgis, 1974, Eshete Dejen *et al*., 2004, Irvine and Waya, 1999; Seyoum Mengistou and Fernando, 1991, Ayalew Wondie and Seyoum Mengistou, 2006). However, this finding is different from the previous study by Ayalew Wondie (2007) reported that *T. galebi* was not only the dominant species but also the most frequently recorded of all the copepods in all areas of the lake. This difference may arise from the frequency of sampling months or other environmental factors.

Cladocerans increased during the wet (post-rainy season). The density of *Bosmina*, *Daphnia* and *Diaphanosoma species* were higher during the dry season. This finding is in agreement with Ayalew Wondie (2007) who reported a high peak of abundance of cladoceran species that occurred mainly in May during post-rainy season in Lake Tana.

There was a clear disturbance spatial pattern in the zooplankton distribution and density being high in the shore zone and declined towards the open water areas. This is in accordance with the findings of Tesfaye Wudneh (1998), and Akinbuwa and Adeniyi (1991) that the bulk of the zooplankton often occurs at the littoral zones. However, a possible factor explaining the low abundance of zooplankton in the deeper part of the lake could be the high predation pressure in the open water. According to Eshete Dejen *et al*. (2004), adult *Clarias gariepinus*, *Barbus brevicephalus* and *Barbu trispilopleura*, are important predators on zooplankton and are more abundant in the open water. The impact of predation on zooplankton abundance is also indicated by Serruya and Pollingher (1983), where significantly lower plankton density was associated with the presence of the planktivore fish, *Gambussia affinis,* in Lake Mariut.

In general, the total number of zooplankton taxa reached a peak during the wet season (post-rainy season) as compared with dry season. The highest density and diversity of zooplanktons were recorded in the shore area but less in the open area at all sampling sites.

5.6. Socio-economic benefits and status of wetlands in the shore of Lake Tana

The fertile shores of Lake Tana have provided provisioning, structural, regulating and cultural values for the local communities for thousands of years.

There are huge differences among the wetlands studied. Gedromesk and Agid kirgna sites are highly affected by agricultural activities and overgrazing. Their buffer zone vegetation are highly degraded by overgrazing, drainage and recession agriculture mainly during the dry season. Agid kirgna wetland is devoid of buffer vegetation. Gedromesk wetland is relatively covered by *Echinochola* plant species. However, Gumetirs wetland is dominantly covered by *Echinochola* meadow and Cyprus papyrus reed.

In the study sites, the majority of the household sources of incomes are mainly originated from within and around the wetlands directly or indirectly. These include crop farming, forestry production, livestock rearing, and land renting, and growing of fruits, vegetables, and grass and papyrus reeds production.

The result indicates that the main source of livelihoods for the local community is crop production. On average, the majority of the households share that crop production as the main practice and sources of income for the local community mainly in Gedromesk and Agid kirgna sites. This result shows that crop production is the common agricultural practice to generate income for the local community. This is because wetlands have fertile soils as a result of regular sediment deposition during flood events (Verhoeven and Setter, 2010). The local community perceives crop production has higher income compared to other livelihood types. Due to this reason, households demand more farming land to get more products. The local people need to expand the crop farming area beyond their previous territory of land. This also further suggests that local households are less likely to depend on other sources of livelihoods and more likely depend on crop production mainly the cultivated one. As a result, the local community increases pressure to nearest lake shore areas to cultivate more crops.

Furthermore, degradation of water quality and biodiversity increases when they apply fertilizer and pesticide chemicals to crop farming. Anthropogenic pollution on water bodies is severe because it leads to a decline in the water quality and biodiversity in wetlands (Porte and Gupta, 2017). To see each site separately, fruit, vegetable and grass for fodder are more produced in Gumetirs sampling site. This indicates that majority of the respondents grow and sell these wetland benefits without altering the ecosystem.

The sources of livelihoods mainly affect the number of families that depend on the wetlands. The result revealed that the number of a family that depend on the wetland ranged from 1-5 person per family. This shows that the pressure on wetlands increases as the number of people increases as a means of a source of income in the local community even though their degree of dependency is partial on average of 58.9%.

On the other hand, on average, 62.3% of the respondents agreed that the overall trends of benefits in the last five years decreased even though Gumetirs wetland benefits increased. The majority of the local households lack well understanding and adopting sustainable use of wetland resources. On average, the majority of the respondents are not concerned highly about those anthropogenic activities and impacts. Lack of adequate knowledge and awareness about wetlands results in wetland deterioration from overexploitation and thereby affects their sustainable existence (Dereje Tewabe, 2014). The low level of community awareness concerning wetlands and their benefits also accelerates the loss of wetlands in the country (Unbushe, 2013).

The majority of the respondents in Gumetirs sites are highly concerned and largely aware of biodiversity and the impacts of anthropogenic activities. This implies that Gumetirs site provides better ecosystem services compared to the other two reference sites. This is most probably due to the awareness raising effort together with other intervention activities at the lakeshore of the wetland. On the other hand, the local households in Gumetirs site have better concern and awareness of biodiversity and anthropogenic activities impacts on the ecosystem than the other two sites. Public awareness creation is one of the most important ways to conserve wetlands and enable the public to be more environmentally conscious (Ibrahim Mohammed, 2015). For successful conservation and management, the participating local communities should be fully aware of the importance of wetlands as part of water cycles, as well as the nature and effects of human impacts (Williams, 2002). However, awareness creation about the importance of wetlands in the Lake Tana Sub-basin is virtually lacking (Woube Mengistu, 2008).

Moreover, the Gumetirs site was found in good protection status as compared to the other wetlands. This is due to community participation and coordination with integrated water resource management organizations on using the water and land resources sustainably. Andrade and Rhodes (2012) report that the higher the level of community participation, the higher their compliance to the resource conservation; community inclusion is a must for long-term conservation.

The protection status of the wetlands indicates that many respondents agreed that free grazing and pollution are not prohibited in Gedromesk and Agid kirgna wetlands. This in turn easily degrades and minimizes the benefits provided by wetlands. Comparatively, free grazing, overgrazing and pollution is strictly prohibited in Gumetirs site. As a result of proper protection in Gumetirs site, wetland benefits are sustainable throughout the year.

On average, across the site, grazing and crop production are the major use of the wetlands. The result shows that in Gumetirs site grass production, vegetable and fruit, chat (*Catha edulis*) production and reed gathering are the major uses of the wetland. Therefore, this indicates that many of these products demand more water during the dry season. Comparatively, there is less water abstraction in Gedromesk and Agid kirgna sites because of few water demanding products around the wetlands.

Half of the respondents (50%) understand that anthropogenic activities have great impacts on the sustainable use of wetland benefits and overall ecosystem health.

On average 51.1%, majority of the respondents positively recognize that vegetation cover is important. Most respondents perceived that vegetation cover serves as fodder for their livestock. But few of the respondents recognize that vegetation cover is important for fish as a source of food, and breeding ground, nutrient uptake, stabilize water temperature as well as to keep water quality and quantity. This finding is somewhat similar to Ayalew Wondie (2018). However, about 50% of respondents were not aware of the use of vegetation cover. As a result of it, the coverage of vegetation within and around the lakeshore may favor for continuous degradation of macrophytes.

It is good to note that much of the wetland resources were obtained from the Gumetirs. Wetland benefits such as fish, vegetables, fruits, grass, papyrus reed, milk, biogas, fattening, and compost productions are some of the direct and indirect wetland benefits used by the local households.

The result from the households survey and direct observation indicates that both Gumetirs and Gedromesk currently provide more goods and services such as cultivated of fruits and vegetables (Chat, Cabbage, Mango and Avocado), grass (fodder) production and milk production predominantly provided by Gumetirs wetland, followed by reference wetlands, contributing to more than 97% of the total value of the wetland goods and services for the local people.

More fruits and vegetables were obtained in Gumetirs wetland due to water accessibility and availability from the wetland. This implies that the community who lives around this wetland has multiple livelihoods. Hence, well-managed wetlands are among the most productive ecosystems which provide the opportunity for sustainable development, helping to meet the needs for improved living standards in developing countries like Ethiopia (Dagne Tafa, 2018).

Furthermore, the importance of this study point towards the change in the wetland area, water regime and quality, extent of exploitation, the invasive species invasion condition, and the management strategies. On average, 66.67 % of respondents agreed that the main causes of change in wetland's area are the conversion of wetland into agricultural land through recession farming. Due to this reason, the area of land has been shrinking from time to time. Degradation and loss of wetland is now a big threat to the benefits provided by the wetland for the local community. Similarly, Amare Minale and Kameswara (2011) reported that most of the wetlands in the catchment have been continuously declined, while the farming lands and settlement areas have been increasing.

The change in wetland regime can be caused by the building of a dam, drainage of water to expand agricultural land, channelization, and abstraction of water for irrigation purposes. It increases and decreases the water level depending on the season. Wetland water level decreases during the dry season. In this case, the expansion of recession farming also increases. Different studies indicated that the abstraction of water from wetlands for irrigation is a major factor for the loss of wetlands (Ajibola *et al.,* 2012).

The change in water quality in the wetland is caused by both changes in land use and nutrient (fertilizer, pesticide, and herbicide) runoff from agricultural fields. Nutrient runoff might be mainly caused by the severe upland erosion in the catchment. The discharges of surplus nutrients in the upper catchment easily enter into the wetland through flooding. The nutrients in the lake without vegetation cover causes eutrophication which affects living things in the water. Additionally, a high load of sediment affects the growth and regeneration of macrophytes.

According to the respondents, the main cause of exploitation in the wetlands is overgrazing. Grazing pressure has damaged wetlands especially in Gedromesk and Agid kirgna sites quite badly. This, in turn, has an impact on the vegetation cover and enhances eutrophication due to livestock's wastes. When grazing continuous livestock trample and compact the soil destroys natural vegetation, affects the infiltration capacity of the soil, and erode drainage channels leading to gullies and water outflow (McKee, 2007). Overgrazing damage wetlands through soil compaction, removal of vegetation, and stream bank destabilization.

