Macrophyte Ecology, Nutrient Dynamics and Water Quality of the Littoral Zone, and Yitamot Wetland, Lake Tana, Ethiopia

Yezbie Kassa Brihanu

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Doctor of Philosophy in Biology (Fisheries and Aquatic Sciences Stream)

Department of Zoological Sciences

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Abstract

Macrophyte Ecology, Nutrient Dynamics and Water Quality of the Littoral Zone, and Yitamot Wetland, Lake Tana, Ethiopia

Yezbie Kassa Brihanu
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Nutrient dynamics plays an important role in establishment and proliferation of macrophytes in freshwater bodies. Recently Lake Tana has experienced some undesirable ecological changes due to decrease in water level, increasing trend of sedimentation and silt load (with loading rate of 8.96-14.84 million tons of soil per year) and invasion by the exotic weed, *Eichhornia crassipes* (Water hyacinth). With a view to come up with scientific information usable in the protection of aquatic resources, this study was carried out between 2011 to 2014 to assess the macrophyte species composition, biomass and diversity in Lake Tana in relation to abiotic factors and the nutrient uptake and storage dynamics of some species in constructed wetlands and their overall water quality improvement in a natural Yitamot wetland near Bahir Dar.

Macrophytes were collected manually using a belt transect method and physicochemical parameters were measured *in situ* using a YSI 556 multi-probe system. Selected nutrients (SRP, TP. Nitrate) and metals (K, Na, Ca, Mg, Mn, Fe, Cu, Zn, Al, Cd, As, Cr) were analyzed using standard methods from water, sediment and plant tissue.

In Lake Tana, a total of 30 species of macrophytes which belonged to 15 families were identified in the south western littoral zone and 41 species that belonged to 20 families in the north eastern littoral zone of the lake. The emergent vegetation had the highest percentage composition (83 %) and attained the highest relative frequency and density, followed by floating and other forms in the south western littoral zone whereas in the north eastern zone, *Eichhornia crassipes (*Water

hyacinth) was the dominant macrophyte.

Tissue TN and TP content varied significantly between species and plant parts (paired sample T-test, $P < 0.01$) and leaves of all macrophyte species stored more nutrients than the stems. Results of RDA indicated that Nitrate, SRP, TP, pH and Secchi depth were among the factors that had significant impact on the diversity, distribution, biomass and plant tissue nutrient contents of the macrophytes in the lake. *Azolla africana*, *Cyperus alopecuroides, Ceratophyllum demersum, Cyperus macrostachyos and Digitaria milanjiana,* were almost restricted to sites where there was higher SRP and TP and *Echinochloa stagnina*, *Brachiaria sp.* and *Phragmites karka* to sites where there was higher nitrate concentration and *Ceratophyllum demersum* was mainly restricted to sites with high Secchi depth reading.

Studies done in the natural wetland of Yitamot indicated that water quality was improved as the levels of DO (1.54 to 5.01 mg/l) and pH (5.70 to 7.61) significantly increased ($p < 0.05$ ANOVA) and TSS (0.41 to 0.04), Turbidity (276.40 to 10.80 NTU) and COD (207.00 to 5.25 mg/l) significantly decreased ($p < 0.05$ ANOVA) to optimal levels at the outlet due to uptake by macrophytes. Nutrients were removed from the natural wetland via assimilation by vegetation, sediment adsorption or pore water retention. The higher concentration of nitrogen and phosphorus of aboveground tissue of almost all macrophyte species studied in Yitamot natural wetland (% TN ranged from 3.70 to 12.13 % N g DW and %TP ranged from 0.26 - to 1.69 % g DW) was higher than the value for emergent and floating-leaved plants in natural wetlands, which suggests that these macrophytes have a higher nitrogen and phosphorus retention capacity and can contribute to overall water quality improvement. However, in the influent water (S1), most of the parameters except temperature, EC and TDS were beyond the Ethiopian effluent allowable discharge limits into water courses, despite high rates of nutrient retention (for nitrogen species; 99.85% for NO_2-N, 99.29% for TN, for phosphorus species: 89.21% for SRP, 95.27% for TP) in the wetland. The heavy metals such as As, Cr, Cu and Fe were not removed in the wetland and were also higher than the maximum allowable concentration ranges for fisheries and aquatic life. This indicated that heavy metals could cause adverse health effect to end users unless removed by additional treatment processes before they entered the wetland.

Further study in experimental treatment beds in HSSFCW showed that the progressive increase in the plant density, shoot length and stem diameter was positively correlated with the nutrient removal efficiency of the two macrophyte species, which had maximum removal efficiency of 58% for nitrate and 84% for phosphate. Pollutant removal efficiency differences were statistically significant ($p < 0.05$) between planted and unplanted treatment beds for $PO4^{3-}$.

In conclusion, the *in-situ* and experimental data obtained indicate that the dynamics of nutrients has great impact on composition, biomass and diversity of the macrophyte species in Lake Tana, and the high nutrient uptake and storage capacity of some macrophytes can potentially contribute to the overall water quality improvement in natural and constructed wetland systems. The increasing trend in concentration of nutrients and reduction in transparency and water level could favor the dominance of turbidity-tolerant floating and emergent macrophytes in Lake Tana.

Acknowledgement

First and foremost, I would like to express my sincere gratitude to my advisors, Prof. Seyoum Mengistu and Dr. Ayalew Wondie for taking me in as a student of their own and encouraging me to work on problems related to Lake Tana ecosystem and Yitamot Natural wetland and their support including arrangement of financial support during the research work. Their invaluable advise, patience and fatherly approach and support encouraged me to pursue my study smoothly which otherwise would have been difficult as the fund allocated to this study was very limited especially during the beginning of the project.

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Abbreviations and acronyms

ANOVA	Analysis of Variance
ANRS	Amhara National Regional State
APHA	American Public Health Association
AWWA	American Water Work Association
BMPs	Best Management Practices
BoEPLAU	ANRS Bureau of Environmental Protection, Land Administration and Use
CCA	Canonical Correspondence Analysis
COD	Chemical Oxygen Demand
CW	Constructed wetland
DCA	Detrended Correspondence Analysis
DO	Dissolved Oxygen
DOM	Dissolved organic matter
DW	Dry Weight
EC	Electrical Conductivity
EEPA	Ethiopian Environmental Protection Authority
EMA	Ethiopian Meteorology agency
EPA	Environmental Protection Authority
H'	Shannon and weiver index
HLR	Hydraulic loading Rate
HRT	Hydraulic Retention Time
HSSFCWs	Horizontal Subsurface flow constructed wetlands
IBC	Institute of Biodiversity Conservation
IEP	Institute of Environmental Protection
LSD	Least Significant Difference
m.a.s.l.	Meter above sea level.
MoWIE	Ministry of Water, Irrigation and Energy
MPL	Maximum Permissible Limit
N	Nitrogen

NAPP	Net Aboveground Primary Productivity
NTU	Nephelometeric Turbidity Unit
OLR	Organic Loading Rate
P	Phosphorus
PAST	Paleontological Statistics
PCA	Principal Component Analysis
pH	Potential Hydrogenation
POM	Particulate organic matter
Q	Flow rate
Qav	Average Flow rate
SD	Standard Deviation
SF	Surface flow
SPSS	Statistical Package for Social Science
SRP	Soluble reactive phosphorous
TaSBO	Tana Sub Basin Organization
TBIWRDP	Tana-Beles Integrated Water Resource Development Project
TN	Total Nitrogen
TP	Total Phosphorus
UNEP	United Nations Environmental Program
USA	United States of America
USEPA	United States of Environmental Protection Agency
VIF	Variance Inflation Factor
WFD	Water Framework Directive

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Dedication

My mom, Emahoy Guday Azene, Her strength of character and perseverance has guided me through my life. when other relatives complained for sending daughters to school after she become a widow during my childhood, she always kindly responded with a true belief “God knows the situation; I am not alone He is always with them to help”. She always tolerates the pressure and provides support to me for better success by any means. That is how I learn, Thanks mom and long live to you!

Chapter 1: General introduction

1.1 Introduction

Macrophytes are aquatic plants which are visible to the naked eye and grow permanently or temporarily in aquatic habitats (Chambers *et al.*, 2008; Thomaz *et al.,* 2008).They are classified into four groups on the basis of their water requirements, life forms and habitats as submerged, floating leafed, free- floating and emergent. Macrophytes are regarded to be the most productive plant communities in the world (Reddy, 1984). They are also known to be the underpinnings of biological diversity, providing water and primary productivity upon which countless species of organisms depend for survival (Chapman *et al*., 2001). For instance, they are an important source of organic matter for benthic organisms and probably are the main substratum for periphyton (Padial *et al*. 2012). Also, these plants can influence different communities by providing hydraulic resistance, increasing food supply, and providing refuges (Declerck *et al*. 2007; Thomaz *et al*. 2008). Macrophytes act as efficient filters of excessive nutrients from the catchments, which could otherwise lead to eutrophication of water bodies (Dhote, 2007). They are also often used for retention of heavy metals and other pollutants present in the water and submerged sediments (Sheikh *et al*., 2011). Conversely, invasive macrophyte species may have negative features as they change the normal functioning of aquatic ecosystems (Masifwa, 2001).

Reducing the discharge of nutrients from point and non-point sources is the primary measure to control eutrophication. Recent researches on nutrient removal by different macrophytes have proven that they are effective for water quality improvement (Wu et al., 2011; Borin and Salvato, 2012; Xu, *et al*., 2014). Changes in ecosystem properties like water transparency and nutrient concentrations can be caused by changes in the composition of aquatic plants (Lopes *et al*., 2011). Therefore, major changes in the abundance of individual species and community composition usually provide valuable information on the cause and effect of the change. Macrophytes interact with every biotic component in the littoral zone of shallow lakes and generally reflect the nutrient status of their immediate habitat by presence/absence and abundance; as mostly sessile organisms, they react slowly to the changes in nutrient conditions and can be used as a long term indicators. Hence, studies on macrophytes contribute considerably to conservation of aquatic resources, and important for numerous applied issues such as wetland restoration, wastewater treatment, and management of invasive species (Lavoie, 2010; Casanova, 2011).

Due to climatic and land use changes, shallow lakes may be threatened: For instance, increased water demand or climate change leading to a shift in the water balance and lake levels, increased land degradation and soil erosion in the riparian zones leading to sediment pollution and deposition in the lakes, thereby reducing their storage capacity, change in ecosystem services and hence the livelihood for the people that depend on these lakes.

The Lake Tana sub-catchment area has been identified as the growth corridor for development and reducing food insecurity problem in Amhara Region and at the national level. The lake is important for fisheries, local transport, hydroelectric power generation, ecological restoration, dry season irrigation supply and tourism attractions. Also the catchment`s biodiversity is striking with the presence of many endemic plant species, endemic birds, endemic fishes and large areas of wetlands (Poppe *et al*., 2013; Shimelis Setegn *et al*., 2010; Colot, 2012).

A number of studies haven carried in Lake Tana over the past decades towards the study of various aspects of Lake Tana with greater emphasis on the lake‟s itchy fauna especially *barbus* and *cyprinids* (Eshetie Dejen *et al*, 2004; Wassie Anteneh *et al*., 2008). Records of plankton composition, assemblages and seasonal variations include Tesfaye Wudneh (1998), Eshetie Dejen *et al*. (2003), Eshetie Dejen *et al*., (2004), Ayalew Wondie (2006), Ayalew Wondie and Seyoume Mengistou (2006) and Ayalew Wondie *et al*., (2007), (Ayalew Wondie and Seyoume Mengistou, 2014) (Akoma and Imoobe,2008, 2009); Studies about the species composition, distribution, relative abundance and habitat association of the bird Fauna (Shimelis Aynalem, 2007; Mundt, 2011), Studies about invertebrates; like nematode communities of Lake Tana by Eyualem Abebe, (2001). There are also few studies on macrophyte composition, assemblages and seasonal variations. Ayalew Wondie (2010) identified three dominant plant communities throughout the shore area of the lake as Trees (e.g. *Syzgium guineense)* and shrubs dominated in rocky shore areas, *Scirpus and Polygonum* species dominated in the north and east shore area, and Papyrus and Typha dominated in the south western golf of shore area of the lake.

Lake Tana ecosystem has undergone substantial changes; especially the area covered by papyrus which is reduced to one tenth and limited to the southern gulf of the lake during the last two decades (Ayalew Wondie, *et al*., 2012). Currently large parts of the northern shore of Lake Tana are highly infested by invasive weed, *Eichhornia crassipes* (Mart.) Solms (water hyacinth) (Ayalew Wondie *et al*., 2012). The survey in 2012 by BoEPLAU estimated the weed covered an area of 20 hectares (Wassie Anteneh *et al*., 2014). Its distribution in 2013 has been reported by Wassie Anteneh *et al*. (2014). Their report has stated that water hyacinth seems replacing the indigenous macrophyte, *Cyperus papyrus* in the north eastern shore of the lake. Moreover, recently the lake limnology and hydrology have shown undesirable changes due to factors, such as an increase in net annual loss of water from the lake as evaporation losses (Molla and Menelik, 2004), increasing trend of sedimentation and silt load (Berhanu Teshale *et al*., 2001), (Eshetie Dejen et al., 2004, Ayalew wondie *et al*., 2007).

However, Until now, little attempt has been made to determine the diversity of aquatic macrophytes with specific focus on distribution, occurrence and species composition in relation to the current nutrient dynamics of the lake. little attempt has also been made to determine the quantity of nutrients taken up and stored by these plants and the situation in Lake Tana and associated wetlands is non-existent. The percentage coverage and distribution of this invasive weed, *Eichhornia crassipes* (water hyacinth) and its impact on diversity and composition of other macrophytes in the lake is not also investigated.

Currently, the direct discharge of partly treated and sometimes-untreated wastewater into surface waters or through wetlands is a practice in many countries of the world. Wetlands are increasingly becoming popular alternatives for treatment of various types of wastewaters (Browning, 2003). The importance of wetlands in the accumulation of various compounds and in their immobilization or treatment via natural biogeochemical cycles has been emphasized by various researchers (Mitsch and Gosselink, 2000; Vymazal, 2009; Calijuri *et al*., 2011). The nutrient assimilative and storage capacity of seasonal wetlands embedded within agricultural and urban landscapes determines their role as nutrient sinks, but also as potential nutrient sources within the landscapes (Gathumbi *et al.,* 2005). In wetlands, human activities can have profound effects on plant community composition and ultimately ecosystem function. Developing an understanding of how species respond to those activities is essential to predicting the impacts of human activities on both species composition and ecosystem function.

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/or biological effects on wetlands. Many changes are manifestation of nutrient enrichment, including increased biomass production, dominance of faster growing plant species, accelerated N cycling and reduced N retention (Aerts and Chapin, 2000).

All forms of wetlands are characterized in Ethiopia except coastal and marine-related wetlands, extensive swamp-forest complexes (Abebe Yilma, 2003) and fens. Hillman (1993) listed a total of 77 wetlands in Ethiopia and Eritrea and estimated that Ethiopian wetlands covered an area of 13,699 km^2 or 1.14% of the country‟s land surface. Statistical reports showed the total area of wetlands in Ethiopia may exceed 2 % or 22,500 km^2 of the country‟s land surface (McKee, 2007). Here are some of previous studies that are contributing to the knowledge of the current status and uses of Ethiopian wetlands: List of the major threats of Ethiopian wetlands with their all over impacts, the distribution and status and classification major Ethiopian wetlands by their habitat, physical and biological characters; major wetland plants of Ethiopia with examples from Illubabor; assessment of sustainable management of wetlands in Ethiopia and local knowledge (Leykun Abunye, 2003; McKee, 2007; Wood *et al*., 2002; Zerihun Woldu and Kumulachew Yeshitila, 2003).

There are also some research works in constructed treatment wetlands in Ethiopia (Andualem Mekonnen *et al*.,2015; Asaye Ketema, 2009; Berhanu Genet and Seyoum Leta, 2011; Girum Feleke, 2011; Kenatu Angassa, 2011; Tadesse Alemu *et al*., 2012; Alemayehu Haddis, 2014; Sahu and Seid Yimer, 2014). However, these studies did not investigate the frequently used macrophytes species in HSSCWDs (*Phragmites karka* and *Cyperus papyrus*) using domestic wastewater. None of these studies also investigated growth parameters and biomass production in relation to nutrient uptake of these plants. Therefore, rigorous comparison studies under controlled conditions are necessary to evaluate the potential of these species for wastewater treatment using HSSFCW system.

Despite the recognition of wetlands as a key feature in watershed management in national water resources management policy, the practical implementation of conservation strategies for wetlands is almost none or very minimal. Currently most of the wetlands are still being depleted and are under severe stress due to the expansion of human settlement and industrialization around wetlands in some parts of the country (Zinabu Gebre Mariam, 2002). Consequently, many of wetlands in the country are at the edge of collapse due to continuous threats they are facing. (Ketema Dessalegn, 2013). Scientific data on the ecological status of these wetlands are very vital for the right decision and long term sustainable use of these resources in the country. The discharge from point and nonpoint sources directly to Ethiopian wetlands (Zinabu GebreMariam, 2002; Tenagne Addissu, 2009) is apparent while most of these systems were not designed for wastewater and stormwater treatment. The potential of Ethiopian wetlands, both natural and constructed treatment wetlands, as a surface water quality improvement and nutrient and pollutant removal comparatively are not still well studied and in particular for the wetland of interest (Yitamot wetland) are non-existent. Therefore, the aim of this research is to fill these gaps by applying appropriate methodologies and to provide baseline information for informed decision for the sustainable use of the resources in the lake and available wetlands.

1.2 Objectives of the project

General objective

The general objective of the study is to provide comprehensive assessment of the macrophyte species composition, biomass and diversity in Lake Tana in relation to nutrient dynamics and the nutrient uptake and storage dynamics of some species in constructed wetlands and their overall water quality improvement in a natural Yitamot wetland

Specific objectives:

1. To determine the abundance and distribution of the macrophytes in Lake Tana in relation to nutrient dynamics and investigate the impact of the invasive weed, *Eichhornia crassipes* (waterhyacinth), on macrophyte composition, abundance and diversity in the lake; the objective is addressed in chapter two.
2. To determine macrophyte aboveground biomass accumulation and tissue nutrient storage in relation with nutrient dynamics and quantify differences in biomass and nutrient concentrations in the different plant organs. This objective is addressed in chapter three.
3. To assess if surface water nutrient concentrations decrease downstream from sources of input and if nutrient uptake by aquatic vegetation, nutrient adsorption to sediment and nutrient retention in pore water improves water quality within Yitamot natural wetland. This objective was addressed in chapter four and four.
4. To assess the direct uptake of major macronutrients by the macrophytes in constructed wetlands; addressed in chapter five.

1.3 Research questions

The following corresponding research questions were formulated for each specific objective:

1. How do the nutrient dynamics affect the macrophyte species composition and distribution in the lake? The research question is addressed in chapter two.
2. Do the nutrient dynamics of the lake affect the biomass and nutrient storage of macrophytes in the lake? The research question is addressed in chapter three.

3. What is the contribution of macrophytes in a natural and constructed wetland for the overall water quality improvement by the wetland? The research question is addressed in chapter four and five
4. Are the growth parameters of macrophytes correlated with the pollutant removal rate in wastewater treatment in a constructed wetland? The research question is addressed in chapter five

1.4 Description of the study area

Lake Tana is the largest fresh water body in Ethiopia, containing half the country‟s freshwater resources, and the third largest in the Nile Basin (Vijverberg *et al.*, 2009) with surface area of 3150 km^2. The lake has a maximum length of 78 km and width of 68 km (Eshete Dejen, 2003). It is located at an altitude of 1786 m.a.s.l. (Ayalew Wondie, 2010). The lake is a shallow lake with average depth of 9 m and maximum depth of 14 m. It is the source of the Blue Nile River, with a catchment area of ca 16,500 km^2 and a volume of 28 km^3 (Ligdi, *et al.*, 2010). The lake is fed by more than 40 rivers and streams, but 93% of the water comes from four major perennial rivers: Gilgel Abbay, Ribb, Gumara and Megech Figure 1.1.

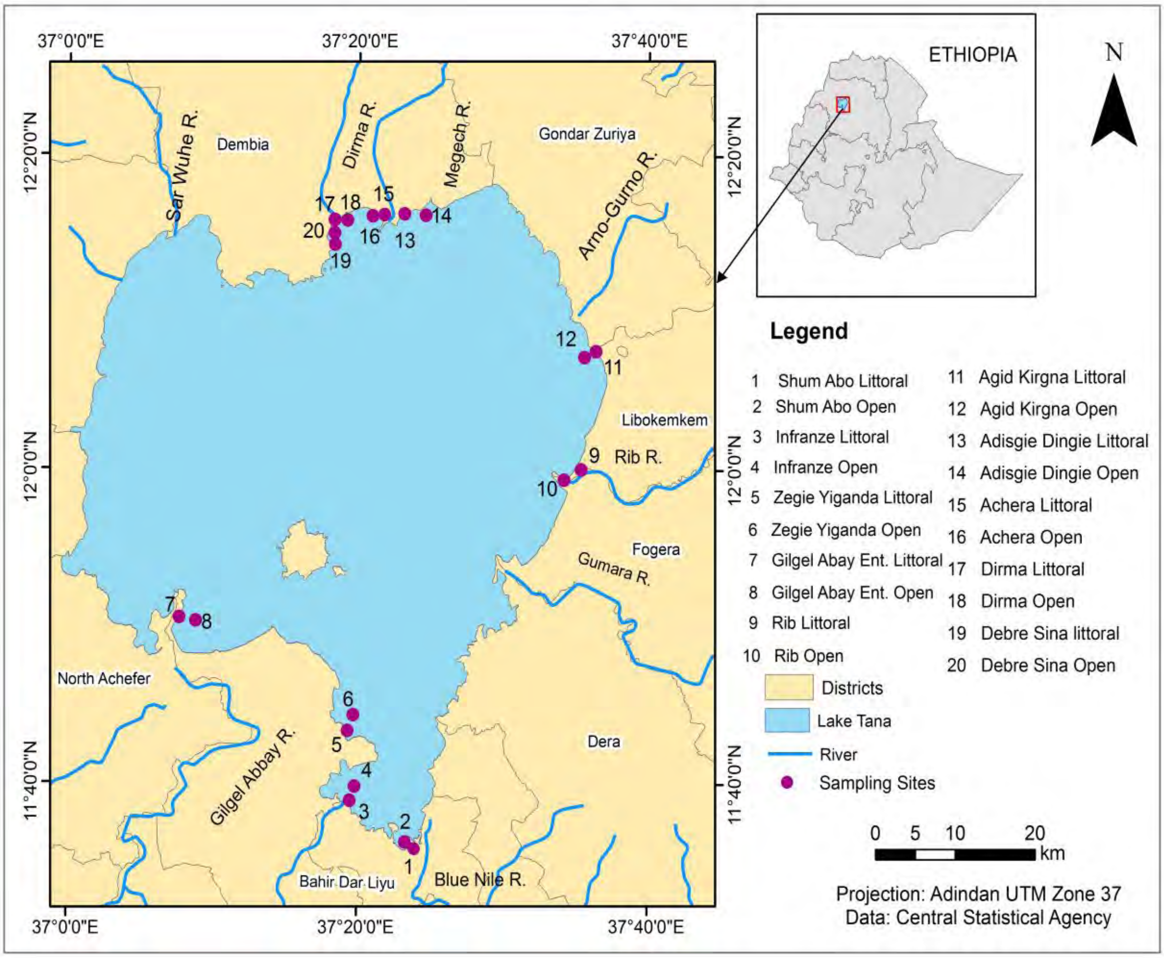


Figure 1.1 Location map of sampling sites in Lake Tana

Based on chemistry, Lake Tana is described as mesotrophic (Berhanu Teshale *et al*., 2001), but based on chlorophyll content and primary production it is oligotrophic (Ayalew Wondie *et al*., 2007) freshwater lake with low nutrient concentrations and fairly high silt concentrations with loading rate of 8.96-14.84 million tons of soil per year (Ayalew Wondie *et al*., 2007; Berhanu Teshale *et al*., 2001; Gorraw Goshu *et al*., 2010). In the main rainy season the inflowing rivers carry heavy loads of suspended silt into the lake, thereby increasing the turbidity of the lake water (Vijverberg *et al*., 2009). Some physico-chemical feature of southern Gulf of Lake Tana is given in Table1.1

Table 1.1 Some physicochemical feature of southern Gulf of Lake Tana

Parameter	Range	Source
Turbidity(NTU)	20-28	Eshete Dejen, 2003
Conductivity(μscm^{-1})	152-232	Osondu, 2010
PO_4^{-3} (mgl^{-1})	x= 1.00$\pm$0.8	Ayalew Wondie *et al.*, 2007
pH	6.5-8.5	Ayalew Wondie, 2009
Temperature (^{o}c)	22.5-25	Osondu, 2010
NO_3-N(mgl^{-1})	0.1-1.0	Ayalew Wondie *et al.*, 2007
TDS(mgl^{-1})	63-135	Ayalew Wondie, 2010
DO(mgl^{-1})	5.9-7.3	Ayalew Wondie, 2006
BOD_5(mgl^{-1})	>20*	Ayalew Wondie, 2010
Chlorophyll a (μgl^{-1})	3.34-12.0	Ayalew Wondie, 2006

*At point of discharge

The climate in Lake Tana region is characterized by four seasons: post-rainy season (October–November), main rainy seasons (July–September), dry season (December–April) and pre-rainy season (May–June). The rainfall pattern of the lake region is uni-modal with a highly variable annual rainfall ranging from 628.30 to 3152.80 mm with a mean value of 1355.74 mm. Long-term rainfall distribution data indicates that most of the rain occurs in July followed by August (Figure 1.2). The mean annual air temperature of the Lake area varies between 12.5 ^{o}C and 27.3 °C. Maximum temperature was occurred in March and April and the minimum in December and January (Figure 1.3).

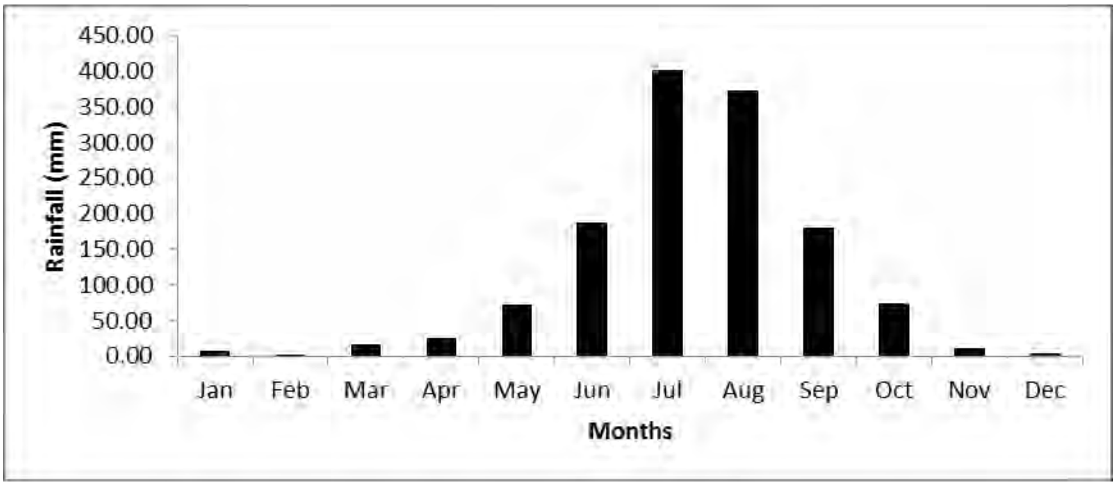


Figure 1.2 Mean monthly rainfall of Lake Tana data collected from Bahir Dar airport, Bahir Dar meteorology, Bahir Dar new, Dek Istifanos, Enfranz, Makisegnit, Meshenti, Wereta, Yifag, and Zegie from 1995 -2014(after EMA).

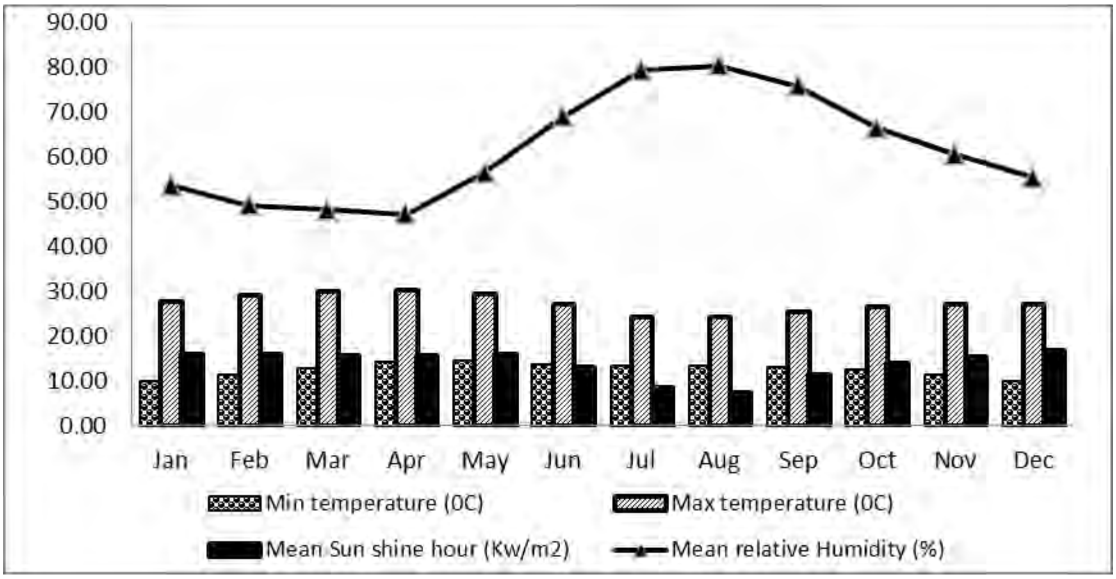


Figure 1.3 Mean monthly temperature (min & max), number of hours of sunshine and relative humidity of Lake Tana from 1995 -2014(after EMA)

According to Meteorological data obtained from Bahir Dar Airport, Bahir Dar meteorology, Bahir Dar new, Gorgora and Yifag stations, mean monthly relative humidity of the lake‟s region averaged 61.71%, varying from 47.12% (April) to 80.33% (August). The mean monthly wind speed was highest in February (2.13 m/s) and lowest in October (0.94 m/s) (Figure 1.4).

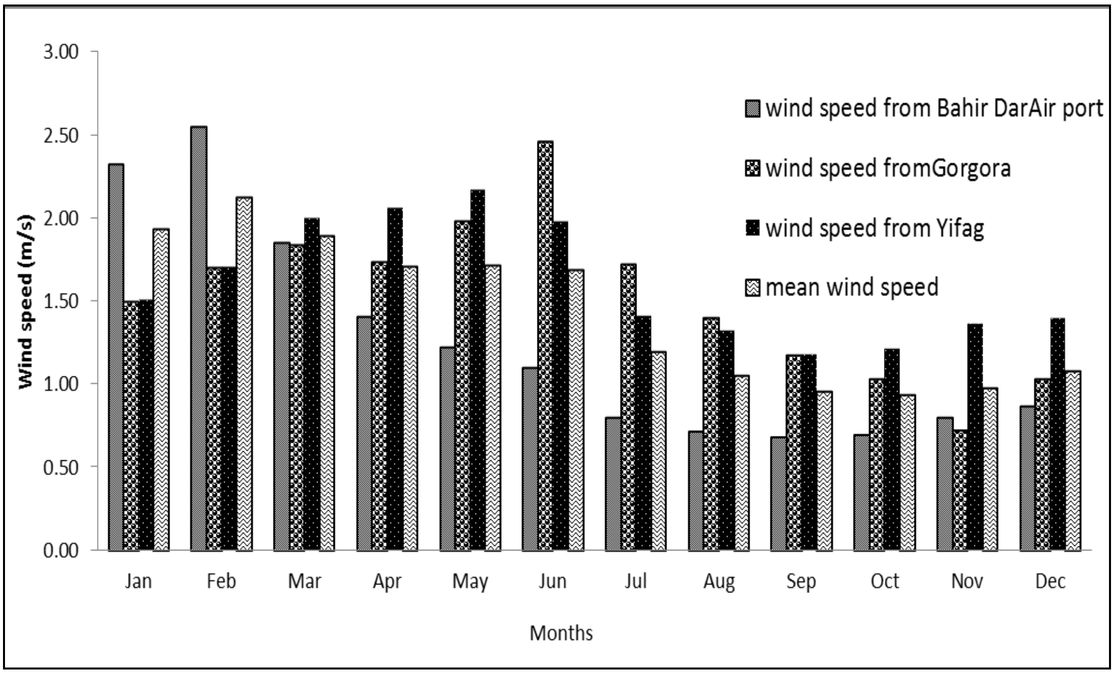


Figure 1.4 Mean monthly wind speed of Lake Tana‟s region from 1995 -2014(after EMA)

The total annual inflow of water to the lake is 10.3 × 109 m^3 yr^{-1} and the outflow as Blue Nile River is ca 36% of this, i.e.3.7 × 109 m^3 yr^{-1}. The water residence time is ca 3 years (Berhanu Teshale, 2003). This large difference between inflow and outflow is caused by the high evaporation losses. During October to June evaporation exceeds input via rainfall and during this time many of the inflowing streams dry up completely (Molla and Menelik, 2004). The water level of the lake follows a seasonal pattern with an amplitude of around 3.5 meters (Karlberg *et al.*, 2015), in which the highest level occurs at the end of the main-rainy season and during the post-rainy period, slowly decreasing to a minimum around the end of the dry season (Fig. 1.5).

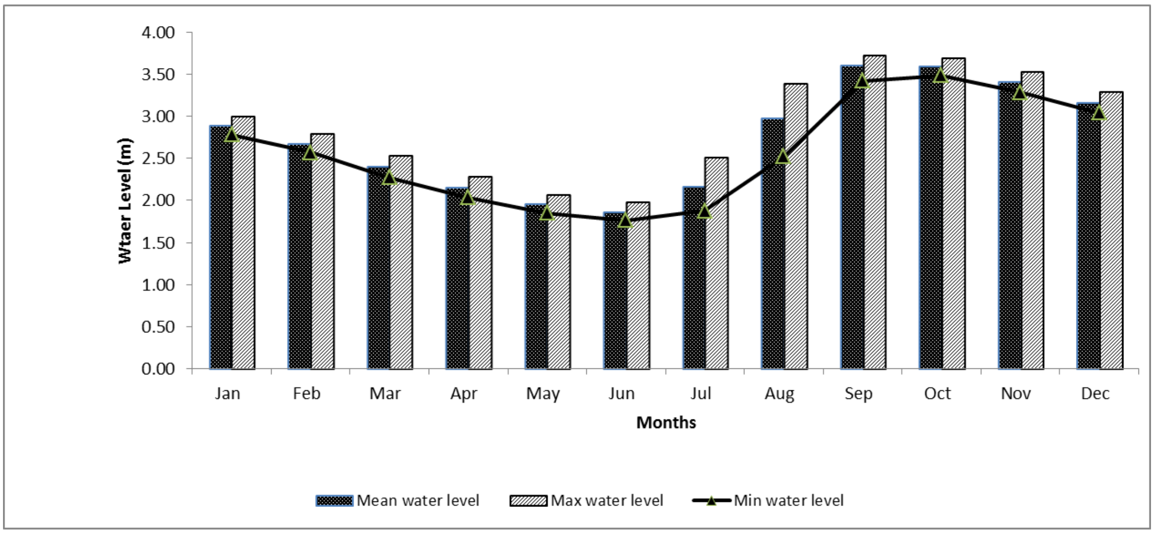


Figure 1.5 Mean monthly water level of Lake Tana from 1995 -2014(after MoWIE)

The various habitats and ecosystems of the lake and associated wetlands provide a refuge for many species of flora and fauna, many of which are known to be endemic species (Amare Sewnet and Kameswara, 2011). The Lake is home for 85 phytoplankton species (Ayalew Wondie, 2006), responding to the seasonal changes in nutrient and sediment loadings with plankton population maxima during the post-rainy season (Ayalew Wondie and Seyoume Mengistou, 2006; Ayalew Wondie *et al*., 2007). The gross primary production rates of Lake Tana are among the lowest, compared with other tropical lakes (Ayalew Wondie *et al*., 2007). The lake consist of fourty four zooplankton species composed of sixteen species of rotifers, sixteen species of cladocerans and twelve species of copepods (Imoobe and Akoma, 2008), and relatively high densities of micro-benthic ostracods in the in shore zone and low densities of Macro-benthic invertebrates such as oligochaetes, *Chaoborus* spp. and chironomids both inshore and offshore areas (Vijverberg *et al*., 2009)

The Lake Tana catchment gives home to numerous birds, mammals, fish, amphibians and reptiles - several of them endemic. Lake Tana is well known for its endemic fish species. About a quarter of the 65 fish species found in the lake are endemic (Tadesse Alemayehu, *et al*., 2010). Tilapia (*Oreochronmis niloticus* and catfish (*Clarias gariepinus*) are also fish species occurring in Lake Tana (Vijverberg *et al*., 2009; Tadesse Alemayehu, *et al*., 2010).

Lake Tana and its wetlands are rich in bird life, in total ca 215 bird species were observed of which ca 83 typical wetland species (Frances and Shimelis Aynalem, 2007). Lake Tana is inhabited by Hippopotamus (*Hippopotamus amphibious*), which are mainly restricted to pocket habitats. Vijverberg *et al*. (2009) reported about Otters that are sometimes caught in the nets of local fishermen.

The livelihood of more than five hundred thousand people depends on the lake and adjacent wetlands (Vijverberg *et al*., 2009). In addition the area is an important tourist destination in the country. The lake is one of the six fresh water eco-regions recognized as living laboratory with unique fish flocks, and international bird site by IUCN (Eshete Dejen, 2003; Abebe Getahun and Eshete Dejen, 2012). The Lake Tana region has become the center of interest for Ethiopia‟s water resources development for irrigation and hydroelectric power (McCartney *et al*., 2010).

Yitamot Natural wetland

Yitamot Wetland is a natural wetland located at 037°23'51.7" of East and 11°33'58.2" of North with an altitude of 1790 m. a. s. l. It is located in Amhara National Regional State in the city of Bahir Dar, in the southern side of Bahir Dar University Pedagogical Campus. The Wetland is connected to Abay (Blue Nile) river in the east.

It has an area of about 57 hectares (Figure 1.6). According to the Ethiopian agro-ecological zonation, the wetland and its surrounding areas lie in „Woina Dega‟ or Sub-Tropical Zone and the mean maximum temperature ranges from 24.17 ^{0}c to 30.29^{0}c and the mean minimum temperature ranges from 9.96^{0}c to 14.51^{0}c (Figure 1.3).The maximum temperature usually occurs from March to May with the highest at April and the minimum temperature from November to February at its lowest during January.

The wetland is seasonal-type and its size and water level varies at different seasons. It is predominantly fed by ground water and/or spring flow, as well as surface flow during the wet season. Being located in the same area with Lake Tana, the wetland has similar climatological conditions.

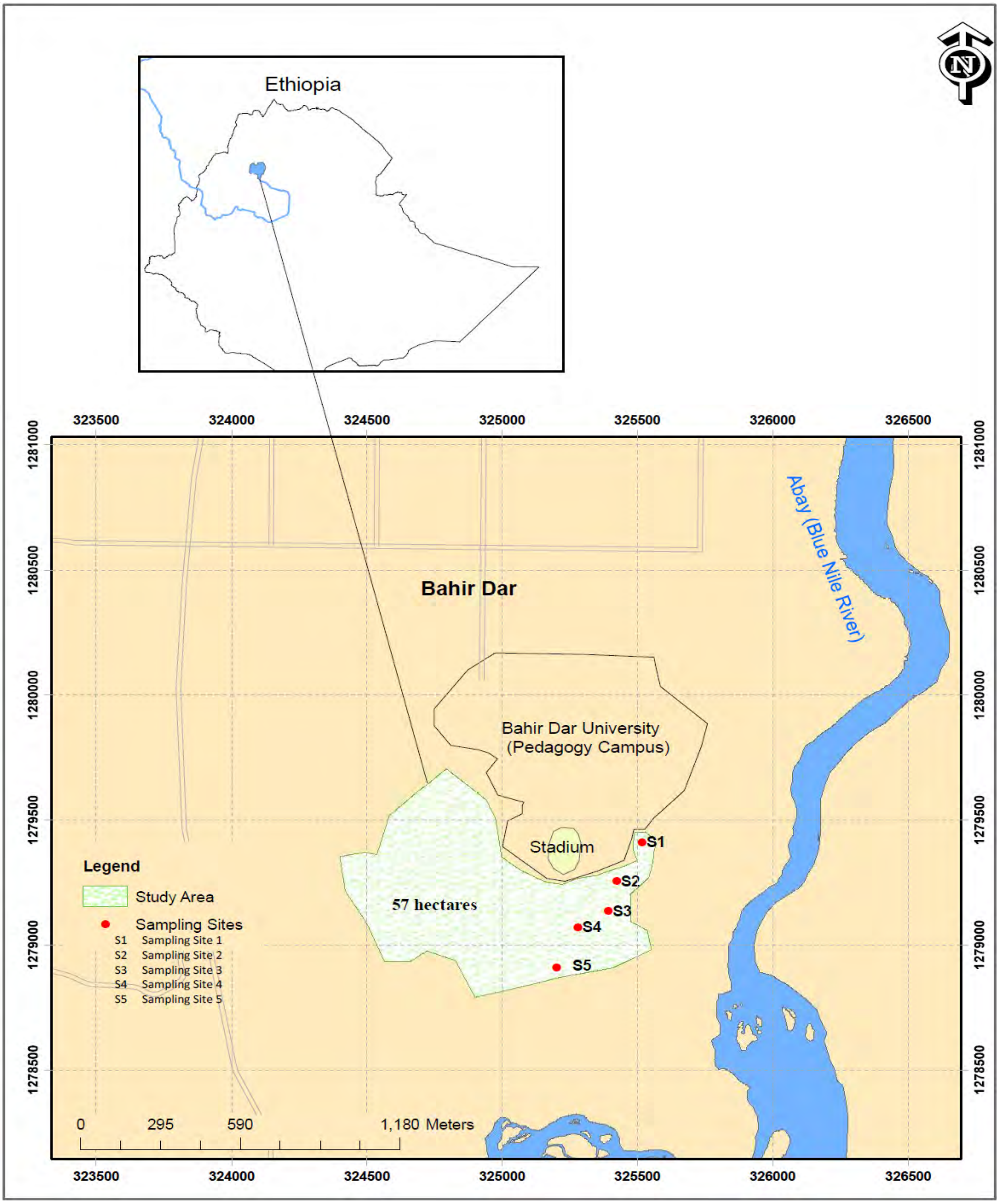


Figure 1.6 Map of Yitamot wetland indicating the five sampling sites

There are sparsely distributed trees and shrubs like vegetation in the shore area such as *Carissa edulis* (Agam), *Euphobiaceae* (Bisana), *Acacia lahae* (Tikur girar), *Vernonia amygdalina* (Girawa), *Cordia africana* (Wanza), *Ficus species* (Shola), *Eucalyptus camaldulensis* (Barzaf) and the like. The wetland has also different emergent, floating and submerged macrophytes with dominant species being *Echinochloa stagnina*, *Cyperus papyrus*, *Phragmites karka*, *Spheranthus suaveolens*, *Cyperus digitatus*, *Scirpus validus*, *Typha latifolia, Ludwigia abysinica, Polygonum senegalense* and others. As floating leaved species *Hydrocotyle ranunculoides, Azolla africana, Pistia stratiotes Nymphaea caerulea* and *Nymphaea lotus* and as submergent *Ceratophyllum demersum* are noted as the most important plants with varied coverage seasonally. Most of these macrophyte species identified in this wetland except *Pistia stratiotes* are found in Lake Tana. Farmers living near the wetland have livelihoods directly linked to the wetland. They benefit from the wetland in several ways: for instance, a large majority of them are engaged in livestock grazing, others are engaged in small scale irrigation using water from the wetland mainly when it has enough water level. Apart from the economic benefit of the wetlands, people use water from the wetland for sanitation purposes and for household purposes, except drinking. All of the cattle, horses and other animals from different parts of the city and surrounding area are entirely dependent on the wetland for drinking, in addition to grazing.