Weed infestation in wetlands is a big problem particularly on the northeast shore of Lake Tana. Water hyacinth is the most invasive and destructive weed found in Agid kirgna. As a result of complete coverage of water hyacinth, the previous benefits provided by Agid kiregna wetland for the local community are being impaired. The overall ecosystem health and benefits are under risk. Nearly, 60% of the respondents agreed that overexploitation are mainly observed in Gedromesk and Agid kirgna sites. As a result, many lakeshore areas of macrophytes were replaced by invasive weeds such as water hyacinth especially in Agid kirgna site (33.33%). Invasive species are one of the major threats to biodiversity in the world due to their effect on the homogenization of the ecosystems (Enserink, 1999).

Respondents were asked their opinion and preference on alternative management strategies. The result indicates that on average the majority of the respondents share that the most management strategies to conserve and safeguard the wetland ecosystem and benefits are the prohibition of overgrazing and recession farming. The intensive cultivation and free grazing activities in Shesher and Welala wetlands, for example, resulted in drastic shrinkage of their coverage (Negash Atnafu *et al*., 2011; BoEPLAU, 2015). Recession agriculture is still considered as an advanced mode of development for many people.

Generally, the survey result indicates that the majority of the sampling sites are mainly affected by the changes in the area, water quality and quantity, and the invasion of invasive species. As a result, goods and services provided by the wetlands have decreased. According to the results from the survey of respondents, wetland faces several challenges as a result of human activities on the wetlands. Activities such as recession farming, crop cultivation, free grazing, intensive agricultural land use, nutrient runoff from the upland catchment, unregulated fishing, and illegal hunting are some of the major causes of wetland degradation.

According to the respondents, Gumetirs site was found in a good ecological condition compared to the other two wetlands. In Gumetirs site, free grazing is not allowed rather cut and carries of *Echinochola* grass species and *Cyprus papyrus* reeds are utilized in a sustainable and manageable way.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Biological abundance and diversity, physiochemical conditions, and socioeconomic benefits are the main ecological and socio-economic impacts identified in this research. This study has identified distinct human disturbance gradients along which physico-chemical conditions, abundance, diversity of macrophytes, macroinvertebrate, planktons and socio-economic status assemblage structure changed within the sampling sites on the wetlands along the shore of Lake Tana. This study confirmed that low disturbed wetland supports higher abundance and diversity of macrophytes, macroinvertebrates, phytoplankton, zooplankton and socio-economic benefits than moderately and highly disturbed wetlands. All but the protected (intervened) wetland were found degraded associated with the degree of human disturbances. The result of this study also assured that the presence of high abundance and diversity of biological groups, good water quality and better ecosystem services indicate that the wetland is found in good conditions. The significant variations in physico-chemical, biological and socio-economic attributes among sampling sites might be due to anthropogenic activities such as agriculture, water abstraction, and pollution.

The abundance and diversity of macrophytes, macroinvertebrates, phytoplankton and zooplankton species and socioeconomic status among sampling months, sites and habitats were varied and this might be due to the difference in physico-chemical parameters, water level fluctuation, degree of disturbance, protection status, food availability and level of awareness.

About 12 macrophyte species were identified during the study period from all sampling sites, and the most dominant species in terms of relative abundance, density, frequency and importance value index were *Echinochloa* species followed by *Cyprus papyrus.* Based on the Shannon diversity index (H' = 0), the Agid kirgna wetland could be grouped under highly polluted followed by Gedromesk wetland (H' = 1.00) when they were compared with Gumetirs wetland (H' = 1.24). Agid kirgna wetland was completely covered by water hyacinth weed.

A total of 975 macroinvertebrate individuals belonging to 15 families were collected from all sampling sites during the study period, and the most dominant family were Hydrophilidae Coenagrionidae and Physidae. Based on the Shannon diversity index (H' = 2.39), the Gumetirs wetland might be grouped under good ecological condition as compared to the remaining two reference wetlands. Moreover, correlation analysis between physico-chemical parameters and macro-invertebrate abundance showed that organic carbon and temperature are most likely positively correlated with macro-invertebrate abundance.

On the other hand, a total of 23 phytoplankton species from all sampling sites were identified, and the dominant phytoplankton were *Navicula*, *Planktothrix, Osilatoria, and Aulacoseira* species. Based on the Shannon diversity index (H' = 2.38), Gumetirs and (H' = 1.41), Agid kirgna wetland showed the highest and lowest diversity, respectively. Similarly, a total of 9 zooplankton species, four rotifers, three copepods and two cladocerans species were identified during the sampling periods, and the most dominant species were *Lecane* sp. and *T. galebi*. The highest individual per milliliter was observed in the Gumetirs wetland followed by Gedromesk and the lowest at Agid kirgna wetland. Based on the Shannon diversity index (H' = 2.12) and Hilsenhoff Family-level Biotic Index (HFBI= 4.68), Gumetirs and (H' = 1.54) and (HFBI= 6.77), Agid kirgna wetland showed the highest and lowest diversity and water quality, respectively.

As a result of human disturbances, the abundance of biological groups, Physico-chemical components, and wetland benefits varied with sites and seasons along the wetlands. Overall, the socio-economic survey result confirmed that the ranges of wetland benefits significantly related to the degree of disturbance and awareness level of the local community. All but the Gumetirs wetlands were found to be degraded with extensive human activity. The overall results of the study showed Gumetirs wetland has better biodiversity, water quality and provides diversified livelihoods. This is mainly due to the positive impacts of ecohydrology system solutions. However, Gedromesk and Agid kirgna wetlands have less biodiversity, water quality and wetland benefits and they are under risk due to multiple human disturbances. In conclusion, emphasis should be given to the factors which may lead to the degradation of these wetlands within and its catchment especially recession farming, overharvesting, overgrazing and invasion of water hyacinth.

Majority of the local people viewed the ecohydrological intervention activities and its impacts on their livelihoods opportunities improvement positively.

Based on this research finding, the ecohydrological intervention approaches have the potential to improve the ecological and socio-economic conditions through harmonization and holistic way.

6.2. Recommendations

- Further awareness creation on the ecohydrological system solutions should be created to promote and strengthen harmonious and holistic approaches for progressive development and utilization of aquatic resources sustainably.
- Further attentions should be given to planning conservation awareness-raising efforts platforms to the local community about the importance of wetlands and their conservation, engaging the local stakeholders and increase community participation in any restoration and conservation approaches of wetlands and optimizing diversified livelihoods opportunities by safeguarding wetlands and protecting their multidimensional functions.
- Immediate ecohydrological based intervention approaches should be implemented to restore degraded wetlands, enhance ecosystem services and carrying capacity of ecosystems against human impacts and also to avoid further degradation along the shore and catchment area of Lake Tana of Ethiopia, as well as elsewhere.
- Most notably, future development progresses around Lake Tana should pay attention to the holistic views of ecosystem functioning and integrated societal uses.
- Buffer zone development along the lakeshore as a green belt and catchment management should be implemented to increase buffering roles of the Lake against human disturbance.
- Recreation and restoration of shore zone Cyprus papyrus, particularly along the lakeshore areas and at the river mouth regions for sequential trapping of nutrients and sediments from rivers and agricultural runoff at different discharge regimes.
- Ecohydrology should be institutionalized to be used as a tool for mitigation measure for degraded wetlands and other water bodies in Ethiopia.
- Further investigation is required to determine the degree of anthropogenic impacts within the wetland and catchment.

7. REFERENCES

Abe, K., Ozaki, Y. and Mizuta, K. (1999). Evaluation of useful plants for the treatment of polluted pond water with low N and P concentrations. *Soil science and plant nutrition*. **45**: 409-417.

Abebe Tariku; Seyoum Aynalem and Feyssa Dejene (2014). Benefits of wetland conservation interventions to local households in southwestern Ethiopia: empirical evidence from attributes based valuation. *Journal of Environmental Science. Water Resource*. **3**: 060–068.

Adekola, O. and Mitchell, G. (2011). The Niger Delta wetlands: threats to ecosystem services, their importance to dependent communities and possible management measures. *International Journal of Biodiversity Science, Ecosystem Services and Management*. **7**: 50-68.

Adhikari, B. (2002). Household Characteristics and Common Property Resource Management: A Model for Households Dependency on Local Commons. In *Proceedings of the Ninth Bennial Conference of the International Association for the Study of Common Property,* Victoria Falls, Zimbabwe.

Afework Hailu (2005). Ethiopian wetlands distribution, benefits and threats. In *Proceedings of the second Awareness Creation Workshop on Wetlands in Amhara Region. Bahir Dar*.

Agostinho, A. A., Bonecker, C. C. and Gomes, L. C. (2009). Effects of water quantity on connectivity: the case of the upper Paraná River floodplain. *Ecohydrology and Hydrobiology*. **9**: 99-113.

Akinbuwa, O. and Adeniyi, I. F. (1991). The Rotifers fauna of Opa Reservoir,Ile- Ife, Nigeria. *J. Afr Zool*. 105, 383-391. Arcifa, M. S. (1984). Zooplankton composition of ten reservoirs in southern Brazil. *Hydrobiologia.* **113**:137-145.

Alcamo, J., Bennett, E.M. and Millennium Ecosystem Assessment Program (2003). Ecosystems and human well-being: a framework for assessment. Island Press, Washington, DC. Pp 245.

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annu. Rev. Ecol. Evol. Syst.* **35**: 257-284.

Amarasinghe, P. B., Vijverberg, J., and Boersma, M. (1997). Production biology of copepods and cladocerans in three south-east Sri Lankan low-land reservoirs and its comparison to other tropical freshwater bodies. *Hydrobiologia*. **350***:*145-162.

Amare Admasu (2005). Study of sediment yield from the Watershed of Angereb reservoir. *Master thesis, Department of Agricultural Engineering,* Alemaya University, Ethiopia.

Amare Minale and Kameswara, R. (2011). Hydrological dynamics and human impact on ecosystems of Lake Tana, northwestern Ethiopia. *Ethiopian Journal of Environmental Studies and Management*. P. 4

ANZECC (1992) Australian and New Zealand Environment and Conservation Council 1992, Australian Water Quality Guidelines for Fresh and Marine Waters, National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council, Canberra

Asbjornsen, H. (2015) Assessing impacts of payments for watershed services on sustainability in coupled human and natural systems. *Bioscience.* **65**: 579–591

Ayalew Wondie (2010). "Improving management of shoreline and riparian wetland ecosystems: the case of Lake Tana catchment." *Ecohydrology and Hydrobiology.* **10**: 123-131.

Ayalew Wondie (2018). "Ecological conditions and ecosystem services of wetlands in the Lake Tana Area, Ethiopia." *Ecohydrology and Hydrobiology.* **18**: 231-244.

Ayalew Wondie and Seyoum Mengistou (2006). Duration of development, biomass and rate of production of the dominant copepods (calanoida and cyclopoida) in Lake Tana, Ethiopia. *SINET: Ethiopian Journal of Science*. **29**: 107-122.

Ayalew Wondie, Seyoum Mengistou, Vijverberg, J. and Eshete Dejen (2007). Seasonal variation in primary production of a large high altitude tropical lake (Lake Tana, Ethiopia): effects of nutrient availability and water transparency. *Aquatic Ecology*. **41**: 195-207.

Ayalew Wondie and Seyoume Mengistou (2014). Seasonal variability of secondary production of cladocerans and rotifers, and their trophic role in Lake Tana, Ethiopia, a large, turbid, tropical highland lake, *Afr. J. Aquat. Sci.***39**: 403-416.

Ayenew Gezie, Wassie Anteneh, Eshete Dejen, and Seid Tiku Mereta (2017). Effects of human-induced environmental changes on benthic macroinvertebrate assemblages of wetlands in Lake Tana Watershed, Northwest Ethiopia. *Environmental monitoring and assessment*. **189**: 152.

Baldwin, D. S., Nielsen, D. L., Bowen, T., and Williams, J. (2005). *Recommended methods for monitoring floodplains and wetlands*. Murray-Darling Basin Commission. Canberra, Australia.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R. E. and Munro, K. (2011). Economic reasons for conserving wild nature. *Science*. **297**: 950-953.

Baral, H., Keenan, R. J., Fox, J. C., Stork, N. E. and Kasel, S. (2013). Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity*. **13**: 35-45.

Baral, H., Keenan, R. J., Stork, N. E. and Kasel, S. (2014). Measuring and managing ecosystem goods and services in changing landscapes: a south-east Australian perspective. *Journal of Environmental Planning and Management*. **57**: 961-983.

Barta, V., Schmidt-Mumm, U. and Janauer, G.A. (2009). Adapting floodplain connectivity conditions – a presolving requisite for sustaining aquatic macrophyte diversity in the UNESCO Biosphere Reserve Lobau (Austria). *Ecohydrology and Hydrobiology*. **9**:73-81

Bastian, O., Grunewald, K., Syrbe, R. U., Walz, U. and Wende, W. (2014). Landscape services: the concept and its practical relevance. *Landscape Ecology*. **29**: 1463-1479.

Batzer, D. P., Pusateri, C. R. and Vetter, R. (2000). Impacts of fish predation on marsh invertebrates: direct and indirect effects. *Wetlands*. **20**: 307-312.

Bedilu Mengistu, Unbushe, D. and Eyualem Abebe (2017). Invasion of Water Hyacinth (*Eichhornia crassipes*) Is Associated with Decline in Macrophyte Biodiversity in an Ethiopian Rift-Valley Lake-Abaya. *Open Journal of Ecology*. **7**: 667-681.

Berry, L. (2003). Land degradation in Ethiopia: Its extent and impact. *Commissioned by the GM with WB support*. Pp 2-7.

Bhatta, L. D., van Oort, B. E. H., Stork, N. E. and Baral, H. (2015). Ecosystem services and livelihoods in a changing climate: Understanding local adaptations in the Upper Koshi, Nepal. *International Journal of Biodiversity Science, Ecosystem Services and Management*. **11**: 145-155.

Bode, R. W., Novak, M. A., Abele, L. E., Heitzman, D. L., and Smith, A. J. (2002). Quality assurance work plan for biological stream monitoring in New York State. New York State Department of Environmental Conservation. *Technical Bulletin, Albany, New York*.

Borre, L., Barker, D.R., Duker, L.E. (2001). Institutional arrangements for managing the great lakes of the world. Results of a workshop on implementing the watershed approach. *Lakes and Reservoirs: Research and Management.* **6**: 199-209.

Boyd, J. and Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological economics*. **63**: 616-626.

Brauman, K. A., Daily, G. C., Duarte, T. K. E. and Mooney, H. A. (2007). The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annu. Rev. Environ. Resour.* **32**: 67-98.

Brendonck, L., Maes, J., Rommens, W., Dekeza, N., Nhiwatiwa, T., Barson, M. and Stevens, M. (2003). The impact of water hyacinth (Eichhornia crassipes) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). II. Species diversity. *Archiv für Hydrobiologie*, **158**: 389-405.

Brown, K., Daw, T., Rosendo, S., Bunce, M. and Cherrett, N. (2008). Ecosystem services for poverty alleviation: marine and coastal situational analysis; Synthesis Report; Report for NERC/DFID: London, UK, 2008.

Burgis, M. J. (1974). Revised estimates for the biomass and production of zooplankton in Lake George, Uganda. *Freshwater Biology*. **4**: 535-541.

Burlakoti, C., and Karmacharya, S. B. (2004). Quantitative analysis of macrophytes of Beeshazar Tal, Chitwan, Nepal. *Himalayan Journal of Sciences*. **2**: 37-41.

Butler, S. (2009). Macquarie concise dictionary. Macquarie University, Sydney

Cain, S. A. (1938). The species-area curve. *American Midland Naturalist*. Pp. 573-581

Caldwell, P. V., Sun, G., McNulty, S. G., Cohen, E. C. and Myers, J. M. (2012). Impacts of impervious cover, water withdrawals, and climate change on river flows in the conterminous US. *Hydrol. Earth Syst. Sci.* **16***:* 2839–2857

Chapin, F.S., Matson, P.A. and Mooney, H.A., (2002). *Principles of terrestrial ecosystem ecology*. Springer, New York, xiv. Pp. 436

Chapman, D. V. (Ed.). (1996). *Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring*. 2nd Edition, CRC Press, Abingdon.

Chaudhary, S., McGregor, A., Houston, D. and Chettri, N. (2015). The evolution of ecosystem services: A time series and discourse-centered analysis. *Environmental Science and Policy*. **54**: 25-34.

Chen, H. G., Peng, F., Zhang, Z. Y., Zhang, L., Zhou, X. D., Liu, H. Q. and Xu, X. F. (2012). Effects of engineered use of water hyacinths (*Eicchornia crassipes*) on the zooplankton community in Lake Taihu, China. *Ecological Engineering*. **38**: 125-129.

Chicharo, L., Radhouane, B. H., Ana, A., Pedro, R., Carmen, M., David, P., Rute, M., Pedro, M., and Maria, A. C. (2009). "Application and demonstration of the Ecohydrology approach for the sustainable functioning of the Guadiana estuary (South Portugal)." *Ecohydrology and Hydrobiology*. **9**:55-71.

Chicharo, L., Wagner,I ,Chicharo,M., M. Łapinska,M. and Zalewski,M. (2009). "Practical experiments guide for ecohydrology". *UNESCO Manual*, Faro, Portugal. P. 121.

Cochran, W. G. (1977). Sampling Techniques. 3rd ed. *New York, N.Y. (USA) John Wiley and Sons.* Pp. 400-411

Convention on Biological Diversity (2014). Global Biodiversity Outlook 4. Secretariat of the Convention on Biological Diversity. http://www.cbd.int/gbo4/

Coomes, O. T., Barhamb, B. L. and Takasakic, Y. (2004). Targeting conservation–development initiatives in tropical forests: insights from analyses of rain forest use and economic reliance among Amazonian peasants. *Ecological Economics.* **51**: 47– 64.

Costanza, R. (2006). Nature: ecosystems without commodifying them. *Nature*. **443**: 749

Coulter, G. W. (1963). Hydrological changes in relation to biological production in southern Lake Tanganyika. *Limnology and Oceanography*. **8** :463-477.

Curtis, J.T. (1959). *The vegetation of Wisconsin*. University of Wisconsin Press, Madison.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L. and Shallenberger, R. (2009). Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*. **7**: 21-28.

Dearing, J.A., Battarbee, R.W., Dikau, R. (2006). Human–environment interactions: Learning from the past. *Regional Environmental Change.* **6**: 1–16.

Dechasa Jiru (2010). Indiscriminate devegetation under improper farming system: a root cause for surface and underground water and food crisis in Ethiopia. *Ecohydrology and Hydrobiology*. **10**: 201-209.

Deepa, P., Raveen, R., Venkatesan, P., Arivoli, S., and Samuel, T. (2016). Seasonal variations of physicochemical parameters of Korattur lake, Chennai, Tamil Nadu, India. *International Journal of Chemical Studies*. **4**: 116-123.

Dereje Tewabe (2014). Impacts of Furrow Irrigation on Shesher and Welala Natural Reservoirs of Lake Tana Sub Basin, Ethiopia. *Journal of Biodiversity, Bioprospect and Development*. **1**: 1-7.

Dhembare, A. J. (2011). Statistical approaches for computing diversity and density of zooplankton with water factors in Mula Dam, Rahuri, MS, India. *European Journal of experimental biology*. **1**: 68-76.

Difranco, J. (2006). Protocols for sampling aquatic macroinvertebrates in freshwater wetlands. *Maine Department of Environmental Protection.* No. *DEPLW0640*.

Dorney, J., Savage, R., Tiner, R. W., and Adamus, P. (Eds.) (2018). *Wetland and Stream Rapid Assessments: Development, Validation, and Application*. Academic Press.

Eagleson, P. S. (2005). *Ecohydrology: Darwinian expression of vegetation form and function*. Cambridge University Press. Cambridge.

Edmondson, W.T and G.G. Winberg (eds.). (1971) A manual on methods for the assessment of secondary production. IBP Handbook. P. 358

Emmanuel, B. E. and Onyema, I. C. (2007). The Plankton and fishes of a tropical creek in South-western Nigeria. *Turkish Journal of Fisheries and Aquatic Sciences*. **7**: 105-113.

Environmental Protection Agency, U. S. (2003). National primary drinking water standards. *Office of Water, US Environmental Protection Agency. Washington, DC, United States Environmental Protection Agency.*

Environmental Protection Authority of Ethiopia (2003). "Provisional Emission Standard for Ethiopia," EPA, Addis Ababa.

FDREEPA and UNIDO, Federal Democratic Republic of Ethiopia EPA and UN Industrial Development Organization (2003). Guideline ambient environment standards for Ethiopia. Ecologically sustainable industrial development (ESID). Addis Ababa, Ethiopia.