Anthropogenic activities are directly and indirectly generating a drastic change in the ecosystems of both the study areas (Lake Tana and Yitamot natural Wetland). For instance besides agricultural runoff, every day activities such as excavation at construction site, driving, maintaining vehicles, disposing of wastes, collecting wastes in failed septic systems and sewer structures contribute substantial amount of contaminant to runoff. The ever-increasing unwise utilization of resource coupled with land use and climate changes, agricultural expansion with its close proximity have become sever threats to both the long term survival of the lake to function as habitats for aquatic organisms and Yitamot wetland to prevent much of the pollutant load from being transported to the receiving water body (Abay/Blue Nile river). With increasing negative trends, resulted from multiple interests of resource users, irreversible ecological damages and biodiversity losses are inevitable before long.

1.5 Thesis outline

This dissertation compiles the research done on macrophyte species composition, abundance, diversity, biomass and nutrient uptake with special reference to *Cyperus papyrus, Phragmites karka and Typha latifolia and* the assessment of percentage coverage and distribution of the invasive weed, *Eichhornia crassipes* (water hyacinth) and its impact on diversity and composition of other macrophytes in the lake. It also compiles the study on evaluation of the contribution of macrophytes in the overall water quality improvement by a natural wetlands and the application of some macrophytes in domestic wastewater treatment using constructed wetlands. The dissertation has six main chapters in total.

The first chapter (this chapter) presents the general introduction, objectives and research questions of the study. The second and third chapters were done in the lake. The second chapter deals with the species composition, abundance, diversity and seasonal variation of the macrophytes in relation to nutrient dynamics in the lake. The historical changes in species composition were assessed by comparing with earlier reports. The probable reasons for decline of percentage coverage of *Cyperus papyrus* and water hyacinth dominance in north eastern littoral zone in the lake currently are also discussed.

The third chapter describes seasonal and spatial trends of biomass accumulation and storage of selected nutrients in three dominant macrophytes and its relationship to nutrient dynamics of the lake. The biomass production of macrophytes in Lake Tana was compared with similar plants in other lakes and the probable impact of the current anthropogenic practices around the lake on macrophyte biomass and nutrient content dynamics was also discussed. Moreover, comparison of macrophyte biomass and nutrient accumulation in different above ground plant tissue parts was done in the dominant macrophytes in different sites.

The fourth chapter presents the contribution of macrophytes in the overall water quality improvement function in a natural system, having specific inlet and outlet (Nutrient gradient) but having almost similar type of macrophytes and climatic conditions with the lake. It is important to understand the nutrient cycling through ecosystems and also to develop appropriate technologies that can help reduce the discharge of nutrients and other pollutants into the environment. These types of studies though very important; they are limited existence in the country. In this chapter the role played by plants and the sediment in nutrient and other pollutants like heavy metal removal was determined. This Chapter is organized such that it highlights the fundamental ecological and hydrological principles and processes determining the functioning of the natural wetland, Yitamot wetland as a treatment system for wastewater.

The fifth chapter presents the findings of an ex-situ experiment to evaluate the growth condition and nutrient storage capacity of macrophytes in a controlled environment, horizontal subsurface flow constracted wetland (HSSFCW) for their potential application in domestic wastewater treatment. It was designed to investigate the structural development and recruitment rates of new shoots and the general growth rate of the macrophytes in relation to the pollutant removal efficiency of the treatment wetlands. The last chapter (Sixth chapter) concludes the major findings of the whole work and suggests some management options and research gaps for further studies.

Chapter 2: Abundance, diversity and distribution of macrophytes in relation to nutrient dynamics in littoral zone of Lake Tana, Ethiopia

2.1. Introduction

A study of macrophyte species composition, diversity and distribution is an essential component for understanding lake ecosystems. This is due to the important ecological role of macrophyte vegetation and the ability of the vegetation to characterize the water quality (Ciecierska and Kolada, 2014). Species composition and distribution of macrophytes in lake ecosystems depend on various environmental factors such as light, water temperature, substrate composition, disturbance and quality of the lake water (Wetzel, 2001; Jafari *et al*., 2003). Macrophytes are important components of the lake ecosystem in that they influence water quality by taking up nutrients, releasing dissolved organic matter, and increasing sedimentation by absorbing turbulent energy (Schallenberg and Waite, 2004). In view of the significant role played by macrophytes in lake ecosystems, understanding and quantifying the species composition and abundance in relation to the nutrient dynamics is very vital for integrated management practices of these ecosystems.

Some of the dominant macrophyte species in Lake Tana were listed in the study of Nagelkerke (1997), Ayalew wondie *et al*, (2007), Imoobe and Akoma (2008), Negash Atinafu *et al*.(2011), and Ayalew Wondie and Seyoum mengistu (2014). Historical data on macrophyte distribution pattern, abundance and diversity of the littoral zone of Lake Tana were not reported in detail in these and other similar works (e.g. Hughes and Hughes, 1992). However, Some of the recent studies in Lake Tana limnology and on hydrology have shown evidence of some undesirable changes that have occurred in the lake, such as an increase in net annual loss of water from the lake as evaporation losses during October to June exceed input via rainfall (Molla and Menelik, 2004), increasing trend of sedimentation and silt load (Berhanu Teshale *et al*., 2001), (Eshetie Dejen et al., 2004, Ayalew wondie *et al*., 2007). However, diversity of aquatic macrophytes with respect to distribution, occurrence and species composition in relation to the current nutrient dynamics of the lake water has not been investigated in detail so far. The area coverage of the weed has been estimated to be 20,000 hectares in 2012 and in the reports of Wassie Anteneh *et al*. (2014), it has been stated that the weed seems replacing the indigenous macrophyte, *Cyperus papyrus* in the north eastern shore of the lake hence, needs further study to know the real status of the weed relative to the indigenous macrophyte species in the lake to produce basic data for its proper management.

The aquatic macrophytes of Lake Tana are among the least understood and least studied components of the Lake biota. Therefore, this study was undertaken to assess the status of occurrence and species composition of macrophytes in relation to physico-chemical factors in the littoral zone and to investigate percentage coverage and distribution of the invasive weed, *Eichhornia crassipes* (water hyacinth) and its impact on diversity and composition of other macrophytes in the lake.

2.2. Materials and methods

2.2.1. Sampling design

Samples were collected from twenty sampling points in south western and north eastern side of the lake; Shum Abo, Infranz, Zegie Yiganda, Gilgel Abay enterance , Rib river mouth, Agid Kirgna, Adisgie Dingie, Achera, Dirma river mouth and Debre Sina at both the littoral zone (shore area) and the open water zone about 10 km from each of the littoral sites (Figure 1.1 and Table 2.1 Samples of water for physico-chemical variables and macrophyte samples were collected for the four seasons (post-rainy, dry, pre-rainy and main-rainy season) during the study period of October 2013 – September 2014.

The choice of sampling sites considered to be representative was made to reflect the greatest plant diversity of the study area. These sites were selected based on their distance from human settlements and anthropogenic effect and accessibility for quantitative study. Each site can be characterized as: Shum-Abo (near to Shum-Abo Resort) and Infranz site (close to human settlements and some fisheries activity), Zegie Yiganda site (relatively far from such impacts), Gilgel-Abay, Rib and Dirma sites (entrance of the three rivers, Gilgel Abay, Rib and Dirma rivers in to the lake), Agid Kirgna (near to the sand beach), Adisgie Dingie (near to Megech river mouth) and Achera (farm land). Besides, sampling sites in the north eastern side were selected on the basis of the extent of invasion by the weed and subsequently categorized as infested, minimal infested and non-infested sites. Agid Kirgna, Adisgie Dingie and Achera were selected as infested sites, while Debre Sina and Dirma were chosen as minimal infested (supported very few water hyacinth plants) and Rib as reference site, which was free from weed infestation. The aim of such site selection was to encompass varying environmental conditions in the assessment of distribution and abundance of macrophytes and to note the variation in macrophyte distribution and abundance along different environmental gradients. The sample size used was believed to be adequate to observe the effect of variation in physico-chemical variables among the sites on macrophyte distribution. In addition, the river mouth sites were selected in order to compare the species composition between the regions around the river mouths and other parts of the lake. This was done to assess if the nutrient inputs from river inlets could trigger different species composition.

Table 2. 1 Locations of the sampling sites in Lake Tana

Littoral zone	Id.No.	Sampling site description	Abbr.	North	East	Elevation (m)
South western	1	Shum Abo littoral	SAL	$11^0$35'58.7"	$037^0$23'42.7"	1790
	2	Shum Abo open	SAO	$11^0$36'05.5"	$037^0$23'30.7"	1790
	3	Infranz littoral	INL	$11^0$38'50.8"	$037^0$19'30.8"	1791
	4	Infranz open	INO	$11^0$39'44.5"	$037^0$19'50.4"	1783
	5	Zegie littoral	ZEL	$11^0$43'17.3"	$037^0$19'20.0"	1786
	6	Zegie open	ZEO	$11^0$44'17.7"	$037^0$19'43.7"	1787
	7	Gilgel Abay entrance littoral	GAL	$11^0$50'28.4"	$037^0$07'42.7"	1790
	8	Gilgel Abay entrance open	GAO	$11^0$50'15.6"	$037^0$08'50.8"	1788
North eastern	9	Rib littoral	RBL	$12^0$02'27.7"	$037^0$35'54.1"	1792
	10	Rib open	RBO	$12^0$02'11.1"	$037^0$31'31.2"	1794
	11	Agid Kirgna littoral	AKL	$12^0$07'29.4"	$037^0$36'22.1"	1794
	12	Agid Kirgna open	AKO	$12^0$07'17.2"	$037^0$35'47.6"	1789
	13	Adisgie Dingie littoral	ADL	$12^0$16'12.8"	$037^0$23'06.8"	1789
	14	Adisgie Dingie open	ADO	$12^0$16'07.5"	$037^0$24'35.1"	1785
	15	Achera littoral	ACL	$12^0$16'59.9"	$037^0$21'43.5"	1784
	16	Achera open	ACO	$12^0$16'09.7"	$037^0$21'16.6"	1791
	17	Dirma littoral	DRL	$12^0$15'49.6"	$037^0$18'18.5"	1791
	18	Dirma open	DRO	$12^0$15'50.7"	$037^0$18'58.0"	1791
	19	Debre Sina littoral	DSL	$12^0$14'33.5"	$037^0$18'02.2"	1799
	20	Debre Sina open	DSO	$12^0$14'59.3"	$037^0$18'18.1"	1794

2.2.1.1 Macrophyte sampling, identification and quantitative studies

Macrophytes were collected manually from all the study sites for the four sampling seasons (Post rainy, Dry, Pre-rainy, and Main rainy seasons). After collection, the macrophyte samples were rinsed *in situ*, blotted, pressed and transported to the National Herbarium, Addis Ababa University, Ethiopia, for identification, which was made to the species level using Ethiopian flora such as those of Hedberg and Edward (1989) and Edwards et al. (1995), and by matching with collections in the National Herbarium.

Quantitative study was carried out in all study sites of the littoral zone of the lake. To analyze the macrophyte community, a belt transect method was employed as recommended by IEP (2009). Two 50 m transects were laid from the shore towards the open water of the lake as far as the depth where submerged species occurred following Burlakoti and Karmacharya (2004). Three quadrates at every 25 m distance (Gaudet and Muthuri, 1981) were laid at each transect. A total of 120 quadrats of 0.25 m^2 size in the study sites were taken following the suggestion of Sutherland (1996). Macrophyte species in each quadrat were counted by hand picking. The relative frequency and relative density of each species were calculated as in the study by Singh et al. (2013) following the following formula:

$$\text{Frequency (\%)} = \frac{\text{No. of quadrats in which the species occurs}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Density/quadrat} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Abundance/quadrat} = \frac{\text{Total number of individuals of a species in all the quadrats}}{\text{Total number of quadrats in which the species occurs.}}$$

Relative frequency = (frequency of species A / total frequency of all species) X 100

Relative density = (density of species A / total density of all species) X 100

Relative abundance = (abundance of species A / total abundance of all species) X 100

2.2.1.2. Physicochemical parameters

Physicochemical parameters including Dissolved Oxygen (DO), pH, electrical conductivity (EC), Total Dissolved Solid (TDS), temperature, Secchi depth, Depth of the water level and nutrients as nitrate, Soluble Reactive Phosphate (SRP) and Total Phosphorus (TP) were measured seasonally (dry, pre-rainy, main-rainy, post-rainy) in the study period. DO, pH, EC, TDS and temperature were measured *in situ* using a YSI 556 multi-probe system. Transparency of the water was measured by lowering a 20 cm diameter circular disc (Secchi disc) into the water column.

100ml duplicate water samples were collected from each site to analyze for nitrate, SRP and TP at each sampling visit. The analysis of SRP and nitrate were based on Palintest Phosphate LR method and Palintest Nitratest method respectively using a portable water analysis kit (Photometer 7100) whereas TP was done for unfiltered water sample using standard procedures as indicated in APHA *et al*., (1999), using a spectrophotometer (Jenway 6405 UV) in the limnology laboratory of Addis Ababa University. Nitrate and SRP analyses were made immediately after sample collection using water samples filtered through Whatman GF/F.

Sediment samples were taken from each study site, for analysis of TP and TN concentration, using a modified sediment core sampler after Powel (2008), from approximately 10 cm of the sediment surface. The collected sediment samples were air dried and sieved through a 2 mm seive. In the process 5 g dry sediment was added to 50 mL 0.002N H_2SO_4 solution in 500 mL Erlenmeyer flask and shaken for 30 minutes with mechanical shaker and filtered through a whatman No. 42 filter paper. Finally, this solution was analyzed according to the methods mentioned in water sample analysis for total phosphorus, (persulfate digestion followed by ascorbic acid method) while for total nitrogen using Kjeldahl method which involves two-step process. First, the sample was digested with a sulfuric acid to convert organic nitrogen compounds to ammonium ion. Secondly the converted ammonium ion was converted to ammonia in an alkali distillation process. The liberated ammonia in this process was finally quantified for determination of the total nitrogen in the original digest as stated in APHA *et al*. (1999)

2.2.2. Data analysis

The relationship between macrophyte species abundance and physicochemical variables was evaluated by redundancy analysis (RDA) for south western littoral zone and by CCA for the north eastern littoral zone using CANOCO for windows 4.5. Prior to conducting RDA and CCA, detrended correspondence analysis (DCA) was employed to check the response of the data, and it was found that the length of longest gradient was 1.337 and 3.299, for the south western and north eastern littoral zones respectively. Therefore, RDA for the south western and CCA for the north eastern littoral zones was used as the species data showed linear response and unimodal response to the environmental variables according to Leps and Smilauer (1999). All physicochemical parameters were included in the RDA ordinations since there were no variable with high Variance Inflation Factors (VIF > 20) (ter Braak and Sˇmilauer, 1998) that indicate strong multicollinearity for the south western littoral zone. Whereas for the north eastern littoral zones although all physicochemical parameters were included in the early CCA ordinations, TDS was with high variance inflation factor (VIF > 20) indicating very strong multi-collinearity with other variables and so eliminated from the analyses. In addition, variables were log transformed [log (x + 1)] before the RDA and CCA analysis to prevent extreme values (outliers) from excessively influencing the ordination.

Principal components analysis (PCA) was employed to observe the difference among the study sites with respect to their physicochemical properties using PAST software. The PCA was carried out using correlation because the variables were on different scales. Significance differences in mean measurements of physico-chemical factors and significant differences in the abundance of macrophytes among the four seasons were analyzed using One-way ANOVA. Macrophyte species diversity in the lake was computed using Shannon and Weiner Diversity Index following Shannon and Weiner (1963) using the following formula:

$$H` = \sum_{i=1}^{s} - (P_i * \ln P_i) = H` = -\sum_{i=1}^{s} pi \log_e pi, \; E = H`/H_{max} = H`/\log s$$

Where:

E = evenness, H_{max} = the maximum diversity of a sample, H` = the value of Shannon-Winner diversity index, Pi = the proportion of the ith species, Log_e = the natural logarithm of pi, S = the number of species in the community, N = total Number of organisms in each species, ∑ = sum from species 1 to species S.

2.3. Results

2.3.1. Species composition, abundance and distribution of macrophytes in south western littoral zone of the lake

A total of thirty macrophyte species, which belonged to fifteen families, were identified, and their relative frequency and density were determined (Table 2.2). The occurrence and percentage of coverage for the macrophyte species identified is shown in Table 2.3. Two of the macrophytes are rooted with floating leaves (*Ipomoea aquatica*, and *Nymphaea lotus*), one is free floating (*Azolla africana*), two are submerged (*Potomagton pectinatus and Ceratophyllum demersum*), and the rest are emergent. The percentage compositions of the different macrophytic species were found maximum in the emergent group (83%), which was then followed, by the submerged species and rooted floating (each account 7%). The lowest percentage (3%) was contributed by free-floating species (Figure 2.1).

Table 2.2 Macrophyte Species identified and their relative frequency and density in the south western littoral zone of Lake Tana

Species	Family	Lifeforms	Relative Frequency (%)	Relative Density (%)
Achyranthes aspera L.	Amaranthaceae	Emergent	3.17	0.94
Amaranthus hybridus L.	Amaranthaceae	Emergent	6.35	1.7
Azolla africana Desv.	Azollaceae	Free floating	0.79	8.49
Bothriocline schimperi Olivo & Hiern ex Benth	Asteraceae	Emergent	0.79	0.47
Brachiaria sp.	Poaceae	Emergent	3.57	1.13
Ceratophyllum demersum L.	Ceratophyllaceae	Sumerged	6.75	5.19
Cyperus alopecuroides Rotb.	Cyperaceae	Emergent	1.59	0.57
Cyperus digitatus Roxb.	Cyperaceae	Emergent	3.57	18.87
Cyperus fischerianus A. Rich	Cyperaceae	Emergent	4.37	2.08
Cyperus macrostachyos Lam.	Cyperaceae	Emergent	0.79	1.6
Cyperus papyrus L.	Cyperaceae	Emergent	7.54	11.89
Digitaria milanjiana (Rendle) Stapf	Poaceae	Emergent	1.19	0.57
Echinochloa stagnina (Retz.) P. Beauv.	Poaceae	Emergent	1.19	2.26
Hibiscus diversifolius Jacq	Malvaceae	Emergent	2.38	0.57
Ipomoea aquatica (L.) Sweet	Convolvulaceae	Rooted floating	1.19	0.57
Leersia hexandra SW.	Poaceae	Emergent	3.57	1.23
Ludwigia abysinica A. Ric	Onagraceae	Emergent	6.35	3.68
Nymphaea lotus L.	Nymphaeaceae	Rooted floating	1.98	0.57
Panicum repens L.	Poaceae	Emergent	0.4	0.47
Panicum maximum Jacq	Poaceae	Emergent	4.76	2.08
Phragmites karka (Retz.) Trin.	Poaceae	Emergent	9.13	15.94

ex Steud.				
Polygonum glabrum Willd	Polygonaceae	Emergent	5.16	3.02
Potomagton pectinatus L.	Potamogetonaceae	Submerged	4.76	1.89
Pyscnochys coerulea Hook	Lamiaceae	Emergent	1.19	1.04
Sacciolepis africana C.E.Hubb.& Snoden	Poaceae	Emergent	3.17	1.89
Scirpus pallidus (Britton) Fernald	Cyperaceae	Emergent	1.59	0.75
Solenostemon latifolius (Benth) J.K Morton	Lamiaceae	Emergent	0.4	0.09
Triumfetta annua L.	Tiliaceae	Emergent	1.98	0.75
Typha latifolia L.	Typhaceae	Emergent	6.35	7.08
Vossia cuspidata (Roxb.) Griff.	Poaceae	Emergent	3.97	2.64

Table 2.3 Occurrence and percentage of coverage of macrophyte species in the south western littoral zone of Lake Tana

Species	Shum Abo	Infranz	Gilgel Abay enterance	Zegie Yiganda
Achyranthes aspera	1.20	-	4.92	1.92
Amaranthus hybridus	0.90	1.27	6.56	1.28
Azolla africana	40.39	-	-	-
Bothriocline schimperi	-	2.38	-	-
Brachiaria sp.	-	0.95	4.92	2.56
Ceratophylum demersum	4.49	2.04	1.64	1.92
Cyperus alopecuroides	1.35	-	-	-
Cyperus digitatus	1.20	59.59	-	3.42
Cyperus fischerianus	2.02	1.19	-	3.42
Cyperus macrostachyos	10.77	-	-	6.41
Cyperus papyrus	6.96	6.28	9.84	8.01
Digitaria milanjiana	1.80	-	-	-
Echinochloa stagnina	-	-	1.64	14.10
Hibiscus diversifolius	-	-	4.92	-
Ipomoea aquatica	-	-	4.92	-
Leersia hexandra	-	0.95	3.28	2.56
Ludwigia abysinica	2.69	2.54	11.48	-
Nymphaea lotus	0.90	0.95	-	1.92
Panicum repens	-	-	-	6.41

Panicum maximum	1.80	1.90	4.92	2.14
Phragmites karka	4.67	6.50	9.84	12.18
Polygonum glabrum	2.24	0.95	4.92	4.49
Potomagton pectinatus	1.12	-	6.56	3.21
Pyscnochys coerulea	6.28	-	1.64	3.85
Sacciolepis africana	1.35	2.38	1.64	5.13
Scirpus pallidus	3.59	0.95	1.64	2.56
Solenostemon latifolius	-	0.95	-	-
Triumfetta annua	0.90	-	-	2.56
Typha latifolia	2.51	5.16	9.84	7.37
Vossia cuspidata	-	3.09	4.92	2.56

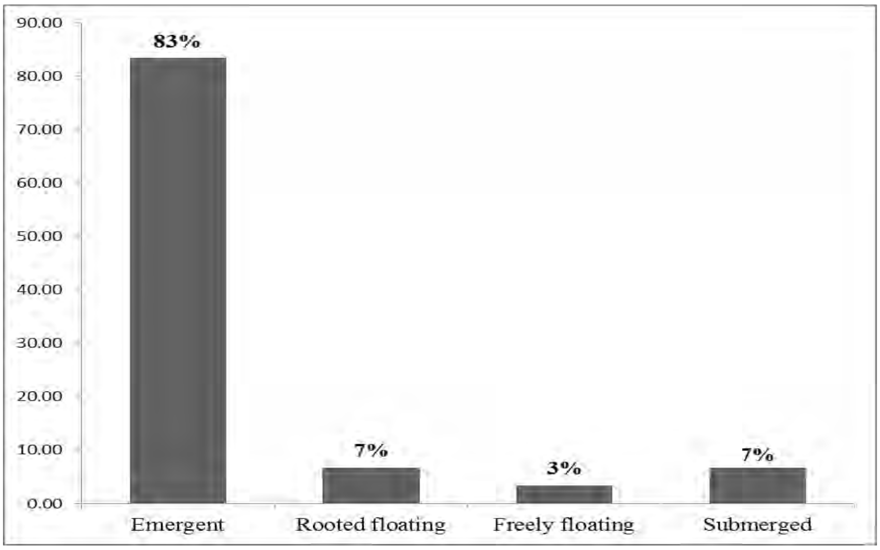


Figure 2.1 Percentage coverage of macrophyte lifeform classes to the total macrophyte counts in the littoral zone of south western Lake Tana

All the sites were dominated by emergent macrophytes that attained the highest relative frequency and density, followed by floating species and other forms. Comparatively; the most frequent species recorded in the Lake were *Phragmites karka* (9.13%), *Cyperus papyrus* (7.54%), *Ceratophylum demersum* (6.75%), *Amaranthus hybridus, Ludwigia abysinica and Typha latifolia* each accounting 6.35% and *Polygonum glabrum* 5.16%. The remaining species account less than 5% frequency of occurrence. The highest density was recorded by *Cyperus digitatus (18.87%), Phragmites karka* (15.94%), *Cyperus papyrus* (11.89%) followed by *Azolla* *africana (*8.49%) and *Typha latifolia (7.08%)* and *Ceratophylum demersum* 5.19%. The remaining species account for less than 4% coverage. The plant family having the greatest diversity of macrophytes was Poaceae with 9 species (30%), followed by the Cyperaceae with 6 species (20%). Other families like Amaranthaceae and Lamiaceae comprise 2 species each contributing to 6.67%. The remaining families viz., Asteraceae, Azollaceae, Ceratophyllaceae, Convolvulaceae, Malvaceae, Nymphaeaceae, Onagraceae, Polygonaceae, Potamogetonaceae, Tiliaceae, Typhaceae comprised 1 species each constituting 3.33% (Figure 2.2). However, there were no significant differences in the abundance of macrophytes among the four sampling seasons (P > 0.05; Kruskal - Wallis Test).

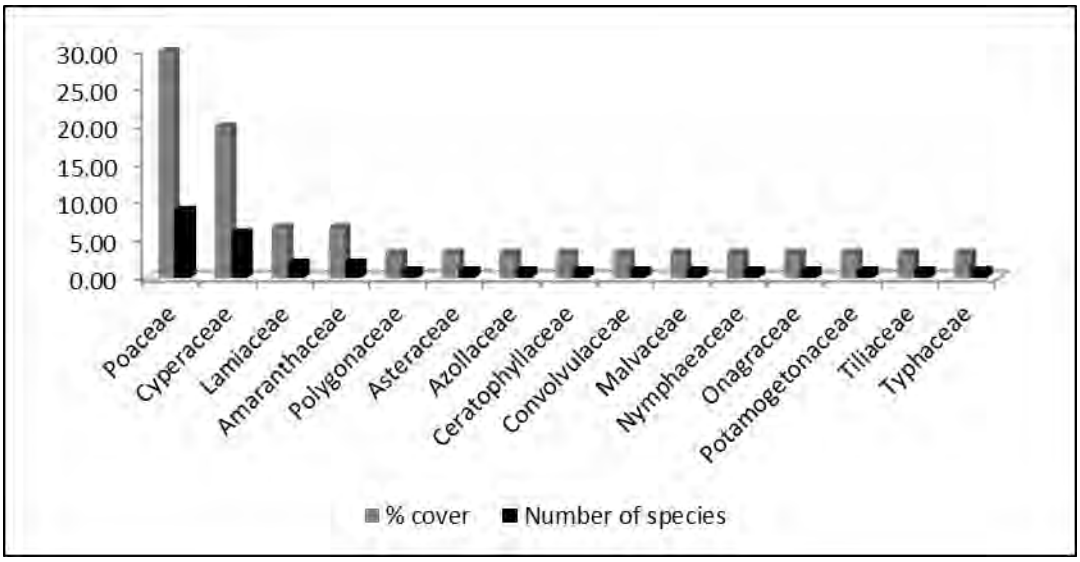


Figure 2.2 Percentage of macrophyte family classes in the south western littoral zone of Lake Tana

The mean macrophyte species diversity of southwestern littoral zone of Lake Tana had H′ value of 2.34 (Table 2.4). The result for the four sampling sites followed the order as Zegie Yiganda littoral site with H′ value of 2.63 > Shum Abo littoral site with H′ value of 2.48 > Gilgel Abay entrance littoral site with H′ value of 2.38 > Infranz littoral with H′ value of 1.86 (Table 2.4). The evenness index of macrophytes of the area also shows similar order of the species diversity index. The values are: 0.54 for Shum-Abo littoral, 0.36 for Infranz littoral, 0.57 for Gilgel-Abay entrance littoral and 0.63 for Zegie Yiganda littoral (Table 2.4). The seasonal macrophyte species diversity also showed certain variations. It follows the order: post rainy with H′ value of 3.02 > pre-rainy with H′ value of 2.92 > dry with H′ value of 2.67 > main rainy season with H′ value of 2.36 (Table 2.5).

Table 2.4 Spatial Shannon Weiner diversity index H‵‵ and Evenness Value of South western littoral zone of Lake Tana macrophytes, n= 8

Sampling site	Site Characteristics	No. of spp.	H` value	Evenness value
Shum Abo	Near to Shum-Abo Resort	22	2.48	0.54
Infranz	Close to human settlements and some fisheries activity	18	1.86	0.36
Gilgel Abay entrance	At the entrance of Gilgel Abay River	19	2.38	0.57
Zegie Yiganda	Better protected from anthropogenic impacts	22	**2.63**	**0.63**
Mean H` value = 2.34				

Table 2.5 Mean Temporal Shannon Weiner diversity index H‵‵ Value macrophytes from four sampling sites in south western littoral zone of Lake Tana, n= 8.

Parameter	Post	Dry	Pre-rainy	Main-rainy
No.of spp	25.00	19.00	23.00	27.00
H` value	**3.02**	2.67	2.92	2.36
Evenness value	**0.82**	0.76	0.80	0.39

2.3.2. Changes and characteristics of physico-chemical parameters in south western littoral zone of Lake Tana

The spatial variation of physico-chemical water quality parameters investigated is listed in Table 2.6. More variation in mean values of physical-chemical parameters among sites was observed for EC, TP, TDS and depth of the lake. The mean values ranged between 152.48 - 164.18 μS/cm for EC, 94.95 - 101.88 mg/L for TDS, 7.61 - 8.92 for pH, 6.41 - 7.54 mg/L for dissolved oxygen, 24.15 - 26.34 ^{0}C for temperature and 1.28 - 6.37 and 0.29 - 0.68 m for depth and Secchi depth measurements respectively.

Table 2.6 Characteristics of physico-chemical variables of the study sites in the south western littoral zone of Lake Tana (Mean± S.D) (n=8)

Site	DO(mg/L)	pH (Range)	EC (μS cm^{-1})	TDS(mg/L)	Temp (0c)	Sec. (m)	Depth(m)	Nitrate(mg/L)	SRP(mg/L)	TP(mg/L)
SAO	6.89±0.49	7.61-8.92	161.70± 7.24	101.20± 3.85	24.32±0.67	0.68±0.10	5.14±0.52	0.50±0.09	0.22±0.06	0.59±3.93
SAL	6.81± 0.75	8.92± 0.27	164.18± 7.19	101.73± 2.97	25.52±0.97	0.63±0.11	2.60±0.38	1.10±0.56	0.34±0.11	1.00±5.09
INO	6.85± 0.57	8.43± 0.39	160.60± 5.63	99.63± 2.79	24.15±0.70	0.45±0.15	5.57±0.46	0.81±0.31	0.23±0.09	0.73±3.27
INL	6.41± 0.58	8.14± 0.35	163.40± 6.81	101.88± 3.69	25.18±0.92	0.56±0.11	2.35±0.37	1.53±0.35	0.26±0.05	0.53±2.07
GAO	6.72± 0.37	8.31± 0.37	155.13± 9.55	97.23± 4.80	24.53±0.61	0.46±0.16	4.83±1.28	1.00±0.48	0.15±0.05	0.60±2.77
GAL	6.65± 0.92	7.61± 0.15	152.48±17.90	94.95± 10.05	24.50±0.93	0.29±0.08	2.05±0.42	1.83±0.91	0.22±0.04	0.53±2.06
ZEO	7.02± 0.43	8.54± 0.16	156.45±5.25	97.95± 2.91	25.05±0.30	0.61±0.16	6.37±0.64	0.89±0.53	0.15±0.04	0.22±0.40
ZEL	7.54± 1.00	8.50± 0.32	162.88±7.77	101.70± 4.34	26.34±0.39	0.48±0.10	1.28±0.23	1.09±0.65	0.28±0.04	0.37±0.92

Abbreviations: S.D = Standard deviation,SAO =Shum Abo open, SAL= Shum Abo littoral, INO = Infranz open, INL = Infranz littoral,GAO = Gilgel Abay entrance open, GAO = Gilgel Abay entrance littoral, ZEO =Zegie Yiganda open, ZEL = Zegie Yiganda littoral

The study showed significant temporal variation in all physico-chemical variables. The mean concentration of DO was significantly higher during the main-rainy season than the pre-rainy season ($F = 4.54$, $p < 0.05$, Tukey Test). The mean pH value was significantly lower during the post-rainy season than the rest three seasons ($F = 6.42$, $p < 0.05$, Tukey Test) and the mean TDS concentration was significantly higher during the pre-rainy season than that of post-rainy season ($F = 20.14$, $p < 0.05$, Tukey Test). However, the main-rainy season mean TDS concentration was significantly lower than the other three seasons and EC also followed the same seasonal trend as TDS. The mean water surface temperature was significantly lower during dry season than that of post and main-rainy seasons ($F = 6.94$, $p < 0.05$, Tukey Test). The ANOVA result also showed that transparency of the water in terms of Secchi depth measurement was significantly higher during the dry season ($F = 6.51$, $p < 0.05$, Tukey Test). There was also significantly higher mean Secchi depth measurement during the pre-rainy season than the main-rainy season and the mean depth measurement was significantly higher during the main-rainy season ($F = 3.15$, $p < 0.05$, Tukey Test).

The mean values for nutrients ranged from 0.22 – 1.00 mg/L, 0.15 - 0.34 mg/L and 0.50 - 1.83 mg/L for TP, SRP and nitrate respectively. The nutrients (SRP and nitrate) and depth mean measurements were significantly higher in the littoral sites than its open water zone ($p < 0.05$, paired - samples t-test). Significant temporal variations were also observed in mean nutrient concentrations. Mean nitrate concentration was significantly higher during the dry season than the rest three seasons ($F = 15.76$, $p < 0.05$,Tukey Test) and mean SRP concentration was significantly higher during post rainy season than pre-rainy season ($F = 7.28$, $p < 0.05$, Tukey Test). Significantly higher mean TP concentration was measured during the post rainy season than the dry and pre- rainy seasons ($F = 5.38$, $p < 0.05$, Tukey Test).

The three components of the principal components analysis (PCA) explained 87.88 % of the total variance with eigenvalue of 4.51, 2.70 and 1.58 respectively (Figure 2.3). Eigenvalues of 1.0 or greater are considered significant (Shrestha and Kazama, 2007).

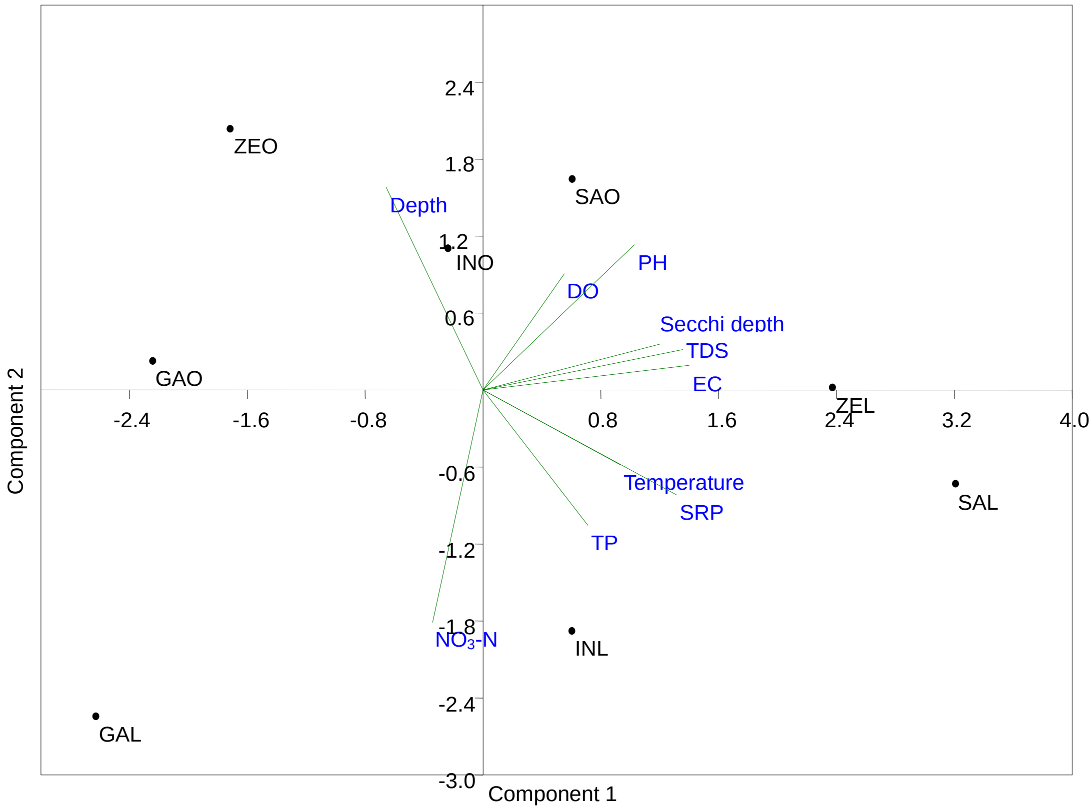


Figure 2.3 Principal components analysis ordination diagram of the physicochemical factors in south western littoral zone of Lake Tana (Abbreviations: SAO – Shum Abo open, SAL – Shum Abo littoral, INO – Infranz open, INL – Infranz littoral, GAO – Gilgel Abay entrance open, GAL – Gilgel Abay entrance littoral, ZEO – Zegie Yiganda open, ZEL – Zegie Yiganda littoral, SRP – Soluble reactive phosphate, TP – TP, EC – Electrical conductivity, TDS – Total dissolved solids, DO – Dissolved oxygen).

In the present study, a Scree plot also shows the eigenvalues sorted from large to small as a function of the principal components number. After the third PC (Figure

2.4), starting the elbow in the downward curve, other components can be omitted. The Scree plot was used to identify the number of PCs to be retained in order to comprehend the underlying data structure (Palma *et al*., 2010).

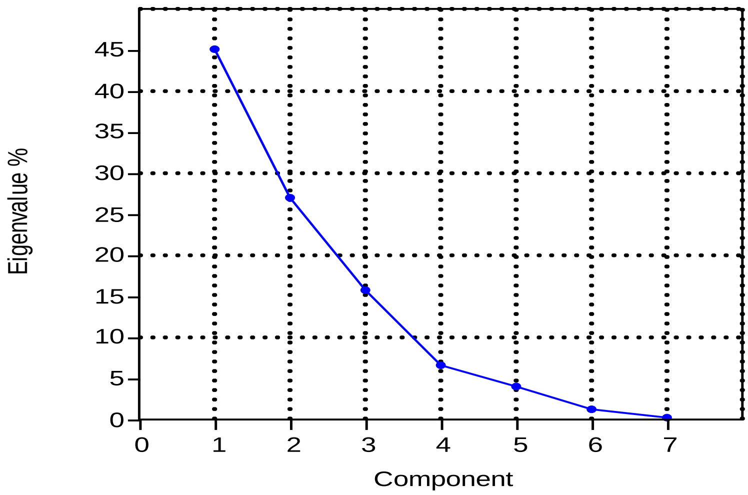


Figure 2.4 PCA Scree plot of the eigenvalue.

The result of the PCA analysis discriminates Shum Abo littoral and Zegie Yiganda littoral sites from the others (by axis 1), owing to higher values of EC, TDS, SRP and Secchi depth, which had highest loading factor on the first axis (0.93, 0.90, 0.87, and 0.80, respectively) and were positively correlated with the axis (Table 2.7). Zegie Yiganda open and Infranz open sites are discriminated from other sites by axis 2, owing to higher value of depth but correlated negatively (-0.93) with the axis. Nitrate (-0.23) and depth (-0.44) were negatively correlated with the first axis (Figure 2.3). Gilgel Abay entrance littoral and Infranz littoral sites were different from others by having relatively higher nitrate values (Figure 2.3).

Almost all the physico-chemical parameters best described in axis 1 and axis 2 and the littoral zone of the lake in each sampling sites. Only depth can describe the open water zone. This could be because of the maximum human interference in the littoral zone which may result for the maximum inputs which may lead for the fluctuation in nutrient, EC, TDS, pH and temperature condition than that of the open water. Macrophytes have also a great role in this regard.

Table 2.7 Correlation coefficient of the environmental variables used with the first three principal component axes in the south western littoral zone of Lake Tana (strong correlations are marked bold)

Environmental variables	**component 1**	**component 2**	**component 3**
DO	0.37	**0.47**	**-0.77**
pH	**0.68**	**0.58**	0.10
TDS	**0.90**	0.16	0.13
EC	**0.93**	0.10	0.18
Temp	**0.62**	-0.30	**-0.60**
Secchi	**0.80**	0.18	0.07
Depth	-0.44	**0.81**	0.37
NO_3-N	-0.23	**-0.93**	-0.15
SRP	**0.87**	-0.42	0.09
TP	0.47	**-0.54**	**0.62**

2.3.3. Relationship between physicochemical parameters and density of macrophytes using multivariate analysis

The results of the redundancy analysis (RDA) between water quality data and macrophyte data showed the first two axes make 75.3% of the cumulative percentage of variance in species–environmental relationship (Table 2.8). The first axis, which contributed 39.9% of the variance, was positively and strongly correlated with TP, SRP, pH and Secchi depth. TDS and EC showed the strongest and positive correlations with axes 2 (Figure 2.5).

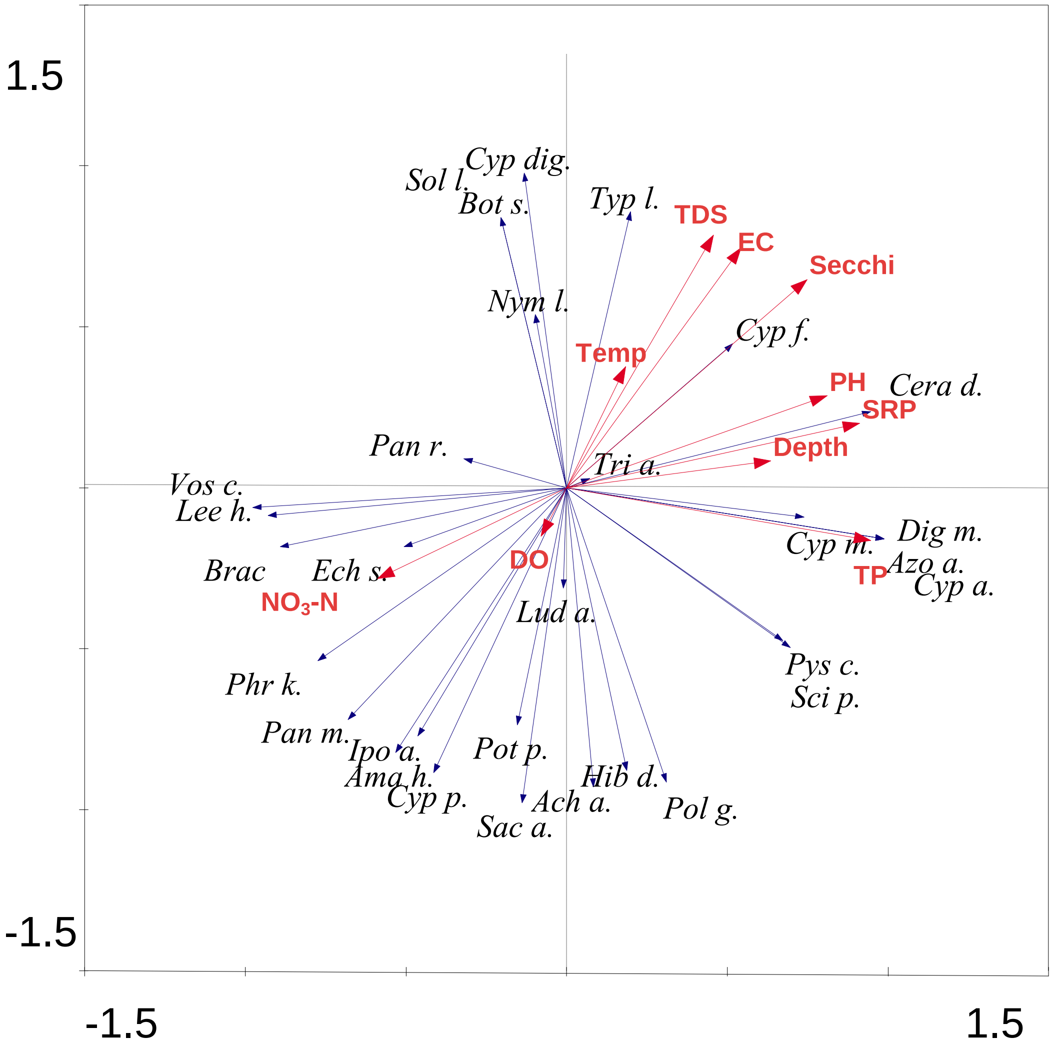


Figure 2.5 Plot of the first two axes of the redundancy analysis (RDA) for macrophyte species and physicochemical variables in the south western littoral zone (Abbreviations: Ach a. - *Achyranthes aspera*, Ama h. - *Amaranthus hybridus*, Azo a. *Azolla africana*, Bot s. - *Bothriocline schimperi,* Bra c. - *Brachiaria sp.,* Cera d. - *Ceratophyllum demersum,* Cyp a. - *Cyperus alopecuroides,* Cyp dig. - *Cyperus digitatus,* Cyp f. - *Cyperus fischerianus,* Cyp m. - *Cyperus macrostachyos,* Cyp p. - *Cyperus papyrus,* Dig

m. - *Digitaria milanjiana,* Ech s. - *Echinochloa stagnina,* Hib d. - *Hibiscus diversifolius,* Ipo a. - *Ipomoea aquatica,* Lee h. - *Leersia hexandra*, Lud a. - *Ludwigia abysinica*, Nym l. - *Nymphaea lotus*, Pan r. - *Panicum repens*, Pan m. - *Panicum maximum*, Phr k. - *Phragmites karka*, Pol g. - *Polygonum glabrum*, Pot p. *Potomagton pectinatus*, Pys c. - *Pyscnochys coerulea*, Sac a. - *Sacciolepis africana*, Sci p. - *Scirpus pallidus*, Sol l. - *Solenostemon latifolius*, Tri a. - *Triumfetta annua,* Typ l. - *Typha latifolia,* Vos c. - *Vossia cuspidata,* SRP – Soluble reactive phosphate, TP – Total phosphorus, EC – Electrical conductivity, TDS – Total dissolved solids, DO – Dissolved oxygen, Sec – Secchi depth)

Table 2.8 Eigenvalues, cumulative percentage variance of species-environment relation, and correlation coefficient of physico-chemical variables with the first two axes in the south western littoral zone (strong correlations are marked bold)

Environmental variables	Axis 1	Axis 2
Eigen values	0.399	0.354
Cumulative percentage of variance of species data	39.9	75.3
DO	-0.08	-0.15
PH	**0.81**	0.29
TDS	0.46	**0.78**
EC	0.54	**0.75**
Tem	0.18	0.38
Sec	**0.75**	0.65
Depth	0.64	0.08
NO_3-N	-0.59	-0.28
SRP	**0.91**	0.20
TP	**0.95**	-0.16

The density of *Azolla africana*, *Cyperus alopecuroides, Ceratophylum demersum, Cyperus macrostachyos, Digitaria milanjiana, Pyscnochys coerulea* and *Scirpus pallidus* was positively and strongly associated with SRP, pH, TP and Secchi depth (Figure 2.5). The density of *Vossia cuspidata, Brachiaria sp. and Leersia hexandra* was also negatively and strongly associated with SRP and pH whereas the density of *Typha latifolia* was positively and strongly associated with TDS and EC (Figure 2.5).

2.3.4 Percentage coverage and distribution *Eichhornia crassipes* (waterhyacinth) and its impact on diversity and composition of macrophytes in the north eastern littoral zone of Lake Tana

A total of 41 macrophyte species belonged to 20 families were identified in the North Eastern littoral zone of Lake Tana, and their relative frequency and density were presented (Table 2.9). Among families, Poaceae (10 species) and Cyperaceous (6 species) were most species diverse. Asteraceae and Polygonaceae are represented by 3 species each, three families; Amaranthaceae, Commelinaceae and Nymphaeaceae have two species each and the remaining 13 families were mono-species (Table 2.10).

*Eichhornia crassipes (*Water hyacinth) is the dominant macrophyte in most of the sampling sites that attained the highest relative frequency and density. Comparatively; the most frequent and densely populated species recorded were P*ersicaria senegalensis* and *Phragmites karka* in non- water hyacinth infested site (Rib sampling site) and in the two minimal-infested sites (Dirma and Debre Sina sampling sites) respectively. *Echinochloa stagnina* was the most frequently observed species together with *Eichhornia crassipes* in the water hyacinth infested sites (Agid kirgna, Adisgie Dingie and Achera sampling sites). *Eichhornia crassipes* was with the highest density recorded in all water hyacinth infested sites including Dirma sampling site. However, *Echinochloa stagnina and Ceratophyllum demersum* accounted the highest density in Rib and Debre Sina sampling sites respectively (Table 2.10).

Table 2.9 Macrophyte species identified and their relative frequency and density on sampling sites with varied water hyacinth infestation level in the north eastern littoral zone of Lake Tana

spp	Family	Non-infested		Infested						Minimal infested			
		RB		AK		AD		AC		DR		DS	
		rel-fr	rel-d	rel-fr	rel-d	rel-fr	rel-d	rel-fr	rel-d	rel-fr	rel-d	rel-fr	rel-d
Achyranthes aspera L	*Amaranthaceae*	-	-	-	-	-	-	-	-	-	-	3.31	0.81
Amaranthus spinosus L	*Amaranthaceae*	3.95	1.56	-	-	-	-	-	-	-	-	-	-
Artemisia absinthium L	*Asteraceae*	3.95	4.3	-	-	-	-	-	-	-	-	-	-
Brachiaria sp.	Poaceae	-	-	-	-	-	-	-	-	15.48	8.06	-	-
Ceratophyllum demersum L	Ceratophyllaceae	-	-	-	-	-	-	-	-	3.57	2.78	9.52	13.14
Commelina diffusa Burm.f.	*Commelinaceae*	-	-	-	-	-	-	-	-	-	-	4.35	2.59
Commolina africana L	*Commelinaceae*	-	-	-	-	-	-	-	-	-	-	2	1.12
Cyperus digitatus Roxb.	Cyperaceae	-	-	-	-	-	-	-	-	-	-	2.25	1.63
Cyperus distans L.f.	Cyperaceae	-	-	-	-	-	-	2.78	2.8	-	-	-	-
Cyperus macrostachyos Lam.	Cyperaceae	-	-	-	-	-	-	-	-	-	-	0.93	0.46
Cyperus papyrus L.	Cyperaceae	-	-	-	-	-	-	-	-	-	-	3.56	8.15
Cyperus sp.	Cyperaceae	-	-	-	-	-	-	-	-	-	-	3.93	8.4
Digitaria milanjiana (Rendle) Stapf	*Poaceae*	-	-	-	-	-	-	-	-	-	-	2.64	1.66
Echinochloa crus-galli (L.) Beauv	*Poaceae*	-	-	-	-	2.5	0.22	-	-	17.86	17.22	1	0.28
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	*Poaceae*	-	-	13.17	6.49	8.75	3.22	8.43	1.44	20.24	21.11	-	-
Echinochloa stagnina (Retz.) P. Beauv.	*Poaceae*	11.11	28.68	29.11	33.87	29.17	30.13	29.32	24.99	0	0	2.18	2.29
Eichhornia crassipes (Mart.) Solms.	Pontederiaceae	-	-	20.78	47.53	22.92	51.29	29.32	63.15	11.9	32.78	1.85	2.08
Glinus lotoides L.	Molluginaceae	3.95	10.55	2.78	3.95	-	-	-	-	-	-	-	-

Hibiscus diversifolius Jacq	Malvaceae	4.86	0.98	-	-	-	-	-	-	-	-	3.31	1.04
Hydrocotyle ranunculoides L. f.	*Apiaceae*	-	-	-	-	-	-	-	-	-	-	1	1.12
Hygrophilia schulli (Hamitt) & Almeide	*Acanthaceae*	2.78	1.56	-	-	-	-	-	-	-	-	-	
Ipomoea aquatica (L.) Sweet	*Convolvulaceae*	-	-	-	-	6.25	5.3	5.95	1.73	-	-	6.02	5.52
Leersia hexandra SW.	*Poaceae*	3.4	0.59	7.32	1.92	-	-	-	-	-	-	2.85	0.98
Ludwigia abysinica A. Ric	Onagraceae	-	-	-	-	5	4.57	12.15	4.19	-	-	6.24	8.92
Nymphaea lotus L.	Nymphaeaceae	-	-	20.02	5.58	-	-	1.79	0.22	-	-	3.89	1.89
Nymphoides indica (L.) O.Kuntze	Nymphaeaceae	-	-	-	-	8.33	2.19	-	-	-	-	-	-
Panicum maximum Jacq	*Poaceae*	-	-	-	-	-	-	-	-	-	-	2.25	2.16
Paspalidium geminatum (Forssk.) Stapf	*Poaceae*	-	-	-	-	-	-	-	-	-	-	5.18	4.68
Persicaria senegalensis (Meisn.) Sojak	*Polygonaceae*	19.3	15.21	-	-	1.67	0.24	-	-	7.14	6.94	1.25	2.66
Phragmites karka (Retz.) Trin. ex Steud.	*Poaceae*	6.25	0.91	4.55	0.47	13.75	2.36	8.48	1.26	23.81	11.11	10.27	12.86
Polygonum glabrum Willd	Polygonaceae	-	-	2.27	0.18	-	-	-	-	-	-	0.93	0.46
Polygonum lapathifolium L.	Polygonaceae	6.8	3.67	-	-	-	-	1.79	0.22	-	-	-	-
Potomagton pectinatus L.	Potamogetonaceae	3.4	0.7	-	-	-	-	-	-	-	-	4.81	2.12
Sacciolepis africana C.E.Hubb.& Snoden	*Poaceae*	-	-	-	-	-	-	-	-	-	-	4.43	2.92
Salix subserrata Willd	Salicaceae	2.78	3.13	-	-	-	-	-	-	-	-	-	-
Scirpus pallidus (Britton) Fernald	*Cyperaceae*	-	-	-	-	-	-	-	-	-	-	1	2.81
Sphaeranthus suaveolens (Forssk.) DC.	*Asteraceae*	16.59	24.33	-	-	1.67	0.48	-	-	-	-	-	-
Triumfetta annua L.	Tiliaceae	5.48	1.1	-	-	-	-	-	-	-	-	1.93	0.51
Typha latifolia L.	Trapaceae	-	-	-	-	-	-	-	-	-	-	4.95	5.96
Xanthiumum strumarium L.	Asteraceae	5.41	2.73	-	-	-	-	-	-	-	-	-	-
Zehneria scabra (L.f.) Sond.	*Cucurbtaceae*	-	-	-	-	-	-	-	-	-	-	2.18	0.76

Abbreviations: RB = Rib, AK = Agid Kirgna, AD = Adisgie Dingie, AC = Achera, DR = Dirma, DS = Debre Sina, rel-fr = relative frequency, rel-d = relative density

Among these identified species, the Occurrence and percentage of coverage (in %) of macrophyte species in the sampling sites, water hyacinth accounted the dominant coverage (89.86%, 56.09%, 46.71% and 34.83% in Agid kirgna, Achera, Adisgie Dingie and Dirma sampling sites respectively).Whereas the non-infested sampling site Rib and minimal infested site Debresina were dominated by *Echinochloa stagnina (33.66%)* and *Cyerus papyrus* (12.51%) respectively.

Table 2.10 Occurrence and percentage of coverage in (in %) of macrophyte species in the north eastern littoral zone of Lake Tana

SPP	Non-Infested	Infested			Minimal Infested	
	RB	AK	AD	AC	DR	DS
Achyranthes aspera L	-	-	-	-	-	1.31
Amaranthus spinosus L	1.23	-	-	-	-	-
Artemisia absinthium L	3.40	-	-	-	-	-
Brachiaria sp.	-	-	-	-	9.75	-
Ceratophyllum demersum L	-	-	-	-	5.66	10.52
Commelina diffusa Burm.f.	-	-	-	-	-	1.61
Commolina africana L	-	-	-	-	-	0.96
Cyperus digitatus Roxb.	-	-	-	-	-	2.27
Cyperus distans L.f.	-	-	-	6.57	-	-
Cyperus macrostachyos Lam.	-	-	-	-	-	0.58
Cyperus papyrus L.	-	-	-	-	-	12.51
Cyperus sp.	-	-	-	-	-	9.39
Digitaria milanjiana (Rendle) Stapf	-	-	-	-	-	2.39
Echinochloa crus-galli (L.) Beauv	-	-	0.60	-	11.36	0.48
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	-	13.76	7.99	2.86	21.62	-
Echinochloa stagnina (Retz.) P. Beauv.	33.66	46.92	26.20	21.75	-	2.85
Eichhornia crassipes (Mart.) Solms.	-	89.86	46.71	56.09	34.83	1.31
Glinus lotoides L.	8.33	6.43	-	-	-	-
Hibiscus diversifolius Jacq	1.48	-	-	-	-	1.60
Hydrocotyle ranunculoides L. f.	-	-	-	-	-	1.91
Hygrophilia schulli (Hamitt) & Almeide	2.03	-	-	-	-	-
Ipomoea aquatica (L.) Sweet	-	-	4.29	3.82	-	3.35
Leersia hexandra SW.	1.39	6.81	-	-	-	0.91
Ludwigia abysinica A. Ric	-	-	4.03	5.96	-	6.96
Nymphaea lotus L.	-	8.25	-	0.59	-	1.53
Nymphoides indica (L.) O.Kuntze	-	-	4.37	-	-	-

Panicum maximum Jacq	-	-	-	-	-	2.93
Paspalidium geminatum (Forssk.) Stapf	-	-	-	-	-	4.13
Persicaria senegalensis (Meisn.) Sojak	11.33	-	0.64	-	7.08	3.29
Phragmites karka (Retz.) Trin. ex Steud.	1.38	0.65	3.93	1.77	9.70	9.37
Polygonum glabrum Willd	-	2.01	-	-	-	0.58
Polygonum lapathifolium L.	4.27	-	-	0.59	-	-
Potomagton pectinatus L.	1.61	-	-	-	-	1.82
Sacciolepis africana C.E.Hubb.& Snoden	-	-	-	-	-	2.56
Salix subserrata Willd	4.05	-	-	-	-	-
Scirpus pallidus (Britton) Fernald	-	-	-	-	-	4.78
Sphaeranthus suaveolens (Forssk.) DC.	20.34	-	1.27	-	-	-
Triumfetta annua L.	2.54	-	-	-	-	0.77
Typha latifolia L.	-	-	-	-	-	6.42
Xanthiumum strumarium L.	3.42	-	-	-	-	-
Zehneria scabra (L.f.) Sond.	-	-	-	-	-	0.95

Abbreviations: RB = Rib, AK = Agid Kirgna, AD = Adisgie Dingie, AC = Achera, DR = Dirma, DS = Debre Sina

In this study mean macrophyte species diversity of north eastern littoral zone of Lake Tana was ranged from 1.3 - 2.99 where higher H′ values are observed in minimal infested and non-infested sampling sites; in DS (H`= 2.99) and in RB (H`= 2.11) sampling sites while the lowest H′ value (1.36) was in one of the water hyacinth infested site, AK sampling site. Comparatively, all the waterhyacinth infested sites have lower H′ values than none and minimal water hyacinth infested sites (Table 2.11). Similarly, the highest evenness index was in the minimal infested site, DR sampling site (0.82) and its lower value is observed in the water hyacinth infested site, AC sampling site (0.43).

Table 2.11 Macrophyte diversity index of the north eastern littoral zone of Lake Tana

Parameer	Non-infested	Infested			Minimal infested	
	RB	AK	AD	AC	DR	DS
No.of spp	15	8	10	9	7	29
H`value	2.11	1.36	1.56	1.36	1.75	2.99
Evenness value	0.55	0.49	0.47	0.43	0.82	0.69

Abbreviations: RB=Rib, AK=Agid Kirgna, AD=Adisgie Dingie, AC=Achera, DR=Dirma, DS=Debre Sina

2.3.5 Physicochemical characteristics of the water quality in the north eastern zone of Lake Tana

The spatial variation of physico-chemical water quality parameters and sediment nutrient investigated are summarized in Table 2.12. More variation in mean values of physical-chemical parameters among sites was observed for DO, TDS Temperature and depth of the lake and for almost all nutrients in both water and sediment.

The value of dissolved oxygen (DO) ranged from 5.19 – 7.43 mg/L with the highest value measured at the minimal infested site, DRO and the lowest value at the weed infested site, AKL. Similarly the highest value for pH was measured in DRO sampling site with values ranged from 7.91- 8.70. The mean value of EC and TDS ranged from 142.0 – 225.0 µS/cm and 93.25 – 127.75 mg/L, respectively, with the highest value measured at littoral sites of Rib (RBL) and Agid Kirgna (AKL) sampling sites while the lowest values for EC and TDS were measured at open water zones in ADO and DSO respectively. The mean values ranged between 0.18 – 0.42 and 0.36 – 6.65 m for Secchi depth and depth measurements respectively, with the highest and lowest measurements for Secchi depth were in the weed infested sites where as that of depth were in the non- infested sites.

The values of nutrients in water ranged between 0.281.56, 0.11 – 0.47, 0.44 – 2.06 mg/L for nitrate, SRP and TP in the water sample, respectively, and from 0.1 – 0.54 mg/kg and 9.54 – 26.57% for TP and TN measurements in the sediment samples respectively. Both TP and TN in sediment sample and TP in water sample was attained highest concentration at the weed infested site, AKL and nitrate also was highest at minimal weed infested site DRL. However, SRP was highest at RBO sampling site.

Table 2.12 Mean Physico-chemical characteristics of the water quality in the north eastern littoral zone of Lake Tana (Mean ± S.D) (n=8)

Site	DO mg/L	pH(Range)	EC(µs/cm)	TDS mg/L	Temp.(0c)	Secchi.(m)	Depth(m)	NO_3-N mg/L	SRP mg/L	TP mg/L	SedimentT N (%)	Sediment TP (mg/Kg)	Sampling site status
RO	5.75±0.30	7.91- 8.70	170.50±16.66	100.75±1.49	22.71±0.45	0.33±0.04	**6.65±0.85**	0.42±0.10	0.14±0.05	0.81±3.93	0.15±0.05	20.53±1.33	**Non-Infested**
RL	6.32±1.07	8.16±0.22	**225.00±41.63**	116.00±6.01	22.87±2.10	0.23±0.05	**0.36±0.09**	0.79±0.15	0.47±0.18	1.20±1.57	0.18±0.05	18.36±2.35	
AKO	5.78±0.15	8.29±0.38	156.50±2.02	103.25±2.17	23.50±0.82	0.31±0.05	3.52±0.57	**0.28±0.11**	0.17±0.06	0.70±3.61	0.16±0.10	15.96±5.90	
AKL	**5.19±0.17**	8.07±0.04	165.00±6.84	**127.75±24.77**	**25.72±0.75**	**0.18±0.03**	0.93±0.33	0.91±0.27	0.31±0.09	**2.06±8.32**	**0.54±0.05**	**26.57±1.72**	
ADO	6.37±0.22	8.29±0.53	**142.00±9.94**	93.75±4.89	22.88±0.58	**0.42±0.05**	4.38±0.59	0.46±0.10	0.11±0.04	0.51±2.18	0.12±0.03	15.41±2.77	**Infested**
ADL	7.03±1.12	8.12±0.20	151.75±8.32	98.50±5.20	**20.86±1.56**	0.24±0.04	0.69±0.18	0.96±0.28	0.32±0.06	0.81±3.47	0.25±0.09	17.91±3.43	
ACO	6.84±0.55	8.39±0.26	148.50±4.17	96.00±3.34	23.17±0.64	0.31±0.07	2.90±0.26	0.79±0.22	0.16±0.03	**0.44±2.13**	**0.10±0.0**3	**9.54±3.30**	
ACL	5.81±0.39	7.96±0.28	156.25±5.75	101.75±3.82	23.48±0.79	0.28±0.08	0.94±0.14	1.43±0.45	0.20±0.04	0.55±1.85	0.31±0.10	13.42±2.87	
DRO	**7.43±1.00**	**8.70±0.36**	144.75±6.09	93.75±4.42	22.95±0.78	0.38±0.09	5.31±2.33	0.58±0.14	0.19±0.06	0.80±3.23	0.12±0.02	11.75±3.04	
DRL	7.15±0.68	8.07±0.35	150.75±5.31	98.00±3.54	23.88±0.81	0.25±0.04	1.15±0.25	**1.56±0.70**	0.38±0.15	1.07±3.64	0.17±0.02	11.49±1.50	**Minimal infested**
DSO	7.17±0.39	8.67±0.48	144.75±6.37	**93.25±4.87**	22.91±0.65	0.40±0.06	4.31±0.18	0.58±0.17	0.15±0.09	0.51±1.40	0.12±0.02	14.90±1.49	
DSL	7.09±0.69	**7.91±0.67**	147.25±5.50	95.75±3.57	23.04±0.73	0.36±0.04	1.99±0.37	1.32±0.58	0.35±0.09	0.62±2.92	0.22±0.01	19.77±3.36	

(**Abbreviations:** S.D - Standard deviation, RBO – Rib open, RBL – Rib littoral, AKO – Agid Kirgna open, AKL –Agid Kirgna littoral, ADO – Adisgie Dingie open, ADL –Adisgie Dingie littoral, ACO – Achera open, ACL – Achera littoral, DRO – Dirma open, DRL – Dirma Littoral DSO – Debre Sina open, DSL Debre Sina littoral, SRP – Soluble reactive phosphate, TP – TP, EC – Electrical conductivity, TDS – Total dissolved solids, DO – Dissolved oxygen)

The two components of the principal components analysis (PCA) explained 73.55 % of the total variance each contributing 46.61% and 26.94% respectively (Table 2.13). Among the water quality parameters analyzed depth, SRP, pH and TDS correlate strongly to Axis 1, which discriminates the littoral sampling sites of RBL, ACL and AKL (with high loading factor of SRP (0.84), TDS (0.75) and TP (0.73), all correlated positively to the axis) and open water sampling sites, ACO, DSO, DRO and ADO (with high loading factor of depth (-0.88) and pH (-0.76), both correlated negatively to the axis) from other sampling sites (Figure. 2.6). DSL, ADL, and DRL are discriminated from other sites by axis 2; owing to higher value of DO (0.81) and Secchi depth (0.73) each correlate positively (Figure. 2.6).

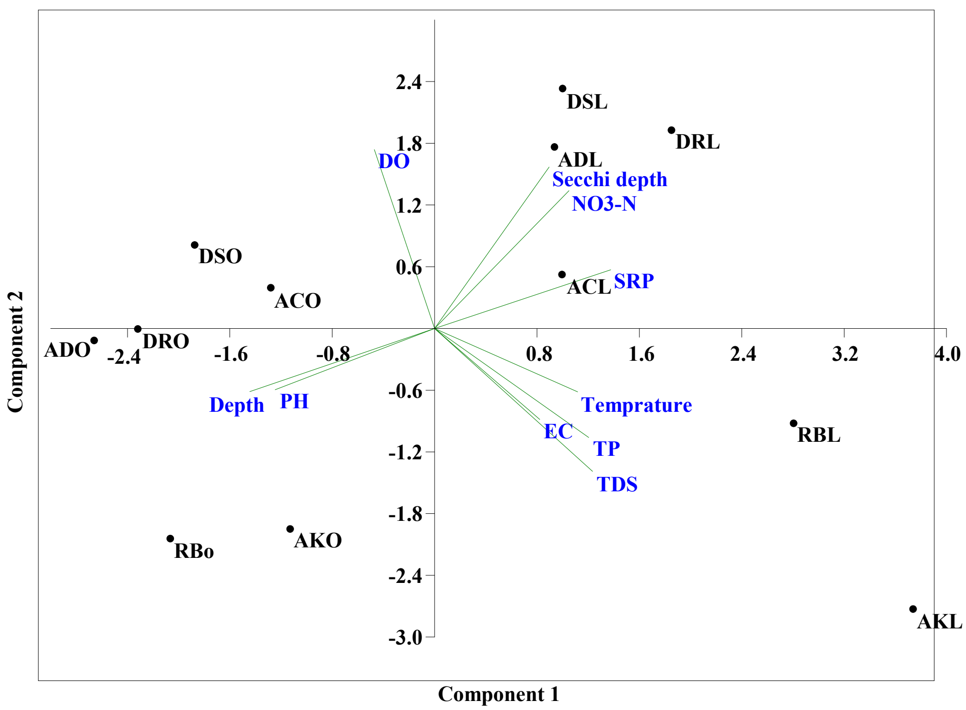


Figure 2.6 Principal components analysis ordination diagram of the physicochemical factors at study sites in the north eastern littoral zone (Abbreviations: RBO – Rib open, RBL – Rib littoral, AKO – Agid Kirgna open, AKL –Agid Kirgna littoral, ADO – Adisgie Dingie open, ADL –Adisgie Dingie littoral, ACO – Achera open, ACL – Achera littoral, DRO – Dirma open, DRL – Dirma Littoral DSO – Debre Sina open, DSL

Debre Sina littoral, SRP – Soluble reactive phosphate, TP – TP, EC – Electrical conductivity, TDS – Total dissolved solids, DO – Dissolved oxygen).

Most of the physico-chemical parameters best described in axis 1 and axis 2 and the littoral zone of the lake in each sampling sites. Only pH and depth can describe the open water zone which could indicate the existence of interference in the littoral zone that may result for the maximum fluctuation in these water quality conditions than that of the open water. Water hyacinth has also a great role in this regard.

Table 2.13 Correlation coefficient of the environmental variables used in this study with the first two principal component axes in the north eastern zone (strong correlations are marked bold)

Environmental variables	Axis 1	Axis 2
DO	-0.29	**0.81**
PH	**-0.76**	-0.28
TDS	**0.75**	-0.64
Cond	0.50	-0.41
Temp	0.68	-0.29
Secchi	0.54	**0.73**
Depth	**-0.88**	-0.28
NO_3-N	0.64	0.62
SRP	**0.84**	0.26
TP	**0.73**	-0.49

2.3.6 Relationship between physicochemical parameters and density of macrophyte species in the north eastern zone of Lake Tana using multivariate analysis

Results of canonical correspondence analysis (CCA) showed that the first two axes make 64.6% of the cumulative percentage of variance in species–environmental relationship (Table 2.14). The first axis, which contributed 34.5% of the variance, was positively and strongly correlated with EC and pH and depth of the water level and NO_3-N were negatively but strongly correlated to the axis (Figure 2.7).

From the analysis, the density of *Brachiaria* sp., *Eichhornia crassipes, Echinochloa pyramidalis, Echinochloa crus-galli and Nymphoides indica, w*as positively associated with temperature, *Nymphaea lotus, Phragmites karka, Ludwigia abysinica* and *Ipomoea aquatica* was positively associated with nitrate, however, negatively to SRP and EC (Figure 2.7). In contrast, positive associations to these parameters were observed with that of *Glinus lotoides, Triumfetta annua.* These species are also positively associated with pH but negatively to nitrate (Figure 2.7).

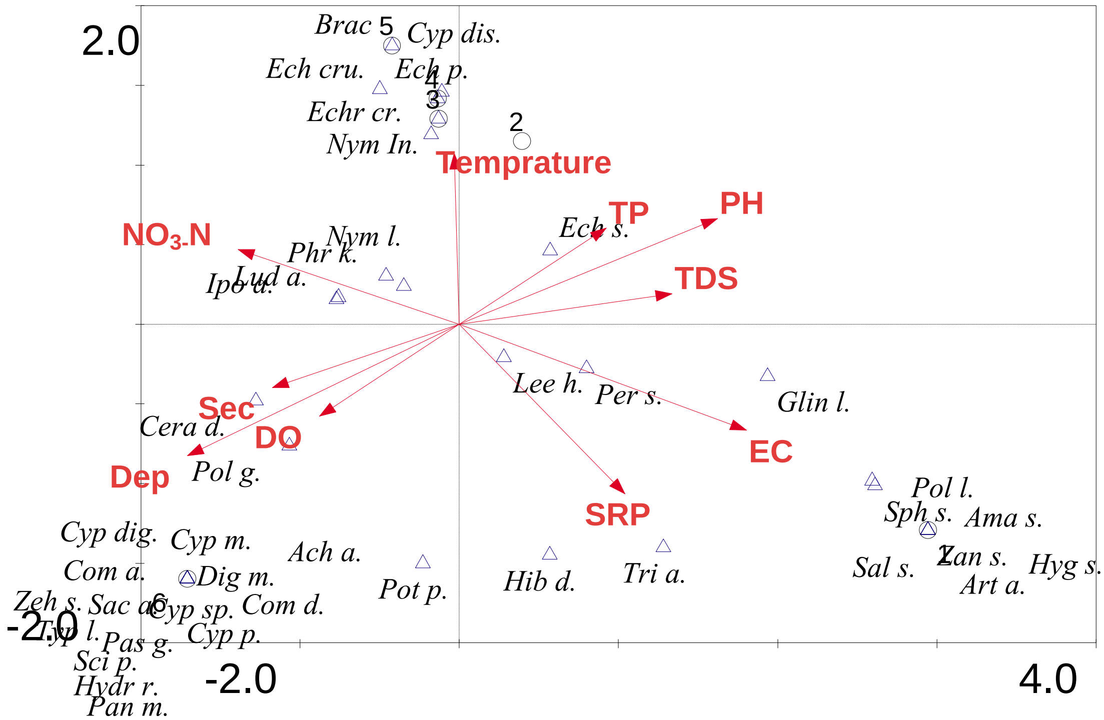


Figure 2.7 Plot of the Canonical Correspondence Analysis (CCA) for macrophyte species and physicochemical variables in the north eastern littoral zone (Abbreviations: Ach a. - *Achyranthes aspera*, Ama s. - *Amaranthus hybridus*, Art. a.- *Artemisia absinthium,* Bot s. - *Bothriocline schimperi,* Bra c. - *Brachiaria sp.,* Cera *Amaranthus spinosus*, d. - *Ceratophyllum demersum,* Com a. - *Commolina africana*, Com d. - *Commelina diffusa*, Cyp dig. - *Cyperus digitatus,* Cyp dis.- *Cyperus digitatus,* Cyp f. - *Cyperus fischerianus,* Cyp m. - *Cyperus macrostachyos,* Cyp p. - *Cyperus papyrus,* Cyp sp.- *Cyperus sp,* Dig m. - *Digitaria milanjiana,* Ech cru. - *Echinochloa crus-galli,* Ech s. - *Echinochloa stagnina,* Ech p. - *Echinochloa pyramidalis,* Echr cr. - *Eichhornia crassipes*, Glin l. - *Glinus loto "ides,* Hib d. - *Hibiscus diversifolius,* Hydr r.- *Hydrocotyle ranunculoides*, Hyg s.- *Hygrophilia schulli* , Ipo a. - *Ipomoea aquatica,* Lee h. - *Leersia hexandra*, Lud a. - *Ludwigia abysinica*, Nym l. - *Nymphaea lotus*, Nym in. - *Nymphoides indica*, Pan m. - *Panicum maximum*, Pas g. - *Paspalidium geminatum*, per s.- *Persicaria senegalensis*, Phr k. - *Phragmites karka*, Pol g. - *Polygonum glabrum*, Pol l. - *Polygonum lapathifolium* , Pot p. *Potomagton pectinatus,* Pys c. - *Pyscnochys coerulea*, Sac a. - *Sacciolepis africana*, Sal s.- *Salix subserrata*, Sci p. - *Scirpus pallidus*, Sol l. - *Solenostemon latifolius*, Sph s. - *Sphaeranthus suaveolens*, Tri a. - *Triumfetta annua,* Typ l. - *Typha latifolia,* Zan s. - *Xanthiumum strumarium* , Zeh s.- *Zehneria scabra*, SRP – Soluble reactive phosphate, TP – Total phosphorus, EC – Electrical conductivity, TDS – Total dissolved solids, DO – Dissolved oxygen, Sec – Secchi depth)

Table 2.14 Eigenvalues, cumulative percentage variance of species-environment relation, and correlation coefficient of physico-chemical variables with the first two axes in the north eastern littoral zone (strong correlations are marked bold at $p < 0.05$).

Parameter	Axis 1	Axis 2
Eigenvalues:	0.61	0.53
Cumulative percentage of variance of species data	34.50	64.60
DO	-0.46	-0.28
PH	**0.85**	0.32
EC	**0.95**	-0.32
Tem	-0.02	0.51
Sec	-0.62	-0.19
Dep	**-0.90**	-0.40
NO_3-N	**-0.73**	0.22
SRP	0.55	-0.51
TP	0.48	0.29

2.4. Discussion

2.4.1. Macrophyte species diversity in Lake Tana

The highest macrophyte species diversity index (H′) and evenness index values among the four sampling sites in the south western littoral zone was in Zegie Yiganda littoral with H′ value of 2.63 and evenness index value of 0.63 respectively. While that of the north eastern littoral zone is in Debre Sina littoral with H′ value of 2.99 and Dirma littoral with evenness index value of 0.82. Zegie Yiganda littoral site is better protected from anthropogenic impacts (not threatened by industrial and urban expansions and forest clearing) and is expected to have high diversity of species. Similarly, Debre Sina littoral is one of the Monasteries found near the lake and the church forests are well protected (Moreaux, 2011), not threatened by industrial expansions and was also minimal impacted from water hyacinth. Lower diversity index (H′) and evenness index values were observed in sampling site, Infranz littoral among the sampling sites in the south western littoral zone and Agid Kirgna littoral and Achera littoral sites in the north eastern littoral zone where Infranz littoral site being close to human settlements higher anthropogenic impacts are expected to cause a decrease species diversity and composition. Besides, Agid Kirgna and Achera sites are also the highly water hyacinth infested and impacted sites, consequently could have low diversity of macrophytes. Although larger and shallow lakes are potentially expected to have a wider range of habitats than smaller lakes, and more polymorphic flora could be expected in such lakes (Nurminen 2003), in Lake Tana, higher turbidity, fluctuations in water level and other factors also seem to limit the macrophyte diversity to mainly turbidity-tolerant species such as *Nymphaea lotus* (Nurminen, 2003), floating species like *Eichhornia crassipes* (Water hyacinth) and emergent species. The macrophyte species diversity of Lake Tana is low compared with some published data of similar works on tropical shallow lakes and reservoirs (e.g. Burlakoti and Karmacharya, 2004; Udomsri *et al*., 2004) but higher than that of lake Ziway (Girum Tamire and Seyoum Mengistu, 2012).

The concentration of SRP in Lake Tana is higher compared to some Ethiopian lakes (e.g. Lake Chamo, Abaya (Ababu Teklemariam, 2005), Ziway (Girum Tamire and Seyoum Mengistu (2012) and some African Lakes like Nakuru and Elementaita (Njenga, 2004) and it is lower than some other African lakes like Lake Naivasha (Njenga, 2004), whereas the concentration of nitrate in the lake is still lower than that of lakes mentioned above except Lake Ziway, although it is showing an increasing trend. In addition, low diversity is expected in lakes that have an outflow, because accumulated nutrients produced from different sources could be flushed out (Burlakoti and Karmacharya, 2004; Girum Tamire and Seyoum Mengistu, 2012).

Lake Tana is becoming highly turbid; its Secchi depth reading decreased considerably (18 -68 cm) as compared to the previous situation (Table 2.15), and as a result, the growth of many submerged species is limited. The lake has also a shorter water retention time (about 3 years) (Seifu Kebede *et al*., 2006), and establishment of new macrophytes could be hindered. Cronk and

Fennessy (2001) have generalized that macrophyte diversity depends on the ability of each species to become established and persist under sustained environmental conditions.

2.4.2. Seasonal variation in macrophyte diversity and trends in macrophyte species composition

The observed seasonal macrophyte species diversity variation in the south western littoral zone followed the order: post rainy > pre-rainy > dry > main rainy season (Table 2.5), although the variation was not significant it is attributable to the seasonal variation in requirements of the diverse growth forms. As species diversity decreased with high level of water accompanied with flooding and turbidity, low species diversity in the main rainy season indicated that the studied habitat have high volume of water with full of suspended solids and high concentration of silt (Berhanu Teshale *et al*., 2001) reducing water transparency that consequently has effect on the existence of the submerged species. However, the highest diversity of species was observed during the post rainy 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 of Ayalew Wondie (2006) also described as macrophytes are more common in the post rainy season because of absence in human interference due to high volume of water and flood condition. This hydraulic phenomenon on Lake Tana therefore probably created conducive environment for emergent macrophytes on the littoral zone of the lake to thrive during this period. Similarly the highest evenness index was observed in the post rainy season.

Only some of the dominant macrophyte species in the southern and eastern shore of Lake Tana were listed in the study of Ayalew wondie *et al*, (2007), Nagelkerke (1997), Hughes & Hughes (1992). They noted that *Cyperus papyrus*, *Echinochloa pyramidalis*, *Echinochloa stagnina*, *Polygonum barbatum*, *Polygonum senegalense* and *Typha domingensis* as being dominant emergent macrophytes; *Nymphaea caerulea*, *Nymphaea lotus* and *Pistia stratiotes as* dominant floating leaved species; *Ceratophyllum demersum* and *Vallisneria spiralis as* the dominant submerged macrophytes occurring in flat swampy parts of the shoreline of the lake. How ever,Data from compressive studies about abundance, distribution and other aspects of macrophytes in Lake Tana are scarce. Therefore, it is difficult to compare the result of this work with previous ones.

Among the most dominant species in the current study, *Phragmites karka, Cyperus digitatus, Ludwigia abysinica* and *Amaranthus hybridus*, were not reported by earlier researchers. This may be because they were not present or may be these studies were not comprehensive studies for macrophytes. Egertson *et al*. (2004) reported macrophytes can respond to water level fluctuation within two-year time lags. The reduction trend in water level and transparency of the lake (e.g. Ayalew wondie, 2007; Imbooed and Akoma, 2008) and increasing trend of silt and sediment load (Berhanu Teshale *et al*., 2001) could have contributed to this conspicuous shift in macrophyte composition of Lake Tana.

Cyperus papyrus, which was reported as the most dominant macrophyte by all the above researchers, is still present in the lake but is not the most dominant one, it is the second dominant next to *Phragmites karka* in terms of relative frequency and the third dominant next to *Phragmites karka* and *Cyperus digitatus* in terms of relative density in the south western littoral zone. *Eichhornia crassipes (*Water hyacinth) is the dominant macrophyte in most of the sampling sites that attained the highest relative frequency and density in the north eastern littoral zone.

Relatively higher transparency reading was observed among the littoral sampling site on Shum Abo littoral. The site dominantly contains *Cyperus* species *(Cyperus papyrus, Cyperus digitatus, and Cyperus macrostachyos), Phragmites karka*, *Azolla africana* and *Typha latifolia* which are known to serve as important silt and nutrient filters in aquatic ecosystems (e.g. Chale, 2003).

The littoral region and wetlands of the lake are currently under severe degradation by the local inhabitants. Especially the area covered by papyrus has been decreasing recently (Woldegabriel Gebrekidan and Solomon Teka, 2006; Ayalew Wondie, *et al*., 2012) by the ever growing human population. The local community harvests papyrus reed during low water level to use it for different purposes (Figure 2.8).

Figure 2.8 Local community harvesting papyrus reed for different purposes

In addition there has been increased sedimentation on the lake shore and siltation on the floodplain (Berhanu Teshale *et al.,* 2001). This has resulted in significant reduction in abundance of *Cyperus papyrus* while grasses such as *Phragmites karka* and other emergents have increased in the larger parts of the studied sites.

2.4.3. Emergent macrophyte and Water hyacinth dominance in Lake Tana

Lake Tana is highly dominated by emergent macrophytes and Water hyacinth, which could be due to their high tolerance for turbidity and water-level fluctuation (Nurminen, 2003) and increasing trend in nutrient concentration as well. Any land use changes within a particular watershed may cause a change in the level of a lake within the watershed. The increased demand of water for agriculture, industries, domestic, and power generation in Lake Tana sub-basin requires huge amount of water from the lake (Amare Sewnet and Kameswara, 2011). Recent historical fluctuation and shrinkage of wetlands of Lake Tana are also reported by Seifu Kebede *et al*. (2006), Abeyou Wale (2008), Rientjes *et al*. (2011), Yirgalem Chebud and Ayalew Melesse (2009), Negash Atinafu *et al*. (2011).

Currently, several dams like Tana Beles hydro electric power dam using the lake water, and other dams from the tributaries (Koga irrigation dam, Ribb irrigation dam, Megech irrigation dam are constructed which might also contribute much for greater water level fluctuation in the lake. The depth measurement in this study (the maximum measurement, 6.37 m) indicated that the water level reduction is getting worse than the earlier reports. It was also reported that there is an increase in net annual loss of water from the lake (Molla and Menelik, 2004). Personal observations during the study also confirmed the occurrence of high seasonal variation in water level in the lake (Figure 2.9).

Figure 2.9 Dry season decrease of Lake Tana water level near Bahir Dar City

The higher dominance of emergent macrophytes in terms of species diversity (compared with submerged macrophytes) also indicates the advancement of littoral vegetation (Burlakoti and Karmacharya, 2004). Some studies have reported that this condition indicates a succession stage towards a marshy condition and is associated with decreasing water level (Wetzel, 2001). An increasing trend in anthropogenic activities like irrigation, excessive water abstraction around the lake, organic matter accumulation from litters and siltation could further aggravate the condition. Previous studies have reported that the areas around Dirma river mouth are characterized by the dominating macrophytes *Echinochloa pyramidalis* and *Echinochloa crus-galli (*Mundt, 2011; Woldegabriel G/kidan & Solomon Teka, 2006*)*. According to them, *Cyperus macrostachyos, Eichhornia crassipes* and *Lemna* species were companion species. However, Currently *Eichhornia crassipes* takes the highest relative frequency and density in the site. This could be due to different human interferences taking place in the site that might increase the nutrient input in to the lake. In the dry season wetland areas around fall completely dry and with the end of the rainy season and residing water levels local farmers, often young and landless, immediately start draining and farming of these wetlands. Furthermore those *Echinochloa* - Meadows are used as grazing areas throughout the whole year.

Previous studies have also reported that the areas in and around Adisgie Dingie (Megech river mouth), Achera and Agid Kirgna sampling sites were characterized by *Ipomoea aquatica* and the occurrence of several Poaceae species, often so called hippo-grasses accompanied by *Nymphaea lotus, Nymphoides* species, *Cyperus macrostachyos, Trifolium* species*, Echinochloa pyramidalis* and *Eichhornia crassipes* (Mundt, 2011). But currently the area is completely occupied by *Eichhornia crassipes.* This could be due to human activities causing the increase in nutrient input in to the lake and the aggressive nature of the invasive weed. In the rainy season large areas around are used as grazing areas and during the dry season those areas fall completely dry and are immediately converted into farming land (pers. observation.). Most of the natural vegetation could be destroyed for farm land expansion (Recession farming), for settlement and intensive grazing. Besides, Agid Kirigna is an example of degradation of shores and wetlands due to sand mining practices (Mundt, 2011).

Woldegabriel G/kidan & Solomon Teka (2006) identified point and non-point sources of sand mining during their survey. Non-point source sands are deposited at the shoreline of the lake, fetched by wave actions and currents, whereas point source sands are fetched by a particular ephemeral and perennial river and stream during summer and are deposited along its banks or at its delta or siltation zone (Mundt, 2011) and might consequently cause habitat fragmentation. The impact of waterhyacinth on the growth of other macrophytes species has also noticeable effect. This effect has been reported by different studies. For instance, the decimation effect of water hyacinth on the floating leafed *Nymphaea lotus* and the submerged plants, *Ceratophyllum demersum* has been reported by (Aloo *et al.*, 2013) in Lake Victoria, Kenya.