Eshete Dejen, Sibbing F. and Vijverberg J. (2003). The reproductive biology of two „small barbs" (Barbus humilis and B. tanapelagius: Cyprinidae) in Lake Tana, Ethiopia. Netherlands. *J. Zool*.**52**: 281–299.

Eshete Dejen, Vijverberg, J., Nagelkerke, L. and Sibbing, F. (2004). Temporal and spatial distribution of micro crustacean zooplankton in relation to turbidity and other environmental factors in large tropical lake (Lake Tana, Ethiopia). *Hydrobiologia*. **513**:39-49.

Eshete Dejen, Wassie Anteneh and Vijverberg, J. (2017). The decline of the Lake Tana (Ethiopia) fisheries: causes and possible solutions. *Land Degradation and Development*. **28**:1842-1851.

Ethiopian Wildlife and Natural History Society (EWNHS) (1996). Important Bird Areas of Ethiopia. First inventory. *Ethiopian Wildlife and Natural History Society*. Addis Ababa, Ethiopia.

Ethiopian Wildlife and Natural History Society and Wetlands International (2018). *A First Directory of Ethiopian Wetlands*: Descriptions, Ecosystem Services, Causes of Degradation and Recommendations for Restoration and Sustainability. *Ethiopian Wildlife and Natural History Society and Wetlands International*. Ethiopia

Environmental Protection Authority of Ethiopia (2003). "Provisional Emission Standard for Ethiopia," EPA, Addis Ababa.

Falkenmark, M. (2003). Freshwater as shared between society and ecosystems: from divided approaches to integrated challenges. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*. **358**: 2037-2049.

Falkenmark, M., Gottschalk, L., Lundqvist, J. and Wouters, P. (2004). Towards integrated catchment management: increasing the dialogue between scientists, policy-makers and stakeholders. *International Journal of Water Resources Development*. **20**: 297-309.

Fish, G.R. (1957). A seiche movement and its effect on the hydrology of Lake Victoria. *Fish Pub., Lond.* **10**: 1-68.

Gaudet, J. and Muthuri, F.M. (1981). Nutrient relationships in shallow water in an African lake, Lake Naivasha. *Oecologia*. **49**:109–118.

Galatowitsch, S. M., Whited, D. C., Lehtinen, R., Husveth, J. and Schik, K. (2000). "The vegetation of wet meadows in relation to their land-use." *Environmental Monitoring and Assessment*. **60**: 121-144.

Gasse, F., (1987). Ethiopie et Djibouti. In *African wetlands and shallow water bodies*. In M. J.

Burgis and J. J. Symoens (eds.). Travaux et documents/ Institut Francais de Recherche Scientifique pour le Development en cooperation no. 211 Paris, ORSTOM: 300-311.

Gell, P., Fritz, S.C. and Battarbee, R.W. (2007) LIMPACS – Human and climate interactions with lake ecosystems: Setting research priorities in the study of the impact of salinization and climate change on lakes. *Hydriobiologia.* **591**: 99–101.

Gencer, T. and Nilgun, K. (2010). Applications of Various Diversity Indices to Benthic Macroinvertebrate Assemblages in Streams of a Natural Park in Turkey. Hacettepe University, Science Faculty, Biology Department, Hydrobiology Section, Ankara, Turkey. *Review of Hidrobiology*. **32**: 125.

Gereta, E., Mwangomo, E. and Wolanski, E. (2009). Ecohydrology as a tool for the survival of the threatened Serengeti ecosystem. *Ecohydrology and Hydrobiology*. **9**: 115-124.

Giraldo, E. and Garzon, A. (2002). The potential for water hyacinth to improve the quality of Bogota River water in the Muña Reservoir: comparison with the performance of waste stabilization ponds. *Water Science and Technology*. **42**: 103-110.

Gleick, P.H. (2003). Global freshwater resources: soft-path solutions for the 21st century. *Science* **302**:1524–1528

Gopal, B.; Wolfgang, J.; Junk, C.M.; Finlayson, C. and Breen, C.M. (2008). Present state and future of tropical wetlands'. In *Aquatic Ecosystems*; Polunin, N., Ed.; Cambridge University Press, for the Foundation for Environmental Conservation: Cambridge, UK. Pp. 141–154.

Goraw Goshu (2010). Enhancing wetland ecosystem services through engineering intervention: A management plan for treatment of municipal wastewater, Bahir Dar Gulf of Lake Tana, Ethiopia. Amhara Regional Agricultural Research Institute.

Gret-Regamey, A., Brunner, S. H. and Kienast, F. (2012). Mountain ecosystem services: who cares?. *Mountain Research and Development*. **32**: 23–34.

Grootjans, A. B., van Wirdum, G., Kemmers, R. and van Diggelen, R. (1996). Ecohydrology in The Netherlands: principles of an application-driven interdiscipline. *Acta Botanica Neerlandica*. **45**: 491-516.

Hakanson, L. (1981). Morphometric parameters, in chapter 4.4 of '*A manual of Lake Morphometry'*. Springer-Verlag, Berlin, Heidelberg. Pp. 26-70.

Hanibal Lemma, Frankl, A., Poesen,J., Enyew Adgo, and Nyssen, J. (2017). Classifying land cover from an object -orented approach- Applied to LANDSAT 8 at the regional scale of the Lake Tana Basin (Ethiopia). Poster presented at EGU General Assembely. *Geophysical Research Abstracts*. **19**: EGU2017-EGU3526

Hecky, R.E. and Kling, H.J. (1981). The phytoplankton and protozooplankton of the eutrophic zone of Lake Tanganyika: species composition, biomass, chlorophyll content and spatio-temporal distribution. *Limnol. Oceanogr.* **26**: 548-564.

Hilsenhoff, W. L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American benthological society*. **7**:65-68.

Hobbs, R. J., Hallett, L. M., Ehrlich, P. R. and Mooney, H. A. (2011). Intervention ecology: applying ecological science in the twenty-first century. *BioScience.* **61**: 442-450.

Hobbs, R.J., Cramer, V.A. (2008). Restoration ecology: Interventionist approaches for restoring and maintaining ecosystem function in the face of rapid environmental change. *Annual Review of Environment and Resources.* **33**: 39–61

Humbert, J. F. and Dorigo, U. (2005). Biodiversity and aquatic ecosystem functioning: A mini-review. *Aquatic Ecosystem Health and Management*. **8**: 367-374.

Ibrahim Mohammed and Minwyelet Mengist (2019). Status, threats and management of wetlands in the Lake Tana sub-basin: a review. *Journal of Agriculture and Environmental Sciences*. **3:56-95**

IEP (2009). *Overview and Comparison of Macrophyte Survey Methods Used in European Countries and A Proposal of Harmonized Common Sampling Protocol to be Used for WISER Uncertainty Exercise Including a Relevant Common Species List*. WISER, Warsaw. 32pp

International Council for Science and United Nations Educational, Scientific and Cultural Organization and United Nations University (2008). Ecosystem Change and Human Well-being: Research and Monitoring Priorities Based on the Millennium Ecosystem Assessment; International Council for Science. Paris, France.

International Fund for Agricultural Development (2007). *Baseline Information on Agronomy/Crop Production.* Bahir Dar, Ethiopia: Amhara National regional State.

International Fund for Agricultural Development (2007). *Community-Based Integrated Natural Resources Management Project in Lake Tana Watershed - Ethiopia. IFAD project document (third draft: 31 August 2007).* Government of the Federal Democratic Republic of Ethiopia & International Fund for Agricultural Development.

International Union for Conservation of Nature (1992). Guideline for Aid Agencies for Improved Conservation and Sustainable Use of Tropical and Sub-Tropical Wetlands; OECD: Paris, France.

Irvine, K., Waya, R., (1999). Spatial and temporal patterns of zooplankton standing biomass and production in L. Malawi. *Hydrobiologia.* **407**: 191–205.

Jackson, R. B., Carpenter, S. R., Dahm, C. N., McKnight, D. M., Naiman, R. J., Postel, S. L. and Running, S. W. (2001). Water in a changing world. *Ecological applications*. **11**:1027-1045.

Janse, J. H., Kuiper, J. J., Weijters, M. J., Westerbeek, E. P., Jeuken, M. H. J. L., Bakkenes, M., and Verhoeven, J. T. A. (2015). GLOBIO-Aquatic, a global model of human impact on the biodiversity of inland aquatic ecosystems. *Environmental Science and Policy*. **48**: 99-114.

Jorgensen, S. E. (1996). The application of ecosystem theory in limnology. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen*. **26**: 181-192.

Junk,W.J. (1989).The use of Amazonian floodplains under an ecological perspective. *Interciencia*. **14**: 317-322.

Kalff, J. (2002). *Limnology: Inland waters Ecosystems.* Prentice-Hall.Inc. USA.

Karunamoorthi, K. (2009). Toxic effects of traditional Ethiopian fish poisoning plant Milletia ferruginea (Hochst) seed extract on aquatic macroinvertebrates. *European Review for Medical and Pharmacological Sciences*. **13**:179–185

Seifu Kebede, Travi, Y., Tadesse Alemayehu, Marc, V.(2006). Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia. *Journal of Hydrology*. **316**: 233-247.

Keddy, P. A. (2010). *Wetland ecology: principles and conservation*. Cambridge University Press.

Keeler, B. L., Polasky, S., Brauman, K. A., Johnson, K. A., Finlay, J. C., O'Neill, A. and Dalzell, B. (2012). Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences*. **109***:* 18619-18624.

Khanna, D. R. and Bhutiani, R. (2003). Ecological status of Sitapur pond at Hardwar (Uttarnchal), India. *Indain J. Env and Eco. Pla*. **4**: 109-122.

Khanna, D. R., Gautam, A., Chug, T. and Sarkar, P. (2000). Impact of abiotic factors on the planktonic population of pond. *Env. Cons. J*. **1**: 41-46.

Kimmel, B. L. (1990). Reservoir primary productivity. *Reservoir limnology-ecological perspectives*. Pp.133-199.

Kratzer, E. B. and Batzer, D. P. (2007). Spatial and temporal variation in aquatic macroinvertebrates in the Okefenokee Swamp, Georgia, USA. *Wetlands.* **27**: 127-140.

Kumar, N.J.I., Verma, Y., Kumar, R.N. (2011). Spatial Analysis of Composition and Species Interactions with Temporal Variation of Zooplankton Community of Shallow Tropical Lake: Thol Bird Sanctuary, India. *Universal Journal of Environmental Research and Technology*. **1**: 151-159.

Kundzewicz, Z. W. (1999). Flood protection-sustainability issues. *Hydrological Sciences Journal*. **44**: 559-571.

Kurki, H., Vuorinen, I., Bosma, E., Bwebwa, D., (1999). Spatial and temporal changes in copepod zooplankton communities of Lake Tanganyika. *Hydrobiologia.* **407**: 105–114.

Lamprecht, H. (1989). Silviculture in the Tropics. *GTZ, Eschborn, Germany*. P. 296.

Lampert, W. and Sommer, U. (1997). *Limnoecology: the ecology of lakes and streams*. Oxford University Press. New York.

Lewis Jr, W. M. (1987). A revised classification of lakes based on mixing. *Canadian Journal of Fisheries and Aquatic Sciences*. **40***:*1779-1787.

Leykun Abunie (2003). The distribution and status of Ethiopian wetlands: an overview. *Wetlands of Ethiopia*. P.12

Ligdi, E. E. (2008). Ecohydrology as an important tool for integrated water resources management in the Nile basin portion in Ethiopia: *The case of the Lake Tana sub-basin: a case study report Paper presented to the 2nd eco-hydrology component workshop*, Nairobi, Kenya.

Ligdi, E. E., El Kahloun, M. and Meire, P. (2010). Ecohydrological status of Lake Tana-A shallow highland lake in the Blue Nile (Abbay) basin in Ethiopia. *Ecohydrology and Hydrobiology*. **10**: 109-122.

Loh, J., Wackernagel, M. (2012). Living Planet Report. WWF, Gland.

Lolis, L. A., Alves, D. C., Fan, S., Lv, T., Yang, L., Li, Y., and Thomaz, S. M. (2020). Negative correlations between native macrophyte diversity and water hyacinth abundance are stronger in its introduced than in its native range. *Diversity and Distributions*. **26**: 242-253.

Magurran, A. E. (1988). *Ecological diversity and its measurement*. Princeton university press. Chapman and Hall, London.

Maksimovic, C. (2005). Proceedings of the International UNESCO Workshop" Aquatic Habitats in Integrated Urban Water Management" within the framework of the International Hydrological Programme (IHP) and the Man and the Biosphere (MAB) Programme. 18-20 September 2005, Lodz, Poland. *Ecohydrology and Hydrobiology*. **5**: 261.

Malinga, R., Gordon, L. J., Lindborg, R. and Jewitt, G. (2013). Using participatory scenario planning to identify ecosystem services in changing landscapes. *Ecology and Society*. **18**: 10

Mareau, J., Nyakageni, B., Pearce, M. and Petit, P. (1993). Trophic relationships in the pelagic zone of Lake Tanganyika (Burundi Sector). In *Trophic models of aquatic ecosystems. ICLARM Conf. Proc*. **26**: 138-143.

Masifwa, W. F., Twongo, T., and Denny, P. (2001). The impact of water hyacinth, Eichhornia crassipes (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. *Hydrobiologia*. **452**: 79–88.

Mcallister, E., Craig, J. F., Davidson, N., Delany, S., and Ii, M. S. (2001). Biodiversity Impacts of Large Dams Background Paper No. 1; Prepared for IUCN/UNEP/WCD: Gland, Switzerland.

McVea, C. and Boyd, C. E. (1975). Effects of waterhyacinth cover on water chemistry, phytoplankton, and fish in ponds. *Journal of Environmental Quality*. **4:** 375-378.

Meerhoff, M., Fosalba, C., Bruzzone, C., Mazzeo, N., Noordoven, W., and Jeppesen, E. (2006). An experimental study of habitat choice by Daphnia: plants signal danger more than refuge in subtropical lakes. *Freshwater Biology*. **51**: 1320-1330

Meqaunint Asres and Seleshi Awulachew (2010). SWAT based runoff and sediment yield modelling: a case study of the Gumera watershed in the Blue Nile basin. *Ecohydrology & Hydrobiology*. **10**: 191-199.

Meybeck, M. (2003). Global analysis of river systems: from Earth system controls to Anthropocene syndromes. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*. **358**: 1935-1955.

Millennium Ecosystem Assessment Program (2005). Ecosystems and human well-being: *Synthesis*. Island Press,Washington, DC, USA. **5**: 563

Misra, R. (1968). *Ecology workbook.* Oxford and IBH Publishing Co., New Delhi.

Mitsch, W. J. (1996). Ecological engineering: a new paradigm for engineers and ecologists. *Engineering within Ecological Constraints. National Academy Press, Washington, DC*. Pp. 114-132.

Mitsch, W. J. and Gosselink, J. G. (2000). The value of wetlands: importance of scale and landscape setting. *Ecological economics*. **35**:25-33.

Mitsch, W.J. and Gosselink, J.G. (1993). *Wetlands*(second edn). John Wiley Inc., New York, USA.

Mitsch, W.J. and Gosselink, J.G. (2007). *Wetland*, 4th ed.; John Wiley: New York, USA.

Mohammed Ibrahim and Minwyelet Mengist (2018). "Status, Threats and Management of Wetlands in the Lake Tana Sub-basin: A Review." *Journal of Agriculture and Environmental Sciences.* **3**:23-45.

Mopelwa, G. and Blignaut, J. N. (2006). The Okavango Delta. The value of tourism: economic. *South African Journal of Economic and Management Sciences*. **9**:113-127.

Morrison, E. H. and Harper, D. M. (2009). Ecohydrological principles to underpin the restoration of Cyperus papyrus at Lake Naivasha, Kenya. *Ecohydrology and Hydrobiology*. **9**: 83-97.

Naiman R.J., Magnuson J.J., McKnight D.M. and Stanford J.A. (1995). *The freshwater imperative*, Island press. P. 165

Naiman, R. J. and Decamps, H. (1990). *The ecology and management of aquatic-terrestrial ecotones*. UNESCO MAB series. The Parthenon Publishing Group/UNESCO, Paris, France. Vol. **4**

Narasimha, R. K. and Benarjee, G. (2013). Physico-chemical factors influenced plankton biodiversity and fish abundance-a case study of Nagaram tank of Warangal, Andhra Pradesh. *International Journal of Life Sciences Biotechnology and Pharma Research*. **2**: 248-260.

Negash Atnafu, Eshete Dejen and Vijverberg, J. (2011). Assessment of the ecological status and threats of Welala and Shesher Wetlands, Lake Tana sub-basin (Ethiopia). *Journal of Water Resource and Protection.* **3**: 7-540.

Nuttle, W. K. (2002). Eco-hydrology's past and future in focus. *Eos, Transactions American Geophysical Union*. **83**: 205-212.

Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Haile, M. and Lang, A. (2004). Human impact on the environment in the Ethiopian and Eritrean highlands- A state of the art. Earth-Science Reviews. **64**: 273–320. https://doi.org/10.1016/S0012-8252(03)00078-3

Ostrom, E., Janssen, M. A. and Anderies, J. M. (2007). Going beyond panaceas. *Proceedings of the National Academy of Sciences*, USA. **104**: 15176-15178.

Owuor, J. B., Raburu, P. O., and Kwena, F. (2012). Community based approach to the management of Nyando wetland, Lake Victoria Basin, Kenya.

Paudyal, K., Baral, H., Burkhard, B., Bhandari, S. P. and Keenan, R. J. (2015). Participatory assessment and mapping of ecosystem services in a data-poor region: Case study of community-managed forests in central Nepal. *Ecosystem services*. **13**: 81-92.

Phul, K.S. R. (2016). Physico-chemical study of Mohan Ram Lake Shahdol (M.P.*). International Journal of Applied Research*. **2**: 1

Pickett, S. T. A., and Parker, V. T. (1994). Avoiding the old pitfalls: opportunities in a new discipline. *Restoration Ecology*. **2**: 75-79.

Prasad, S. N., Ramachandra, T. V., Ahalya, N., Sengupta, T., Kumar, A., Tiwari, A. K. and Vijayan, L. (2002). Conservation of wetlands of India-a review. *Tropical Ecology*. **43**:173-186.

Purushothama, R., Sayeswara, H. A., Goudar, M. A., and Harishkumar, K. (2011). Physicochemical profile and zooplankton community composition in Brahmana Kalasi Tank, Sagar, Karnataka, India. *Ecoscan*. **5**: 99-103.

Ramachandra, T. V. (2001). Restoration and management strategies of wetlands in developing countries. *Electronic Green Journal.* **1***:* 1076-7975.

Ramachandra,T.V., Alakananda, B., Rani, A., and Khan, M. A.(2011).“Ecological and socio-economic assessment of Varthur wetland, Bengaluru (India),” *Journal of Environmental Science and Engineering*. **53**: 101–108

Ramsar Convention Secretariat (2007). Wise use of wetlands: A conceptual framework for the wise use of wetlands. In *Ramsar Handbooks for the Wise Use of Wetlands*, 3rd ed.; RCS: Gland, Switzerland. pp. 8–9.

Rebelo, L. M., McCartney, M. P., and Finlayson, C. M. (2010). Wetlands of Sub-Saharan Africa: distribution and contribution of agriculture to livelihoods. *Wetlands Ecology and Management*.**18**: 557-572.

Revenga, C., Campbell, I., Abell, R., de Villiers, P. and Bryer, M. (2005). Prospects for monitoring freshwater ecosystems towards the 2010 targets. *Philosophical Transactions of the Royal Society B: Biological Sciences*. **360**: 397-413.

Rewati, N. (2012). Evaluation of the limnological status of Beeshazar Lake, a Ramsar Site in central Nepal. *Journal of Water Resource and Protection*. **4**: 256–263.

Ricaurte, L. F., Wantzen, K. M., Agudelo, E., Betancourt, B. and Jokela, J. (2014). Participatory rural appraisal of ecosystem services of wetlands in the Amazonian Piedmont of Colombia: elements for a sustainable management concept. *Wetlands ecology and management*. **22**: 343-361.

Rocha-Ramirez, A., Ramirez-Rojas, A., Chávez-Lopez, R., and Alcocer, J. (2007). Invertebrate assemblages associated with root masses of *Eichhornia crassipes* (Mart.) Solms-Laubach 1883 in the Alvarado lagoonal system, Veracruz, Mexico. *Aquatic Ecology*. **41**: 319–333.