2.4.4 Physico-chemical conditions in comparison with past data

The range value of DO in this study (5.19 -7.54 mg/L) showed almost on the same range of the previous studies (5.9 – 7.3 mg/L) by Eshetie Dejen *et al*., 2003 and Ayalew wondie, 2006 (Table 2.15). The possible entry of organic matter during runoff from the surrounding urban areas and agricultural fields and their decomposition contributed to the low levels of dissolved oxygen in the littoral sites. Lake Tana is shallow tropical lake with relatively low water temperatures, varying only within small limits (Eshetie Dejen *et al*., 2004). The range value of the surface water temperature showed almost no change during the last decade as the value found in this study (20.86 -26.34 °C) fell within the range value (20 -27 ^{0}c) reported by Eshetie Dejen *et al*. (2003) and Ayalew wondie (2006) (Table 2.15). The range was within the range of variation observed in most tropical water bodies (John 1986). The observed pH value (pH = 7.61 -8.92) also fell within the range reported by Hughes and Hughes (1992) (Table 2.15); however, significant temporal variation was noted during the study as significantly lower value was measured during the post rainy season than the other three seasons. The pH value could mainly be controlled by freshwater swamp exudates that regulate the acidity of the water body.

Table 2.15 Comparison of physico-chemical water quality parameters in this study and previous studies (mg/L)

parameter	This study	After 2005	Author/Year	Before 2005	Author/Year
DO	5.19 -7.54	5.90 - 7.30	Ayalew Wondie, 2006	7.00 - 9.00	Rzoska. 1976
pH	7.61 - 8.92	7.30 - 8.50	Akoma and Imboobe, 2009	6.80 - 8.30	Eshetie Dejen, 2003
TDS	93.25 -127.75			148.00 - 178.00	Eshetie Dejen, 2003
EC (µS/ cm)	142.00 -225.00	115.00 - 148.00	Ayalew Wondie, 2006		
Tem (^{0}c)	20.86 -26.34	20.00 -27.00	Ayalew Wondie, 2006		
Secchi (m)	0.18 -0.68	0.51 -1.82	Ayalew Wondie, 2006		
		0.40 - 0. 90	Akoma and Imboobe, 2009		
NO_3-N	0.28 – 1.83	0.10 - 1.00	Ayalew Wondie *et al*., 2007	0.20$\pm$0.17	Rzoska, 1976
		0.92 - 4.18	Akoma and Imboobe, 2009		
SRP	0.11 – 0.47	1.00$\pm$0.8	Ayalew Wondie *et al*., 2007	1.00$\pm$0.8	Rzoska,1976
TP	0.22 – 2.06				

The range of value of EC in this study (142.00 - 225.00 µS/ cm) is higher than that reported value by previous studies like Ayalew Wondie, 2006 (115 – 148 µS/ cm) (Table 2.15). The electrical conductivity of most freshwaters ranges from 10 to 1,000 µS/ cm but may exceed 1000 µS/ cm, especially in polluted waters, or those receiving large quantities of land run-off (APHA *et al*., 1999). Higher conductivity values were measured at the littoral sites than in the open water, though this was not statistically significant and could be attributed to influx of dissolved solutes from the surrounding urban areas and agricultural fields. TDS also followed the same trend as that of EC as EC is sensitive to variations in dissolved solids, mostly mineral salts, and there were significantly lower value of EC and TDS during the main rainy season which may be because of dilution. Similar low value of EC and TDS measurement during the main rainy season was observed in the study of Ayalew Wondie *et al*. (2007). Measurements of depth and transparency (Secchi depth reading) decreased considerably when compared with the results of previous studies. For example, the range of Secchi depth reading in this study (18– 68 cm) is lower than the value of 51 – 182 cm and 40 - 90 cm reported by Ayalew Wondie (2006) and Akoma and Imoobe (2009), respectively (Table 2.15). The declining trend in Secchi depth reading is one of the indications which suggest the increasing trend in turbidity of the lake, which can be mainly attributed to catchment degradation and siltation. Significantly low Secchi-disk depths were recorded during the main-rainy season because of high silt loads from the inflowing rivers. The significantly lower water transparency in littoral zone than open water zone is most likely due to wind-induced re-suspension of shallow bottom sediments. Similar situation was noted in the study of Ayalew Wondie *et al*. (2007).

The spatial as well as seasonal variations of nitrate, SRP and TP mean concentrations were significantly higher at littoral sites compared to the open water sites and it was noted that higher nitrate concentrations were measured than results reported earlier (Rzoska, 1976; Ayalew Wondie *et al*., 2007) (Table 2.15). A higher value of nitrate concentration (0.92 to 4.18 mg/L) in the lake was also measured in 2008 by the study of Akoma and Imoobe (2009). The increasing trend in nitrate is probably because of nutrient enrichment of the littoral zone of the lake from anthropogenic sources in the catchment area. The range value of the concentration of SRP in this study (0.11 – 0.47 mg/L), although lower than the previous studies (Table 2.15) exceeded the threshold (0.05 to 0.1 mg/L) for natural waters (Jeppeesen *et al*., 1997). One can observe that although the trophic status of Lake Tana is meso-oligotrophic (Ayalew Wondie and Seyoum Mengistu, 2014; Eshetie Dejen *et al*., 2003), there is an increasing trend in concentration of nitrate and phosphorous, especially in shore areas and river mouths, that would eventually lead to eutrophication and infestation and expansion of invasive weeds. These could happen as a result of improper disposal of waste water, and poor soil and water conservation practices in the catchment (Berhanu Teshale *et al*., 2001). Nutrients are closely associated with agricultural runoff, domestic and industrial sewage discharged into the lake (Akoma and Imoobe, 2009). This suggests that Lake Tana is experiencing high influxes of phosphorus and nitrogen species from external sources.

2.4.5. Density of macrophyte species in relation to physicochemical factors

The result of the sites versus physico-chemical association in the south western littoral zone showed Shum Abo littoral and Zegie Yiganda littoral sites were different from the others and were characterized by higher values of EC, TDS, SRP and Secchi depth however, Zegie Yiganda open and Infranz open sites were different from other sites and were characterized by higher value of depth. Gilgel Abay entrance littoral and Infranz littoral site were different from others by having relatively higher nitrate values (Figure 2.3). On the other hand the north eastern littoral zone sampling sites of RBL, ACL and AKL were different from the others and were characterized by higher values of SRP, TDS, TP and depth while ACO, DSO, DRO and ADO were different from the others and were characterized by higher values of depth and pH. DSL, ADL, and DRL are discriminated from other sites by having higher value of DO and Secchi depth. *Triumfetta annua* and *Panicum repens* in the south western littoral zone, *Leersia hexandra*, *Nymphaea lotus*, *Phragmites karka* and *Ipomoea aquatica* in the north eastern littoral zone and *Ludwigia abysinica* in both littoral zones were found in both nutrient-rich and nutrient-poor sites. The occurrence of these macrophytes in the lake seems not to be affected by differences in the nutrient condition among sites, and their ability to colonize these varied sites indicates their potential to adapt to diverse trophic conditions. Nevertheless, the density of *Triumfetta annua* showed positive association with major dissolved inorganic nutrients like SRP and TP, *Leersia hexandra with SRP*, whereas the density of *Ludwigia abysinica, Nympha lotus, Phragmites karka* and *Ipomoea aquatica* showed positive association with nitrate, which implies that if these nutrient concentrations of the lake increases to a certain level, it may further encourage infestation by these macrophytes (even though they can also exist under low nutrient conditions). On the other hand, *Azolla africana*, *Cyperus alopecuroides, Ceratophylum demersum, Cyperus macrostachyos and Digitaria milanjiana,* were almost restricted to sites where there was higher SRP and TP (Figure 2.3) which suggests that these species need or can indicate high nutrient levels (SRP and TP) of lake water. It is important to note that understanding the mechanisms behind aquatic plant community shifts is of considerable practical importance especially in tropical, poor countries, where eutrophication is one of the greatest issues threatening water bodies. The increase in nutrient concentration and further reduction in water level may create conducive environment for invasive floating macrophytes. The possibility of expansion of water hyacinth into this (south western) side of the Lake is very high as the opposite side of the lake is already infested by this weed. As can be learned from the case of similar lakes such as Lake Naivasha, which is one of the world‟s top ten important bird areas, such trends will lead to severe ecological consequences unless prompt mitigation is taken (Jimoh *et al*., 2007; Mironga et al. 2012). The density of *Azolla africana*, *Cyperus alopecuroides, Ceratophylum demersum, Cyperus macrostachyos, Digitaria milanjiana, Pyscnochys coerulea* and *Scirpus pallidus* had a positive and strong association with SRP and TP (Figure 2.3). The result indicated that the increase in pH, SRP, TP and Secchi depth could significantly and negatively affect the density of *Amaranthus hybridus, Cyperus papyrus, Ipomoea aquatic, Panicum maximum*, *Potomagton pectinatus*, *Sacciolepis Africana, Vossia cuspidata, Brachiaria sp. and Leersia hexandra (Figure 2.3).* However, depth, Secchi depth and DO affect strongly and positively the density of *Ceratophyllum demersum,* and *Polygonum glabrum* (Figure 2.6). Similar observations of negative effects of increase pH, SRP and TP on *Cyperus papyrus, Echinochloa stagnina* was noted in some studies in the Ethiopian rift valley lakes (e.g. Girum Tamire and Seyoume Mengistu, 2012).

In conclusion, the study found that aquatic macrophyte species abundance and diversity of Lake Tana was low compared to some other water bodies where similar studies were carried out. The decreasing trend in water level and transparency of the lake and increasing trend of nutrients like nitrate and SRP levels have contributed to this conspicuous shift in macrophyte composition and reduction in abundance of some macrophytes in the lake. Results of all the physico-chemical parameters in the littoral zone of the lake and the open water zone indicated the existence of maximum human interference in the littoral zone. Lake Tana has higher concentration of SRP compared to some Ethiopian lakes (e.g. Lake Chamo, Abaya and Ziway). *Azolla africana*, *Cyperus alopecuroides, Ceratophyllum demersum, Cyperus macrostachyos and Digitaria milanjiana,* were almost restricted to sites where there was higher SRP and TP and *Echinochloa stagnina*, *Brachiaria sp.* and *Phragmites karka*, was to sites where there was higher nitrate concentration and they were among the macrophyte species that indicate high nutrient levels (SRP, TP and nitrate) of lake water.

Chapter 3: Spatial and temporal aboveground biomass accumulation and storage of selected nutrients in dominant emergent macrophytes

3.1 Introduction

Aquatic macrophytes are excellent indicators of the ecological state of water bodies, mainly because they integrate environmental changes over periods of a few years, and reflect the cumulative effects of successive disturbances (Lawniczak *et al*., 2010). Researchers have used them to effectively distinguish environmental quality changes like hydrologic alterations, excessive siltation, nutrient enrichment and human disturbance (Zedler and Kercher, 2004; Johnson & Rejmankova, 2005; Ghavzan *et al*., 2006; Alahuhta *et al*., 2011). The degree of their influence on ecosystem depends on species composition, biomass, distribution in the lake and surface covered (Fonge *et al*., 2012). They are used as phyto-indicators of status of water bodies (Hellsten, 2000, 2001) due to their relatively high levels of species richness, rapid growth rates and direct response to environmental changes. Failure to understand these interactions between ecological changes and change in species composition, biomass and bio-concentration of chemicals by macrophytes may lead to misjudging the impacts of these environmental quality changes (Fonge *et al*, 2012).

Since Macrophytes have no mechanisms regulating the uptake of nutrients; their impact upon environment is demonstrated through the process of chemical bio-concentration and excretion while increased nutrient in their tissues may be the result of increased concentrations in aquatic environment Stanković *et al*., 2000. Bio-monitoring of aquatic environments by plants hyper accumulators of pollutants is based upon the relationship between concentration of pollutants in plant tissue and in the environment. Therefore, when the number of macrophyte species and their spatial and temporal distribution are used to evaluate the status of aquatic ecosystems, it is very important to employ also data on chemical composition of plants as biological parameters since bio-concentration of chemical elements in macrophyte tissue is a reliable parameter for the assessment of the environmental chemical load (Pajevic *et al.,* 2005). On the other hand, as the biomass and productivity of macrophytes and tissue compositions can be highly influenced by the dynamics of many chemical elements and physical parameters, it is important to measure these parameters to explain trends in macrophyte biomass and tissue nutrient composition (Wetzel, 2001).

Utilization of aquatic plants for a biological clean-up technique in various polluted ecosystems is highly acceptable due to their high biomass production resulting in a high uptake of macronutrients (N, P, K, S) and heavy metals (Pajevic *et al.,* 2005). Tissue nutrient compositions correspond with eco-physiological differences between growth strategies and with nutrient conditions present in the habitats to which these growth strategies are best matched (Willby *et al*. 2001). Tissue nutrient contents thus can be used to predict changes in vegetation and corresponding ecosystem processes caused by anthropogenic impacts, or to detect such changes at early stages before they become difficult to reverse. Knowledge on the chemical composition of aquatic macrophytes is also of great importance, because it informs about the capacity of storage of nutrients and their availability for growth of the plants (Costa & Henry, 2010).

The water quality issues regarding lakes throughout the world are of great concern (Lone et al., 2014). In most water bodies of Ethiopia including Lake Tana, where this study was conducted, many water bodies are degraded by elevated nutrients and sediment loadings, mostly from the agricultural watershed (Berhanu Teshale *et al*., 2001; Eshetie Dejen *et al*., 2004; Ayalew wondie *et al*., 2007; IBC, 2005; Tenalem Ayenew and Dagnachew Legesse, 2007). Some of the lakes are getting shallow and dominated by emergent vegetation (Girum Tamire and Seyoum Mengistu, 2014).

Lake Tana is the largest freshwater body situated in the north western highlands of Ethiopia. The lake has emerged as one of the global top 250 lake regions most important for biological diversity (Lakenet, 2004). It is one of the six fresh water eco-regions recognized as living laboratory with unique fish flocks, and international bird site by IUCN (Eshete Dejen *et al*., 2003;

Shimelis Aynalem and Afework Bekele, 2008; Abebe Getahun and Eshete Dejen, 2012). It is also a growth corridor both nationally and internationally, which is potentially used as the source of hydropower generation, irrigation, navigation, fishery industry and ecotourism. However, recently, the lake ecosystem has undergone substantial changes. Massive blooms of algae in the southern gulf have developed, and come increasingly to be dominated by the potentially toxic blue-green variety especially during the post rainy season (Figure 3.1, Ayalew wondie 2006, Ayalew wondie *et al*., 2007) and Large parts of the northern shore of Lake Tana are now highly infested by an invasive weed *Eichhornia crassipes*, water hyacinth (Ayalew Wondie *et al*., 2012). The lake water transparency has declined due to high silt load of the inflowing rivers during the rainy seasons and daily suspension of sediments in the inshore zone (Ayalew wondie *et al*., 2007).

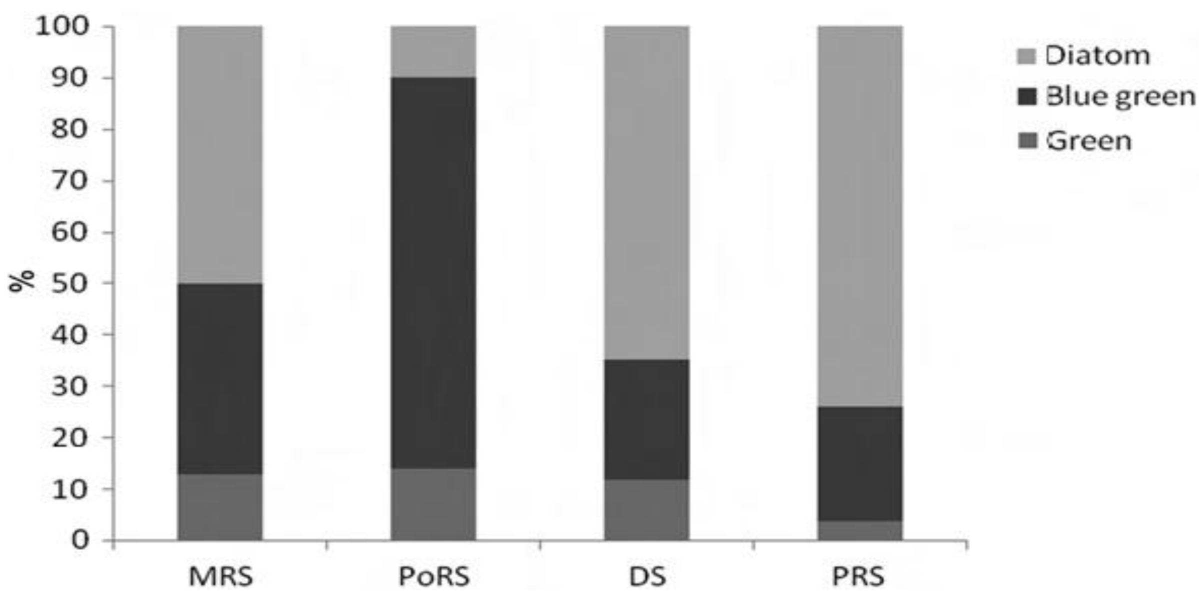


Figure 3.1 Seasonal Variation in percentage of phytoplankton in the Lake Tana. MRS- main rainy season, PoRS- Post rainy season, DS- Dry season and PRS – Pre-rainy season (Ayalew Wondie, 2006).

The Lake Tana Basin is one of the most affected areas by soil erosion, sediment transport and land degradation (Shimelis Setegn *et al*., 2010). An accelerated deforestation in the Lake Tana Basin and surface run-off from agricultural fields has resulted in higher accumulation of sediments in the lake. According to the review of Etafa *et al* (2010) about the eco-hydrological status of Lake Tana, the lake showed reduced lake water level with its annual fluctuations and seasonal floods associated with high flows which are becoming amplified and frequent, and the total average annual sediment load of the four major tributaries showed an increasing trend. Recently, Tana Sub Basin Organization (TaSBO) already established water quality monitoring stations at Lake Tana within the framework of Tana-Beles integrated water resource development project (TBIWRDP) (Yirga Kebede and Hassen Muhabaw, 2015). Besides monitoring the water quality determination of the status of the dominant emergent macrophytes biomass and their tissue nutrient content is increasingly important in evaluating the environmental quality of the lake ecosystem. Vegetation-based indicators are a promising tool for assessment of Lake Ecosystem (Craft *et al.*, 2007) as they are the best indicators of the ecological state of the system.

The emergent macrophytes of lake Tana and its watershed as mentioned in chapter two were described during the 1940s, 1970s, 1990s, 2000s (Brunelli and cannicci, 1940; Rzoska, 1976; Hughes & Hughes, 1992; Nagelkerke, 1997; Ayalew wondie *et al*, 2007), Imoobe and Akoma , 2008 and Negash Atinafu *et al*., 2011). However, none of the above studies and other works attempts to determine the biomass accumulation of macrophytes and the tissue nutrient storage which are reflector of the cumulative effects of successive disturbances in the lake.

In view of this the present study was undertaken to determine the status of the dominant emergent macrophytes biomass and their tissue nutrient content which will help to suggest appropriate measures that will promote the conservation and sustainable utilization of the lake resources. Among the dominant emergent macrophyte species P*hragmites karka, Cyperus papyrus and Typha latifolia* were taken for analysis of biomass accumulation, tissue nutrient storage in relation to nutrient dynamics. The seasonal and spatial variation in biomass composition and tissue nutrient concentration (TN, TP) were assessed and analyzed using multivariate analysis techniques

3.2 Materials and methods

3.2.1 Macrophyte aboveground biomass

Plant samples were collected from four sampling sites in south western side of the littoral zone of the lake; Shum Abo, Infranz, Gilgel Abay entrance and Zegie Yiganda (Figure 2.1). The biomass of macrophytes was obtained by using quadrate method and harvesting the plants on seasonal basis during Post rainy, Dry, Pre-rainy and main rainy seasons. The quadrant size of 0.25 m^2 area was used for sampling of emergent macrophytes as in Lee (1990), to harvest the macrophytes along transect that extended from the shore towards the open water of the lake as far as the depth where submerged species were found. At least three quadrats were laid in each site at 25 m interval along the transect following Piotrowicz *et al*., (2006) and the quadrat samples were averaged for analysis. All aboveground parts of the plants, dead and live, were harvested. The macrophytes were washed to remove any attached organisms. Samples were segregated by species and placed in plastic containers. All aboveground material was placed in plastic bags and taken to the laboratory for separation in to plant parts (stem and leaf) and determination of dry weight. The aboveground dry weight biomass of each macrophyte species was measured seasonal bases (at pre-rainy, main rainy, post rainy and dry season) by drying in an oven at 105 ^{0}C for 24 hours (Wetzel and Likens, 2000). The biomass of the stem and leaf was evaluated separately so as to know which part contributes more percentage for the total biomass.

3.2.2 Physicochemical parameters

Physicochemical parameters: Dissolved Oxygen (DO), pH, electrical conductivity (EC), Total Dissolved Solid (TDS), temperature, Secchi depth, Depth of the water level and nutrients: nitrate, soluble reactive phosphate (SRP) and Total phosphorus (TP) were measured seasonally (dry, pre-rainy, main-rainy, post-rainy) in the study period. DO, pH, EC, TDS and temperature were measured *in situ* using Portable HACHTM model 150 multi-probe system. Transparency of the water was measured by lowering a 20 cm diameter circular disc (Secchi disc) into the water column.

Duplicates of 100 ml water samples were collected from each site using acid washed bottles to analyze for nitrate, SRP and TP at each sampling visit. Nitrate and SRP analyses were made immediately after sample collection using water samples filtered through Whatman GF/F according to APHA *et al*. (1999) with a portable water analyzer kit (Wagtech international, Palintest transmittance display photometer 5000, Palintest Ltd., UK). The nitrate and phosphate concentration of the water were determined photo-electrically based on Palintest Nitratest method and Palintest Phosphate LR method respectively. Analysis of TP was done for unfiltered water sample using standard procedures as indicated in APHA *et al*. (1999), using a spectrophotometer (Jenway 6405 UV in the limnology laboratory of Addis Ababa University. The analysis for TP was done by persulfate digestion followed by the ascorbic acid method. In the persulfate digestion process, the polyphosphates are converted to the orthophosphate form by a sulphuric acid digestion and organic phosphorus is converted to orthophosphate by a persulfate digestion. The resulting orthophosphate (PO_4^{3-}) from the unfiltered sample was analyzed by ascorbic acid method (APHA *et al*., 1999).

3.2.3 Tissue Nutrient Analysis

After determining dry weight of the biomass of each plant aboveground parts, a representative sample was pooled, ground to pass sieve with 20 mesh screen (0.841 mm size), and analyzed for total nitrogen and phosphorus content. The plant nutrients (TN and TP) were determined following Zhu *et al*. (2011) from the above ground parts (stem and leaf) of each emergent macrophyte on dry weight basis. The concentration of total nitrogen (in % N) in each macrophyte biomass was determined by Kjeldahl method as stated in Blamire (2003) after digesting with sulfuric acid whereas total phosphorous concentration in the macrophytes tissue was determined by ash drying (vanadate-molybdate yellow) method following the procedure of Chapman and Pratt (1961), after ashing and nitric acid digestion.

3.2.4. Data Analysis

The significance of the differences between the aboveground biomass production and nutrient concentrations within the study sites, seasons and species were assessed statistically using ANOVA and Tukey‟s test. Paired sample T-test was also employed to see the significance of the differences between stem and leaf tissue TN and TP contents. Redundancy analysis (RDA) was performed to observe the relation of species biomass and plant tissue nutrient content data to environmental factors using CANOCO 4.5 software. Before selecting RDA for this analysis, DCA (Detrended Correspondence analysis) was conducted to check the response of the species data (biomass and plant tissue nutrient content) to the environmental variables. The results showed that the species data had linear responses to environmental variables and the range of variation of the environmental variables was narrow, as observed from the length of longest gradient which was less than 3 in both cases. According to Ter Braak (1987), RDA has to be used if the species data is assumed to show linear response to the environmental variables or if length of longest gradient is less than 3 during DCA analysis. All physicochemical parameters were included in the RDA ordinations since there were no variable with high variance inflation factors (VIF > 20) (ter Braak and (Sˇmilauer, 1998). Both species data (biomass and nutrient content) and environmental data were log-transformed so as to normalize the data. Pearson‟s Product Moment Correlation Coefficient (r) was used to determine the effect of environmental variables on the aboveground biomass and tissue nutrient concentrations (significant or non-significant).

3.3 Results

3.3.1 Spatio-temporal macrophyte aboveground biomass

The aboveground biomass obtained showed among the three species, the measurement was highest in *Cyperus papyrus,* intermediate in *Typha latifolia* and the lowest in *Phragmites karka* (Table 3.1.a, b). The highest *Cyperus papyrus* biomass value (1164.90 g DW m^{-2}) was measured in Gilgel Abay entrance littoral site and the lowest *Phragmites karka* biomass value (180.49 g DW m^{-2}) was measured in Infranz littoral sampling site. All three species of emergent aquatic plants had higher biomass values in Gilgel Abay entrance littoral site than the other sites. In terms of seasonality, the highest *Cyperus papyrus* biomass value (1281.55 g DW m^{-2}) was measured during the post rainy season and the lowest *Phragmites karka* biomass value (178.65 g DW m^{-2}) was measured during the dry season. P*hragmites karka* and *Cyperus papyrus* had higher biomass values during post rainy season while *Typha latifolia* achieved its highest biomass during pre-rainy season

With regard to the plant parts, the highest (812.59 g DW m^{-2}) aboveground biomass was measured in the stem biomass of *Cyperus papyrus* and the least (49.13 g DW m^{-2}) was in the leaf of *Phragmites karka (*Figure 3.2). One way ANOVA, Tukey test showed that there is no significant variation in aboveground biomass both stem and leaf among sampling sites ($p > 0.05$). However, the aboveground biomass in *Phragmites karka* was significantly higher during the post rainy season than that of pre rainy and dry seasons ($P < 0.05$).

Table 3.1 Spatial and temporal total aboveground biomass (g DW m^{-2}) of the three dominant macrophytes from four sampling sites

a) Spatial mean aboveground biomass measurements (Mean ± S.D) (n = 8)

Sampling sites	*Phragmites karka* (gm^{-2})	*Cyperus papyrus* (gm^{-2})	*Typha latifolia* (gm^{-2}))
Shum Abo	346.16±187.80	951.30 ± 459.06	461.46 ± 144.52
Infranz	180.49 ± 41.46	592.10 ±116.43	709.70 ±317.68
Gilgel Abay	361.78±126.19	1164.90±200.13	950.20±433.21
Zegie Yiganda	258.70±55.13	749.14±61.18	465.33±120.94

S.D = standard deviation

b) Temporal mean above ground biomass measurements (Mean ± S.D) (n = 8)

Sampling season	*Phragmites karka* (gm^{-2})	*Cyperus papyrus* (gm^{-2})	*Typha latifolia* (gm^{-2})
Post rainy	516.54±174.85	1281.55 ±440.35	661.53±331.23
Dry	178.65±17.94	636.75± 183.12	225.84±23.65
Pre rainy	193.87± 48.64	649.80±101.65	933.58±374.46
Main rainy	258.08 ± 71.58	889.35±35.11	765.73±191.76

S.D = Standard deviation

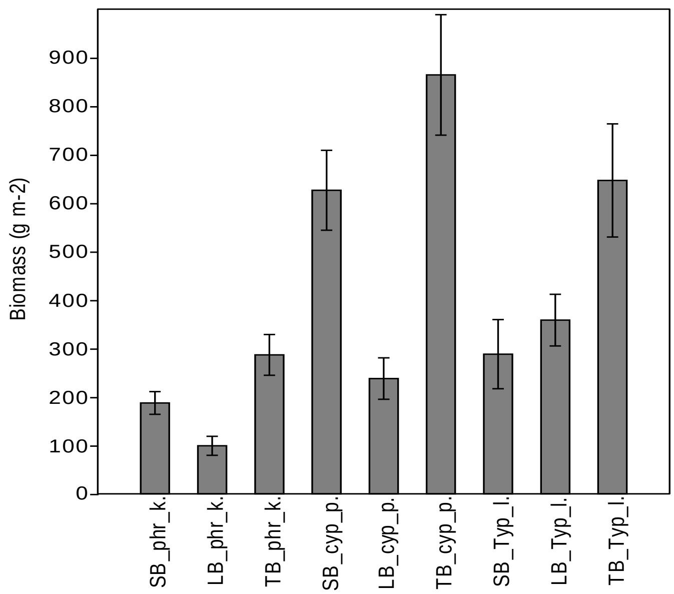


Figure 3.2 Mean of aboveground biomass (Stem, Leaf and Total) (g m^{-2}) in three dominant macrophytes from four sampling sites (Abrevations: SB_Phr_K. = stem biomass of *Phragmites karka*, LB_Phr_K. = leaf biomass of *Phragmites karka,* TB_Phr_K. = total biomass of *Phragmites karka, S*B_Cyp_p.= stem biomass of *Cyperus papyrus*, LB_Cyp_p.= leaf biomass of *Cyperus papyrus*, TB_Cyp_p.= total biomass of *Cyperus papyrus*, SB_Typ_l. = stem biomass of *Typha latifolia*. LB_Typ_l. = leaf biomass of *Typha latifolia*, TB_Typ_l. = total biomass of *Typha latifolia)*

3.3.2. Plant Tissue Nutrient content

Aboveground plant tissue (Stem and leaf) nutrient (TN, TP) contents are summarized in Tables 3.2 and 3.3 respectively. Comparing the means of total nitrogen and total phosphorus contents in these macrophytes, were higher in *Cyperus papyrus* and *Typha latifolia* respectively. The highest value for TN (1.30% of DW) was measure in the leaf of *Cyperus papyrus* whereas the highest value of TP was measured not only in the leaves of *Cyperus papyrus* but also in the leaves of *Typha latifolia.* However, the least value of TN (0.17% of DW) and TP (0.03% of DW) was on the *Cyperus papyrus* stem and Phragmites stem respectively. The average tissue nutrients in the studied macrophytes ranged from 0.54- 1.00 % of DW for TN and from 0.05 – 0.14 % of DW for TP (Table 3. 2 and Table 3.3).The tissue TN and TP content was varied much significantly between species and plant parts (paired sample T- test, P< 0.01) where leaves of all species contain more nutrients (TN and TP) than the stem. However, there was no significant variation ($p > 0.05$) in contents of nutrients in tissues of macrophytes among sites.

Seasonally, higher levels of nutrients (TN and TP) were recorded in the leaf portion of *Phragmites karka* and *Cyperus papyrus* during post rainy season and *Typha latifolia* during pre-rainy season where the highest TN (1.45%) was measured in leaf of *Phragmites karka* and highest TP (0.76%) in the leaf of *Cyperus papyrus* (Figure 3.3 & Figure 3.4 respectively). Lower nutrient content was measured during dry season. Statistical test for nutrient contents between tissue parts (stem and leaf) with in the same species showed the nitrogen content in leaf of *Phragmites karka* was significantly higher during the post rainy season than that of pre rainy season and the nitrogen content in leaf of *Cyperus papyrus* was significantly higher during the post rainy season than that of pre rainy and dry seasons (one way ANOVA, Tukey test, $P < 0.05$). At the same time the phosphorus content in the stem of *Phragmites karka* was significantly higher during the post rainy season than that of pre rainy and dry seasons and the phosphorus content in the leaf of P*hragmites karka* was significantly lower during the dry season than that of post and main rainy seasons (one way ANOVA, Tukey test, $P< 0.05$).

Table 3.2 Total nitrogen (TN) content of plant tissue parts from four sampling sites (Mean± S.D) (%)

Sampling sites	%TN Phr.k Stem	%TN Phr.k Leaf	%TN Phr.k mean	%TN Cyp.p Stem	%TN Cyp.p Leaf	%TN Cyp.p mean	%TN Typ.l Stem	%TN Typ.l Leaf	%TN Typ.l mean
Sum Abo	0.55	1.20	0.88±0.23	0.26	1.14	0.70±0.31	0.69	0.96	0.83±0.10
Infranz	0.70	1.03	0.87±0.12	0.42	1.02	0.72±0.21	0.54	1.05	0.80±0.18
Gilgel Abay	0.61	1.27	0.94±0.24	0.69	1.30	1.00±0.22	0.51	1.04	0.78±0.19
Zgie Yiganda	0.54	1.27	0.91±0.26	0.17	0.91	0.54 ±0.26	0.67	0.83	0.75±0.06

S.D = Standard deviation

Table 3.3 Total phosphorus (TP) contents of plant tissue parts from four sampling sites (Mean± S.D) (%)

Sampling sites	%TP Phr. k Stem	%TP Phr. k Leaf	%TP Phr. k mean	%TP Cyp. p Stem	%TP Cyp. p Leaf	%TP Cyp. p mean	%TP Typ. l Stem	%TP Typ. l Leaf	%TP Typ. l mean
Sum Abo	0.03	0.09	0.06±0.02	0.04	0.16	0.10±0.04	0.14	0.13	0.14±0.01
Infranz	0.03	0.06	0.05±0.01	0.07	0.14	0.11±0.03	0.05	0.10	0.08±0.02
Gilgel Abay	0.04	0.10	0.07±0.02	0.06	0.12	0.09±0.02	0.07	0.08	0.08±0.01
Zgie Yigand	0.05	0.11	0.08±0.02	0.05	0.16	0.11±0.04	0.08	0.16	0.12±0.00

S.D= Standard deviation

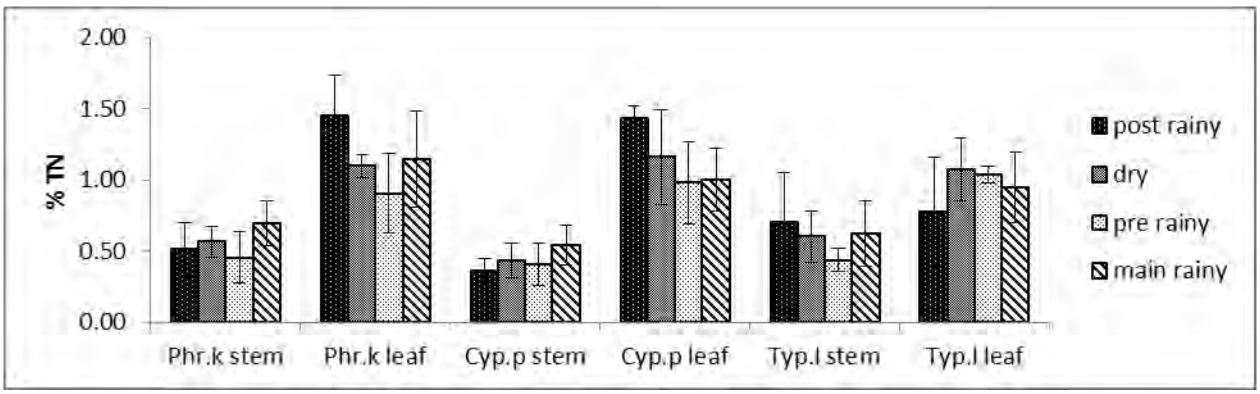


Figure 3.3 Mean nitrogen (TN) contents (%) of emergent macrophytes sampled from four sampling sites for four sampling seasons. Error bars indicate standard error of mean.

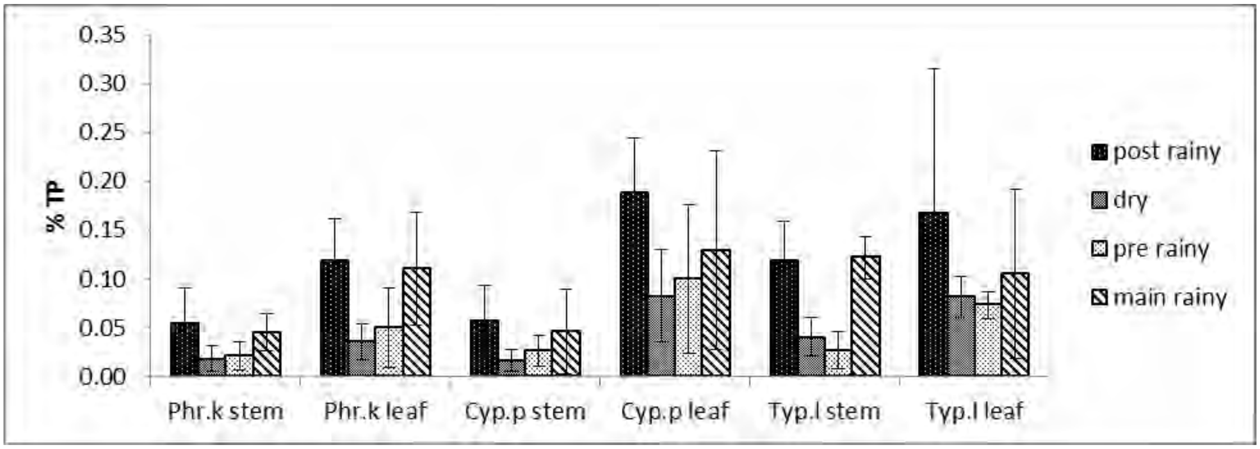


Figure 3.4 Mean of phosphorus (TP) contents (%) of emergent macrophytes sampled from four sampling sites for four sampling seasons. Error bars indicate standard error of mean.

3.3.3 Macrophyte above ground biomass and tissue nutrient content in relation with physico-chemical parameters

RDA was used to identify environmental variables associated with variation in macrophyte biomass. The first two axes of the RDA explained 99.2% of the species-environment variance (Table 3.4). The RDA ordination of the species-biomass association indicated that nitrate was positively correlated with the first axis which contributed 60.7% of this variance whereas; TDS, EC, Secchi depth and temperature were negatively and strongly correlated to the axis. The second axis was negatively and strongly correlated with SRP (Figure 3.5, Table 3.4).

3.3.3.1 Macrophyte above ground biomass in relation with physico-chemical parameters

High total biomass of *Typha latifolia* was positively and significantly correlated (Pearson‟s correlation, $p<0.01$) with nitrate ($r = 0.996$) and negatively and significantly correlated ($p <0.05$) with pH ($r = 0.952$). The *Typha latifolia* biomass was also strongly and negatively correlated with temperature (r = 0.952), EC(r = 0.952), TDS(r = 0.952), SRP (r = 0.952), Secchi depth, TDS(r = 0.952), SRP (r = 0.952) and DO (r = 0.952) (Table 3.5) and it dominantly occurred in the Gilgel Abay entrance littoral site of the lake where nitrate concentration was relatively high (Table 2.1). Though the correlation was not significant, all the species showed positive correlation with nitrate and depth but negative associations with EC and TDS. Relatively, high total biomass of *Cyperus papyrus* was negatively associated with high values of TDS and EC (Pearson‟s correlation, r = 0.816 and r = 0.766) respectively. Similarly, the total biomass of *Phragmites karka* was negatively correlated with TDS and EC (Pearson‟s correlation, r= 0.609 and r = 0.544) respectively (Table 3.5).

3.3.3.2 Macrophyte Tissue nutrient content in relation with physico-chemical Parameters

With regard to the above ground tissue nutrient contents, (TN, TP) of *Cyperus papyrus* showed significant positive association (Pearson correlation, P < 0.05, r = 0.951; and P < 0.01, r = 0.999) with nitrate content of the water respectively (Table 3.5) while the Tissue nutrient (TN, TP) content of *Cyperus papyrus* showed negative significant associations with Temperature (P < 0.05, r = 0.967) and with pH (P < 0.05, r = 0.959). The result of this study showed that the nutrient contents (TP, TN) of almost all species except the phosphorus contents of *Typha latifolia* showed positive association with nitrate. Similarly, except the phosphorus content of *Phragmites karka* all showed positive associations with depth. On the other hand, the nutrient contents (TP, TN) of almost all species except the phosphorus contents of *Typha latifolia* showed negative associations with pH, EC and TDS.

TN contents *of Typha latifolia* showed significant positive association (Pearson correlation, P < 0.05, r = 0.967) with depth of the water while TP contents showed significant positive correlation (Pearson correlation, P < 0.05) with SRP (r = 0.960) and pH (r = 0.953). Though the association is not significant positive association had also observed in above ground tissue nitrogen contents of *Phragmites karka* with all the nutrient content of the water studied. Table 3.4 showed the detail of the associations between each species above ground biomass and tissue nutrient content with the water quality parameters. Nitrate, SRP and temperature seem to have high contribution in affecting both biomass and nutrient content of most macrophytes, as their correlations with the macrophytes biomass and nutrient content varies significantly (Figure 3.5 and Table 3.5)

Table 3.4 Redundancy analysis (RDA) of aboveground biomass and tissue nutrient content of macrophytes versus physico-chemical parameters

Parameters	Axis 1	Axis2
Eigenvalues :	0.61	0.39
Species-environment correlations :	1	1
Cumulative percentage variance of species data :	60.7	99.2
of species-environment relation:	60.7	99.2
DO	-0.38	-0.62
PH	-0.65	-0.66
EC	**-0.92**	-0.19
TDS	**-0.95**	-0.14
NO_3-N	**0.73**	0.68
SRP	-0.45	**-0.72**
TP	0.13	-0.51
Tem	**-0.82**	-0.47
Sec	**-0.74**	-0.22
Dep	0.23	0.11

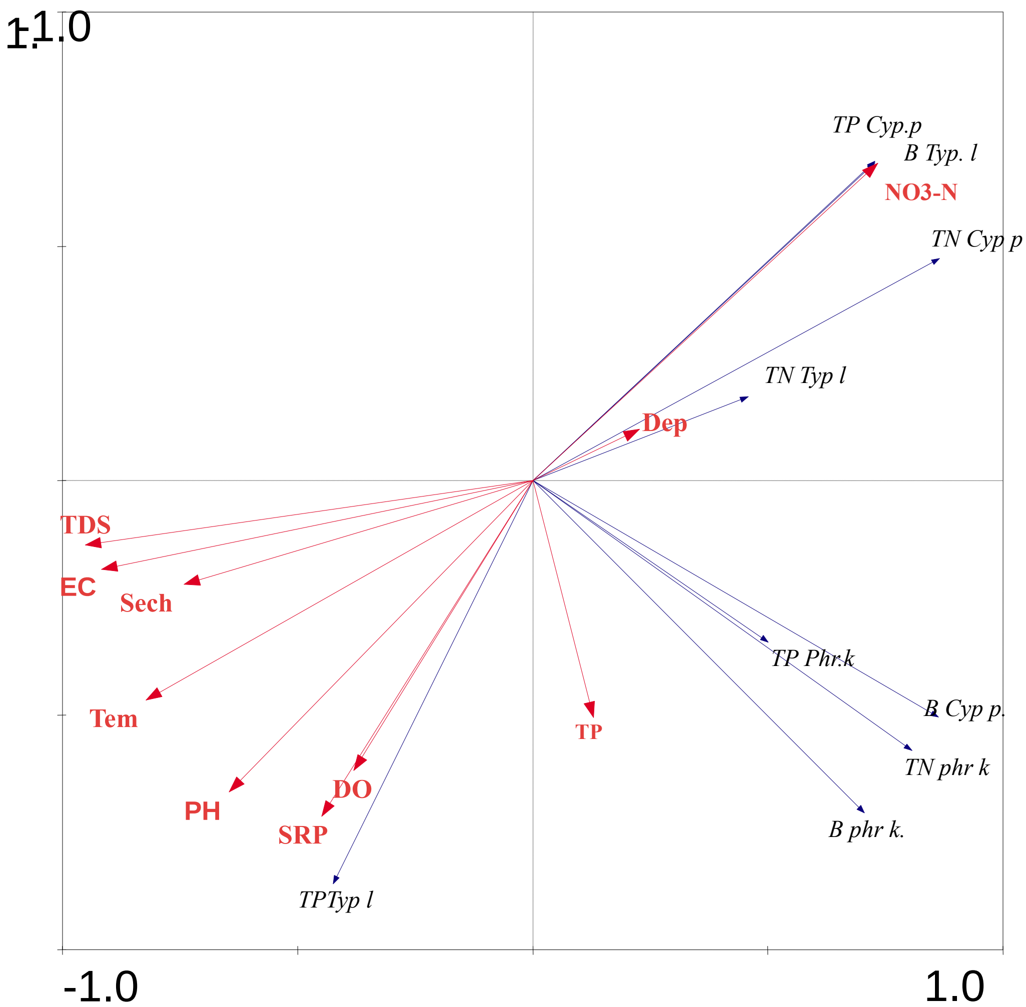


Figure 3.5 Plot of the first two axes of the redundancy analysis (RDA) for macrophyte Biomass and Tissue nutrient (TN, TP) versus physicochemical variables (Abbreviations: B phr. k- biomass for P*hragmites karka, B* Cyp. p - biomass for *Cyperus papyrus,* B Typ. l – biomass for *Typha latifolia,* TN Phr. k- TN for *Phragmites karka,* TP Phr. k –TP for *Phragmites karka,* TN Cyp. p- TN for *Cyperus papyrus,* TP Cyp. p - TP for *Cyperus papyrus,* TN Typ. l –TN for *Typha latifolia,* TP Typ. l –TP for *Typha latifolia,* SRP – Soluble reactive phosphate, TN – Total nitrogen, TP – Total phosphorus, EC – Electrical conductivity, TDS – Total dissolved solids, DO – Dissolved oxygen, NO_3-N – Nitrate, Sech – Secchi depth)

Table 3.5 Pearson correlations between macrophyte aboveground biomass and tissue nutrient contents and with physico-chemical water quality variables

Plant	DO	PH	EC	TDS	NO_3N	SRP	TP	Tem	Sech	Dep
B Phr.k	.078	-.020	-.543	-.608	.101	.166	.479	-.328	-.368	.156
B Cyp.P	-.067	-.316	-.765	-.816	.384	-.126	.300	-.540	-.593	.129
B Typ .L	-.605	-.952*	-.869	-.856	.996**	-.849	-.303	-.895	-.769	.141
TN Phr.k	-.054	-.087	-.586	-.655	.199	.119	.511	-.444	-.377	.257
TN Cyp.p	-.668	-.838	-.876	-.890	.951*	-.677	-.042	-.967*	-.694	.327
TN Typ.L	-.884	-.079	-.147	-.220	.405	.134	.714	-.740	.199	.967*
TP Phrag. K	.566	-.396	-.674	-.648	.181	-.404	-.441	.005	-.810	-.692
TP Cyp. P	-.622	-.959*	-.834	-.816	.999**	-.869	-.339	-.882	-.744	.136
TP Typ. L	.491	.953*	.649	.597	-.907	.960*	.628	.654	.678	.092

*. Correlation is significant at the 0.05 level (2-tailed).