Rodriguez-Iturbe, I. (2000). Ecohydrology: A hydrologic perspective of climate-soil-vegetation dynamies. *Water Resources Research*. **36**: 3-9.

Rommens, W., Maes, J., Dekeza, N., Inghelbrecht, P., Nhiwatiwa, T., Holsters, E. and Brendonck, L. (2003). The impact of water hyacinth (*Eichhornia crassipes*) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). I. Water quality. *Archiv für Hydrobiologie*. **158**: 373-388.

Ryszkowski, L. (2002). The functional approach to agricultural landscape analysis. *Landscape Ecology in Agroecosystems Management*. P. 1

Sarandón, R., Novillo, M. G., Muschong, D. and Borges, V. G. (2009). Lacar Lake demonstration project for ecohydrology: improving land use policy at Lacar Lake Watershed based on an ecohydrological approach (San Martín de los Andes–Neuquén–R. Argentina). *Ecohydrology and Hydrobiology*. **9**: 125-134.

Saulnier-Talbot, E. (2016) Paleolimnology as a tool to achieve environmental sustainability in the Anthropocene: An overview. *Geosciences.* **6**: 26.

Schabhuttl, S., Hingsamer, P., Weigelhofer, G., Hein, T., Weigert, A. and Striebel, S. (2013). Temperature and species richness effects in phytoplankton communities. *Oecologia*, **171**: 527–536.

Schuyt, K. and Brander, L. (2004). *Living Waters: Conserving the Source of Life: the Economic Values of the World's Wetlands*. World Wide Fund for Nature. Gland, Switzerland.

Schuyt, K. D. (2005). Economic consequences of wetland degradation for local populations in Africa. *Ecological economics*. **53**:177-190.

Serruya, C. and Pollingher, U. (1983). *Lakes of the warm belt*. London, Cambridge University Press. pp 1-569

Sewmehon Demissie and Girma Tesfahun (2004). Lake Tana: a socioeconomic synopsis. In *Amhara Regional Agricultural Research Institute, Bahir Dar. Paper presented to The Lake Tana Resource Management Workshop.* Bahirdar, Ethiopia.

Seyoum Mengistou and Fernando, C.H., (1991). Biomass and production of major dominant crustacean zooplankton in a tropical rift valley lake, Awasa, Ethiopia. *J. Plankton Res*. **13**: 831–852.

Shannon, C. and Weiner, W. (1963). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, Illinois. Pp. 117.

Shewit Gebremedhin, Minwyelet, M., Tesfaye, M., Lewoye, T., and Ferehiwot, M. (2017). Land use change and its drivers in Kurt Bahir wetland, north-western Ethiopia. *African Journal of Aquatic Science*. **42**: 45-54.

Shewit Gebremedhin, Abebe Getahun, Wassie Anteneh, Bruneel, S., and Goethals, P. (2018). A drivers-pressure-state-impact-responses framework to support the sustainability of fish and fisheries in Lake Tana, Ethiopia. *Sustainability*. **10**: 2957.

Shimelis Aynalem and Afework Bekele (2008). Species composition, relative abundance and distribution of bird fauna of riverine and wetland habitats of Infranz and Yiganda at southern tip of Lake Tana, Ethiopia. *Tropical Ecology*. **49**:199-209.

Shimelis Setegn , Srinivasan, R., Dargahi, B., and Assefa Melesse (2009). Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. *Hydrological Processes: An International Journal*. **23**: 3738-3750.

Shimelis Setegn, Srinivasan, G. R. and Dargahi, B. (2008). "Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model." *The Open Hydrology Journal.* Vol. **2**

Shimelis Setegn, Srinivasan, R., Dargahi, B. and Assefa Melese (2009). Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. *Hydrological Processes: An International Journal*. **23**:3738-3750.

Simon, M., Grossart, H. P., Schweitzer, B., and Ploug, H. (2002). Microbial ecology of organic aggregates in aquatic ecosystems. *Aquatic microbial ecology*, *28*(2), 175-211.

Sisay Misganaw (2018). *Assessment of the impact of anthropogenic activities on water quality, biodiversity and livelihood in Lake Tana, Northwestern Ethiopia* (Doctoral dissertation), University of South Africa

SMEC, X. (2008). Hydrological study of the Tana-Beles sub-basins, main report, Surface *water investigation,* Ministry of Water Resource, Addis Ababa, Ethiopia.

Solomon Mulugeta (2004). Socio-economic determinants of wetland cultivation in Kemise, Illubabor Zone, Southwestern Ethiopia. *Eastern Africa social science research review*. **20**: 93-114.

Somlyody, L., Yates, D. and Varis, O. (2001) Challenges to freshwater management. In: *Catchment Processes Land/Water Ecotones and Fish Communities* (Guest eds: Zalewski, M., Schiemer, F. and Thorpe, J.). *International Journal of Ecohydrology and Hydrobiology.* **1**: 65-96.

Staskraba, M. and Tundisi, J.G. (1999). Reservoir ecosystem functioning: theory and application. In: *Theoretical Reservoir Ecology and its Applications* (ed. by Staskraba, M. and Tundisi, J.G), Backhuys, Leiden, the Netherlands. Pp. 565-597.

Stave, K., Goraw Goshu and Shimellis Aynalem, (eds.) (2017). *Social and ecological system dynamics*: Characteristics, trends and integration in the Lake Tana basin, Ethiopia. AESS Interdisciplinary Environmental Studies and Sciences Series. Springer Verlag.

Sun, G. and Vose, J. M. (2016). Forest management challenges for sustaining water resources in the Anthropocene. *Forests*. **7**: 68.

Sutherland, W. (1996). *Ecological Census Techniques a Handbook*. Cambridge University Press, Cambridge. P 336

Talling, J.F. (1966). The annual cycle of stratification and phytoplankton growth in Lake Victoria (East Africa). *Int.Rev.ges. Hydrobiologie.* **51**: 545-621.

Talling, J.F. (1986). The seasonality of phytoplankton in African lakes. *Hydrobiologia.* **138**: 139-160.

Tana, Ethiopia. PhD thesis, Wageningen Agricultural University. Pp. 143.

Tesfaye Wudneh (1998). *Biology and Management of Fish Stocks in Bahar Dar Gulf, Lake Tana, Ethiopia*. Ph.D. thesis, Wageningen Agricultural University.

Tilahun Amede and Yitbarek Nigatu (2001). Interaction of components of sweetpotato-maize intercropping under the semi-arid conditions of the Rift-Valley, Ethiopia. *Tropical agriculture*. **78**: 1-7.

Tundisi, J. G. and Straskraba, M. (Eds.) (1999). *Theoretical reservoir ecology and its applications*. Ann Arbor: International Institute of Ecology.

Turyahabwe, N., Tumusiime, D.M., Kakuru, W., Barasa, B. (2013). Wetland use/cover changes and local perceptions in Uganda. Sustain. *Agric. Res*. **2**: 95.

U.S. Environmental Protection Agency (1990). “The Quality of our Nation’s Water: A Summary of the 1988 National Water Quality Inventory,” EPA Report 440/4-90-005, Washington D.C.

United Nations Educational, Scientific and Cultural Organization (UNESCO) World Healthorganization (WHO) United Nations Environment Programme (UNEP) (1996. Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition. Pp.651

USEPA (U.S Environmental Protection Agency) (2002). Summary of biological assessment programs and bio-criteria development for states, tribes, territories, and interstate commissions: streams and wadeable rivers. *USEPA, Office of Environmental Information and Office of Water*. Washington, D.C.

Valentina, S., Momir, P., Branko, M. Vasil, K., Milica, R. and Donka, M. 2011. Water Quality Assessment Based on the Macroinvertebrate Fauna - the Pcinja River Case Study. Water Research and Management. **1**: 63-69.

van Oort, B., Bhatta, L. D., Baral, H., Rai, R. K., Dhakal, M., Rucevska, I. and Adhikari, R. (2015). Assessing community values to support mapping of ecosystem services in the Koshi river basin, Nepal. *Ecosystem Services*. **13**: 70-80.

Verhoeven, J. T., Arheimer, B., Yin, C., and Hefting, M. M. (2006). Regional and global concerns over wetlands and water quality. *Trends in ecology and evolution*. **21**: 96-103.

Villamagna, A. M. and Murphy, B. R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): a review. *Freshwater biology*. **55**: 282-298.

von Weizsacker, E. U., Lovins, A. B. and Lovins, L. H. (2014). Factor Four: Doubling Wealth-Halving Resource Use: A New Report to the Club of Rome. In *Ernst Ulrich von Weizsäcker.* London, UK. Pp. 127-141.

Vorosmarty, C.J. (2002). Global water assesment and potential controbutions from Earth Systems Science. *Aquatic Science*. **64**:328–351

Wagner, W., Gawel, J., Furumai, H., De Souza, M. P., Teixeira, D., Rios, L. and Hemond, H. F. (2002). Sustainable watershed management: an international multi-watershed case study. *Ambio*. **31**: 2-13

Wagner, I., Marsalek, J. and Breil, P. (2008). *Aquatic habitats in sustainable urban water management: Science, policy and practice.* UNESCO Publishing. Taylor and Francis. Balkema: Leiden. Pp. 229

Wagner, I., Izydorczyk, K., Kiedrzyńska, E., Mankiewicz-Boczek, J., Jurczak, T., Bednarek, A. and Zalewski, M. (2009). Ecohydrological system solutions to enhance ecosystem services: the Pilica River Demonstration Project. *Ecohydrology and Hydrobiology*. **9**: 13-39

Wang, Z. and Yan, S. H. (2017). Direct and Strong Influence of Water Hyacinth on Aquatic Communities in Natural Waters. In *Water Hyacinth.* CRC Press. Pp. 44-65.

Wei, Q., Tong, L., Gondwe, J., Lv, X., Tong, W. and Liu, Y. (2015). Non-use value trends analysis of wetland ecosystem in the Sanjiang Plain, Northeast China. *Wetlands ecology and management*. **23**: 347-355

Wei, H., Fan, W., Ding, Z., Weng, B., Xing, K., Wang, X. and Dong, X. (2017). Ecosystem services and ecological restoration in the Northern Shaanxi Loess Plateau, China, in relation to climate fluctuation and investments in natural capital. *Sustainability*. **9**: 199.

Wetzel, R and Likens, G. (2000). *Limnological analysis*, 3rd ed. New York: Springer-Verlag.

Wetzel, R. (2001). *Limnology: lake and river ecosystems*. Elsevier Academy Press, St Louis, USA. P. 1006

Williamson, C. E., Dodds, W., Kratz, T. K., and Palmer, M. A. (2008). Lakes and streams as sentinels of environmental change in terrestrial and atmospheric processes. *Frontiers in Ecology and the Environment*. **6**: 247-254.

Williamson, M. (1999). Invasions. *Ecography*. **22**: 5-12.

Wittmann, F., Schöngart, J., Queiroz, H. L., de Oliveira Wittmann, A., dos Santos Conserva, A., Piedade, M. T. and Junk, W. J. (2009). The Amazon floodplain Demonstration Site: Sustainable timber production and management of Central Amazonian white-water floodplains. *Ecohydrology and Hydrobiology*. **9**: 41-54.

Woube Mengistu (2008). The role of Wetlands in Biodiversity Conservation and Management in Ethiopia: a case study of Berga Floodplain. In *An overview in Proceedings of the National Stakeholders' Workshop on Creating National Commitment for Wetland Policy and Strategy Development in Ethiopia Shimeles Sima and Geremew G/Selassie (eds)*.

Wu, J. (2013). Landscape sustainability science: ecosystem services and human well-being in changing landscapes. *Landscape ecology*. **28**: 999-1023.

Xu, J., Zhang, M. (2012). Primary consumers as bioindicator of nitrogen pollution in lake planktonic and benthic food webs. *Ecological Indicators*. **14**: 189-196.

Yezbie Kassa (2016). *Macrophyte ecology, nutrient dynamics and water quality of the littoral zone, and Yitamot wetland, Lake Tana, Ethiopia* (Doctoral dissertation, Ph. D. Thesis, Addis Ababa University Addis Ababa, Ethiopia).

Yirga Kebede and Hassen Muhabaw (2015). Spatial Variation of Sediment Physicochemical Characteristics of Lake Tana, Ethiopia. *J. Environ. Earth Sci.* **5**: 95-109.

Yitaferu Birru, Hurni H. and Getu Zeleke (2004). "Processes of land degradation in the Lake Tana Basin (LTB), Amhara region, Ethiopia." In *Proceeding of the Symposium on Lake Tana watershed management.* Bahir Dar University. Pp. 5-12.

Yohannes Zerihun (2016). *Capacity Building in ecohydrology and promotion of ecohydrology demonstration site practices. Ecohydrology web platform*. Addis Ababa, Ethiopia.

Zalewski, M. (2002)**.** Ecohydrology, the use of ecological and hydrological processes for sustainable management of water resources**.** *Hydrological Sciences-Journal des Sciences hydrologiques.* **47**: 823-832

Zalewski, M., (2011). Ecohydrology for implementation of the EU water framework directive. *Proceedings of the Institution of Civil Engineers* (ICE Publishing). Pp. 11

Zalewski, M. (1992). Ecotones at the river basin scale: global land/water interactions. In *Proceedings of Ecotones Regional Workshop,* Burmera, South Australia. Pp. 13-17

Zalewski, M. (1995). Freshwater habitat management and restoration in the face of global changes. In *Condition of the World's Aquatic Habitats, Proceedings of the World Fisheries Congress, Theme.* Athens. *Oxford Acad. Publ*. **1**: 170-194

Zalewski, M. (2000). Ecohydrology-the scientific background to use ecosystem properties as management tools towards sustainability of water resources. *Ecological Engineering.* **16**: 1-8

Zalewski, M. (2002). Ecohydrology-the use of ecological and hydrological processes for sustainable management of water resources/Ecohydrologie—La prise en compte de processus écologiques et hydrologiques pour la gestion durable des ressources en eau. *Hydrological Sciences Journal*. **47**: 823-832.

Zalewski, M. (2010). Ecohydrology for compensation of global change. *Brazilian Journal of Biology*. **70**: 689-695.

Zalewski, M. (2011). Ecohydrology for implementation of the EU water framework directive. In *Proceedings of the Institution of Civil Engineers-Water Management.* **164***:* 375-385

Zalewski, M. (2014). Ecohydrology, biotechnology and engineering for cost efficiency in reaching the sustainability of bio-geosphere. *Ecohydrology and Hydrobiology.* **14***:* 14–20.

Zalewski, M. (2015). 'Ecohydrology Conference' *Measuring, modelling and managing of the natural processes related to water flows* – social values of the linked ecosystem services, Lyon, France.

Zalewski, M. (2015). Ecohydrology and hydrologic engineering: regulation of hydrology-biota interactions for sustainability. *Journal of Hydrologic Engineering*. **20**: 14

Zalewski, M. and Harper, D. (2001). *Rationale*. Ecohydrology—the use of ecosystem properties as management tool for enhancement of" absorbing capacity of ecosystem against human impact (UNESCO IHP-V). *Ecohvdrology and Hvdrobiology*. Vol. **1**

Zalewski, M. and Wagner, I. (1998). Temperature and nutrient dynamics in eutrophic Freshwater ecosystems. *Geographia Polonica*. **71**: 79-92.

Zalewski, M. and Wagner, I. (2005). Ecohydrology- the use of water and ecosystem processes for healthy urban environments. *Ecohydrology and Hydrobiology*. **5**: 263-268.

Zalewski, M. and Wagner-Lotkowska, I. (Eds.). (2004). *Integrated watershed management-ecohydrology and phytotechnology: manual*. United Nations Environment Programme, Division of Technology, Industry and Economics-International Environmental Technology Centre, UNESCO, IHP. 246p.

Zalewski, M., Bis, B., Lapinska, M., Frankiewicz, P. and Puchalski, W. (1998). The importance of the riparian ecotone and river hydraulics for sustainable basin-scale restoration scenarios. *Aquatic Conservation: Marine and Freshwater Ecosystems*. **8**: 287-307.

Zalewski, M., Brewinska-Zaras, B., Frankiewicz, P. and Kalinowski, S. (1990). The potential for biomanipulation using fry communities in a lowland reservoir: concordance between water quality and optimal recruitment. *Hydrobiologia*. **200**: 549-556.

Zalewski, M., Fazi, S. and Wolanski, E. (2018). Ecohydrology for water, biodiversity, ecosystem services, and resilience in Africa. *Ecohydrology and Hydrobiology*. **18**: 93-95.

Zalewski, M., Harper, D., and Wagner, I. (2009). Ecohydrology–why Demonstration Projects throughout the world? *Ecohydrology and Hydrobiology*. **9**: 3–11.

Zalewski, M., Janauer, G. A. and Jolankai, G. (1997). Ecohydrology. *A New Paradigm for the Sustainable Use of Aquatic Resources. International Hydrological Programme, IHP-V, Technical Documents in Hydrology* No. 7 and IHP-V Projects 2.3/ 2.4. UNESCO, Paris, France

Zalewski, M., Wagner, I., Frątczak, W., Mankiewicz- -Boczek, J. and Paniewski, P. (2012). Blue-green city for compensating global climate change. *The Parliament Magazine*. **350**: 2-3.

Zhou, D., Zhang, H., and Liu, C. (2016). Wetland ecohydrology and its challenges. *Ecohydrology and Hydrobiology*. **16**: 26-32.

Zinabu Gebremariam (2002). The Ethiopian Rift Valley lakes: Major threats and strategies for conservation. *Ethiopian Rift Valley Lakes.* Backhuys, Leiden. Pp. 259-271.

Zinabu Gebremariam and Zerihun Desta (2002). "The chemical composition of the effluent from Awassa textile factory and its effects on aquatic biota." *SINET: Ethiopian Journal of Science*. **25**: 263-274.

Zur Heide, F. (2012). *Feasibility study for a Lake Tana biosphere reserve, Ethiopia*. Bonn: Bundesamt für Naturschutz, BfN

8. APPENDICES

Appendix 1: Socio-economic questionnarie

Date of the interview________________________

Village__________________________ distance from the wetland_________________

Wetland________________________

A. Demographic

Name of the respondent__________________________________

Age ___________ Gender of head of house hold 1/ Female ☐ 2/ Male ☐

Occupation________________

Region; ___________________

Education: 1/ No education 2/ Primary school 3/ Secondary school
4/ High school 5/ College 6/ University 7/Higher than University 7/ other

Occupation (source of income): 1/ Government/city officer 2/ Private/state-owned company employee 3/ Retail trading 4/ Self-employed 5/ Farmer/gardener 6/ University student/ student 7/ Housewife 8/ Construction Worker 9/ Unemployed 10/ Fishing 11/ other…………………

Number of time visiting the wetland: 1/ First time 2/ Second time 3/ Third time 4/ many times

Social status 1/ Single ☐ 2/ Married ☐ 3/ other ☐

B. Sources of livelihood .Tick the choice(s) you select

crop ☐ livestock ☐ forestry ☐ rent land ☐ agriculture wages ☐ hiring out farm machinery ☐ fodder and sale of fruits and vegetables ☐ small-scale businesses ☐ services ☐ foreign and domestic remittances ☐ off farm wages ☐

C. Profile of the Wetland.

1. Name of the Wetland:____________________ Wetland site: ________________

2. Country: Ethiopia

3. Location   (a) Latitude (___________) and Longitude (___________)

(b) Nearest City/ Town and its distance_______________Km.

4. Number of people dependent on the wetland_______________

I) Degree of dependence .Tick the choice(s) you select

Fully ☐   Partially ☐   Independent ☐

II) Types of dependence   Subsistence ☐   Livelihood (Economic) ☐

D. Knowledge of the wetland. Tick the choice(s) you select

1) Do you know this wetland?   1) Yes ☐   2) No ☐

2) Do you know that this wetland is rich in biodiversity?   1) Yes ☐   2) No ☐

3) What wetland type is it?

1) Inland wetland ☐   2) Coastal wetland ☐   3) Both ☐

4) In the past, have you ever used this wetland for fishing, collecting animal, woods, vegetables, grass, and other?

1) Yes ☐   2) No ☐

5) If yes, what they were ….?

____

6) Mention some other local benefits living and working around this wetland

____

7) Does the wetland provide a source of fresh water?

1) Yes ☐   2) No ☐

8) Are any natural materials such as wood, fiber, straw, animal fiber (wool/hide/sinew/antler/other) taken from the wetland?   1) Yes   2) No

If yes, mention

____

9) What spiritual or religious values do people derive from the wetland?