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

3.4 Discussion

This study was sought to determine spatio-temporal, among species and between body parts differences in the aboveground biomass and tissue nutrient (TN, TP) concentrations of three dominant emergent macrophytes in relation with the physico-chemical characteristics of the lake water quality in the littoral zone of Lake Tana.

3.4.1. Spatio-temporal aboveground biomass

Among the studied macrophytes the highest aboveground biomass was recorded by *Cyperus papyrus* and the intermediate was by *Typha latifolia*, while the least aboveground biomass was measured in *Phragmites karka* indicating that biomass accumulation is species specific and it is dependent on environmental factors. Similar result was reported by other research works for example, Mnaya *et al*. (2007) compared the aboveground biomass of *Cyperus papyrus* with that of other perennial emergent macrophytes like *Typha latifolia*, *Typha anguistifolia* and *Phragmites communis* as papyrus unlike these species has its large proportion of its biomass allocated to the aerial organs. According to Mnaya *et al*., 2007 and Terer *et al* 2012, being a C4 plant, papyrus concentrates CO_2 near the site of carboxylation (the enzyme Rubisco) and thus attains lower CO_2 compensation points and minimal photorespiration which in turn allows higher net photosynthesis which also exhibits a higher water and nitrogen use efficiency contributing to its high biomass production.

There are very few published data on macrophyte aboveground biomass in Ethiopian lakes with which to compare the present data. The above ground biomass of *Cyperus papyrus* (1164.90 g DW m-^{2}) observed in this study was higher compared to biomass of the same macrophyte species in Lake Ziway, Ethiopia, 795.1 g DW m^{2} (Girum and Seyoume Mengistu, 2014). It was also higher as compared to the value reported by Thenya , (2006)   in the Yala swamp, Lake Victoria, Kenya (1014 .35 g DW m^{-2}). However, it was lower than in many similar African lakes. According to the reports in the study of Terer *et al* (2012) the above ground biomass value in the wetlands of Lake Naivasia, Kenya was 4652 g m^{-2}; Ousumba *et al*. (2010) in Lake Victoria, Winam gulf, Kenya also reported that the plant has the above ground biomass of 8456 g m^{-2}. Perbangkhem and Polprasert (2010) reported that papyrus can attain aboveground biomass of 2200 to 3100 g DW m^{-2} in tropical climate area with abundant sunlight. This signifies the considerable importance of environmental factors like nutrients in limiting the biomass of this species in the lake.

The range of above ground biomass (180.49 to 361.78 g DW m^{-2}) of *Phragmites karka* in this study was higher than some other tropical freshwater lakes. For example the two year study by Singh *et al*. (2010) in Kharungpat lake, Manipur reported that the above ground biomass of *Phragmites karka* was to be in the range of 10.43 to 27.02 g m^{-2} in the first year and from 12.24 to 27.22) gm^{-2} in the second year. However, the biomass measured for the species in this study was lower than the biomass reported by the study of Manral *et al. (2012)* on Okhla Bird Sanctuary, National Capital Region, India. They reported that the aboveground biomass of *Phragmites karka* was to be 4 kg m^{-2}.   Moreover, the biomass measured for the species in this study was lower than that of the more related species, *Phragmites mauritianus* (982.38 g DW m^{-2}) in the Yala swamp, Lake Victoria, Kenya (Thenya , 2006).

Typha latifolia attained the intermediate biomass among the macrophytes studied in the lake during the present study. The mean aboveground biomass of *Typha latifolia* (705.83 g DW m^{-2}) observed in this study was higher than the mean estimate for the species by Atkinson *et al*. (2010) (309.8 g DW m^{-2}). However, the obtained mean value in this study was lower compared to the biomass recorded in some fresh water systems in Ethiopia like Lake Ziway (813.3 ± 27.8 g DW m^{-2}) (Girum Tamire and Seyoume Mengistu, 2014)

The results of our study showed that all the three species of emergent aquatic plants studied had higher aboveground biomass values in Gilgel Abay entrance littoral sampling site than the other sites and in terms of seasonality, even though the difference was not significant, the biomass of all the species peaked during rainy seasons and the lowest biomass was measured during dry season. The higher values of biomass observed for these species in Gilgel Abay entrance littoral site might be a reflection of the increase in nutrient status of the lake like nitrate concentration especially during rainy season which might be due to nutrient enrichment from agricultural areas. It is evident that seasonal variation of biomass production in tropical regions is usually related to the seasonal variation of rainfall and water level (e.g. Esteves, 2011).

3.4.2. Tissue nutrient content

Our study showed the aboveground tissue nutrients (TN and TP) vary significantly between plant species and plant parts. For example, Total nitrogen content of all species was significantly higher in leaves than their stems. Leaves had more TN and TP than stems; this was because both the structure and function are different among tissues. Leaves are photosynthetic tissues whose metabolism is active, while roots and stems are the storage tissues, which are in charge of transporting water and nutrient (Yu *et al*., 2014). Another reason for variations in TN and TP content between plant portions might be related to differences in the age of various portions which in turn may reflect differences in standing crop and the level of nutrients accumulating in emergent macrophytes (Dar et *al*., 2012). (Ruiz and Velasco (2010) found large seasonal differences in mineral content of the reed, *Phragmites australis*, in the Mar Menor coastal lagoon in the Western Mediterranean.

Different species assimilate and concentrate nutrients to different levels. The above ground tissue mean nutrient concentrations in this study ranged from 0.23 to 1.29% DW for TN and from 0.06 to 0.14% DW for TP. The range value obtained for TN in this study was well within the range of other studies like Mfundisi (2005) and Thenya (2006) in the Yala swamp, Kenya who reported a range value of 1.32 % and 1.2 % respectively. At the same time, the macrophyte nutrient values in this study were within that of Nakivubo natural swamp level reported by Kansiime *et al*. (2003) as well. However, it was lower than the range (0.25 to 2.14% DW for TN and 0.13 to 1.07% DW for TP) reported by the study of Yu *et al*. (2014). It was also lower than the range obtained by the study of (kao *et al*., 2003); which is between the range of 1.4 to 1.5 % DW for N and from 1.8 to 2.3% DW for P.

The highest mean aboveground tissue nitrogen content was observed for *Cyperus papyrus* found in the Gilgel Abay entrance sampling site where there is relatively higher nutrient content which might be because of nutrient enrichment from the agricultural watersheds by the river Gilgel Abay; whereas, the highest mean aboveground phosphorus content was in the tissue of *Typha latifolia* located in the Shum Abo sampling site where the site is receiving wastewater from Shum Abo restaurant which might be rich of phosphorus containing compounds like detergents.

The results showed significant seasonal variability in the content of aboveground tissue nutrients between species and plant parts where leaves of all species contain more tissue nutrients (TP, TN). There was a tendency to higher concentrations of TN and TP in the tissues of macrophytes in the rainy season, However, Biomass was low in the dry season due to the reduced nutrient circulation. The dry season were also characterized by heavy utilization of the lake and associated wetlands by humans for different purposes, livestock and wildlife. On the other hand, biomass increases tremendously during the wet period due to the reduced wetland utilization coupled with the increased nutrient circulation.

3.4.3. Biomass and nutrient content in relation with physico-chemical variables

The results of redundancy analysis (RDA) of aboveground biomass and tissue nutrient content of the macrophytes versus physico-chemical variables showed nitrate, SRP, and Temperature of the water have significant impact on biomass and tissue nutrient contents of the emergent macrophytes studied. The species showed positive correlation with nitrate and depth and negative associations with EC and TDS. Pearson‟s correlation also showed these associations.

There are several studies that have emphasized the direct relationship between the primary production dynamics of macrophytes and light regime, temperature, water depth, sediment composition and the amount of available nutrients (Shilla & Dativa, 2008; Zhu *et al.,* 2008). In this study we also found that ecological factors like nutrients (nitrate, SRP), temperature and depth affected the aboveground biomass production and tissue nutrient content in emergent macrophytes of Lake Tana.

This study showed the biomass of all species has positive correlation with nitrate concentration of the water and the most significant association with r value of 0.996 was observed with the biomass of *Typha latifolia.* Other studies also showed aboveground biomass increased asymptotically with N (Craft *et al*., 2007). According to Craft *et al*. (2007), Aboveground biomass and biomass of aggressive species, like Typha spp. increased asymptotically with surface water N whereas leaf P, senesced leaf N and senesced leaf P increased linearly with N. This study also showed the phosphorus content of *Typha latifolia* was positively and significantly correlated with SRP of the water. The findings of this study were in line with results from the nutrient enriched agricultural drainage for a fen wetland in upstate New York where aboveground biomass, nutrient (P) uptake and dominance by *Typha latifolia* are positively correlated with P enrichment (Drexler and Bedford, 2002).

Other studies have also reported that phosphorous input into wetlands will result in expansion of *Typha latifolia* biomass and can even invade wetlands resulting in near monotypic Typha stands and the plant had become a serious aquatic weed (Macek and Rejmankova, 2007). It is understood that availability of nutrients is considered one of the main factors affecting the aquatic plants growth. Many nutrients required for growth, nitrogen (N) and phosphorus (P) are the elements typically of shortest supply in aquatic ecosystems and therefore most likely to affect the growth of aquatic macrophytes species (Lacoul and Freedman, 2006; Thomaz *et al*., 2007).

All the species showed positive correlation with depth of the water and the correlation was significant with the tissue total nitrogen content of *Typha latifolia.* According to Aulio (2015), the widest and most productive stands of *Typha latifolia* occupy habitats with the water depth of 5-47 cm, with the mean depth of 19 cm. Its high ability to accumulate water- and sediment-borne nutrients is well known (Aulio, 2015). In Lake Tana, variations in the water depth are high (Etafa *et al.,* 2010). *Typha latifolia* is known to tolerate wide variations in the hydrological conditions of habitats. In the comparison between 17 wetland macrophytes, the broad-leaved cattail was classified as an aggressively colonizing plant tolerating fluctuations in the water depth – from flooding to long-time drying of the sites (Kercher and Zedler, 2004)

In this study significant negative correlation between aboveground biomass of *Typha latifolia* and Tissue total phosphorus content of *Cyperus papyrus* were observed. Studies have reported that pH has important influence on aquatic plants growth and distribution (Heegaard *et al*., 2001; Lacoul and Freedman, 2006; Kenzawi, 2007). The chemical analysis of the water samples collected from the flooding water surrounding the rhizosphere of *Cyperus papyrus* in the study of El-Ghani *et al*. (2010) revealed that *Cyperus papyrus* grows in fresh water with pH ranges from 6.6 to 7.5. pH affects the rate of nutrient uptake by macrophytes (Girum Tamire and Seyoum Mengistu, 2014). Titus and Stone (1982) observed that the increase in pH from 7.0 to 9.0 significantly reduced the rate of uptake of inorganic carbon by *Myriophyllum spicatum.* Many researches like (Heegaard *et al*., 2001; Lacoul and Freedman, 2006; Serag and Khedr, 2001; Thomas *et al*., 2007) also observed negative relationships between increases in pH and decreases in CO_2 availability and the photosynthetic rate for *Hydrilla verticillata.* According to Shuman

(1994), the rate of uptake of phosphorus by plants is highly pH-dependent and optimal uptake occurs at 6.5. Thus, a relatively high pH also might have hindered the expansion of macrophytes such as *Typha latifolia and Cyperus papyrus* which require higher soluble phosphorous.

The negative associations between EC and TDS of water and macrophyte biomass in all species in this study may be one of the factors for the lowest values of biomass of macrophytes to be seen in the lake in general and in Infanz sampling site in particular where there was relatively higher values of EC. Biomass production can be affected by EC, because osmotic forces can cause lethal water loss and also affected nutrient uptake, and that reflect the lowest values beside other factors such as water depth and human impact on vegetation by cutting and grazing during study period. Similar Results were observed on the study of Al-Abbaw and Al-Mayah (2009) for the situation of biomass of common reed (*Phragmites australis*) in relation with depth, EC, TDS, and nutrients. The findings of El-Ghani *et al*. (2010) have also demonstrated that pH, EC and concentrations of nitrate along with other factors were the major environmental factors that affect the diversity and distribution of macrophytic vegetation in the Nile Delta of Egypt.

In conclusion, the variation in the macrophyte biomass and tissue nutrient concentrations across both seasons and plant species was found to be closely linked to the changes in nutrient levels in water. Significant correlations between nitrate and pH in water with biomass in plants and between nitrate, SRP, depth and pH in water with plant tissue nutrient contents, indicate that these plant species may be used in the chemical qualification of the environment of the examined lake in addition to the chemical monitoring of water. Moreover, in most cases, lower biomass production of the studied macrophytes was observed as compared to other studies done on these macrophytes in other regions. Besides the water quality changes, damages by human activities (settlement and livestock grazing) which made negative effects on plant cover that led to decrease of biomass in comparison with sites of less or no human activities of plant cutting should be take into account.

Chapter 4: Evaluation of the Contribution of Macrophytes in the Overall Water Quality Improvement by Yitamot Natural Wetland at the Vicinity of Bahir Dar City

4.1 Introduction

The ability of wetlands to improve the quality of water has long been recognized and this had led to the use of wetlands as a means to treat diffuse and point source pollutants from a range of land uses. Water pollution is becoming a serious issue of the entire world due to the rapid population growth, unsuitable treatment technology and inadequate management (Kumar, 2015). Due to the experience of wastewater treatment plants, biological treatment system like the use of natural systems with low operational and capital costs is preferred especially for developing countries like Ethiopia, with warm climate all year round. In natural treatment systems the environment uses its own recovery capacity and natural processes as a form of treatment **(**Shah *et al*., 2014**)**. A variety of physical, chemical and biochemical processes, such as microbial degradation, assimilation, precipitation, and adsorption to soil particles operate within the wetland environment, contribute to improvement in water quality.

Wetlands remove contaminants, such as total suspended solids, nutrients, toxic trace elements and metals, pathogenic contaminants, herbicides and pesticides from wastewater primarily through adsorption on the organic and clay sediments and through biotransformation of pollutants by a diverse community of wetland organisms. Trace metals can readily form complexes with the organic matter contained in wetland sediments, as organic soils have been shown to have a high cation exchange capacity (Kennedy and Mayer, 2002). Pathogens, such as bacteria and viruses, are removed and deactivated in wetland systems through sorption to sediments, excretion of antibiotics from the roots of macrophytes, UV radiation, and predation by other organisms (Kennedy and Mayer, 2002).

Plant nutrient uptake and sedimentation has been recognized as important process in removing of nutrients from wastewater (Wetzel, 2001; Browning, 2003; Shah *et al*., 2014**)** Wetland systems can naturally treat wastewater by dispersing water from a point source over a large area, which facilitates nutrient uptake by aquatic vegetation. In addition to direct nutrient uptake, the physical effect of wetland plants decrease water flow , which increases settlement of solid particulates and volatilization rates and enhances microbial activity, removing organic and inorganic pollutants from aquatic habitats (Dhote and Dixit, 2009; Shah *et al*., 2014). Water quality improvement by aquatic plants become widespread because, in general, they have effect on the suspended solids, turbidity, Biological Oxygen Demand, nutrients like Phosphorus, Nitrogen, Potassium, Sodium, Calcium, Magnesium, and some other metals **(**Shah *et al*., 2014).

In systems influenced by wastewater, macrophyte species with rapid growth rates, high plant tissue nutrient content and high biomass accumulation tend to reflect high rates of nutrient uptake (Mitsch and Gosselink, 2000) and would have higher potential for nutrient removal from the water column. Measuring plant tissue nutrient content of various wetland plants downstream from sources of enriched nutrient input as well as relating relative uptake rates of plants to water column nutrient concentrations can quantify nutrient retention within the system. This can help determine if specific aquatic wetland plants are effectively serving as nutrient storage compartments that will ultimately improve water quality downstream (Parnell, 2011).

The proper use of a natural wetlands system for the treatment of wastewater or storm water involves a number of considerations. At high organic and nutrient loadings for example, some natural wetlands may be significantly degraded. Its plant species are likely to shift to herbaceous marsh species such as cattails (*Typha* spp) （Sizo *et al*., 2015). Optimal treatment occurs when the pretreated water is well distributed throughout the wetland and travels through as sheet flow (Koelsch *et al.,* 2006. Ideally, alternative discharge areas or "treatment cells" are used to reduce the hydraulic and nutrient loadings that might otherwise affect the vegetation community in the treatment cells (Sizo *et al*., 2015)

An illustration of a conceptual model for nutrient storage compartments in wetlands influenced by increased nutrient loading, nutrient assimilation by aquatic vegetation, adsorption to sediment, or nutrient retention in pore water and dilution of water column nutrients to decrease water column nutrients downstream from source input is shown in Figure 4. 1. A linear decline in water column nutrient concentrations with increasing distance from source input suggests dilution (Officer 1979) (Figure 4. 2). A curvilinear relationship suggests wetland plants, sediment and pore water are sinks for pollutants (Figure 4. 2) thus improving water quality downstream more efficiently than expected from dilution alone.

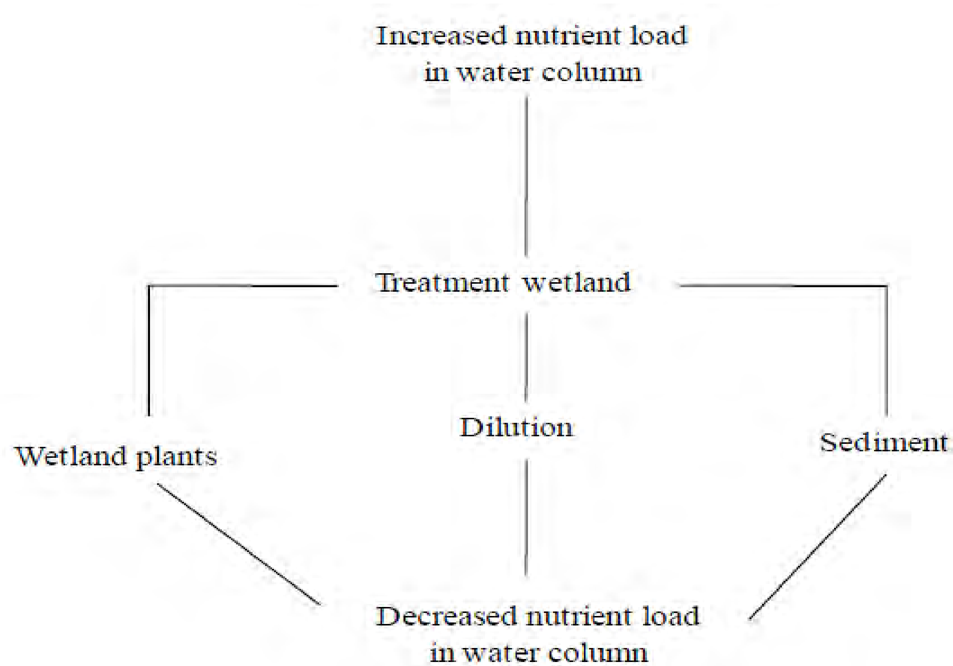


Figure 4.1 Conceptual model for nutrient storage compartments in wetlands influenced by increased nutrient loading (source: Parnell, 2011)

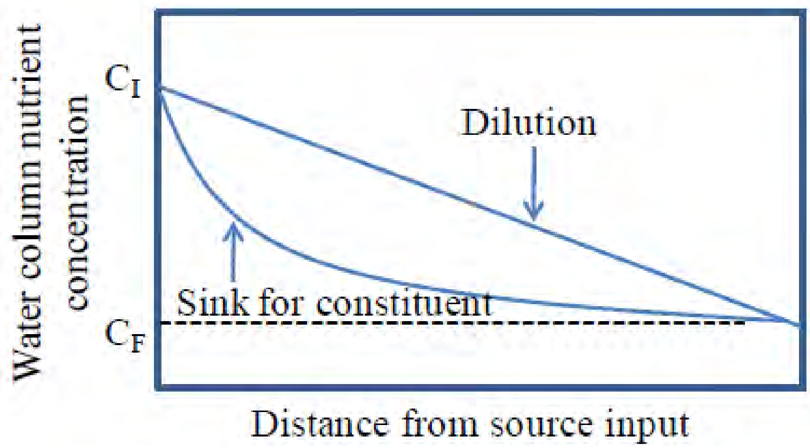


Figure 4.2 Conceptual graph illustrating mixing plots (water column nutrient concentration vs distance from nutrient source) where CI is the water column nutrient concentration at the source of input and CF is the water column nutrient concentration downstream from source input （Source Parnell, 2011).

In most countries of the world, partly treated and sometimes-untreated wastewater with nutrients is discharged directly to surface waters or through wetlands which are in close proximity to urban centers (Okurut, 2000) and Africa, in particular Ethiopia, is no exception to this problem. The presence of these wastes in water bodies becomes undesirable, as it hinders the sustainable life of organisms (Mugisha *et al*., 2007； Kanyiginya *et al.*, 2010). Many Ethiopian natural wetlands are depleted and are under severe stress (Abebe Yilma, 2003). There are also some research gaps regarding the sustainable utilization and conservation of Ethiopian wetlands. The expansion of human settlement and industrialization around wetlands in some parts of the country, e.g Bahir Dar, Hawassa, Debrezeit, has become an major source of pollution and are threatening the stability of these ecosystems (Zinabu GebreMariam, 2002). Other major threats include deforestation, over grazing, planting of high water demanding plants, spread of invasive plants species, pesticides and fertilizer applications in nearby farms and construction of dams (Afework Hailu, 2004;　McKEE, 2007).

Yitamot natural wetland is one of the wetlands in Ethiopia, located at the vicinity of Bahir Dar and is threatened with increased inflow of nutrients and extensive encroachment for various land use activities, like agriculture, and high settlement densities and being an effluent discharge site.

The city of Bahir Dar is a rapidly expanding city and has no particular zones for industrial, commercial or other activities. Shops and residences are generally present in all city sectors. There are no major industries in the contributing areas; the main industries, textile factory and two tanneries are located outside the watershed that contributes to the urban storm water and sanitary sewer joining the wetland. However, most of the domestic waste collecting tanks in Bahir Dar are constructed using poor quality materials that can leak all the liquid waste to the ground or over flow to open ditches when the ground water rises to the surface during the rainy season (Tenagne Addissu, 2009). The mass movements of these wastes together with urban storm water runoff to the wetland will have serious and irreversible effect on the wetland ecosystem and water quality in the future.

The wetland is under threat of two main channels; the storm water drainage network direct water from the runoff especially during rainy seasons and untreated sanitary effluents from Bahir Dar University directly into the wetland. This system receives pulses of pollutants each time it rains, and although it is believed that the wetlands help to prevent much of the pollutant load from being transported elsewhere (Abay/Blue Nile river in this case), it is necessary to confirm this hypothesis and understand the dynamics of this process. The wetland received untreated effluents from the University continuously both dry and wet season, throughout the year. There is a possibility that nutrients (N and P) reach the Blue Nile River and can cause pollution of the river. As a result, information on water quality in the wetland is needed for the planning of sustainable use of the wetland. It is currently assumed that the Yitamot natural wetland retains the nutrients and heavy metals carried with the wastewater, but there is no quantitative data of this function. Such information is necessary for the efficient planning of long-term sustainable use of the wetland. This study was carried out to address the uncertainty regarding the functioning of the Yitamot wetland and the lack of information on the processes taking place therein.

Therefore this study was aimed at (1) evaluating the potential of the existing natural wetland (Yitamot natural Wetland) to remove nutrients and other pollutants like metals from wastewater discharged into it in a sustainable way; (2) describing the processes and sinks of nitrogen, phosphorus and other pollutants like metals.

4.2. Materials and methods

4.2.1 Sampling design

The study was investigated the ability of the natural wetland (Yitamot) to remove pollutants by analyzing physicochemical variables in the water, nutrients and heavy metals in the water, sediments, and dominant macrophytes using a series of five sampling points running in a transect along the longitudinal axis of the wetland (Figure 1.6).

To avoid distortion of the results by pulses of rainfall, which can greatly but temporarily increase pollutant loads, collection was made of surface water, sediments, and macrophyte samples in dry season months (January and May) and averaged. The water parameters analyzed were pH, TDS, EC, DO, TSS, COD and Temperature and the contents of nutrients (NO_3-N, NO_2-N, NH_3-N, TN, PO_4-P and TP in water and sediment. Nutrients contents (TN and TP) and twelve metals (K, Na, Ca, Mg, Fe, Mn, Cu, Zn, Pb, Cr, Cd, As) were also analyzed in the three compartments (water, plant and sediment) of the wetland.

4.2.1.1 Physico-chemical parameters

DO, pH EC, TDS, temperature, TSS, COD and nutrients: SRP, TP, NH_3-N, NO_2-N, NO_3-N and TN were the variables measured in the surface water. DO, pH, EC, TDS and temperature were measured *in situ* using a Portable HACHTM model 150 multi-probe system.

Water samples were collected from each sampling site (Figure 1.6) to analyze for TSS, COD and nutrients: SRP, TP, NH_3-N, NO_2-N, NO_3-N and TN at each sampling visit and the collected water samples were filtered using glass fiber filter paper (GF/F) prior to analysis for SRP, NH_3-N, NO_2-N and NO_3-N whereas analysis of TSS, COD, TP and TN were done from unfiltered samples.

TSS was analyzed using standard method according to APHA *et al.* (1999), Total Suspended Solids analytical method (method 2540 D), where a volume of well mixed water sample was passed through glass fiber filter paper (GF/F) and was weighed and dried at 103 to 105 °C. The dried material weight was accounted for TSS and measured. The volume of sample filtered was recorded for calculating the total suspended solid content as:

$$\text{Total suspended solids (mg/L)} = \frac{\text{final weight (mg) - initial weight (mg)}}{\text{Volume of sample filtered (L)}} \text{ X } 1000$$

The analytical method used for determination of COD was Dichromate test method (APHA *et al.*, 1999). In the process water sample were added to a cuvette (with reagent) and left it in a heater (Model HACH DRB 200) for 2 hours. At the end of the period the intensity of color in the solution was directly related to the COD value in the sample, and was measured with ultraviolet spectrophotometer (model HACH DR 2800) in Chinese Academy of Sciences, (institute of RCEES, Department of Water Pollution Control Technology lab).

Analysis of SRP from water sample was measured using ascorbic acid method following the standard procedures outlined in APHA *et al.* (1999). The filtered samples were mixed with ammonium molybdate that forms molybdo-phosphoric acid with any phosphate present in the water sample. The acid is then reduced by ascorbic acid to a blue complex known as molybdenum blue. The color intensity, which is proportional to the concentration of phosphate in the water sample, was then measured by a Jenway 6405 UV Visible spectrophotometer at a wave-length of 880 nm. Whereas the analysis for TP was done for the unfiltered sample of water sample using persulfate digestion followed by the ascorbic acid method. In the persulfate digestion process, the polyphosphates were converted to the orthophosphate form by a sulfuric acid digestion and organic phosphorus was converted to orthophosphate by a persulfate digestion.

The resulting orthophosphate from the unfiltered sample was analyzed by ascorbic acid method using a spectrophotometer (Jenway 6405 UV visible spectrophotometer) in the limnology laboratory of Addis Ababa University.

Ammonia (NH_3-N) was determined by Phenate method using spectrophotometer at wave length of 640 nm where an intensely blue compound, indophenol, was formed by the reaction of ammonia, hypochlorite, and phenol catalyzed by sodium nitroprusside. The blue indophenol was proportional to the ammonia concentration in the sample.

Nitrite (NO_2–N) was determined by Colorimetric Method through the formation of a reddish purple azo dye produced at pH 2.0 to 2.5 by coupling diazotized sulfanilamide with N-(1-naphthyl)-ethylenediamine dihydrochloride (NED dihydrochloride). The spectrophotometer measurements were made at a wave length of 543 nm and NO_3-N was determined by salicylate colorimetric method (Yang *et al*., 1998). The analysis was based on the reaction of the nitrate with sodium salicylate in a sulfuric acid medium, which is formed yellow color salt of nitro salicylic acid. The color intensity which is proportional to the nitrate concentration was then measured as mg/L of nitrates as nitrogen by a Jenway 6405 UV Visible spectrophotometer at a wave length of 410 nm. Total nitrogen was analyzed using persulfate method where total nitrogen was determined by oxidation of all nitrogenous compounds to nitrate and measured using UV visible spectrophotometer model TU-1901 UV-Visible spectrophotometer in Chinese Academy of Science (institute of RCEES, Department of Water Pollution Control Technology lab).Sediment samples were taken from each study site, for analysis of SRP, TP, NO_3-N and TN concentration, using a modified sediment core sampler after Powel (2008), from approximately 10 cm of the sediment surface. The collected sediment samples were air dried and sieved (< 2 mm). In the process appropriate amount of distilled water and 0.002 N H_2s0_4 was added and then homogenized with mechanical shaker for an appropriate time and filtered through a whatman No. 42 filter paper. Finally, this solution was analyzed according to the methods mentioned in water sample analysis for soluble reactive phosphate (ascorbic acid method) and total phosphorus, (persulfate digestion followed by ascorbic acid method). While for nitrate using salicylate colorimetric method after preparation of the sample according to the methods in US EPA (1993)

Total nitrogen in sediment was analyzed using Kjeldahl method which involves two-step process. First, the sample was digested with a sulfuric acid to convert organic nitrogen compounds to ammonium ion. Secondly the converted ammonium ion was converted to ammonia in an alkali distillation process. The liberated ammonia in this process was finally quantified for determination of the total nitrogen in the original digest as stated in APHA *et al*. (1999).

4.2.1.2 Determination of the wastewater flow patterns in Yitamot wetland

Electrical conductivity was used as a tracer to determine the major flow paths of the wastewater in the wetland as stated in Kansiime and Nalubega (1999); measurements of electrical conductivity were carried out at five sampling points each 50 m apart along a transect from the inlet to the outlet. The measurements were taken *in situ*; for a week in each month (May, 2014 and January, 2015) using portable HACHTM model 150 multi-probe system.

4.2.1.3 Determination of Nutrient loads into and out of Yitamot wetland

Discharge at the inlet and outlet was measured using a float method according to Water Quality Monitoring Manual Volume II – Manual on Effluent Water Quality Monitoring (JICA Project Technical Assistance Team**,** 2008**).** In the method, the wet cross-sectional area of the channel was measured by measuring the depth of the water inside the channel and the width of the channel, and the mean velocity of the waste stream was determined by measuring the surface velocity using the float method. Two points along the length of the channel from the inlet of the influent into the wetland and from the outlet of the effluent from the wetland were measured by using a meter stick, and the length was recorded. The time it takes a float to travel between two points in a straight length of the channel gives the surface velocity of the water and was recorded using the stopwatch three times. The flow in the channel was obtained by applying the formula:

$$Q = A*Vmean$$

Where, Q = the discharge rate, m^3/sec

A = the wet cross-sectional area of the sewer pipe of wastewater channel, m^2

Vmean = the mean velocity of water flowing, m/sec

The nutrient loads into and out of Yitamot wetland were determined by measuring the discharge at the inlet and outlet of the wetland and taking water samples at these points for laboratory analysis. The results of concentrations obtained from the laboratory were used to estimate the nutrient load at each station. The load can be computed using the method of Huai-en *et al.* (2003) as follows:

L= Q*C
Where, *L* = nutrient load (kg / Day)
Q = discharge (m^3 /s)
C = Concentration (Kg/m^3)

The degree of nutrient retention that took place between stations (within the wetland) was calculated as a difference of the loads at the inlet and outlet.

4.2.1.4 Macrophyte aboveground biomass accumulation analysis

Plant samples were collected from five sampling sites along a transect from the inlet of effluent into the wetland to the outlet: S1, S2, S3, S4 and S5 (Figure 1.6). The biomass of macrophytes was obtained by using quadrat method (size of 0.25 m^2 area) and harvesting the plants aboveground part as in Lee (1990). Two quadrats were laid in opposite side of each sampling site following Piotrowicz *et al*., (2006) and the quadrat samples were averaged. All aboveground material was placed in plastic bags and taken to the limnology laboratory of Addis Ababa University for determination of dry weight following the procedures in Wetzel and Likens (2000) as described in chapter three.

4.2.1.5 Nutrient content analysis in plant tissue

Total nitrogen and total phosphorous were chosen as the basic elements for nutrients used up by the plants. After the aboveground dry weight biomass of each macrophyte species was measured, the plant nutrients (TN and TP) were determined according to the methods in Zhu *et al*. (2011) from each macrophyte on dry weight basis. The concentration of total nitrogen (in % N) and total phosphorous (in %TP) were analyzed using Kjeldahl method and dry ash (vanadate-molybdate yellow) method following the procedure in Blamire (2003) and Chapman and Pratt (1961), respectively, as described in chapter three.

4.2.1.6 Metal analysis in water, sediment and plant tissue

Water, sediment and plant tissue samples were collected from each sampling site and analyzed for metals (K, Na, Ca, Mg, Fe, Mn, Zn, Cu, Cr and As) concentration (mg/L) following the procedures outlined in US EPA (1994), Method 200.7 d.

The composite water sampling method was used for collection of water sample in each sampling station twice covering a period of May 2014 and January 2015. 100 ml sample was collected in thoroughly cleaned polyethylene container bottles. Samples were preserved by adding 5 drops of Nitric acid and stored below 4^0C in a refrigerator before analysis. Sediment samples were taken from each study site, for analysis of the above mentioned metals, using a modified sediment core sampler after Powel (2008), from approximately 10 cm of the sediment surface. The collected sediment samples were thoroughly dried and pooled, ground to pass in a 100-mesh sieve (0.149 mm). Similarly, the plant tissue sample, after determining dry weight of the biomass of each plant aboveground tissue, a representative sample was pooled, ground to pass a 100-mesh sieve(0.149 mm). The preserved water samples and dried sediment and plant tissue samples were digested with a mixture of concentrated HCl-HNO_3-HF-$HClO_4$ in a microwave digestion system (MARS 230/60 CEM MARS XTRACTION MODEL 907500) following the procedures in Bettinelli *et al*., (2000). The measurements of concentration in the digestion solution were performed using Inductively Coupled Plasma Optical Emission Spectrometer, PerkinElmer®

Optima® 8300 ICP-OES coupled with the prep FAST™ Automated In-Line Auto-Dilution/Calibration System (Elemental Scientific Inc., Omaha, NE) in Chinese Academy of Science (Institute of RCEES, Department of Water Pollution Control Technology lab).

4.2.1.7 Nutrient and pollutant removal efficiency of Yitamot natural wetland

The pollutant removal efficiency (PRE`s) of the wetland was evaluated with respect to the pollutants like organic matter (in terms of COD), TSS, nutrients and metal elements in both influent (S1) and effluent (S5) concentrations during the monitoring period. The information collected from the analysis was used for computation of the pollutant removal efficiencies. PRE`s was calculated as percentage by the following equation:

$PRE\ \% = (C_i - C_f) / C_i * 100$

Where: C_i = influent concentration (mg/L)

C_f = effluent concentration (mg/L)

4.2.2. Statistical analysis

Statistical analysis of results was done using SPSS software package version 20. The significance of differences in variations in physicochemical variables, aboveground biomass production of macrophytes, nutrient and metal concentrations within the study sites and macrophyte species of the wetland were assessed statistically using ANOVA and Tukey‟s multiple comparisons for differences between means. In all tests, differences were considered statistically significant at $P < 0.05$.

4.3 Result

4.3.1. Water quality along wastewater flow path

The results of analysis obtained along the transect from the inlet to the outlet (S1, S2, S3, S4 and S5) are summarized in Table 4.1. More variation in mean values for pH, TSS, and COD was observed among the sampling sites.

The value of pH ranged from 5.70 to 8.46 and the value increased significantly ($F = 15.127$, $p < 0.05$, ANOVA) along sampling sites. The mean value of pH at the inlet (site 1) was below the Ethiopian effluent allowable discharge limits into water courses (pH = 6-9) (EEPA/UNIDO, 2003) whereas, the value at the outlet was within the limit. The mean value of temperature was in the range of 25.15 to 29.35 and the mean difference was not significant (ANOVA, $P > 0.05$) along the sampling points. However, the measurements in all the sampling sites were under the Ethiopian effluent allowable discharge limits into water courses (40 ^{0}C) (EEPA/UNIDO, 2003).

The mean value of EC and TDS ranged from 553.20 µS/cm to 1195.50 µS/cm and 353.90 to 765.00 mg/L, respectively, with the highest values measured at S3 and lowest values measured at S5; though the variation was not significant ($p > 0.05$, ANOVA) along the sampling sites.
The results of this study showed that the mean concentration of DO was in the range of 1.11 to 5.01 mg/L and was significantly higher at S3, 4 and S5 than at S1 (ANOVA, $F = 1.097$, $P < 0.05$). The concentration of DO showed progressive increase along the transect from the inlet to the outlet. However, the mean concentration (except at S5) was below the ranges of maximum allowable concentration ranges (5.00 to 9.00 mg/L and 5.00 to 9.50 mg/L) for fisheries and aquatic life set by Commission of European Communities and Environment Canada respectively (CEC, 1978; Environment Canada, 1987) (Table 4.1).

The mean value of TSS ranged from 0.04 mg/L to 0.41 mg/L with the highest and the lowest value at S1 (inlet) and at S5 (outlet), respectively, and it significantly decreased along the subsequent sampling sites (ANOVA, $F = 7801$, $p < 0.05$). The measurements in all the sampling sites were lower than the Ethiopian effluent allowable discharge limits into water courses (50 mg/L) (EEPA/UNIDO, 2003) and the maximum allowable concentration ranges for fisheries and aquatic life set by Commission of European Communities (25 mg/L) (CEC, 1978) (Table 4.1).

The mean value of turbidity was between the range of 10.80 NTU and 276.40 NTU with the highest mean value measured at the inlet and the least at the outlet of the wetland. Significant decreases were observed between the inlet sampling site and all the other sampling sites (ANOVA, $F = 8.434$, $P < 0.05$) (Table 4.1)

Table 4.1 Water quality parameters measured at selected sampling sites in Yitamot wetland (Mean± S.D) (mg/L unless mentioned), (n= 4)

Variable	**S1**	**S2**	**S3**	**S4**	**S5**	EEPA/UNIDO (2003)	CEC (1978)	Env`t Canada (1987)
pH	5.70 ± 0.24	6.21 ±0.27	7.79 ± 0.11	8.46 ± 0.37	Range =5.70-8.46	6.00 – 9.00	6.00– 9.00	6.50-9.00
T (0_C)	25.15^{a} ± 3.75	25.90^{a} ± 4.00	29.35^{a} ± 1.85	27.40^{a} ± 3.60	26.10^{a} ± 2.60	40.00		
EC (µS/cm)	887.50^{b} ± 480.50	834.00^{b} ± 421.00	1195.50^{b} ± 737.50	739.00^{b} ± 356.00	553.20^{b} ± 498.80	300.00*		
TDS	608.50^{C} ± 347.50	533.50^{C}± 269.50	765.00^{C} ± 472.00	473.00^{C} ± 228.00	353.90^{C} ± 319.10	1000.00		
DO	1.54^{d} ± 0.76	1.11^{d} ± 0.43	2.70 ± 0.60	5.00^{e} ± 2.60	5.01^{e} ± 2.81	5.00 *	5.00 – 9.00	4.00 – 6.00
TSS	0.41± 0.00	0.37± 0.00	0.32± 0.00	0.35± 0.00	0.04± 0.00	50.00	25.00	
Turbidity (NTU)	276.40 ± 70.30	163.45^{a} ± 38.15	108.05^{a} ± 11.75	42.80^{b} ± 6.10	10.80^{b} ± 2.11			
COD	207.00^{c}± 0.50	208.25^{c}± 0.25	44.25± 0.25	37.50 ± 4.00	5.25 ± 0.25	100.00		
SRP	2.78± 0.03	3.00± 0.02	2.21± 0.01	0.51 ± 0.01	0.30 ± 0.01	0.10*		
TP	2.96^{d} ± 0.27	2.70^{d} ± 0.22	1.76 ± 0.09	0.81 ± 0.01	0.14 ± 0.01			
NH_3-N	0.99^{a}± 0.11	0.69^{b} ±0.01	1.00^{a} ± 0.05	0.76^{b} ± 0.02	0.28 ± 0.01	0.85*	0.01-0.03	1.37–2.20
NO_2-N	0.15± 0.00	0.02 ± 0.00	0.11 ± 0.00	0.02± 0.00	< 0.01		0.01-0.03	
NO_3-N	0.22 ± 0.01	0.13^{c} ± 0.01	0.17^{c} ± 0.02	0.13^{c} ± 0.00	0.01 ± 0.00	10.00*		
TN	37.04^{d} ± 0.24	36.63^{d}± 0.31	37.91± 0.04	1.01± 0.00	0.34 ± 0.02			

SD = Standard deviation

NTU = Nephelometric turbidity units

<0.01 Implies that the value for nitrite was below the minimum detectable limit of 0.01

Values followed by the same letters in a raw are not significantly different at P <0 .05

* USEPA: Quality Criteria for Water – USEPA, 1986 (EPA, 1986)

The mean concentrations of COD was in the range of 5.25 mg/L and 208.25 mg/L and showed significant and exponential decrease along the subsequent sampling sites (ANOVA, $F = 2977$, $p < 0.05$). The mean concentration of COD at the outlet were below the Ethiopian effluent allowable discharge limits into water courses (COD = 100 mg/L) (EEPA/UNIDO, 2003), however higher mean values than the limit were measured at S1 and S2. All the nutrients (SRP, TP, NH_3-N, $N0_2$-N, NO_3-N and TN) showed high variations in the sampling sites. The concentrations of SRP ranged from 0.30 to 3.00 mg/L with the highest mean value at S2 and the lowest value at S5 and the difference was significant (ANOVA, $F = 6295$, $P < 0.05$) at each sampling site (Table 4.1). Similarly, the mean concentration of TP decreased significantly (ANOVA, $F = 54.88$, $p < 0.05$, ANOVA) between all subsequent sampling sites except between S1 and S2 and the mean concentration ranged from 0.14 to 2.96 mg/L in the wetland.

This study also showed the mean concentration of NH_3-N ranged between 0.28 to 1.00 mg/L with the highest mean value measured at S3 and the least at S5 and the value was significantly lower at S5 (outlet) (ANOVA, $F = 29.66$, $P < 0.05$). The mean concentration of NO_2-N decreased significantly (ANOVA, $F = 63929$, $p< 0.05$) between all subsequent sampling sites from the inlet to the outlet and the mean values ranged from less than 0.01 mg/L (at S5) to 0.15 mg/L (at S1). Moreover, NO_3-N mean concentration ranged from 0.01 to 0.22 mg/L with the highest mean value at S1(inlet) and the lowest value at S5 and the mean concentration significantly decreased at S5 (outlet) (ANOVA, $F = 49.10$, $P < 0.05$); the mean concentration of TN ranged from 0.34 to 37.04 mg/L in the wetland. TN decreased significantly (ANOVA, $F = 12818$, $p < 0.05$) between all subsequent sampling sites from the inlet to the outlet except between S1 (inlet) and S2.

4.3.2. Wastewater flow pattern

Electrical Conductivity (EC) was used as a good natural tracer for wastewater in this study (Kansiime and Nalubega, 1999). The results of EC value measured in each sampling sites indicated in Table 4.1 and the highest wastewater flows into S3 and decreasing to the lower sides of the wetland (outlet site) (Figure 4.3) as the highest conductivity, (1195.00 µs/cm) and the lowest, (553.200 μs/cm), was measured on S3 and S5 respectively. EC at the inlet ranged from 407.00 – 1368.00 μs/cm, whereas at the outlet conductivity ranged from 54.40 – 1052.00 μs/cm However, the variation was not significant ($p > 0.05$, ANOVA) along the sampling sites.

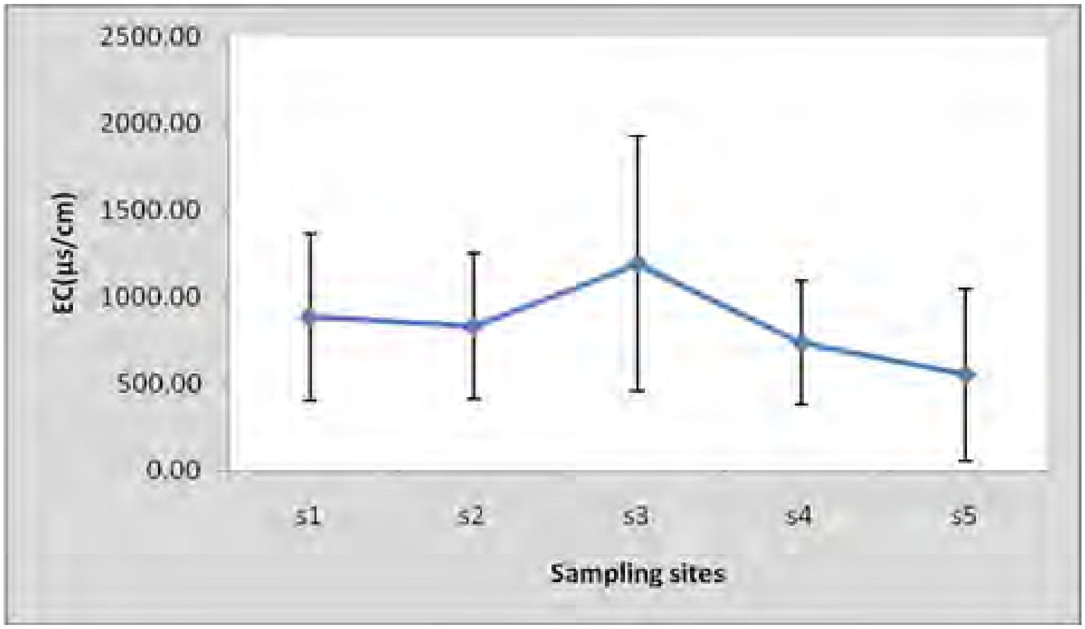


Figure 4.3 Wastewater flow pattern using electrical conductivity as a natural tracer.

4.3.3. Sediment nutrient content

The phosphorus (SRP, TP) and Nitrogen (NO_3-N, TN) concentrations in sediment samples is presented in Table 4.2.The mean concentrations for TP was varied 116.50 to 666.50, for SRP from 174.50 to 249.00, for NO_3-N from 14.50 to 57.00 and for TN 422.00 to 11956.00 mg/kg in which the highest concentrations were in S1 (inlet) and the lowest were in S5 (outlet) for each nutrient species. The highest magnitude of concentration was observed for TN.

Table 4.2 Mean sediment nutrient concentration in Yitamot natural wetland (Mean ± S.D) (mg/kg), (n = 4)

Site	TP (mg/kg)	SRP(mg/kg)	NO_3-N(mg/kg)	TN(mg/kg)
S1	666.50 [a] ± 29.50	249.00 [c] ± 51.00	57.00 [d] ± 3.00	11956.00 [f] ± 4704.00
S2	584.50 [a] ± 14.50	248.50 [c] ± 7.50	29.50 ± 0.50	9464.00 [f] ± 5180.00
S3	523.00 ± 9.00	217.50 [c] ± 22.50	52.50 [d] ± 0.50	2744.00 [f] ± 2268.00
S4	204.50 [b] ± 19.50	198.00 [c] ±13.00	19.00 [e] ± 0.00	644.00 [f] ± 140.00
S5	116.50 [b] ±67.50	174.50 [c] ±7.50	14.50 [e] ± 0.50	422.00 [f] ± 1.00

S.D means Standard deviation

Values followed by the same letters in a column are not significantly different at P < 0 .05

Statistical analysis showed significanly (ANOVA, F = 48.58, 191.73, $p < 0.05$) higher concentration of sediment nutrients (TP and nitrate, respectively) at the inlet than that of outlet sediment samples and there were a decreasing trend of SRP and TN as well along the sampling points from the inlet to the outlet,though the decrease was not significant ($p > 0.05$) implying the concentrations of nutrients showed a decrease trend from the inlet to the outlet sampling site (Figure 4.4).

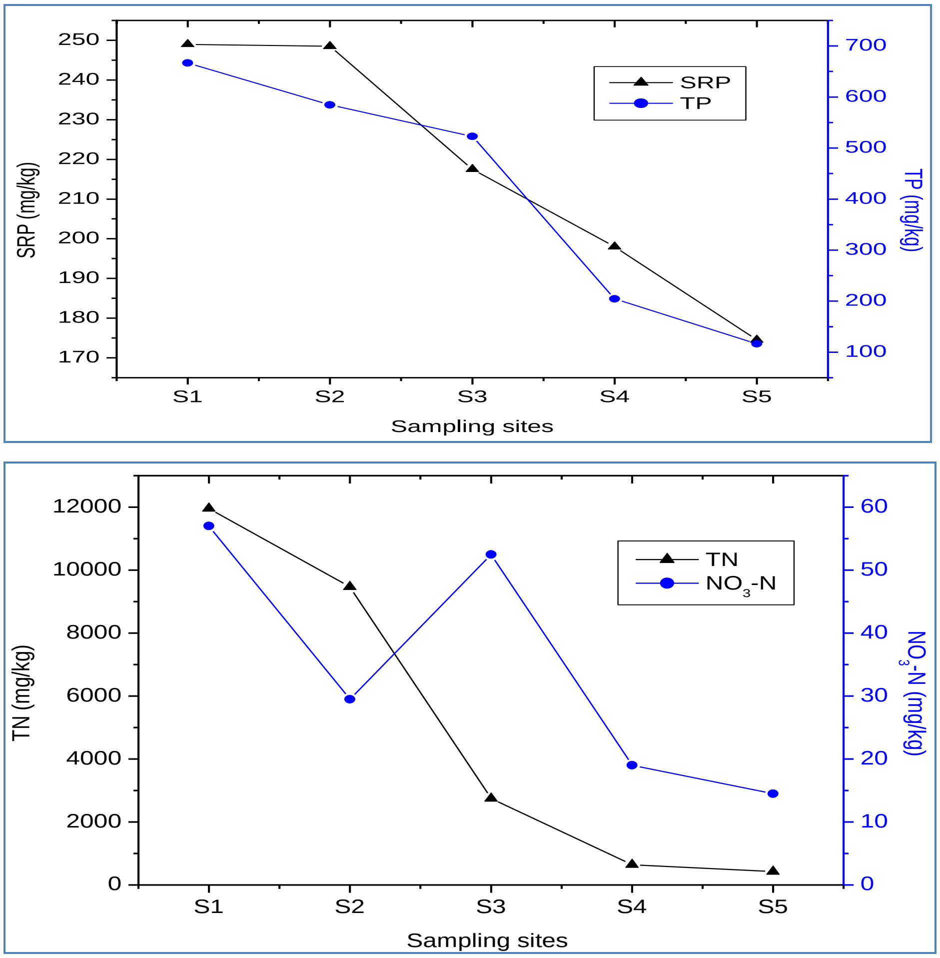


Figure 4.4 Sediment nutrient concentrations along sampling sites in Yitamot natural wetland

4.3.4 Nutrient load into and out of the wetland

Nutrient loads were higher at the inlet than the outlet of the wetland (Table 4.3). The loading was directly proportional to the discharge obtained at the inlet and outlet of the wetland

Table 4.3 Average nutrient concentrations and loads in Yitamot natural wetland

	Concentration in (mg/L)		Load (kg/Day)		
variable	inlet	outlet	inlet	outlet	%Nutrient retention
SRP	2.784	0.295	9.020	0.744	91.749
TP	2.963	0.142	9.600	0.358	96.268
NH_3-N	0.990	0.280	3.208	0.706	77.977
NO_2-N	0.150	0.000	0.486	0.000	99.948
NO_3-N	0.220	0.010	0.713	0.025	96.461
TN	37.040	0.340	120.010	0.858	99.285

Mean discharge values during the study period were 0.038 m^3/s for the inlet and 0.029 m^3/s for the outlet.

4.3.5 Dominant plant aboveground biomass and tissue nutrient content

4.3.5.1 Aboveground biomass production

Cyperus papyrus, Cyperus digitatus, Echinochloa stagnina, Hydrocotyle ranunculoides, Phragmites karka and *Sphaeranthus suaveolens w*ere found to be dominant in terms of aboveground biomass on the sites where they occurred. The largest total aboveground biomass in the wetland was contributed by *Cyperus papyrus* and *Cyperus digitatus* followed by *Phragmites karka*, *Sphaeranthus suaveolens, Hydrocotyle ranunculoides* and *Echinochloa stagnina* (Figure 4.5).

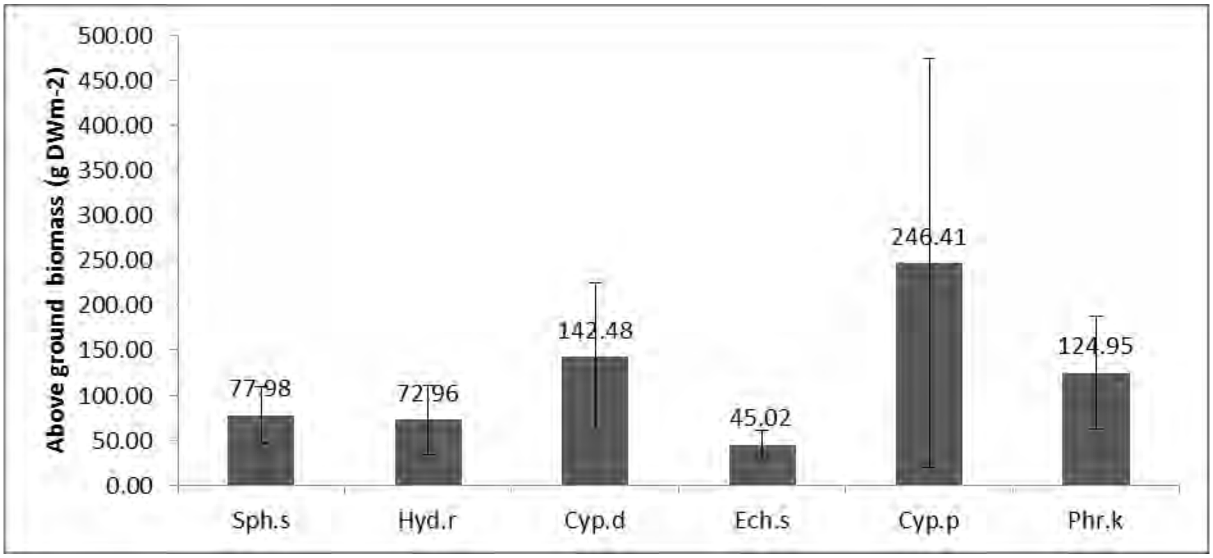


Figure 4.5 Total aboveground biomass contributions by dominant macrophyte species in Yitamot natural wetland. Error bars indicate standard error of mean. (Abbreviations: *Cyp.p* - *Cyperus papyrus, Cyp.d* - *Cyperus digitatus*, *Phr.k* - *Phragmites karka*, *Sph.s - Sphaeranthus suaveolens, Hyd.r* - *Hydrocotyle ranunculoides, Ech.s* - *Echinochloa stagnina)*

All species are not found in each sampling site; the above ground biomass of each macrophyte in the five sampling sites is summarized in Table 4.4.

Table 4.4 Aboveground biomass of dominant macrophytes in the five sampling sites in Yitamot natural wetland (Mean± S.D) (g DW m^{-2}), (n = 4)

Site	*Spher.s*	*Ech.s*	*Cyp.p*	*Phr.k*	*Hyd.r*	*Cyp.d*
S1	88.31±44.60	20.51±0.73	-	-	14.93±2.61	38.10±5.68
S2	103.07±50.29	36.73±24.39	-	19.45±0.53	36.33±18.17	-
S3	62.40±31.20	96.27±3.86	-	41.27±8.71	129.57±25.12	288.83±142.75
S4	136.14±47.70	37.53±6.32	270.38±51.27	-	183.96±12.00	94.44±29.01
S5	-	34.07±17.04	961.68±480.84	529.03±39.74	-	291.05±147.19

S.D = Standard deviation

The statistical test results of this study showed significant variations in aboveground biomass were observed in *Hydrocotyle ranunculoides, Echinochloa stagnina* and *Phragmites karka.*

The aboveground biomass of *Hydrocotyle ranunculoides* was significantly (ANOVA, F = 28.74, P < 0.05) increased along all sampling sites from the inlet to the outlet except between S1 and S2. In *Echinochloa stagnina* significant variations (ANOVA, F = 4.62, P < 0.05)were observed between S1 and S3, S2 and S3, S3 and S4, S3 and S5 showing an increasing trend along the sampling sites from the inlet to the outlet. Significant variations(ANOVA, F = 3.93, P < 0.05) was also observed in aboveground biomass of *Phragmites karka* between sampling S2 and S5, S3 and S5 where the highest biomass was in sampling S5 (outlet).

4.3.5.2 Aboveground Tissue Nutrient Content

Aboveground plant tissue nutrient content (%TN, %TP) for the dominant macrophytes of Yitamot wetland is shown in Table 4.5. The mean %TN in the aboveground plant was ranged from 3.70 to 12.13 % g DW where the highest percentage was measured in the tissue of *Sphaeranthus suaveolens* whereas the lowest was in *Hydrocotyle ranunculoides (*Table 4.5). The %TN content in *Sphaeranthus suaveolens* showed significantly lower values at sampling 4 than at the other sampling sites (ANOVA, F = 5.26, P < 0.05). In *Phragmites karka* also the % TN was significantly lower at S5 (outlet) than at S2 and S3 (ANOVA, F = 274.28, P < 0.05). A decrease in %TN was also observed in the rest species studied though the decrease was not significant (ANOVA, P > 0.05).

Table 4.5 Aboveground plant tissue TN and TP content of dominant macrophytes of Yitamot wetland (%) (Mean ±S.D), (n=4)

Site	Spher.s		Ech.s		Cyp.p		Phr.k		Hyd.r		Cyp.d	
	%TN	%TP	*%TN*	%TP	*%TN*	%TP	*%TN*	%TP	*%TN*	%TP	*%TN*	%TP
S1	12.13 ± 4.43	0.97± 0.02	8.90 ± 0.70	0.82 ± 0.04	-	-	-	-	8.57 ± 0.55	1.20 ± 0.07	8.35± 0.25	0.81± 0.01
S2	11.55 ± 1.85	0.92± 0.20	8.60 ± 0.50	0.89 ± 0.01	-	-	8.99 ± 0.11	0.96 ± 0.04	7.58 ± 0.02	1.69 ± 0.02	-	-
S3	11.40 ± 0.50	1.43± 0.17	10.25± 1.65	0.83 ± 0.04	-	-	9.50 ± 0.30	0.84 ± 0.02	8.12 ± 4.02	1.42 ± 0.06	7.14 ±1.21	0.79± 0.00
S4	10.10 ± *1.20*	0.95± 0.25	8.85± 0.95	0.83 ± 0.01	6.99 ± 0.45	0.83± 0.07	-	-	3.70 ± 0.42	0.94 ± 0.05	6.80± 0.10	0.60± 0.07
S5	-	-	6.58± 2.61	0.70 ± 0.07	6.38 ± 1.04	0.30± 0.13	6.97± 0.56	0.28 ± 0.02	-	-	7.40 ±0.50	0.26± 0.05

S.D = Standard deviation

The mean %TP in the aboveground plant was ranged from 0.26 - to 1.69 % g DW where the highest percentage was measured in the tissue of *Hydrocotyle ranunculoides where*as the lowest was in *Cyperus digitatus (*Table 4.5). The %TP content in *Hydrocotyle ranunculoides also* showed significant decrease values along the sampling site from the inlet to the outlet sampling sites (ANOVA, F = 174.41, P < 0.05). Significantly lower % TP contents were also measured at S5 (outlet) in *Cyperus digitatus*(ANOVA, F = 77.25, P < 0.05)*, Cyperus papyrus* (ANOVA, F = 32.96, P < 0.05)and *Echinochloa stagnina* (ANOVA, F = 3.122, P < 0.05).

4.3.6 Metal concentration in water, sediment, and plant tissue

4.3.6.1 Metal concentration in water

The mean concentrations of metals in the wetland surface water are shown in Figure 4.6 and the related information is summarized in Table 4.6. Based on the mean concentrations, the target elements in the surface water of Yitamot wetland exhibited the following descending order: Ca > Na > Fe > Mg > K > Zn > Cu > As > Cr > Mn and the mean concentrations of Pb and Cd were not detected in all sampling sites.

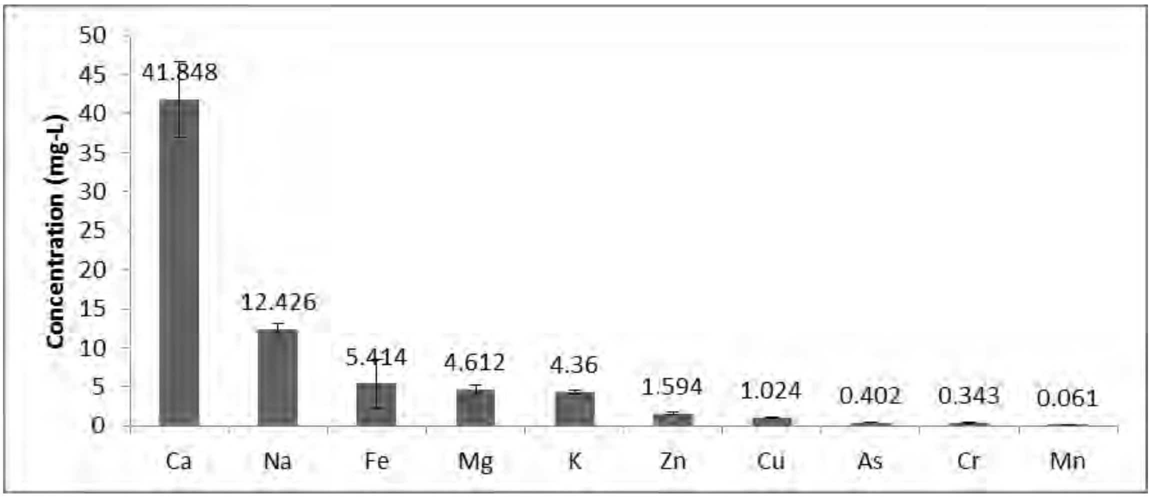


Figure 4.6 means of metal concentration in Yitamot natural wetland water from the five sampling sites. Error bars indicate standard error of mean

The mean concentrations of metals were variable and some of them did not show significant variation among sampling sites (ANOVA, P > 0.05) for example the mean concentrations of Ca and Mg was increased at the outlet (S5) but the variation was not significant. However, the mean concentrations of Fe, Mn and Zn in S3 were significantly higher than the other sampling sites (ANOVA, P < 0.05) and the mean concentration of Mn was significantly lower at the outlet sampling site.

Table 4.6 Concentration of metals in water sample of Yitamot natural wetland at the five sampling sites (mg/L), (n = 4)

Metal element	Metal concentration in sampling sites (mg/L)						USEPA 1986
	S1	S2	S3	S4	S5	Mean± S.D	
K	4.76	3.40	4.20	4.95	4.48	4.360± 0.278	
Na	14.91	10.44	10.75	13.88	12.15	12.426 ± 0.722	
Ca	46.26	27.32	50.18	32.50	52.98	41.848 ± 4.840	
Mg	4.20	2.48	4.51	5.96	5.90	4.612 ± 0.54	
Fe	0.81	1.03	23.82	1.00	0.41	5.414 ± 3.071	
Mn	0.11	0.05	0.17	0.02	un	0.061 ± 0.028	
Cu	1.20	1.08	1.12	1.12	0.59	1.024± 0.124	0.007
Zn	1.69	1.13	2.33	1.35	1.47	1.594± 0.172	
Pb	nd	nd	nd	nd	nd	nd	0.002
Cr	0.43	0.36	0.42	0.36	0.15	0.343± 0.048	0.011
Cd	nd	nd	nd	nd	nd	nd	0.0007
As	0.40	0.41	0.44	0.38	0.38	0.402 ± 0.012	

nd = not detected
S.D= Standard deviation

4.3.6.2 Metal concentration in the sediment of Yitamot natural wetland

The mean concentrations of metals and related information in the sediment of the wetland are summarized in Table 4.7. Based on the mean concentrations, the target elements in the surface sediments of the Yitamot wetland exhibited the following descending order: Fe > K > Na > Ca > Mg > Mn > Cr > Zn > Cu > As > Pb > Cd.

Table 4.7 Concentration of metals in sediment of Yitamot natural wetland (mg/ Kg) (n = 4)

	Metal concentration in sampling sites (mg/ Kg)					
Metal	S1	S2	S3	S4	S5	Mean± S.D
K	12356	14721	7674	2518	3827	8219.2±4721.8
Na	10099	10360	5820	2915	7382	7315.3±2779.3
Ca	5902	6934	5586	2481	5753	5331.1±1500.8
Mg	7571	4044	6450	4591	2843	5100±1696.9
Fe	416556	414512	373813	323324	507679	407176.7±60641.4
Mn	7573	5880	2887	1620	7098	5011.4±2353.1
Cu	603	650	690	645	546	626.7±48.9
Zn	1880	2285	1751	1092	1602	1721.9±388.3
Pb	35	21	32	38	87	42.6±22.9
Cr	2864	2820	1673	1284	1247	1977.6±721.5
Cd	7	7	7	4	5	6±1.3
As	75	111	94	153	nd	73±28.8

nd = not detected
S.D= Standard deviation

The results of statistical analysis among the five sampling sites showed the mean concentrations of K, As, Cd and Cr were significantly lower values in the outlet than in the inlet (ANOVA, $P < 0.05$). However, the mean concentrations of Fe and Pb were significantly higher in the outlet than the inlet sampling sites (ANOVA, $P < 0.05$). Whereas mean concentrations of Ca, Na, Mn and Zn were significantly varied at the middle sampling sites but did not show significant variation between the inlet and the outlet sampling site (ANOVA, $P > 0.05$). Mean concentrations of Cu and Mg did not show any significant variation among sites.

4.3.6.3 Metal concentration in plant tissue

The results of this study for the mean metal concentration in each macrophyte species studied are presented in Table 4.8. The concentration of K, Fe, Cu, Zn, Cr and As ranged 58.73 to 1159.33 kg/L, 2.01 to 213.03 kg/L, 0.06 to 0.85 kg /L, 0.22 to 4.22 kg/L, 0.03 to 0.81 kg/L and 0.08 to 0.94 kg/L respectively where The highest concentration was observed in *Sphaeranthus suaveolens* and the lowest concentration was observed in *Cyperus papyrus.* Na and Mn was ranged from 4.16 to 299.62 kg/L and 2.91 to 7.44 kg/L respectively where the highest concentration was observed in *Sphaeranthus suaveolens* and the lowest concentration was observed in *Phragmites karka*. The concentration of Ca ranges from 11.65 to 122.49 kg/L where the highest on centration was observed in *Hydrocotyle ranunculoides* and the lowest concentration was observed in *Cyperus papyrus* and Mg in the plant tissue was ranged between 1.84 to 30.33 kg/L where the highest concentration was observed in *Echinochloa stagnina* and the lowest concentration was observed in *Cyperus papyrus.*

Table 4.8 Mean metal concentration in above ground plant tissue (Mean± S.D) (mg/Kg) (n= 4)

Metal	*Spher.s*	*Hyd.r*	*Cyp.d*	*Ech. S*	*Cyp.p*	*Phr.k*
K	1159.33±323.14	869.31±256.56	243.12±64.96	453.58±55.11	58.73±75.87	119.57±33.44
Na	299.62± 102.09	161.07±50.14	33.91±16.57	62.65±19.61	10.92±16.46	4.16±1.41
Ca	111.02± 28.33	122.49±24.70	62.91±22.62	87.01±12.31	11.65±15.29	27.05±8.41
Mg	17.56± 4.22	20.73±5.13	11.77±4.17	30.33±11.60	1.84±2.48	4.28±1.20
Fe	213.03± 96.11	70.93±24.20	45.0±519.30	83.00±13.66	2.01±2.84	2.41±0.69
Mn	7.44± 2.62	5.62±1.69	6.47±2.05	7.11±1.07	3.98±5.25	2.91±1.09
Cu	0.85± 0.22	0.62±0.13	0.25±0.09	0.68±0.10	0.06±0.08	0.31±0.09

Zn	4.22± 1.34	2.45±0.66	1.78±0.94	3.06±0.74	0.22±0.30	0.90±0.31
Cr	0.81± 0.38	0.22±0.05	0.14±0.07	0.38±0.08	0.03±0.04	0.14±0.04
As	0.94± 0.35	0.40±0.19	0.15±0.03	0.50±0.25	0.08±0.11	0.29±0.10

S.D= Standard deviation

Each of the macrophytes have varied tendency of accumulation different metals. Most of the metals are in a highest concentration in *Sphaeranthus suaveolens* (Table 4. 9). The highest accumulated metals in the tissue of all macrophytes studied were K, Na, Ca, Mg and Fe in a consecutive order. Mn, Cu, Zn, Cr and As were found in a small concentration. However, the concentrations of Pb and Cd in each species were very low and not detected.

The mean concentrations of metals in each species along sampling sites from the inlet to the outlet were not showed regular trend. Statistical test, Tukey multiple comparisons showed the mean concentrations of K, Na, Fe, Mn, Cu, Zn, As and Cr were significantly higher ($P < 0.05$) in aboveground tissue of *Sphaeranthus suaveolens* growing in sampling site S2 and S3. Similarly, concentrations of K, Na, Mg, As and Zn showed a significant increase in aboveground tissue of *Hydrocotyle ranunculoides* growing in S2 and S3. However, in all the species studied, all the metal concentrations in the aboveground tissue of macrophytes were significantly (ANOVA, $P < 0.05$) lowered at the last sample site from the inlet to the outlet where the species is found indicating these macrophytes are contributing for the retention of metals in the wetland.

4.3.7 Nutrient and pollutant removal efficiency of Yitamot natural wetland

The pollutant removal efficiency (PRE`s) of Yitamot natural wetland was evaluated with respect to the following pollutants: TSS, organic matter (in terms of COD), nutrients and metal elements in both influent and effluent concentrations and calculated and expressed as percentage as shown in Table 4.9

Significant removal effect was observed in most pollutants like TSS, COD, all the nutrients analyzed, metals like Mn, Cr and Cu (>50%). The wetland showed the most removal effect (> 99%) on nutrients like NO_2-N and TN and metals like Mn. Negative percentages of removal was observed on some metals like Mg (-40.41%) and Ca (-14%).

Table 4.9 Percentage of pollutant removal efficiency using Yitamot natural wetland

Pollutants (mg/L)	Inlet	Outlet	Removal efficiency (%)
TSS	0.41	0.04	90.24
COD	207	5.25	97.46
SRP	2.78	0.3	89.21
TP	2.96	0.14	95.27
NH_3-N	0.99	0.28	71.72
NO_2-N	0.15	nd	>99.99
NO_3-N	0.22	0.01	95.45
TN	37.04	0.34	99.08
K	4.76	4.48	5.88
Na	14.91	12.15	18.55
Ca	46.26	52.98	-14.53
Mg	4.20	5.90	-40.41

Fe	0.81	0.41	48.93
Mn	0.11	nd	>99.99
Cu	1.20	0.59	50.48
Zn	1.69	1.47	12.88
Cr	0.43	0.15	64.59
As	0.40	0.38	5.56

4.4 Discussion

4.4.1 Water quality variables

4.4.1.1 Electrical conductivity and Wastewater flow pattern

The dynamics of water movements within a wetland has a significant influence on the efficiency of the pollutant removal interactions between sediments, microorganisms, plants and the wastewater (Kadlec and Wallace 2009). According to the study of Loiselle *et al.* (2006) a significantly higher P removal was observed by the wetland they studied, and the most likely explanation they reported was the improved distribution efficiency due to the installation of a distribution pipe to spread the wastewater at the inlet.

EC was high on the middle sites of the wetland especially at S3 indicating that the wastewater is concentrated on the middle site and decreasing to the outlet sites of the wetland. Such high conductivity value at S3 is due to the high content of organic matter, ammonium ions and other salts in domestic wastewater from the university and urban runoff. The higher EC values in S3 than the inlet (S1) possibly can also be explained by the sloping nature of the wetland towards the site. The conductivity of most freshwaters ranges from 10 to 1,000 µS/cm but may exceed 1,000 µS cm-1, especially in polluted waters, or those receiving large quantities of land run-off (UNESCO/WHO/UNEP, 1996)。 The measurement of this study showed the mean EC value for the wetland was under this range. The conductivity results along the transects of the study site decreased towards the outlet of the wetland (Figure 4.3), similar decreasing trends from a point of discharge to the edge of the wetland were observed in the Nakivubo wetland in the study of Kansiime and Nalubega (1999), who interpreted that as reflecting the flow paths of the wastewater. The nonexistence of significant variations in EC values along the sampling sites S1, S2, S3, and S4 can indicate better distribution of the wastewater. However, it is obvious that the cycling of organic matter and nutrients in the wetland ecosystem itself also contribute ions that are included in the conductivity values, which confounds the interpretation of the observed electrical conductivity. Ammonium-N (Table 4.1) showed a similar trend to electrical conductivity whereby high values were recorded at the S3. Similar relationships between wastewater patterns and nutrient concentrations like ammonium-N were reported in the study of Kansiime *et al.* (2003) and Kanyiginya *et al.* (2010).

The pH value in this study ranged from 5.70 to 8.46 and it is revealed that the pH value at the inlet was slightly acidic which was probably due to the untreated effluent from Bahir Dar University containing organic waste which is discharged into the wetland close to this point. The pH can be decreased by the dissolution of carbondioxide which can be released during bacterial break down of organic wastes (Matovu, 2010). However as the water passes through each sampling stations the pH value showed progressive increased and it lied under the allowable limit (neutral) at the outlet S5.

The mean values of temperature recorded were only slight different among sampling sites and was under the allowable limit, indicating the absence of any thermal pollution, the mean temperature was in the range of 25.15 to 29.35 ^{0}c with the highest and the lowest value recorded in S3 and in S1, respectively. The increase in water temperature results in increase in the rate of chemical reactions together with the evaporation and volatilization of substances from the water. Increased temperature also decreases the solubility of gases in water, such as O_2, CO_2, N_2, CH_4 and others. 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) It is quite interesting to note that the DO is very low (less than 3 mg/L in the first three sampling sites). This may be explained as a result of anthropogenic activities such as open dumping of waste materials into the wetlands which can increase the biological oxygen demand for depletion of DO (Melaku Getachew *et al*., 2012). Concentration of DO below 5 mg/L may adversely affect the functioning and survival of biological communities and below 2 mg/L may also lead to the death of most fish (Chapman and Kimstach, 1992). However, the mean concentrations of dissolved oxygen and TSS also showed progressive improvement from the inlet to the outlet sampling sites.

The results of the study showed the highest mean value of turbidity in the wetland was measured at the inlet and the least value at the outlet of the wetland (Table 4.1). The high value of NTU at inlet is probably due to the presence organic particulate matter in the effluents from the University. Turbidity in natural waters is commonly caused by the presence of clay, silt, organic matter, algae and other microorganisms (Paul, 2011). The values of turbidity range from 1 to 1,000 NTU and levels can be increased by the presence of organic matter pollution, other effluents, or run-off with high suspended matter content (UNESCO/WHO/UNEP, 1996). The type and concentration of suspended matter controls the turbidity and transparency of the water.

A progressive significant decrease in the mean values of both TSS and turbidity were observed along the transect form the inlet to the outlet, showing the wetland is contributing to improve the water quality.

The influent water (S1) and S2 had COD above the Ethiopian effluent allowable discharge limits (100 mg/l) into water courses (EEPA/UNIDO, 2003). The high concentrations of COD above the standard limit at S1 and S2 indicate a heavy load of organic and inorganic pollution that requires more oxygen to oxidize under increased thermal conditions. The mean value of COD in this study, although it was greater in the inlet sampling site than the Ethiopian effluent allowable discharge limits (100 mg/l) into water courses, showed a significant and exponential decrease along the subsequent sampling sites of (S2, S3, S4 and S5) and at the outlet the value fell under the limit mentioned above, indicating that the wetland and its components contributed to water quality improvement.

4.4.1.2 Water nutrient content

The nutrients (SRP, TP, NH_3-N, NO_2-N, NO_3-N and TN) in the surface water also showed a progressive significant decrease between the inlet (S1) and outlet (S5) concentrations and even among subsequent sampling sites. TP decreased significantly ($p < 0.05$, ANOVA) between all subsequent sampling sites along the transect from the inlet to the outlet. However, the mean concentration of SRP was higher at the S2 than the S1; this is possibly due to the release of soluble phosphorus when conditions become anaerobic. The DO concentration at site S2 is very low; under these reduced conditions Fe^{3+} in insoluble ferric oxides may be reduced to soluble Fe^{2+}. Any phosphate ion bound to the ferric oxide may be release back into solution as it dissolves. Gosselink and Turner (1978) and Kramer *et al.* (1972) report that oxygen concentrations of less than 2.0 mg/l result in the release of phosphorus from sediments.

Kim, *et al*. (2004) also reported that Phosphorus release rate is 2.5 times greater under anaerobic conditions than aerobic condition. The mean concentrations of TP in all the sampling sites were higher than the maximum limit (0.05 mg/L) recommended by US EPA (1986) for streams discharged in to reservoirs.

The results of the study also indicated that the range of concentration for NH_3-N in all sampling site were higher and the ranges were higher than ranges of maximum allowable concentration ranges set (0.005 to 0.025 mg/L) for fisheries and aquatic life set by Commission of European Communities (CEC, 1978). Higher concentrations could be an indication of organic pollution such as from domestic sewage, and fertilizer run-off (UNESCO/WHO/UNEP, 1996). NH_3-N was highest at the S3 which might be because of higher temperature there; thus organic nitrogen was being converted to ammonia. However it was under the ranges (1.37 to 2.2 mg/L) set for the same purpose by environment Canada (Environment Canada, 1987). Unpolluted waters contain small amounts of ammonia and ammonia compounds, usually < 0.1 mg/L as nitrogen (UNESCO/WHO/UNEP, 1996). The mean concentration of nitrate increased at S3. This could be due to the site is positioned sloping that lets the inlet of agricultural drainage water in which the dominant nitrogen fraction could be nitrate (Bastviken, 2006). Total nitrogen was also at significantly higher concentration in S3 than in the inflow (S1) (Table 4.1). This could be due to the nitrogen cycling taking place in the wetland, where nutrients are produced by the decaying organic matter and the nitrogen enrichment from the agricultural drainage water. 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). Hence this site was acting as source instead of sink. High TN in the wetland can also be due to biological nitrogen fixation.

The mean value of NO_2-N at the outlet sampling site in this study was under the ranges of maximum allowable concentration ranges (0.01 to 0.03 mg/L) for fisheries and aquatic life set by Commission of European Communities (CEC, 1978) and it was also below the standard value (1 mg/L) set by USEPA, 1986 as the maximum contaminant level (MCL) for regulated public water systems. The mean concentrations of NO_3-N in all sampling site were lower than the concentration for the Ethiopian effluent allowable discharge limits into controlled water courses (20 mg/L as NO_3) (EEPA/UNIDO, 2003) and the standard value (10 mg/L) set by US EPA ,1986 as the maximum contaminant level (MCL) regulated public water systems.

Concentrations of all the nutrients studied were highest at the inlet (S1) and decreased to the outlet registering the lowest concentrations at the outlet. The trend also proves that there was retention of nutrients by the wetland and this decrease may be attributed to uptake by plants and sediment adsorption (Kanyiginya *et al*., 2010). Other studies have also reported nutrient assimilation in treatment wetlands that involve in significant reductions in nitrate, ammonium total nitrogen and phosphate concentrations downstream from source input and improved overall surface water quality (Brantley *et al*. 2008; Blahnik and Day 2000; Mallin *et al*., 2002; Parnell, 2011

4.4.2 Sediment nutrient content

High sediment nutrients (Nitrate, TN, SRP and TP) in each sampling sites (Table 4.2) suggest these storage compartments are providing effective sinks to improve water quality. A similar result has been reported in a subtropical marsh influenced by agricultural runoff which proved to be efficient nutrient sink as a result of high accretion rates and sediment nutrient re-mineralization (Soto-Jimenez *et al*. 2003) (Parnell, 2011). In addition, all the concentrations of nutrients showed significant decreasing trend from the inlet to the outlet sampling sites (Figure 4.4) except nitrate where the concentration was unexpecterdly increased at S3.The probable reason for the nitrate increament in S3 could be the excess availability of NH_3-N that can be readily converted to nitrate in the sediment and also the inlet of agricultural drainage water into the site which could be rich in nitrate.

Some studies showed sediment is an important storage compartment for nutrients through different processes. Phosphorus adsorbs to sediment in a process of rapid exchanges between pore water and sediment; binding to the surface of a sediment particle (Dunne and Reddy 2005). Organic forms of phosphorus readily absorb to sediments composed of clay and organic matter (Dunne and Reddy 2005), effectively immobilizing the nutrient. Sediment is also an important sink for nitrogen, subsequently providing a sink for nutrients and helping to improve water quality in impaired waterways (Parnell, 2011).

4.4.3 Nutrient load and retention in Yitamot natural wetland

Wetlands showing nutrient retention are defined as those where the nutrient loading of waters draining from the wetland less than the nutrient loading of waters is entering the wetlands (Fisher and Acreman, 2004). Nutrient loads in this study were higher at the inlet than the outlet of the wetland indicating retention (Table 4.3). The loading was directly proportional to the discharge obtained at the inlet and outlet of the wetland and the relationship can be attributed to the numerous organic matters from the wastewater that was being discharged into the wetland. This is in agreement with

Kanyiginya *et al.*, 2010 who reported a direct proportionality of discharge and nutrient loading in a natural wetland studied and attributed this relationship to the numerous organic matters that was being washed away from the catchment by runoff into the wetland. The wetland storage compartments investigated in Yitamot wetland (water, sediment and plants) were removing a sufficient amount of nutrients to effectively improve overall water quality downstream from sources of input. Some other studies have also reported nutrient assimilation in treatment wetlands that improved overall surface water quality (Brantley *et al*. 2008; Mallin *et al*., 2002). In this study the highest nutrient retention was observed in nitrogen species; 99.85% for NO_2-N followed by 99.29% for TN. This result is supported by the studies of Nichols (1983) that state wetlands are generally thought to be more efficient at reducing N loadings than P. Similar thoughts are also described by Vanek (1991), as N which can be lost to the atmosphere from the wetland via denitrification, p cannot be lost from the system. However, the result of this study is in contrary to the reports for 57 wetlands reviewed by Fisher and Acreman (2004) that describe a slightly smaller proportion of wetlands exhibited N-retention than P-retention.

In spite of rates of nutrient retention remaining high, the nutrient loading rates in Yitamot natural wetland exceeded the proposed critical loading rates of nitrogen (25 kg ha^{-1} y^{-1}) and phosphorous (10 kg ha^{-1} y^{-1}) for wetlands (Sánchez-Carrillo *et al*., 2011) which can enhance change in species composition of the wetland. Discharge of large storm event may shock the receiving water body many times greater than the small but steady sanitary effluent (Lee and Bang, 2000). Similar reports has been done on wetlands of forested riparian zones in the Netherlands, many of them lost their original plant diversity decades ago but continue to retain high quantities of nitrate (Verhoeven *et al*., 20006).

4.4.4 Macrophyte biomass and tissue nutrient accumulation

4.4.4.1. Macrophyte above ground biomass

Wetland plant species with high growth rates, high biomass accumulation and high tissue nutrient content would have higher potential for nutrient removal. These species provide sufficient storage compartment for storing excess nutrient (Thomaz *et al*., 2007). Among the six dominant macrophyte species studied, the highest mean aboveground biomass was measured in *Cyperus papyrus* and followed the order: *Cyperus papyrus* > *Cyperus digitatus* > *Phragmites karka* > *Sphaeranthus suaveolens* > *Hydrocotyle ranunculoides* > *Echinochloa stagnina.* As explained in chapter 3*, Cyperus papyrus* unlike the other species, has its large proportion of its biomass allocated to the aerial organs. Mnaya *et al*. (2007) and Terer *et al.* (2012) stated, being a C4 plant, papyrus can concentrate CO_2 near the site of carboxylation (the enzyme Rubisco) and thus attains lower CO_2 compensation points and minimal photorespiration which in turn allows higher net photosynthesis contributing to its high biomass production.

On the other hand, the lowest aboveground biomass of *Echinochloa Stagnina* may be attributed partially to the over grazing by animals in the wetland. All cattle, horses and other animals from different parts of the city and surrounding area are entirely dependent on the wetland for grazing, in addition to drinking specially during dry season (Figure 4.7)

Figure 4.7 Excessive grazing in Yitamot natural wetland (Personal observation)

Hydrocotyle ranunculoides, Echinochloa stagnina and *Phragmites karka* showed significant increasing trend in above ground biomass production along the sampling sites, where the highest measurement was in the outlet sampling site (S5). This suggests that these species provide sufficient storage compartment for storing excess nutrient uptake in the form of biomass and is therefore substantially contributing to water quality improvement. This is in contrary to the results reported by the study of Parnell (2011) in Armand Bayou natural wetland, Texas, where macrophyte species biomass studied showed no significant change or decreased with increasing distance from source input and it was suggested that the species‟ storage compartment is no longer used to storing excess nutrient uptake in the form of biomass.