____

10) Have communities formed around the wetland and its uses, including for example fishing (subsistence, commercial and recreational), cropping or stock management, walking and jogging, bird watching and photography, etc?

____

11) Is the wetland used for any educational purposes, organized or informal, ranging from school visits to university research and teaching?

____

12) Does the wetland support a diversity of locally representative biodiversity (plants and animals)?

____

13) Which is the overall trend in the benefits over the last 5 years?

1) No Change ☐ Decreased (%) ☐ Increased (%) ☐

based on your choice above ,what could be the probable reasons?____

E. Status and perception of the wetland with reference to conservation monitoring.

Tick the choice(s) you select

1) What is the present legal conservation status of the wetland?

Protected fully ☐ Protected partially ☐

Unprotected ☐ Proposed for protection ☐

2) If protected, please mention -

(a) Year since which the wetland is being protected ☐

(b) Protected agency:

Forest department ☐ Irrigation department ☐

Municipal Corporation ☐ Any other Agency ☐

(c) Protection Status:

Fishing prohibited or regulated ☐ Hunting prohibition ☐

Wildlife Sanctuary ☐ National Park ☐

Biosphere Reserve ☐ Ramsar Site ☐

World Heritage Site ☐ Other ☐

3) What is the overall concern of local people regarding wetland bio- diversity, sustainable use and its conservation?

Highly concerned ☐ Moderately concerned ☐ Unconcerned ☐

4) What is the level of awareness among local people about wetland degradation (if degradation has occurred?)

Largely aware ☐ Moderately aware ☐ Largely unaware ☐

F. Community livelihoods Perception (Attitude and awareness). Tick the choice(s) you select

1. Do you consider this wetland important to your daily lives?
   1) Yes ☐ 2) No ☐
2. How important in your daily lives is this wetland in the following terms direct, indirect and ethical values?
   1) Direct ☐ 2) indirect ☐ 3) ethical ☐
3. Do you know recession farming, pollutants, fertilizers, over grazing and clearing of vegetation affect biodiversity, water quality and socioeconomic benefits provided by the wetland?
   1) Yes ☐ 2) No ☐
4. Has there been any noticeable change in the quality of water and richness of biodiversity since you started using this wetland?
   1) Yes ☐ 2) No ☐
   If yes, what changes you notice?

____
____
__

5). Do you consider vegetation cover used as a buffer zone for the lake ecosystem health to protect pollutants before they enter to open water? 1) Yes ☐ 2) No ☐ If yes, how?____

6). Do you know anthropogenic activities are the cause for unhealthy wetland conditions? 1) Yes ☐ 2) No ☐ If yes, please mention some of them.____

G. Socio-economic benefits of the wetlands. Tick the choice(s) you select

1. For what purposes do you use this wetland ?

Reed gathering ☐ Grazing ☐ Agriculture ☐ Cultivation of edible water plants ☐ Forestry operation ☐ Irrigation ☐ Fuel wood collection ☐ Fishing ☐ Fish culture ☐ Country boat transportation ☐ Domestic ☐ Clay gathering ☐ Sewage disposal ☐ Factory effluent ☐ Solid waste ☐ drinking water ☐ any other ☐

2) Could you choose what you think are the most important benefits provided by the wetland?

I) Choose the four most important benefits

1.________________ 3.____________

2.________________ 4.____________

II) Rank the benefits you selected. Write 1 to 4 from the most important to the least important.

1st.______________ 3rd.________________

2nd.______________ 4th.________________

II) Why are they important ?(describe)

____

IV) Using the four benefits you choose: in the last 5 years, would you say each has:

(1) deacrease ☐ (2) remained the same ☐

(3) increase ☐ (4) don't know ☐

3) Which economic value of wetland is mostly provided by this wetland?

Fish Availability and Breeding/Spawning ☐ Crop and Livestock Farming ☐

Domestic Water Supply ☐ Nonuse Values ☐

Harvesting of papyrus ☐

4) What type of products /services / goods/ you have obtained from the wetland in terms of amount and cost?

I) **Direct values of wetland**

Wetland benefits (goods/services/products)	**Unit**	**Total amount**	**Price per unit**	**Cost gained/Birr**	
				Before 2019	**Current**
Fish	Kg				

Grass	Tone				
Fruits	Kg				
Cyprus papyrus	Tone				
Vegetables	Kg				
Other					

II) Indirect values of wetland

Wetland benefits	**Unit**	**Total amount**	**Price per unit**	**Cost gained/Birr**	
				Before	After
Milk	liter				
Biogas	Cost/birr				
Fattening	Kg/No.of livestock				
Compost	birr/Tone				
Livestock Productivity rate	Number/ freq				

5) Which is the most important use (rank the most important use as 1, then other uses 2,3 e.t.c

Resources	Tick where applicable	Rank in order of importance
Crop cultivation		
Settlement		
Fishing		
Brick making and sand mining		
Grazing		
Collection of animal fodder		
Craft materials(papyrus, palm leaves		
Other(specify)		

I) Why have you ranked one of these as the most important?

a) Supplement household income
b) Supplement household food supply
c) Employment

6) The general economic condition of the community living around the wetland area.

Poor ☐ Rich ☐ Medium ☐

7) What are the trends of wetland benefits in terms of

I) Local GDP

a) Increased ☐ b) Didn't change ☐ c) Deacreased ☐ d) I don't know ☐
e) Not applicable ☐

II) Estate prices in the area

a) Increased ☐ b) Didn't change ☐ c) Deacreased ☐ d) I don't know ☐
e) Not applicable ☐

III) Number of temporary and permanent jobs

a) Increased ☐ b) Didn't change ☐ c) Deacreased ☐ d) I don't know ☐ e) Not applicable ☐

IV) Health of the local people

a) Increased ☐ b) Didn't change ☐ c) Deacreased ☐ d) I don't know ☐ e) Not applicable ☐

H. What are the major direct drivers of the changes in the wetland?

1. Changes in wetland area

- Land conversion to industrial areas ☐
- Land conversion to urban areas ☐
- Land conversion to tourist development ☐
- Conversion into agricultural land ☐
- Creation of intensive fish farms ☐

2. Changes in the water regime

- Dams ☐
- River extraction ☐
- Groundwater extraction ☐
- Drainage ☐
- Channelization ☐
- Land reclamation ☐
- Irrigation ☐

3. **Changes in the water quality**

Nutrient enrichment ☐

Pesticide/Herbicide runoff ☐

Salinization ☐

Changes in land use ☐

Industrial discharges ☐

4. **Explotation**

Over-fishing ☐

Over-hunting ☐

Over-grazing ☐

5. **Alien species**

Water hyacinth ☐

Others ☐

6. **Management**

Vegetation management ☐

Vegetation restoration ☐

Management of hunting ☐

Management of fishing ☐

Interviewer information

Name: …………………………………………………………………………………

Sex: Male ☐ Female ☐

Age: ……………………………………………………………………………………

Phone number…………………………………………………………………………

Interview date …………………………………………………………………………

Time……………………………

Note on interview………………………………………………………………

Appendix 2: Sampling sites

Gumetirs sampling site

Cultivated fruits and vegetables

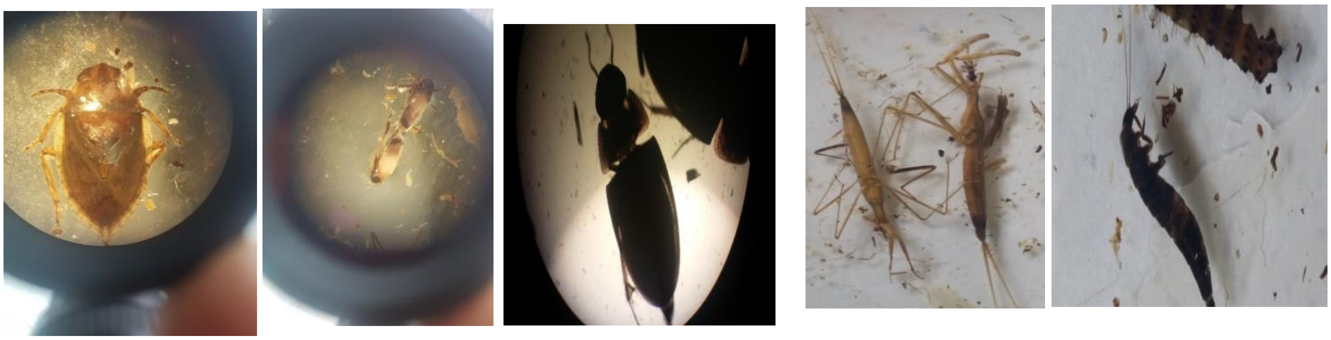
Gedromesk sampling site


Agid kirgna sampling site

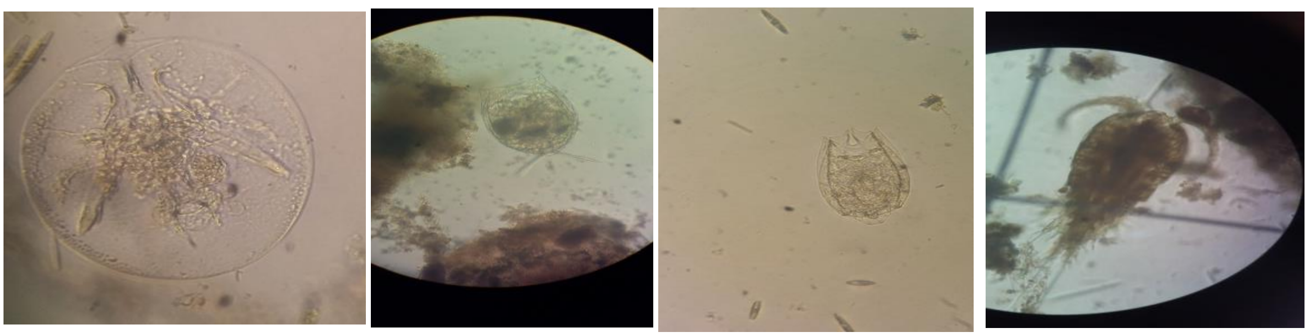

Appendix 3: Activities during field work




Appendix 4: Macroinvertebrate species



Appendix 5: Zooplankton species



Appendix 6: Phytoplankton species