4.4.4.2 Plant tissue nutrient accumulation

A decrease in both %TN and %TP content in all the species at the sampling sites to the outlet was observed. On average macrophyte vegetation under the high influence of wastewater (S1) had higher nutrient content (% TN and % TP) in the above ground biomass than those less affected (sampling sites to the outlet). Similar results were reported in the study of Kansiime *et al*., 2003 on *Cyperus papyrus* in a tropical natural wetland Nakivubo swamp, Kampala Uganda**.**

Several studies have emphasized the use of aquatic macrophytes for the treatment of wastewater and the results have demonstrated that there are significant differences among plant species, plant biotope (e.g., submerged, floating leaves, emergent) and plant diversity. The range of aboveground plant tissue nutrient content for almost all of the species studied in this study, *% TN (*3.70 to 12.13 % N g DW*) and %TP (*0.26 - to 1.69 % g DW) were higher than the value for emergent and floating-leaved plants in natural wetlands (1.86 to 3.79% N g DW) and (0.14 to 0.30 % P g DW) (Parnell, 2011)). This suggests these macrophytes have a higher nitrogen and phosphorus retention capacity to contribute to overall water quality improvement. Macrophytes incorporation of N and P accounted for most of the observed nutrient loss from the sediment and water shown from the previous portions of this chapter. The importance of macrophytes as a sink for nutrients were also reported by other studies (Thomaz *et al*., 2007; Zhanglu, 2014)

4.4.5 Metal concentration in water

Pb and Cd were not detected in all sampling sites in this study indicating that wastewater receive little or no effluents contaminated with these metals. The mean concentrations of Ca, Mg, Fe, Mn and Cr in the outlet (S5) of the wetland were under the Ethiopian effluent allowable discharge limits into water courses (150 mg/L, 150 mg/L, 10 mg/L, 5 mg/L, 1 mg/L, respectively) (EEPA/UNIDO, 2003). On the other hand, the mean concentrations of Cu, Zn and As though decreased at the outlet, in all sampling sites were higher than the limits (0.1 mg/L, 1 mg/L, 0.1 mg/L, respectively) (EEPA/UNIDO, 2003). And the mean concentrations of As, Cr, Cu and Fe were also higher than the maximum allowable concentration ranges for fisheries and aquatic life set by Environment Canada (1987) (0.05 mg/L, 0.02 to 0.002 mg/L, 0.002 to 0.004 mg/L, 0.3 mg/L, respectively) which shows that Yitamot natural wetland can be regarded as relatively influenced by anthropogenic pollution. Heavy metals such as cadmium, chromium, copper, iron, nickel, lead and zinc exhibit aquatic toxicity when present above recommended standard in that they can contaminate surface and ground water bodies, soil, plant, aquatic life and man, through bioaccumulation.

In view of the fact that the major use of water in the study area is for cattle drinking, domestic and irrigation, the concentration levels of heavy metals Cu, Zn and As recorded exceeded the limit for aquatic ecosystem, therefore it is of great concern since these metals are extremely toxic and the consumption of water high in these metals could cause adverse health effect to end users. The high concentration of Cu, Zn, As and Zn in the study area could be attributed to the discharge of domestic wastewater containing compounds of these metals. The domestic wastewater discharged into the wetland could be composed of grey water that may consist of: the bath, dishwasher products, personal care products and laundry detergents; which are good sources of these metal elements (Tjandraatmadja *et al*., 2008; Diaper *et al*., 2008). Also dumping of wood treated with chemicals made from salts of these metals (As, Cr, and Cu and Zn) to prevent fungi and pest attack might provide a potential source of chemical spills and drainage from the treated wood around the wetland, this is in support of other findings (eg. Ndiokwere, 2004). The presence of Iron in the study area could be related to run-off from rusted metallic pipes at the scrap metal dump sites.

Variable mean concentrations of metals among sampling sites were also recorded for example, the increased mean concentrations of Ca and Mg at the outlet sampling site (S5) though non-significant, and the significantly high mean concentrations of Fe Mn and Zn in S3 than the inlet sampling site could be attributed to the chemical cycling of the metals. Some metals can exist being binding to some other chemicals at the inlet (S1) but might be detected later because of certain chemical reactions, the bond may break and the metals can be detected at another sampling site (S3 in this case). For example, the high level of Fe recorded at S3 within the study area could be attributed to the higher temperature with increasing pH and low dissolved oxygen content at the site; thus increased microbial decomposition of organic particulate matter, consequently, Iron can easily be released from the particulate organic matter in the environment. The case is also indicated in other studies (Straub *et al*., 2001). The inclination of the wetland towards this sampling site leads the wastewater to accumulate more in the site than the other sampling sites. Also, high levels of copper above the limits could be due to the effluent containing copper metal chips from metal engineering operations involving Cu scrap. Although copper toxicity in humans is rare, aquatic organisms are potentially at risk from Cu exposures (Paul, 2011).

4.4.6 Sediment and plant tissue metal concentrations

With a combined action of adsorption, hydrolysis and co-precipitation, only a small part of free metal ions stay dissolved in water, and a large quantity of them get deposited in the sediments (Gaur *et al*., 2005). As a result the measurement of metals only in the water is not conclusive due to water discharge fluctuations and low resident time (Varol, 2011; Zhuang and Gao, 2014). The metal concentrations obtained from the sediment samples in this study were compared with US EPA Sediment Quality Guideline (MacDonald and Ingersoll, 2002) and mean concentrations of Cd, Cr, Cu, and Zn exceed the probable effect concentration (PEC) which is 3.53 mg/kg, 90 mg/kg, 197 mg/kg and 315 mg/kg, respectively. The mean concentration of As at the inlet (S1) also exceeded the probable effect concentration (PEC) (17 mg/kg); however, its concentration at the outlet sampling site (S5) was low and was not detected. The mean concentration of Pb was under the probable effect concentration (PEC) limits (91.13 mg/kg) (MacDonald and Ingersoll, 2002).

The mean concentrations of K, As, Cd and Cr in this study were significantly lower in the outlet sampling site (S5) than in the inlet sampling site indicating the sediment of this wetland is an efficient compartment to retain these metals. However, the mean concentrations of Fe and Pb were significantly higher in the outlet than the inlet sampling sites. This indicated the sediment in this case is acting as a source rather than a sink for these heavy metals. When environmental conditions change, sediments may transform from the main sink of heavy metals to sources of them for the overlying waters. According to Prica *et al*. (2008), plant-associated factors, including variation in radial oxygen loss (ROL), pH, microbes and organic matter, may induce great fluctuations in metal retention and may cause wetlands to become sources for soluble metals instead of the assumed sinks.

The mean metal concentration in the six macrophyte species studied indicated that different species have different tendency of accumulation of metals in their tissue. The mean concentration of K, Na, Fe, Mn, Cu, Zn, Cr and As were highest in *Sphaeranthus suaveolens.* Ca and Mg were in highest mean concentration in *Hydrocotyle ranunculoides* and *Echinochloa stagnina,* respectively. The concentrations of Pb and Cd in each species were very low and not detected indicating that these macrophytes are no longer used for retention of these metals or these metals are available in a very limited amount in the environment. The later is the most probable reason in case of this study. Metal accumulations by macrophytes can be affected by metal concentrations in water and sediments (Wang *et al*., 2014). In this study, the mean concentrations of Pb and Cd in the water were very low, below detection limit of the instrument (Table 4.6). Higher mean concentrations of K, Na, Fe, Mn, Cu, Zn, As and were observed in aboveground tissue of *Sphaeranthus suaveolens* and K, Na, Mg, As and Zn in aboveground tissue of *Hydrocotyle ranunculoides* growing in S2 and S3(Tukey multiple comparison $P < 0.05$). One of the major factors affecting metal accumulation by aquatic plants is duration of exposure (Wang *et al*., 2014). The flat nature of the wetland at S2 and S3 can help the wastewater to stay for long time and enhance macrophytes to absorb and assimilate (accumulate) metals in their tissue. In all the species studied, all the metal concentrations in the aboveground tissue of macrophytes were significantly (ANOVA, $P < 0.05$) lower at the outlet sampling site (S5) if the species is found, indicating that these macrophytes had the ability to absorb metals and act as biofilter for these elements, thereby contributing for the retention of metals in the wetland.

4.4.7 Nutrient and pollutant removal efficiency of Yitamot natural wetland

In this study, there were evidences that nutrients in the water were removed from the system via assimilation by vegetation, sediment adsorption or pore water retention. All water nutrient concentrations (NH_4-N NO_2-N, NO_3-N, TN, SRP and TP) showed high removal. The most noticeable removal was observed for nitrogen species. Yitamot natural wetland showed better removal efficiency than other tropical wetlands. For example, 99.08% removal efficiency for TN and 95.27% for Tp were observed in this study whereas a study made by Kansiime and Nalubega (1999) in a papyrus zone of the Nakivubo wetland, Uganda, indicated that the removal of TN and TP amounted to 67 % of the load (Asp, 2009). Yitamot natural wetland system also showed high removal efficiency of TSS (90.24%) and organic matter: COD (97.46%), (Table 4.9). The removal success of TSS could be mainly through physical suspension and filtration, whereas the removal success of organic matter could be attributed to microbial activity. Several workers have shown that the roots and structures of macrophytes are able to add an extra filtration component and attachment for microorganisms, to further reduce TSS and COD (Kyambadde *et al*., 2006; Stefanakis and Tsihrintzis, 2012; Herouvim *et al*., 2011).

However, concentrations of all metals in water (except Ca and Mg) though, decreased at the outlet sampling site (S5), there were no significant removal situations for metal elements like K, Na, and heavy metals like Fe, Zn and As. Mn, Cu and Cr were the only metals which the wetland showed significant removal and the other most noticeable features in this study is the negative percentage for Ca (-14%) and Mg(-40%) which represent that the wetland released these metals rather than acting as a sink.

In conclusion, water quality was improved as DO and pH level significantly increased and TSS, Turbidity and COD significantly decreased to optimal level in the outlet and nutrients were significantly reduced and assimilated indicating the wetland is a sink for the wastewater constituent. Nutrients were removed from the system via assimilation by vegetation, sediment adsorption or pore water retention. The higher concentration of nitrogen and phosphorus content of aboveground tissue of almost all macrophyte species studied suggests these macrophytes have a higher nitrogen and phosphorus retention capacity to contribute to overall water quality improvement. However, in the influent water (S1), most of the parameters, except temperature, EC and TDS, were beyond the Ethiopian effluent allowable discharge limits into water courses and in spite of rates of nutrient retention remaining high, the nutrient loading rates in Yitamot natural wetland exceeded the proposed critical loading rates of nitrogen and phosphorous for wetlands. The mean concentrations of heavy metals: As, Cr, Cu and Fe were also higher than the maximum allowable concentration ranges for fisheries and aquatic life in all sampling points. And there is no significant removal of most heavy metals like Fe, Zn, As in the study. The deterioration of water quality in the wetland might cause irreversible loss of the wetland ecosystem in terms of loss of biodiversity and insufficient nutrient and pollutant recovery. Therefore it is recommended that the untreated wastewater discharge should be minimized by employing alternative methods of wastewater treatment such as application of constructed wetlands and sludge pond near the point of discharge for improving the natural purification process and carrying capacity of the wetland.

Chapter 5: Nutrient uptake efficiency and growth of two aquatic macrophyte species (*Cyperus papyrus* and *Phragmites karka*) under horizontal sub surface flow constructed wetlands.

5.1 Introduction

Excessive nutrient enrichment is one of the most serious threats to wetland ecosystems. Treatment is necessary to improve wastewater quality in such a way that the use of final disposal of the treated effluent can take place in accordance with the rules set by the relevant legislative bodies without causing adverse impacts on receiving water bodies. Constructed wetlands are nowadays considered as low-cost alternative for effective wastewater treatment (Vymazal, 2002), especially in developing countries like Ethiopia where suitable land can be available. Macrophytes are an active component of horizontal subsurface flow constructed wetlands (HSSFCW) (Vymazal, 2011). Wastewater treatment is accomplished through the integrated combination of physical, biological and chemical interactions among biotic and abiotic components of the ecosystem and macrophytes cultivated in constructed wetlands make one of the basic components in the treatment process. They influence plant–microorganisms– wastewater interactions by providing microbial attachment sites, sufficient wastewater residence time, trapping and settlement of suspended wastewater components as a result of resistance to hydraulic flow, surface area for pollutant adsorption, uptake and storage in plant tissues, and diffusion of oxygen from aerial parts to the rhizosphere (Kyambadde *et al.*, 2005).

To evaluate the potential application of a macrophyte in wastewater treatment constructed wetlands, knowledge of structural development and recruitment rates of new shoots and the general growth rate of the macrophyte in question is crucial (Hoffmann & Platzer, 2010). Lack of this knowledge has been the most frequently reported problem for the failure and poor survival of plants in treatment wetlands (Kadlec and Wallace, 2009). There are some comparative studies, for different set of species, but they are not always conclusive (Coleman *et al.*, 2001; Sim *et al*., 2011; Lu *et al.*, 2012). Moreover, species applicability can change with latitude and local climatic condition. There are also research works in treatment wetlands in Ethiopia with different wastewater types and different plant species (Asaye Ketema, 2009; Berhanu Genet and Seyoum Leta, 2011; Girum Feleke, 2011; Kenatu Angassa, 2011 and Tadesse Alemu *et al*., 2012; Alemayehu Haddis, 2014; Sahu and Seid Yimer, 2014). However, these studies did not investigate the frequently used macrophytes species in HSSCWDs (*Phragmites karka* and *Cyperus papyrus*) using domestic wastewater. None of these studies also investigated growth parameters and biomass production in relation to nutrient uptake of these plants. Therefore, rigorous comparison studies under controlled conditions are necessary to evaluate the potential of these species for wastewater treatment using HSSFCW system. Hence, the main objective of this study was to determine the nutrient uptake and growth characteristics of *Cyperus papyrus* and *Phragmites karka* and also assess the potential use of these macrophytes in domestic wastewater treatment using a laboratory scale HSSFCW system.

5.2 Materials and methods

5.2.1 Experimental Design

The experimental study was conducted in a laboratory-scale HSSFCW system at Addis Ababa University, College of Natural Sciences campus. The system consists of four analogous HSSFCWs each with a dimension of 2 meters length, 0.65 meters width and 0.6 meters depth with surface area of 1 .3m^2 aligned in parallel. The floor of the system has 1% slope from inlet to outlet to achieve a hydraulic head-loss. The empty-bed volume of each HSSFCW up to the level of gravel was approximately 0.65 m^3 (650 L). This was done by filling water in empty constructed wetland up to gravel level, 0.5m. The void volume or the free volume after the system was filled with gravelwas around 0.227 m^3 (227 L). Then the porosity of the media was calculated by dividing void volume to total volume, which give 0.35 or 35%.

This system is designed with an average wastewater flow-rate of 26 L/d (0.026 m^3/d) measured using bucket and stop watch method (EMB-DENR, 2008) and a theoretical hydraulic residence time (HRT) of 7 days. The substrate or plant growth media used in this HSSFCW system was 20 to 30 mm diameter sized gravel which is the recommended gravel size by USEPA (2000). A 700 liter tanker was distributing the waste water to the experimental constructed wetlands using PVC pipes. The domestic wastewater was first settled in a sedimentation tank and it was served as a primary treatment to stay one day to settle and passes out to HSSFCWs. About sixty liters of pre-settled wastewater was then passed from the sedimentation tank to an equalization tank before getting into the HSSFCW system with gravitational force.

Fragments of rhizomes about 10 cm long carrying young shoots of *Cyperus papyrus* and *Phragmites karka* plants selected according to Hoffmann & Platzer (2010) were taken from the natural wetlands of Lake Tana and transplanted into their respective treatment beds with surface area of 1.3 m^2 at a density of 6 rhizomes /m^2. The first and the second treatment beds were planted with *Phragmites karka*; the third was planted with *Cyperus papyrus;* and the fourth treatment bed was left unplanted to serve as a control. Each treatment bed was fed with the influent wastewater with the same average flow rate from equalization tank through pipes after 3 weeks acclimation period of the liquid waste. Wastewater used in the study was collected from a small primary treatment plant (oxidative pond) receiving domestic liquid wastes from the students‟ residence at the College.

5.2.1.1 Data collection from the treatment beds

5.2.1.1.1 Measurement of the growth parameters of the plants

Plant density in the treatment bed, plant height, stem diameter and biomass were considered as growth parameters of the young plants. Except biomass, plant density, plant height and stem diameter were measured five times at two weeks intervals. Plant density in the treatment beds was obtained by counting all the plants including each independent morphological unit arising from rhizome as an individual macrophyte as stated in Pompeo and Moschini-Carlos (1996). Shoot length and stem diameter were measured on 15 randomly selected and tagged plants in the treatment bed using a graduated rope. The aboveground and belowground biomasses were measured after harvesting selected individual plants at the end of the experiment. Plants from each cell were harvested from 30 cm × 30 cm quadrat thrown at two corners and at the center of each wetland plot. The selected plants from each cell were put in plastic bag and brought to laboratory to estimate the standing biomass following the methodology described by Silva *et al*. (2010). Plants were divided into three components before drying and dried separately in hot oven at 105 ^{0}C for 24 hrs until constant weight and the dry weights were determined.

5.2.2.1.1.2 Measurement of plant nutrient content

Prior to nutrient analysis; leaf, stem and root samples of each plant species were pulverized and made into fine powder. The powder of each sample was used for total nitrogen (TN) and total phosphorus (TP) analysis by Kjeldahl method as stated in Blamire (2003) and by dry-ashing method, respectively. The molybdo-vanadate method (Ammonium Vanadate-Ammonium molbdate) was used to determine the phosphorus content following the procedures of Zhu *et al*. (2011), with slight modification in such a way that prior to application of the molybdo-vanadate method, the samples were first ash-dried to get complete digestion.

5.2.1.1.3 Analysis and measurement of physico-chemical parameters of water quality

Samples for physico-chemical parameters of water quality were collected from five different points labeled as S1, S2, S3, S4 and S5 as shown in Figure 5.1. S1 represents sampling point for the influent wastewater; S2, S3, S4 and S5 represent sampling points for the treated effluent coming out of treatment beds 1, 2, 3 and 4 respectively. Samples were taken over the period of six weeks after established plants grew fully and extended from January 21 to March 20, 2011.

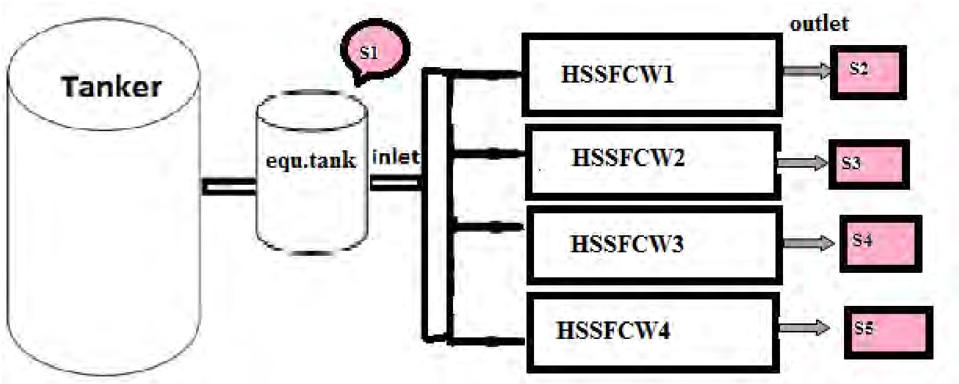


Figure 5.1 Setup of the constructed wetlands showing the five sampling points and treatment beds

The parameters electrical conductivity (EC), pH and temperature (T ^{0}c) were measured on-site at the inlet and outlet using portable EC meter (YSI model 30), and pH/T^{o} meter (Hanna 9024), respectively. Nutrient analysis (NO_3-N and PO_4^{3-}) was made after filtering the water sample through glass fiber filters (GF/F) using standard procedures as indicated in Yang *et al*. (1998) and APHA *et al.* (1999), respectively, using a spectrophotometer (Jenway 6405 UV).

Though the experiment was conducted in the four analogous parallel - lined treatment beds, the second treatment bed failed due to cracking problem; so the results and discussion refer only to the three functional treatment beds. The removal efficiency of the treatment beds for each wastewater quality parameter was calculated using the following formula:

Removal Efficiency (%) = [(Ci – Ce)/Ci] 100

Where, Ci (mg/l)= is the concentration of the waste material in the influent

Ce (mg/l) = is the concentration of the waste material in the effluent

5.2.2 Statistical Analysis

The data were analyzed through one-way analysis of variance (ANOVA) at 95% confidence level to compare the performance efficiency of each treatment bed with respect to removal of nitrate (NO_3-N), soluble reactive phosphate (PO_4^{3-}), EC and pH using Statistical Package for Social Sciences (SPSS) software, Version 20.

5.3 Results

5.3.1 Growth characteristics of the plants in the system

From a density of 6 rhizome fragments per m^2 at the start of the study, 41 plants per m^2 were obtained after 3 weeks acclimation in the treatment bed planted with *Cyperus papyrus* and 16 plants in the treatment bed planted with *Phragmites karka*. Where the system was continuously fed with primary treated (the tank) wastewater; a density of 81 plants per m^2 was recorded for *Cyperus papyrus* and 51 for *Phragmites karka* (Figure 5.2) during the last experimental period in the treatment beds. Statistical analysis (one-way ANOVA) and independent samples test showed that there was significantly higher ($p < 0.05$) mean plant density of *Cyperus papyrus* than that of *Phragmites* species.

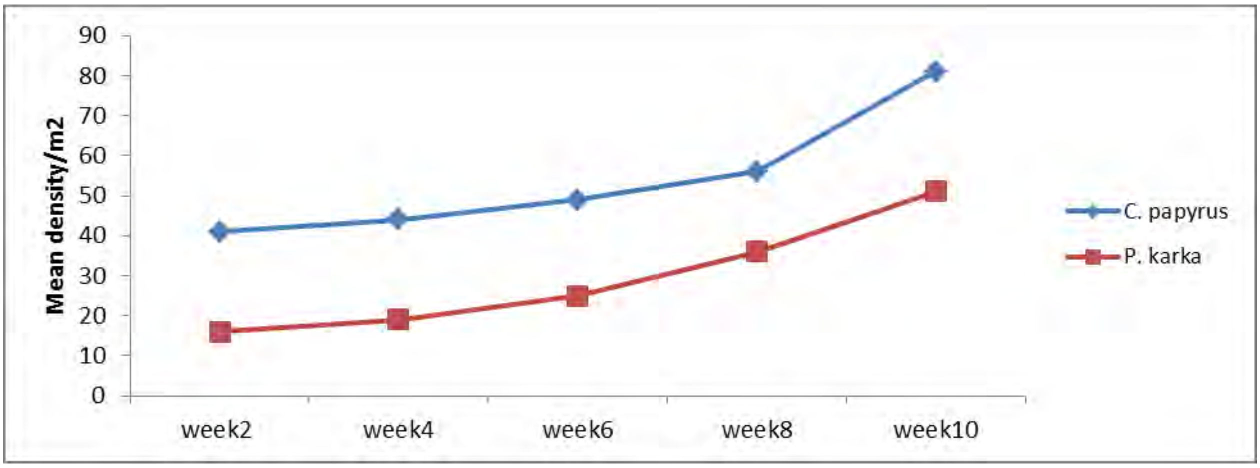


Figure 5.2 Plant densities during the experimental period

Plant height growth slightly increased in both species with increasing time, (Figure 5.3).There was no significant difference ($p > 0.05$) in plant height growth between the two plant species, but there was somewhat a slightly higher growth rate of *Cyperus papyrus* with mean plant height of 21.61 cm than in *Phragmites karka* with mean plant height of 20.59 cm.

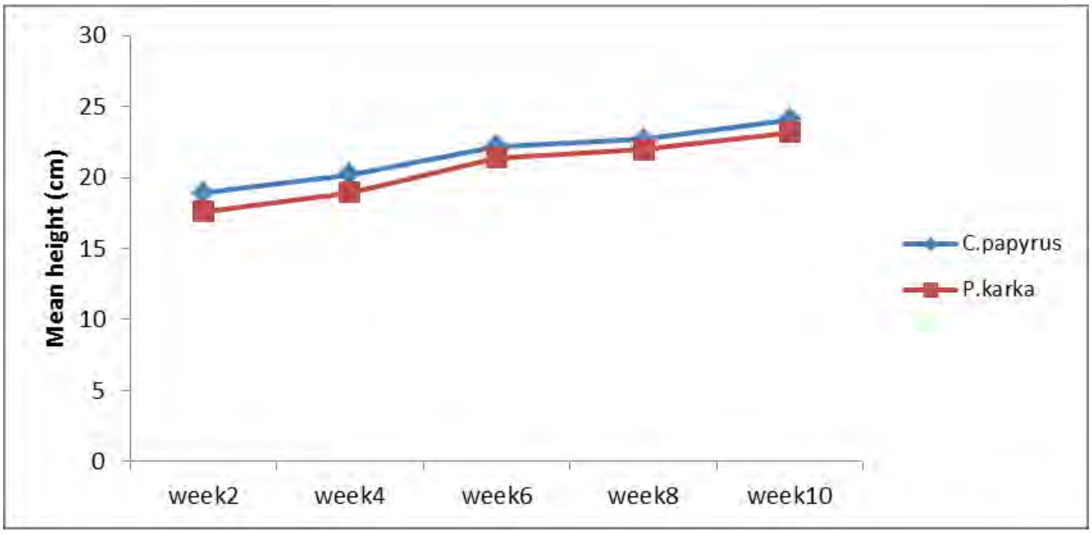


Figure 5.3 Height of plants during the experimental period.

Stem diameter of *Cyperus papyrus* started to increase immediately after the second week while that of *Phragmites karka* started to increase after the fourth week (Figure 5.4).The mean diameter increment was slightly higher for *Cyperus papyrus* compared to *Phragmites karka* (Table 5.1) , but the difference was not statistically significant ($p > 0.05$).

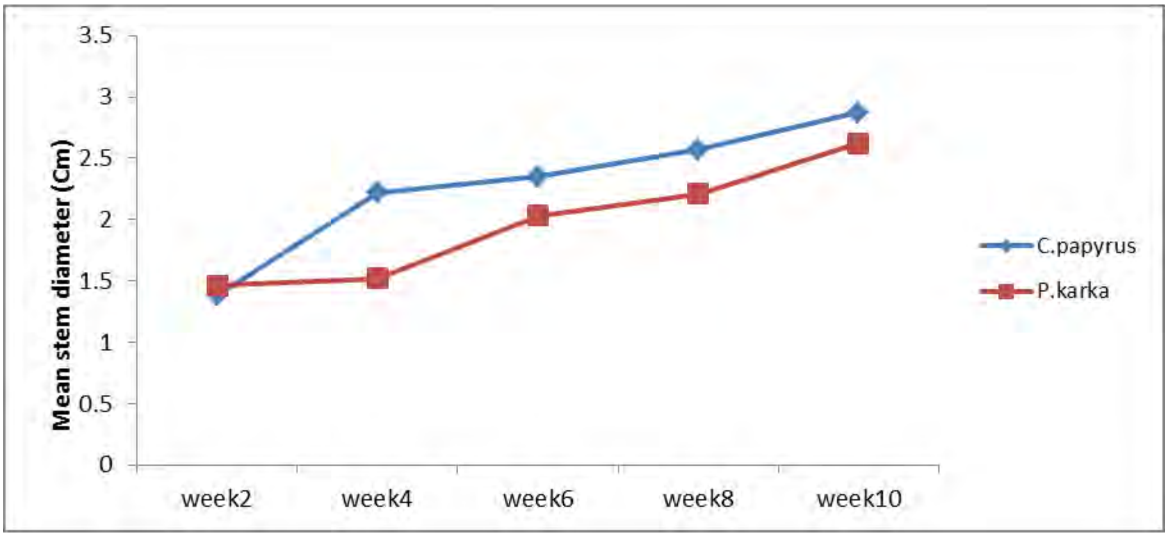


Figure 5.4 Stem diameters of plants during the experimental period

Table 5.1 Plant growth parameter measurements (mean ± S.D) (n =5)

Growth parameter	*Cyperus papyrus*	*Phragmites karka*
Plant Height (cm)	21.61±2.06	20.59±2.32
Density (No.per m^2)	54.20±16.02	29.40±14.29
Stem Diameter (cm)	2.28±0.56	1.97±0.49

S.D= Standard deviation

Biomass Production:

The dry biomass estimates per 30 cm^2 area of the experimental treatment beds is presented in Table 5.2. *Phragmites karka* had significantly higher ($p < 0.05$) leaf dry weight with a mean of 13.74 gm compared to *Cyperus papyrus* with a mean leaf dry weight of 8.49 gm. Paired samples T-test statistics showed that the belowground biomass estimate was significantly higher in *Cyperus papyrus* ($p<0.05$) than in *Phragmites karka. However,* there was no meaningful difference ($P>0.05$) between the aboveground biomasses in the two wetland plant types

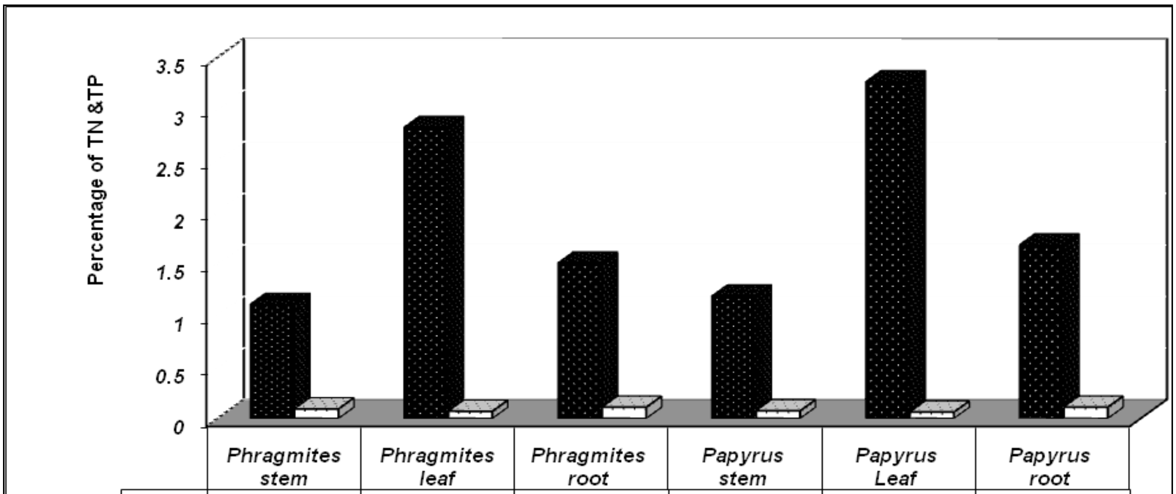
Table 5.2 Mean Leaf, Stem and Root Biomass measurements of macrophytes in the treatment beds per 30 cm^2 areas. (n = 3)

Plant parts	Mean biomass (gm)±S. D	
	Cyperus papyrus	*Phragmites karka*
leaf	8.49±0.03	13.74±0.05
stem	38.17±0.02	26.6±0.3
root	37.27±0.04	16.4±0.4

5.3.2 Plant tissue nutrient analysis

Comparative studies of different parts of the two species (Figure 5.5) showed that *Cyperus papyrus* had higher leaf nitrogen content (x = 3.26% N) compared to *Phragmites karka* (x = 2.82% N). There were significant differences ($p < 0.05$) in nitrogen content within the different body parts of the two species. In many instances, nitrogen content of leaves was significantly higher ($p < 0.05$) than roots.

There were also significant differences ($p < 0.05$) in root, leaf and stem phosphorus content between the two species and among plant parts. *Cyperus papyrus* had slightly higher root phosphorus content than *Phragmites karka* (Figure 5.5). It was found that phosphorus concentration in *Cyperus papyrus* was highest in root followed by stem and leaf. The study revealed that phosphorus concentration in *Cyperus papyrus* was highest in root followed by stem and leaf.



	Phragmites stem	Phragmites leaf	Phragmites root	Papyrus stem	Papyrus Leaf	Papyrus root
■ % TN	1.105	2.821	1.506	1.185	3.263	1.682
□ % TP	0.092	0.069	0.108	0.073	0.061	0.109

Figure 5.5 Comparisons of TN and TP content in plant parts

5.3.3 Effluent and influent characterization of domestic wastewater

Summary of the physico-chemical characteristics of the effluent monitored at the inlet and the outlets of the treatment beds is presented in Table 5.3. Water quality monitoring in the systems revealed that physicochemical characteristics of the effluent progressively improved because a dramatic decline was recorded from the inlets to the outlets of the experimental treatment beds. EC, pH and T^0 mean influent values were 667.85 µS/cm, 7.63 pH units and 17.2 ^{0}c, respectively. pH values were in the range of 7.51 – 7.66 and 7.55 – 7.82 in planted and control treatment, and the papyrus-planted treatment bed showed lowest pH value (7.51) at the end of experiment. Analytical results of ANOVA and least significant difference (LSD) confirmed that values of T^0, pH and EC had no statistically significant differences ($p > 0.05$) between planted and unplanted treatment beds. Effluents from all the treatment beds were within the range of the Ethiopian effluent standard limits for T^0, EC and pH which are 40 ^{0}c, 1000 µs/cm (at 20 ^{0}c) and 6-9 pH units, respectively (EEPA/UNDO, 2003).

Characterization of the domestic wastewater for nutrient (nitrogen and phosphorus) contents is shown in (Table 5.3). The mean influent values for nitrate (NO_3-N) was 26.89 mg/L and the mean effluent concentrations of all three treatment beds were in the range of 11.19 to 17.18 mg/L. The mean influent value PO_4^{3-} was 35.35 mg/L and the mean effluent concentrations were between the ranges of 5.64 mg/L to 17.60 mg/L (Table 5.3).

Table 5.3 Influent and effluent characteristics of domestic wastewater and the experimental HSSFCW system (Mean± S.D) (n = 6)

Parameter	Mean Influent and Effluent Concentrations			
	Influent Conc.	Effluent Conc.		
		HSSFCW 1[a]	HSSFCW3[b]	HSSFCW4 [c]
EC(µS)	667.85±244.35	371.35±130.39	242.52±74.88	372.15±124.95
pH	7.63±0.06	7.63±0.02	7.51±0.13	7.66±0.05
T(°C)	17.02±0.63	16.02±0.42	16.25±0.55	15.87±0.57
SRP (mg/L)	35.35±2.64	11.89±1.19	9.03±3.32	13.54±2.69
NO_3-N(mg/L)	26.89±4.46	11.19±3.88	11.73±4.17	17.18±5.41

[a] Phragmites-planted treatment bed
[b] Papyrus-planted treatment bed
[c] control bed

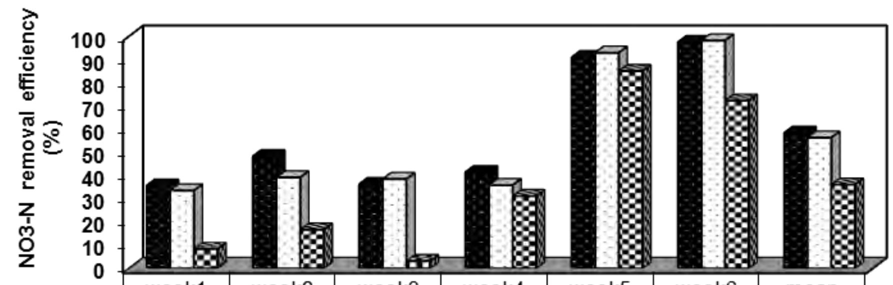
S.D means standard deviation

N.B Treatment bed 2 is missing because of cracking problem.

5.3.4 Nutrient removal efficiencies of the treatment beds

The nitrogen removal efficiency of the three treatment beds is shown in figure 5.6. The maximum NO_3-N removal was observed in treatment bed planted with

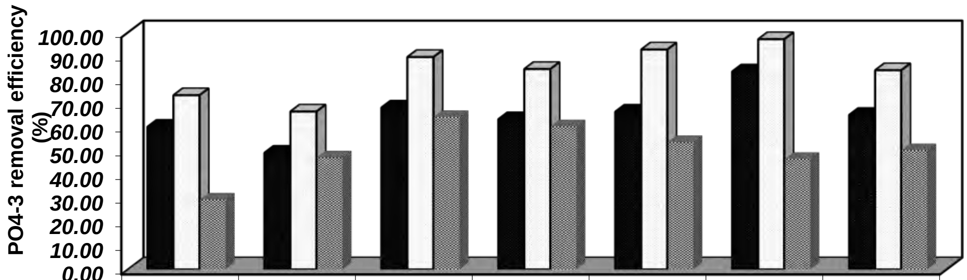
Phragmites karka (x =58.37%) followed by *Cyperus papyrus* (x = 56.37%) and unplanted (x = 36.13%), though the differences is not statistically significant (ANOVA and LSD Post Hoc tests, P>0.05)



	week1	week2	week3	week4	week5	week6	mean
■ Phragmites planted	35.71	48.33	36.31	41.47	90.94	97.43	58.37
□ papyrus planted	33.54	39.21	38.53	35.88	92.91	98.16	56.37
⊠ control (unplanted)	8.38	16.72	3.18	31.17	85.04	72.29	36.13

Figure 5.6 NO_3-N removal efficiencies of the three treatment beds along the experimental period

The average removal efficiency for PO_4^{3-} of the treatment beds was 84.05% for *Cyperus papyrus,* 65.29% for *Phragmites karka,* and 50.20% for the control (unplanted) (Figure 5.7). ANOVA and Post Hoc LSD tests indicated statistically significant differences ($p < 0.05$) in removal of PO_4^{3-} between planted and control treatment bed and also among planted treatment beds. It can be seen that all of the planted treatment beds have better efficiency in the removal of PO_4^{3-} compared to unplanted treatment bed. The Ethiopian domestic effluent standard limits are 20 mg/L for NO_3-N and 5 mg/L for PO_4^{3-} (EEPA / UNIDO, 2003). The mean PO_4^{3-} from all the three treatment beds were out of the range of the standard, while the mean NO_3-N from all the three treatment beds was within the range of the standard.



	week1	week2	week3	week4	week5	week6	mean
Phragmites planted	60.18	49.20	68.27	63.36	66.54	83.50	65.18
papyrus planted	73.50	66.62	89.61	84.56	92.79	97.13	84.04
control (unplanted)	29.39	47.19	64.20	60.30	53.63	46.52	50.21

Figure 5.7 $PO4^{-3}$ removal efficiencies of the three treatment beds along the experimental period

In the experimental treatment beds planted with both *Phragmites karka* and *Cyperus papyrus*, the rate of removal of nutrients progressively increased with time (Figures 5.6 and 5.7). The study showed that there was positive and significant correlations ($p < 0.05$) between the removal of nitrate and phosphate and changes in the plant density ($\rho = 0.806$ and $\rho = 0.648$, respectively) (Table 5.4). Moreover, changes in plant height was positively and significantly correlated ($\rho = 0.661$) with that of removal efficiency of Nitrogen (Table 5.4) whereas changes in diameter was positively and significantly correlated ($p < 0.05$) with removal efficiency of phosphorus ($\rho = 0.648$) (Table 5.4).

Table 5.4 Correlations of growth parameters (density, plant height, stem diameter) and nutrient removal efficiency

			density	height	diameter
Spearman's rho	REN	Correlation Coefficient	.648(*)	.661(*)	.600
		Sig. (2-tailed)	.043	.038	.067
	REP	Correlation Coefficient	.806(**)	.600	.648(*)
		Sig. (2-tailed)	.005	.067	.043
		N	10	10	10

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
REN: Nitrate removal efficiency
REP: Phosphate removal efficiency

5. 4. Discussion

5.4.1 Growth characteristics and tissue nutrient content of *C. papyrus* and *P. karka* in the system

The results of growth response conditions (density, height, diameter) in the present study indicate that these plants showed practical withstand of shock loads and possibly grow very well which is one of the criteria for selecting plants to use in constructed wetlands for wastewater treatment. Comparatively the leaves of *Phragmites karka* showed significantly higher above ground biomass. The observed significantly higher above ground biomass in *Phragmites karka* in the study may be due to the plant species as well as physiological and morphological characters of the plants (Ma *et al.,* 2010; Zhu *et al.,* 2011). The larger leaf area for photosynthesis in *Phragmites karka* could be one of the reasons for more biomass in the species.

It was noted that total nitrogen content in both plant species followed the order: Leaf > Root > Stem while total phosphorus showed the order: Root > Stem > Leaf. This is consistent with studies made by several authors who have reported that nitrogen content of leaves was higher than roots (Mars *et al*., 2003, Kyambadde *et al*., 2005, Mugisha *et al*., 2007). This is because photosynthetically active organs (leaves) generally have higher nitrogen content than other organs (rhizome and roots) under optimal growth conditions and most of the phosphorus was absorbed by plant root and absorption through the leaves and shoot was restricted, hence, phosphate was easily concentrated in the belowground tissue.

The study also revealed that macrophytes had higher nitrogen concentration than phosphorus and similar result was observed by Mueleman *et al*. (2002). This is a consequence of the Redfield ratio that quantifies the molar ratio of elements as follows: C/N/P = 106/16/1. Sim *et al*. (2011) studied macrophytes in a subtropical/tropical climate and reported only slight variability between nutrient content in different plant components (root, rhizomes, stem, and leaves), with nitrogen generally highest in the leaves and phosphorus highest in roots. Similarly, a study by Mars *et al*. (2003) stated that phosphorus storage was highest in belowground components with lowest amount of phosphorus storage in leaves, suggesting that there is translocation of nutrients towards young tissues where climatic conditions are conducive to year-round growth.

5.4.2 Effluent and influent characterization of domestic wastewater

The papyrus-planted treatment bed showed lowest pH value and in general the control treatment bed showed slightly higher pH than planted treatment beds at the end of experiment. Similar result was recorded by USEPA (1999), Coleman *et al*. (2001) and Lin *et al*. (2002) and could be due to algal growth which was observed at the surface of control treatment bed. The algae have the effect of absorbing CO_2 faster than it can be replaced by bacterial respiration. This has the effect of leaving excess hydroxyl ions which cause sudden rises in the pH to around 7.82 (Lin *et al*., 2002).Other reports also explained plants take up significant amounts of sparingly soluble nutrients from the rhizosphere by acidifying the rhizosphere (Rao *et al*., 2002) via excreting H^+ in exchange for cat-ions and exuding organic acids and CO_2 (Hinsinger *et al*., 2003). The high electrical conductivity value recorded could be attributed to the presence of various types of ions in the wastewater. There were only slight differences in temperature and pH between influent and effluents from the three treatment beds, indicating the absence of any thermal pollution.

For the high measurements of nutrients in the system, there are different ways of looking at nutrient sources since there are different water-using fixtures in the campus. It is obvious that the use of a garbage disposal and human waste are the main sources of nutrients in domestic wastewater. The high levels of NO_3-N obtained in the influent could be associated with the sources of the nitrogen form (NO_3-N) which could be protein hydrolysis and Urea from urine. Also it might come from nitrification of the ammonium nitrogen in the wastewater during the periods of sample collection in the system. While the high PO_4^{3-} levels obtained in the influent could be due to the use of phosphorous containing chemicals like phosphates in detergents for washing cloths and kitchen wares (Trepanier *et al*., 2002) and soaps for washing clothes and for Bathing. Dishwasher detergent contains 0.8 grams of phosphate per tablespoon and the concentrated dishwasher detergent tablets contain 1.75 grams of phosphate (Patterson, 2004).

5.4.3 Nutrient removal efficiencies of the treatment beds

Comparison of removal efficiencies showed that planted treatment beds performed better than unplanted treatment beds for both of the parameters. Several experimental studies on nutrient removal treatment have confirmed that unplanted treatment had lower nutrient removal compared with planted treatment (Coleman *et al*., 2001; Yang, *et al*., 2001; Lin *et al*., 2002, Billore *et al*., 2008, Zhang *et al.,* 2010). Similar results were also obtained in the study of treatment wetlands in Ethiopia planted with *P.karka* (Kenatu Angassa, 2011) and (Tadesse Alemu *et al*., 2012).The removal efficiency of the plants may be due to a combination of mechanisms favored by the plants and adsorption of certain nutrients. The most important effects of the macrophytes in relation to the wastewater treatment processes are the physical effects of the plant tissues that give rise to filtration effect and provide surface area for attached microorganisms. The pollutants removal of macrophytes by plant uptake and storage affects the wastewater treatment processes in different ways. In this study, the high nitrogen removal in treatment beds planted with *Phragmites karka* may be due to its high leaf biomass content (13.74 gm/30 cm^2) as compared to that of leaf of *Cyperus papyrus* (8.49 gm/30 cm^2) and its root mat, which enables the plant to take up and store more soluble inorganic nitrogen

Conventional plant growth analysis also indicated that improvements in water quality per unit time by high population density resulted directly from increased plant presence. Zhu *et al*. (2011) studied the growth characteristics, plant aboveground and belowground biomass of seven wetland plants. They suggested that a greater ratio of plant biomass to wetland volume can enhance the contact between plant roots and wastewater resulting in a greater nutrient removal. Similar conclusion was reached by Sushil (2012) and Lu *et al*. (2012). In general, plant morphology such as height of plants and the shape of leaves also affects the overall nutrients in aquatic plant treatment systems (Kyambadde *et al*., 2005). In this experiment, *Cyperus papyrus* has the highest total biomass which may contribute for the highest phosphorus removal (84.04%) in the system as compared to that of *Phragmites karka*.

In conclusion, it was observed that *Cyperus papyrus* and *Phragmites karka* plants significantly influenced the rate of removal of nutrients in domestic wastewater. Progressive increase in the plant density, shoot length and stem diameter were positively correlated with the nutrient removal efficiency of these plants. *Cyperus papyrus*-planted treatment beds had markedly higher phosphorus removal efficiency with higher total biomass and nutrient levels (leaf N and root P) in plant tissues in comparison to *Phragmites karka*. Similarly, more shoots were developed by *Cyperus papyrus* than *Phragmites karka,* possibly indicating differences in nutrient uptake. The result also showed that all of the effluent concentration values (except for PO_4^{3-}) were within the Ethiopian effluent standard discharge limit values. Therefore, the data generated from this study give some insight for the potential use of these plants for nutrient removal in constructed wetlands and their application as an alternative wastewater treatment system. Hence, the development of this experimental system into a large-scale pilot unit offers an attractive alternative for low-level income countries to reduce nutrient pollution and protect the environment. *Cyperus papyrus* and *Phragmites karka* occur locally in tropical regions like Ethiopia. The study suggests that these macrophytes possess high biomass production and remove nutrients, thus making constructed treatment wetlands incorporating these macrophyte-vegetation is a promising wastewater treatment option for wider application.

Chapter 6: Conclusion and recommendations

6.1 Conclusion

The study found that aquatic macrophyte species composition of Lake Tana was low compared to some other water bodies where similar studies were carried out. The lake shows some changes in terms of some physico-chemical parameters and shift in species composition of turbidity-tolerant floating and emergent macrophytes. The decreasing trend in water level and transparency of the lake and increasing trend of nutrients like nitrate and SRP could favor this conspicuous shift in macrophyte composition and reduction in abundance of some macrophytes in the lake. The existence of maximum human interference in the littoral zone of the lake is indicated from the results of all the physico-chemical parameters in the littoral zone and the open water zone. The negative impact of water hyacinth on macrophyte species diversity is also indicated in the results.

In most cases, lower biomass production of the studied macrophytes was observed as compared to other studies done on these macrophytes in other regions. Determination of the aboveground biomass and tissue nutrient (TN, TP) concentrations of three dominant emergent macrophytes in relation with the physico-chemical characteristics of the lake water quality indicated that biomass production and tissue nutrient contents are species specific and it is dependent on environmental factors. The results of (RDA) showed nitrate, SRP, pH, temperature and depth of the water have significant impact on biomass production and tissue nutrient contents of the emergent macrophytes studied. The result also revealed all the species showed positive correlation with nitrate and depth and negative associations with EC and TDS.

Moreover, the spatio-temporal comparison of biomass production in macrophyte species showed that besides the water quality changes, damages by human activities (settlement and livestock grazing) could have negative effects on plant cover and biomass production.

Measurements taken in Yitamot natural wetland at each sampling site indicated that water quality was improved as DO and pH level significantly increased and TSS, Turbidity and COD significantly decreased to optimal level in the outlet and nutrients were significantly reduced and assimilated. Water total nitrogen concentration showed the most significant decrease, which was also followed in water nitrite, nitrate and ammonia concentration. Total phosphorus and SRP also showed significant decrease indicating the wetland is a sink for this constituent being immediately adjacent to the source of effluent discharge. Nutrients were removed from the system via assimilation by vegetation, sediment adsorption or pore water retention. The higher concentration of nitrogen and phosphorus content of aboveground tissue of almost all macrophyte species studied suggests that these macrophytes have a higher nitrogen and phosphorus retention capacity to contribute to overall water quality improvement. However, in the influent water (S1), most of the parameters except temperature, EC and TDS were beyond the Ethiopian effluent allowable discharge limits into water courses. The mean concentrations of heavy metals: As, Cr, Cu and Fe were also higher than the maximum allowable concentration ranges for fisheries and aquatic life in all sampling points and there was no significant removal for some heavy metals like Fe, Zn, As. This indicated the contribution of macrophytes and other compartments of Yitamot natural wetland are not efficient for the removal of these particular contaminants in the wetland.

Evaluation of the potential application of a macrophyte in domestic wastewater treatment constructed wetlands showed that *Cyperus papyrus* and *Phragmites karka* significantly influenced the rate of removal of nutrients in domestic wastewater. Progressive increase in the plant density, shoot length and stem diameter were positively correlated with the nutrient removal efficiency of these plants. The result also showed that all of the effluent concentration values (except for PO_4^{3-}) were within the Ethiopian effluent standard discharge limit values. And comparison of removal efficiencies showed that planted treatment beds performed higher than unplanted treatment beds for many of the parameters. The higher nutrient removal efficiencies associated with planted treatment beds compared to unplanted controls in the study, can indicate the direct uptake of nutrients by macrophytes that can result for the higher removal efficiency of the two planted treatment beds than unplanted.

6.2 Recommendations

Based on the results of this study, the lake shows some changes in terms of macrophyte composition and diversity and some physico-chemical parameters. For instance the lake has higher nutrient concentrations compared to previous studies and some other Ethiopian lakes; therefore, determination of key species of macrophytes performing vital functions such as filters of pollutants and silt, and indicators of environmental change is very vital.

Besides the water quality changes, damages by human activities (settlement and livestock grazing) for the reduction in plant cover and biomass production is indicated in the study. The impact of water hyacinth on macrophyte species diversity is also showed in the study. It is high time to look into the problems of the lake caused due to impact of water hyacinth and overexploitations by the people for different activities therefore, studies for best practices of waterhyacinth control and regulation of harvesting and utilization of macrophytes are needed. Sediment load might have also great effects on macrophyte composition and diversity; therefore, studies on internal and external nutrient load dynamics of the lake should be done and a buffer zone is needed for protection of the lake shore area.

Despite suitable climatic conditions in Ethiopia, little emphasis and efforts have been made to investigate the various types of CWs to treat various types of wastewaters and protect water bodies. So in the future a detailed research that incorporates all issues of wetland should be undertaken. For treatment wetlands to gain wider acceptance in Ethiopia, more specific guidelines and BMPs regarding CWs design, operation, maintenance, and cost effectiveness need to be established.

The study showed the risk of discharge of untreated wastewater by Bahir Dar city in general and Bahir Dar University in particular, therefore, proper wastewater treatment is needed. Untreated wastewater discharge can be minimized by construction of sludge ponds and constructed wetlands near the point of discharge and subsequently improving and intensifying the natural purification process and carrying capacity of the available natural wetland. Better treatment process in Yitamot natural wetland can be also obtained by preventing chanalization of the westwater in the wetland.

The data generated from the study of evaluation of the potential application of a macrophyte in domestic wastewater treatment constructed wetlands can give an insight for the potential use of these plants in constructed wetlands and the constructed wetlands as an alternative wastewater treatment system. Therefore, the development of this experimental system into a large-scale working unit offers an attractive alternative for low-level income countries to protect their environment.

The first two chapters of this thesis are concentrated on the understanding of the ecological factors that bring the possible shift of macrophyte dominance in the largest and shallow lake, Lake Tana. Time frame and logistical issues however limited the findings of this research to some degree. The study was based on vegetation surveys that were only carried out on the south western and north eastern littoral zones of the lake, and therefore conclusions that have been drawn represent to these results only and may not be a representative of conditions throughout the whole-lake. A greater understanding of the possible ecological factors driving the shift in macrophyte dominance will assist in the formulation of successful management strategies in the lake in general and successful management strategies for the control of water hyacinth in particular. Options for further work to build on the findings reported here could be obtained by continuing the spatial and temporal surveys to better define the vegetation dynamics within the whole lake condition for a better understanding in a more diverse range of environmental conditions.

References

Abebe Getahun and Eshete Dejen (2012). *Fish of Lake Tana; A guidebook*. Addis Ababa University Press, Addis Ababa.

Abebe Yilma (2003). Wetlands of Ethiopia: an introduction. **In**: *Wetlands of Ethiopia*: *Proceedings of a seminar on the resources and status of Ethiopia's wetlands* (Abebe Yilma and Kim G. eds), pp. 1-11, IUCN, Nairobi, 123pp.

Abeyou Wale (2008). *Hydrological balance of Lake Tana*, MSc Thesis, International Institute for Geo-Information Science and Earth Observation (ITC), Netherlands.

Aerts, R. and Chapin, F.S. (2000). The mineral nutrition of wild plants revisited: a re-evaluation of processes and patterns. *Adv Ecol Res.* **30**: 1–67.

Afework Hailu (2004). *Ethiopian Wetlands distribution, benefits and threats.* EWNRA.

Akoma, O. and Imoobe, T. (2009). Limnological and Phytoplankton Survey of Bahir Dar Gulf of Lake Tana, Ethiopia. *AJST.* **10***:* 91 – 98

Al-Abbaw, D. and Al-Mayah, A. (2009). Influence of some ecological factors on plant tall, cover percent and biomass of Phragmites australis in marshes of southern Iraq after inundation. *Marsh Bulletin*. ***4:*** 121–136.

Alahuhta, J., Vuori, K. and Luoto, M. (2011). Land use, geomorphology and climate as environmental determinants of emergent aquaticnmacrophytes in boreal catchments. *Boreal Environ. Res.* **16**: 85– 202.

Alemayehu Haddis (2014). *Performance of horizontal subsurface flow constructed wetlands for treating irregular wastewater flow in a tropical climate.*PhD thesis.2014 KU Leuven–Faculty of Engineering Science. ISBN 978-94-6018-821-3 D/2014/7515/45.

Aloo, P., Ojwang, W., Omondi, R. Njitu, J.M.and Oyugi, D. (2013). A review of the impacts of invasive aquatic weeds on the bio- diversity of some tropical water bodies with special reference to Lake Victoria (Kenya). *Biodivers J*. **4**: 471–482.

Amare Sewnet Minale and Kameswara K. (2011). Hydrological Dynamics and Human Impact on Ecosystems of Lake Tana, Northwestern Ethiopia. *EJESM.* **4**:56 -63

American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation (1999). Standard methods for the examination of water and wastewater (20th ed.): Washington, D.C.

Andualem Mekonnen, Seyoum Leta and Njau, K. (2015).Wastewater treatment performance efficiency of constructed wetlands in African countries: a review *Water Sci Technol.* **71**: 1-8

Asaye Ketema. (2009). *Evaluation of Selected Plant Species for the Treatment of Tannery Effluent in a Constructed Wetland System.* Master‟s thesis, in Environmental science, Addis Ababa University, Addis Ababa. (Unpublished)

Asp, K. (2009). Water Storage Capacity and Flow Dynamics in a Papyrus Wetland, Uganda. -Implications for Studies of Water Treatment Effects.

Atkinson, R., Perry, J., Noe, G., Daniels, W. and Cairns, J. (2010). Primary Productivity in 20-year Old Created Wetlands in Southwestern Virginia. *Wetlands*. **30**:200–210.

Aulio, K. (2015). Shoot Growth in *Typha angustifolia* l. and *Typha latifolia* l. in the okem enjoki River Delta Western Finland. *ILNS*. ***28***: 34–46.

Ayalew Wondie (2006). Current status and future challenges of fisheries in Lake Tana. A workshop paper in the proceedings of the national consultative and promotional workshop on Lake Tana and its environs: conservation, utilization, development and threats (pp 93-114); Organized by GEF-IFAD Lake Tana Watershed Project in Bahir Dar, Nov 26-27/2006.

Ayalew Wondie (2010). Improving management of shoreline and riparian wetland ecosystems: the case of Lake Tana catchment. *Ecohydrol*.

*Hydrobiol.***10**:123-132.

Ayalew Wondie and Seyoume Mengistou (2006). Duration of Development, Biomass rate of production of the Dominant Copepods (Calanoida and Cyclopoida) in Lake Tana Ethiopia. *SINET: Ethiop.J.Sci*. **29**: 107-122.

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

Ayalew Wondie, Ali seid, Eyayu Molla, Goraw Goshu, W/Gebriel G/Kidan, Agegnehu Shibabaw, Derje Tewabe, and Mulueh Genanaw (2012). Preliminary Assessment of Water hyacinth in Lake Tana. **In**: *proceeding of Agro-biodiversity in Ethiopia: Risk and opportunities in a changing climate,* 2nd Annual conference of the biological society of Ethiopia. Addis Ababa, Ethiopia.

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

Bastviken, S. 2006. *Nitrogen removal in treatment wetlands –Factors influencing spatial and temporal variations.* Dissertation No 1041. Linköping University, Sweden

Berhanu Genet and Seyoum Leta (2011). *Constructed Wetland for Domestic Wastewater Treatment*: A Case Study in Addis Ababa, Ethiopia. LAP Lambert Academic Publishing:ISBN: 783846504390 https://www.lap-publishing.com/

Berhanu Teshale (2003). Influence of sediment on physico-chemical properties of Lake Tana. Workshop „Fish and Fisheries of Lake Tana: Management and Conservation". 6–8 October 2003, Bahir Dar, Ethiopia.

Berhanu Teshale, Lee, R. and Girma Zawdie (2001). Development Initiatives and Challenges for Sustainable Resource Management and Livelihood in the Lake

Tana Region of Northern Ethiopia. An overview **In**: *Proceedings of the Wetland Awareness Creation and Activity Identification Workshop in Amhara National Regional State.* Ethiopian Wetlands and Natural Resources Association (EWNRA) Facilitated by the University of Huddersfield, UK January 23rd 2001 Bahir Dar, pp: 33-43.

Bettinelli, M., Beone, G. Spezia, S. and Baffi, C. (2000). Determination of heavy metals in soils and sediments by microwave-assisted digestion and inductively coupled plasma optical emission spectrometry analysis. *Anal. Chim. Acta.* **424**: 1–2.

Blahnik, T. and Day, J. (2000). The effects of varied hydraulic and nutrient loading ates on water quality and hydrologic distributions in a natural forested wetland. *Wetlands.* ***20***: 48 -61.

Blamire, J. (2003). *E-Learning for Quantitative analysis: Kjeldahl Method. Science@a distance*.

Borin, M. and Salvato, M. (2012). Effects of five macrophytes on nitrogen remediation and mass balance in wetland mesocosms. *Ecol. Eng*. **46**: 34–42

Brantley, C.G., Day, J.W., Lane, R.R., Hyfield, E., Day, J. and Ko, J. (2008). Primary production, nutrient dynamics, and accretion of coastal freshwater forested wetland assimilation in Louisiana. *Ecol. Eng*. **34**: 7-22.

Browning, C. (2003). Nutrient removal and plant growth in a subsurface flow constructed wetland in Brisbane, Australia. *M. Phil thesis*. Griffith University, Australia.

Brunelli, G. and Cannicci, E. (1940). Le Caratteristiche Biologiche del Lag Tana. Missione di Studio al Lago Tana richerge limnologiche. *Boll. Chem. Biol R.Acc. Ita.* **3**: 71–114.

Burlakoti, C. and Karmacharya, S. (2004). Quantitative analysis of macrophytes of Beeshazar Tal, Chitwan, Nepal. *Him. J. Sci*., **2**:37–41.

Calijuri, M. L., Da Fonseca Santiago, A., Moreira Neto, R., and De Castro Carvalho, I. (2011). Evaluation of the ability of a natural wetland to remove heavy metals generated by runways and other paved areas from an airport complex in Brazil. *Water Air Soil Pollut*. ***219****:* 319–327. http://doi.org/10.1007/s11270-010-0709-1

CEC (Commission of European Communities) (1978). Council Directive of 18 July 1978 on the quality of fresh waters needing protection or improvement in order to support fish life, (78/659/EEC). Official Journal, L/222, 1-10.

Chale, F. (2003). Effects of *Cyperus papyrus* L. swamp on domestic waste water. *Aquat. Bot*., **23**:185–189.

Chambers P., Lacoul P., Murphy K.J. & Thomaz, S.M. (2008) Global diversity of aquatic macrophytes in freshwater. *Hydrobiologia.* **595**: 9 – 26.

Chapman, D. and Kimstach, V. (1992). The Selection of Water Quality Variable In: Water Quality Assessments (Chapman, D. Ed.) Chapman and Hall Ltd., London pp. 51-119.

Chapman, H. and Pratt, F. (1961). Ammonium vandate-molybdate method for determination of phosphorus. **In**: *Methods of analysis for soils, plants and water*. pp 184-203, 1st Ed. California: California University, Agriculture Division, USA, 309pp.

Chapman, L., Balirwa, J., Bugenyi, F., Chapman, C. and Crisman, T. (2001). Wetlands of East Africa: Biodiversity, Exploitation and Policy Perspectives. In: Biodiversity in Wetlands: Assessment, Function and Conservation (Eds B. Gopal; W. Junk & J. Davis) Vol. 2 pp. 101-131. Backhuys Publishers. Leiden, The Netherlands.

Ciecierska, H. and Kolada, A. (2014). ESMI: A macrophyte index for assessing the ecological status of lakes. Environ. *Monit. Assess*. **186**: 5501–5517.

Coleman, J., Hench, K., Garbutt, K., Sexstone, A., Bissonnette, G. and Skousen, J. (2001). Treatment of domestic wastewater by three plant species in constructed wetlands. *Water Air Soil Pollut.* **128**:283–295.

Colot, C. (2012). *Soil-landscape Relation at Regional Scale in Lake Tana Basin (Ethiopia).* Unpublished thesis. KULeuven: Department of Soil and Water Management.

Costa, M. and Henry, R. (2010). Phosphorus, nitrogen, and carbon contents of macrophytes in lakes lateral to a tropical river (Paranapanema River, São Paulo, Brazil). *Acta Limnol. Bras*. ***22***:22–132.

Craft, C., Krull, K. and Graham, S. (2007). Ecological indicators of nutrient enrichment, freshwater wetlands, Midwestern United States (U.S.). *Ecol. Indic*. **7**: 733–750.

Dar, N., Hamid, A. and Ganai, B. (2012). Primary Production Dynamics of Two Dominant Macrophytes in Wular Lake, a Ramsar Site in Kashmir Himalaya. *Ecol. Balk*. ***4***: 77–83.

Declerck, S., Vanderstukken, M. Pals, A. Muylaert, K. and De Meester, L. (2007). Plankton biodiversity along a gradient of productivity and its mediation by macrophytes. *Ecology*. **88:** 2199–2210

Dereje Tewabe, Seid Muhammed and Belay Abdissa (2005). Distribution and abundance of macro-benthic and weed-based faunas in the northern part of Lake Tana. Internal Report ARARI, Bahir Dar, Ethiopia, 14 pp.

Dhote, S. (2007). Role of Macrophytes in improving water quality of an aquatic ecosystem. *JASEM*. ***11***: 133–135.

Dhote, S. and Dixit, S. (2009). Water quality improvement through macrophytes: A review. *Environ. Monit. Assess*. **152**: 149-153.

Diaper, C., Tjandraatmadja, G., Pollard, C., Tusseau, AC., Price, G., Burch, L., Gozukara, Y., Sheedy, C. and Moglia, M. (2008). Sources of critical contaminants in domestic wastewater: contaminant loads from household appliances. CSIRO: Water for a Healthy Country National Research Flagship.

Dolezˇal J., Yakubov V. and Hara T. (2013). Plant diversity changes and succession along resource availability and disturbance gradients in Kamchatka. *Plant Ecol.* **214**:477–488.

Drexler, J. and Bedford, B. (2002). Pathways of nutrient loading and impacts on plant diversity in a New York peatland. *Wetlands*. **22:** 263–281.

Dunne, E. and Reddy, K. (2005). Phosphorus biogeochemistry of wetlands in agricultural watersheds. In: *Nutrient management in agricultural wetlands: A wetlands solution,* eds. E.J. Dunne, K.R. Reddy and O.T. Carton, 105 -119. The Netherlan ds: Wageningen Academic Publishers.

Edwards, S., Mesfin Tadesse and Hedberg, I. (1995). *Flora of Ethiopia and Eritrea, Volume 2 Part 2,* Canellaceae to Euphorbiaceae. The National Herbarium, Addis Ababa, Ethiopia and Uppsala, Sweden, 420pp.

EEPA/UNIDO. (2003). *Standards for Industrial Pollution Control in Ethiopia.* Part Three, Standards for Industrial Effluents (General). FEPE of Ethiopia. 1:45–48.

Egertson, C., Kopaska, J. and Dowing, J. (2004). A century of change in macrophyte abundance and composition in response to agricultural eutrophication. *Hydrobiologia.* **524**:145-156.

El-Ghani, M., El Fiky, A., Soliman, A. and Khattab, A. (2010). Environmental relationships of aquatic vegetation in the freshwater ecosystem of the Nile Delta, Egypt. *AFR J ECOL*. **49:**103-118.

Emoyan, O., Ogban, F. and Akarah, E. (2006). Evaluation of Heavy Metals Loading of River Ijana in Ekpan – Warri , Nigeria. *JASEM*. **10***:* 121–127. http://doi.org/10.4314/jasem.v10i2.43690

Environment Canada (1987). Canadian Water Quality Guidelines [with updates]. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource Ministers, Environment Canada, Ottawa.

Environmental Management Bureau - Department of Environment and Natural Resources (EMB-DENR) (2008). Water Quality Monitoring Manual Volume II - Manual On Effluent Quality Monitoring. JICA Phillippine.

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.

Esteves, F. and Coord. (2011). *Fundamentos de Limnologia*. 3rd ed. Editora Interciência, Rio de Janeiro.

Etafa, E., Mohssine E-K. and Patrick, M. (*2010).* Ecohydrological status of Lake Tana - a shallow highland lake in the Blue Nile (Abbay) basin in Ethiopia: review. *Ecohydrol. Hydrobiol.* **10**:109-122.

Eyualem Abebe, Mees, J. and Coomans, A. (2001). Nematode communities of Lake Tana and other inland water bodies of Ethiopia. *Hydrobiologia.* **462:** 41–73.

Fisher, J. and Acreman, M. (2004). Wetland nutrient removal : a review of the Wetland nutrient removal : a review of the evidence. *Hydrol. Earch Syst. Sci*. **8**: 673–685. doi:10.5194/hess-8-673-2004

Fonge, B., Egbe, E., Fongod, A., Tening, A., Achu, R. and Yinda, Z. (2012). Effects of land use on macrophyte communities and water quality in the Ndop wetland plain, Cameroon. *J. Agric. Soc. Sci.*, **12**: 41–49.

Francis, I. and Shimelis Aynalem (2007). Bird surveys around Bahir Dar- Lake Tana IBA, Ethiopia. Report of RSPB Scotland, Aberdeen, UK, and Addis Abeba University, Biology Department, Ethiopia.

Galatowitsch S., Whited D., Lehtinen R., Husveth J. and Schik K. (2000). The vegetation of wet meadows in relation to their land-use. Environ. *Monit. Assess.* **60**: 121–144.

Gathumbi, S., Bohlen, P. and Graetz, D. (2005). Nutrient enrichment of wetland vegetation and sediments in Subtropical pastures. *Soil Sci Soc America*.

69:539-548.

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

Gaur, V., Gupta, S., Pandey, S. Gopal, K. and Misra, V. (2005). Distribution of heavy metals in sediment and water of River Gomti. *Environ Monit Assess.* **102**: 19–433.

Ghavzan, N., Gunale, V. Mahajan D. and Shirke, D. (2006). Effects of environmental factors on ecology and distribution of aquatic macrophytes. *Asian J. Plant Sci.* **5**: 871–880.

Girum Feleke (2011). *Constructed Wetlands with different substrates for Greywater Treatmen:. The Case of Spa Service Enterprise.* Master‟s thesis, in Insitute of Technology, Department of Chemical Engineering, Addis Ababa University, Addis Ababa. (Unpublished)

Girum Tamire and Seyoum Mengistu (2014). Biomass and net aboveground primary productivity of macrophytes in relation to physico-chemical factors in the littoral zone of Lake Ziway, Ethiopia). *Trop. Ecol*. **55**: 313-326.

Girum Tamire and Seyoume Mengistou (2012). Macrophytes species composition, distribution and diversity in relation to some physicochemical factors in the littoral zone of Lake Ziway, Ethiopia, *Afr. J. Ecol*. **51**: 66–77.

Gorraw Goshu, Byamukama, D., Manafi, M., Kirscher, A. and Farnleitner, A. (2010). A pilot study on anthropogenic faecal pollution impact in Bahir Dar Gulf of Lake Tana, Northern Ethiopia. *Ecohydrol. Hydrobiol.* **10**: 271- 280.

Gosselink, J. and Turner, R. (1978). *The role of hydrology in freshwater wetland ecosystems*. pp. 63–78. Freshwater wetlands, ecological processes and management potential. R.E. Good, and D.F. Whigham, R.L. Simpson, eds. Academic press, New York.

Hautot S, Whaler K., Gebru, W. and Desissa, M. (2006). The structure of a Mesozoic basin beneath the Lake Tana area, Ethiopia, revealed by magnetotelluric imaging. J. *Afr. Earth Sci*. **44**: 331–338.

Hedberg, I. and Edward, S. (1989). Flora of Ethiopia and Eritrea, Volume 3, Pittosporaceae to Araliaceae. The National Herbarium, Addis Ababa and Asmara, Ethiopia; Uppsala, Sweden.

Heegaard, E., Birks, H., Gibson, C., Smith, S. and Wolfe-Murphy, S. (2001). "species-environmental relationships of aquatic macrophytes in Northern Ireland". *Aquat. Bot.* **70**:175-223.

Heilde, Z. (2012). Feasibility Study for a Lake Tana Biosphere Reserve, Ethiopia

Hellsten, S. (2000). Environmental factors in aquatic macrophytes in the Littoral zone of regulated lakes: causes, consequences and possibilities to alleviate harmful effects. *Acta. Univ. Oul.* **348**: 1-46.

Hellsten, S. (2001). Effects of Lake water Level regulation on aquatic macrophytes stands in Northern Finland and options to predict these impacts under varying conditions. *Acta Bot. Fennia*. **171**: 1–47.

Herouvim, E., Christos, A., Tekerlekopoulou, A. and Vayenas, D. (2011). Treatment of olive mill wastewater in pilot-scale vertical flow constructed wetlands. *Ecol. Eng.* **37**: 931-939.

Hillman, J. (ed) (1993). *Ethiopia: Compendium of Wildlife Conservation Information. NYZS - The Wildlife Conservation Society.* International, New York Zoological Park, Bronx, NY and Ethiopian Wildlife Conservation Organisation, 2nd Vol, Addis Ababa, 786 pp.

Hinsinger, P., Plassard, C., Tang, C. and Jaillard, B. (2003). Origins of root- mediated pH changes in the rhizosphere and their responses to environmental constraints. A review. *Plant Soil*. **248:**43–59.

Hoffmann, H., and Platzer, C. (2010). Constructed wetlands for greywater and domestic wastewater treatment in developing countries [draft]. *Technology review "Constructed Wetlands",* Sustainable sanitation and ecosan program of Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Huai-en, L., Joseph ,H. and Ming, C. (2003). Nutrient Load Estimation Methods for Rivers. *IJSR*. **18**: 346-351

Hubble, D. and Harper, D. (2002). Nutrient control of Phytoplankton production in Lake Naivasha, Kenya. *Hydrobiologia.* **488**:99–105.

Hughes, R. and Hughes, J. (1992). A directory of African wetlands, World Conservation Union (IUCN), Gland (Switzerland); UNEP, Nairobi (Kenya); World Conservation Monitoring Centre, Cambridge (UK) pp 104-109.

IBC (2005). *Site Action Plan For The Conservation and Sustainable Use of Lake Ziway Biodiversity (Rift Valley Lakes Project)*. Institute of Biodiversity, Addis Ababa, Ethiopia, 76pp.

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.

Imoobe, T. and Akoma O. (2008). Assessment of Zooplankton Community Structure of the Bahir Dar Gulf of Lake Tana, Ethiopia. *EJESM.* **1**:26-34

Jafari, M., Zare Chahouki, M., Tavili, A., Azamivand, H. and Zahedi, A. (2003). Effective environmental factors in the distribution of vegetation types in Poshtkouh rangelands of Yazd Province (Iran). *J. Arid Environ*. **56**:627–641.

Jeppeesen, E., Jensen,J.,Sondergaard, M., Lnuridsen,T., Pedersen,L. and Jensen, L. (1977). Top ddown control in freshwater lakes: The role of nutrient state, submerged macrophytes and water depth. *Hydrobiologia*. **342/343**: 151-164.

JICA Project Technical Assistance Team (2008). Water Quality Monitoring Manual Volume II - Manual on Effluent Quality Monitoring, Environmental Management Bureau Department of Environment and Natural Resources,Wood fields Consultants, In**c.**

Jimoh, H., Vogler, C. and Waters, J. (2007). *Perceived and Real Sources of Pollution in Lake Naivasha*. Tropical Biology, Kenya, 15pp.

John, D., (1986). Inland waters of tropical West Africa. *Arch. Hydrobiol.* **23**: 1–244.

Johnson, S. and Rejmankova, E. (2005). Impacts of land use on nutrient distribution and vegetation composition of freshwater wetlands in Northern Belize. *Wetlands*. **25**: 89–100.

Jost, L. (2010). The Relation between Evenness and Diversity. *Diversity*. **2***:* 207–232.

Kadlec, R. and Wallace, S. (2009). *Treatment Wetlands.* 2nd ed. CRC press. Boca Raton. FL.

Kansiime, F., Nalubega, M., van Bruggen, J. and Denny, P. (2003). The Effect of Wastewater Discharge on Biomass Production and Nutrient Content of *Cyperus papyrus* and *Miscanthidium violaceum* in the Nakivubo wetland, Kampala, Uganda. *Water Sci. Technol*. **48**: 233 - 40.

Kansiime, F. and Nalubega, M. (1999). Wastewater Treatment by a Natural Wetland: the Nakivubo Swamp, Uganda 336.

Kansiime, F. and van Bruggen, J. (2001). Distribution and retention of faecal coliforms in the Nakivubo wetland in Kampala, Uganda. *Water Sci. Technol*. **44**: 199–206.

Kanyiginya, V., Kansiime, F., Kimwaga, R. and Mashauri, D. (2010). Assessment of nutrient retention by Natete wetland Kampala, Uganda. *Phys. Chem. Earth, Parts A/B/C,* **35:** 657–664. doi:10.1016/j.pce.2010.07.027

Kao, J., Titus, J. and Zhu, W. (2003). Differential nitrogen and phosphorus retention by five wetland plant species. *Wetlands*. ***23***: 979–987.

Karlberg, L., Hoff, H., Amsalu, T., Andersson, K., Binnington, T., Flores-lópez, F., de Bruin, A., Gebrehiwot, S., Gedif, B., zur Heide, F., Johnson, O., Osbeck, M. and Young, C. (2015). Tackling Complexity : Understanding the Food-Energy-Environment Nexus in Ethiopia "s Lake Tackling Complexity : Understanding the Food-Energy- Environment Nexus in Ethiopia`s Lake Tana Sub -basin. *Water Altern*. ***8****:* 710–734.

Kelderman, P., Kansiime, F., Tola, M. and Van Dam, A. (2007). The role of sediments for phosphorus retention in the Kirinya wetland (Uganda). *Wetl. Ecol. Manag*. **15**: 481–488. doi:10.1007/s11273-007-9048-4

Kenatu Angassa (2011). *Evaluation of the performance of constructed wetland system for treatment of brewery wastewater.* Master‟s thesis, Addis Ababa University, Addis Ababa. (Unpublished)

Kenzawi, M. (2007) "Ecological study of aquatic macrophytes in the central part of the marshes of Southern Iraq", Baghdad University-College of Science for Women, 1raq, pp. 270.

Kercher, S. and Zedler, J. (2004). Flood tolerance in wetland angiosperms: a comparison of invasive and noninvasive species. *Aquat Bot.* **80:** 89–102.

Ketema Dessalegn Molla (2013). Analysis of institutional arrangements and common pool resources governance: the case of Lake Tana sub-basin, Ethiopia. PhD Thesis, University College Cork.

Kim, L., Choi, E., Gil, K. and Stenstrom, M. (2004). Phosphorus release rates from sediments and pollutant characteristics in Han River, Seoul, Korea. *Sci. Total Environ*. ***321****:* 115–125. http://doi.org/10.1016/j.scitotenv.2003.08.018

Koelsch, R., Lorimer, J. and Mankin, K. (2006). Vegetative Treatment Systems for Open Lot Runoff: Review of Literature, (June). Biological Systems Engineering: Papers and Publications. Paper 5. *APPL ENG AGRIC*. **22**: 141-153

Kramer, J., Herbes and Allen H. (1972). Phosphorus: analysis of water, biomass, and sediment. pp. 51–101. In Nutrients in natural waters. John Wiley and Sons, Toronto.

Kumar, P. (2015). Waste Water Management through Aquatic Macrophytes. *Int. Res. J. Environment Sci*. **4:** 41–46.

Kyambadde, J., Kansiime F. and Dalhammar, G. (2005). Nitrogen and phosphorus removal in substrate-free pilot constructed wetlands with horizontal surface flow in Uganda. *Water Air Soil Pollut*. **165**:37–59

Kyambadde, J., Kansiime, F. and Dalhammar, G. (2006). Distribution and activity of ammonium-oxidizing bacteria in Nakivubo wastewater channel and wastewater treatment wetland, Uganda. *Acta Hydroch. Hydrob.* **34**: 137-145.

Lacoul, P. and Freedman, B. (2006).“Relationships between aquatic plants and environmental factors along a steep Himalayan altitudinal gradient”. *Aquat. Bot*. **84**: 3-16.

Lake Net (2004). *Lake Tana Symposium*. Bahir Dar University, Bahir Dar, Ethiopia.

Lawniczak, A., Zbierska, J., Choin, A. and Szczepaniak, W. (2010). Response of emergent macrophytes to hydrological changes in a shallow lake ,with special reference to nutrient cycling. *Hydrobiologia***. 656**: 243–254.

Lee, S. (1990). Net aerial primary productivity, litter production and decomposition of the reed *Phragmites communis* in a nature reserve in Hong Kong: Management implications. *Mar. Ecol. Prog. Ser.* **66:** 161-173.

Leps, J., Smilauer, P. (1999). *Multivariate Analysis of Ecological Data*. University of South Bohemia, Ceske Budejovice, Czech, 110pp.

Leykun Abunye (2003). The distribution and status of Ethiopian wetlands: an overview. **In**: *Wetlands of Ethiopia: Proceedings of a seminar on the resources and status of Ethiopia's wetlands (*Abebe Yilma and Kim Geheb eds.), pp 12-17, IUCN, Nairobi, 123pp.

Ligdi, E., El Kahloun, M. and Meire, P. (2010). Ecohydrological status of Lake Tana – a shallow highland lake in the Blue Nile: review. *Ecohydrol. Hydrobiol.* **10**: 109-122.

Lin, Y., Jing, S., Wang, T. and Lee, D. (2002). Effects of macrophytes and external carbon sources on nitrate removal from groundwater in constructed wetlands. *Env. Pollut*. **119**:413–420.

Loiselle S, Cózar A, van Dam, A. Kansiime, F. Kelderman, P. Saunders, M. and Simonit, S. (2006). Tools for Wetland Ecosystem Resource Management in East Africa: Focus on the Lake Victoria Papyrus Wetlands. - In: Verhoeven JTA, Beltman B, Bobbink R and Whigham DF (ed.); Wetlands and Natural Resource

Management, 7th International Wetland Conference. Utrecht, Netherlands, Jul 25-30, 2004. Springer-Verlag, Berlin, p. 97-121.

Lone, P., Bhardwai,A.K and Shah, K.W. (2014). Macrophytes as Powerful Natural Tools for Water Quality Improvement. *Res.J.Bot*. **9**: 24-30.

Lopes, P., Caliman, A., Carneiro, L., Bini, L., Esteves, F., Farjalla, V. and Bozelli, R. (2011). Concordance among assemblages of upland Amazonian lakes and the structuring role of spatial and environmental factors. *Ecol.Indic.* ***11:*** 1171–1176. http://doi.org/10.1016/j.ecolind.2010.12.017

Lu, X., Lu, P. and Chen, J. (2012). Nitrogen and phosphorus removal and morphological and physiological response in Nymphaea tetragona under various planting densities. Toxicol. *Environ. Chem.* **94**:1319–1330.

Ma, X., Ma, C., Li, Mi, Y., Bai, T. and Shu, H. (2010). Biomass accumulation, allocation, and water-use efficiency in 10 Malus rootstocks under two watering regimes. *Agroforest. Syst.* **80**:283–294.

MacDonald, D. and Ingersoll, C. (2002). *EPA A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems*.

Macek, P. and Rejmankova, E. (2007). Response of emergent macrophytes to experimental nutrient and salinity additions. *Func. Ecol.* **21:** 478–488

Mallin, M., Ensign, S., Wheeler, T. and Mayes, D. (2002). Pollutant removal efficacy of three wet detention ponds. *J. Environ. Qual.* **31**: 654-660.

Manral, U., Raha, A., Solanki. R., Hussain, S., Mohan, D., Talukdar, G. and Veeraswami G. (2012). Hydrological characteristics and flood plain vegetation of human impacted wetlands: A case study from Okhla Bird Sanctuary, National Capital Region, India. *AJCB*. **2**: 110 –119

Mars, R., Taplin, R., Ho, G., and Mathew, K. (2003). Grey water treatment with the submergent *Triglochin huegelii*- a comparison between surface sub-surface systems. *Ecol. Eng.* **20**:147–156.

Masifwa, W., 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. *Hydrobiologia.* **452**:79–88.

Matovu Abdallah (2010). *Impact of wastewater discharge and pollution on water qualityand biota in Kiyanja Stream, Kawempe Division, Kampala.* MSc thesis, Makerere University.

McCartney, M., Tadesse Alemayehu, Abeyu Shiferaw and Silesh Bekele Awulachew (2010). Evaluation of current and future water resources development in the Lake Tana Basin, Ethiopia. Colombo, SriLanka: International Water Management Institute. 39p. (IWMI Research Report 134). doi:10.3910/2010. 204.

McKee J. (2007). *Ethiopia Country Environmental Profile*. EC, 132pp.

Melaku Getachew, Argaw Ambelu, Seid Tiku, Worku Legesse, Aynalem Adugna and Kloos H. (2012). Ecological assessment of Cheffa Wetland in the Borkena Valley, northeast Ethiopia: Macroinvertebrate and bird communities. *Ecol. Indic*. **15**:63–71

Mfundisi, K. (2005). *Analysis of carbon pools and human impacts in the yala swamp (Western Kenya): A landscape approach.* Doctoral thesis at Faculty of Math. & Nat. Science, University of Bonn.

Mironga, J., Mathooko, J. and Onywere, S. (2012). Effect of water hyacinth infestation on the physico-chemical characteristics of Lake Naivasha. *Int. J. Hum. Soc. Sci*., **2**:103–113.

Mitsch, W. and Gosselink, J. (2000). *Wetlands*, 3rd edition, 920 pp. New Yourk. John Wiley and Sons.

Mnaya, B., Asaeda, T., Kiwango, Y. and Ayubu, E. (2007). Primary production in papyrus (Cyperus papyrus L.) of Rubondo Island, Lake Victoria, Tanzania. *Wetlands Ecol. Manage*. **15**:269–275.

Molla, M. and Menelik, T (2004). Environmental impact assessment for unusual reduced water level of Lake Tana. **In**: *Proceedings of the Symposium on Lake Tana watershed management*. Lake Net, USA, pp 35–48

Moreaux, R. (2011). Remaining Forests of the Lake Tana Region – Their Social, Ecological, Economical Functions and Possibilities for Rehabilitation. reliminary research finding of a master thesis, Greifswald University, Germany (Unpublished).

Mueleman, A., Beekman, J. and Verhoeven, J. (2002). Nutrient retention and nutrient use efficiency in *Phragmities australis* stands after wastewater application. *Wetlands*. **22:**712–721.

Mueller-Dombois, D. and Ellenberg, H. (1974). *Aims and Methods of Vegetation Ecology*. Wiley and Sons, New York, NY, 547pp.

Mugisha, P., Kansiime, F., Mucunguzi, P. and Kateyo, E. (2007). Wetland vegetation and nutrient retention in Nakivubo and Kirinya wetlands in the Lake Victoria basin of Uganda. *Phys. Chem. Earth*. **32**:1359–1365.

Mundt, F. (2011). *Wetlands around Lake Tana: A landscape and avifaunistic study*. Preliminary research finding of a master thesis, Greifswald University, Germany.

Murphy, K. (2002). Plant communities and plant diversity in softwater lakes of northern Europe. *Aquat. Bot*. **73**: 287–324.

Nagelkerke, L. (1997). *The barbs of Lake Tana, Ethiopia: morphological diversity and its implications for taxonomy, trophic resource partitioning and fisheries.* Ph.D. thesis, Wageningen University, The Netherlands, 296 pp.

Ndiokwere, C. (2004). *Chemistry and Environment*, Inaugural Lecture Series 73, University of Benin, UNIBEN Press, Pp. 33-37

Negash Atnafu (2010). *Assessment of Ecological and Socio-Economic Importance of Fogera Floodplains: the case of Wolala and Shesher Wetlands*, M.S. thesis, Bahir Dar University, Bahir Dar, Ethiopia,

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*). JWARP*. **3**: 540-547

Nichols, D. (1983). Capacity of natural wetlands to remove nutrients fromwastewater. *J. water pollu.cont.fed*. **55**:495-505

Njenga, J. (2004). Comparative studies of water chemistry of four tropical Lakes in Kenya and India. *Asian J. Water Environ. Pollut*. **1**:87–99.

Nurminen, L. (2003). Macrophyte species composition reflecting water quality changes in adjacent water bodies of Lake Hiidenvesi, Finland. *Ann. Bot. Fenn*. **40**:199–208.

Okurut, T. (2000*). A pilot study on municipal wastewater treatment using constructed wetlands in Uganda.* PhD thesis. A.A. Balkema, Rotterdam, The Netherlands.

Osumba, J., Okeyo-Owour J. and Raburu, P. (2010). Effect of harvesting on temporal papyrus regeneration potential among swamps in Winam Gulf of Lake Victoria Basin, Kenya. *Wetlands Ecol. Manage*. **18**: 333–341.

Padial, A., Declerck,S., DeMeester, L., Bonecker,C., Lansac-Tôha,F., Rodrigues,L.C., Takeda,A., Train,S., Velho,L.F. and Bini,L.M. (2012). Evidence against the use of surrogats for biomonitoring of Neotropical floodplains. *Freshwater Biol*. **57**: 2411–2423.

Pajeviü, S., Igiü, R., Krstiü, B., Vukov, D., Borišev, M. and Nikoliü, N. (2005). Chemical compositions of aquatic macrophytes from the Danube – role in biomonitoring and bioremediation. Proceedings of the Balkan scientific conference of biology in Plovdiv (Bulgaria) from 19th till 21st of May 2005 (eds B. Gruev, M. Nikolova and A. Donev), p.485–498.

Palma, P., Alvarenga, P., Palma, V., Fernandes, R., Soares, M. and Barbosa, I. (2010). Assessment of anthropogenic sources of water pollution using multivariate statistical techniques: A case. *Environ. Monit. Assess*. **165**:539–552.

Parnell, A. (2011). *Effects of Antropogenic Nutrient Enrichment on Exotic and Restored Native Aquatic Vegetation.* Msc. Thesis,Texas A&M University

Paul, W. (2011). *Impact of Industrial Effluents on Water Quality of Receiving Streams In Nakawa-Ntinda, Uganda.* MSc. Thesis

Perbangkhem and Polprasert (2010). Biomass production of papyrus (Cyperus papyrus) in constructed wetland treating low-strength domestic wastewater. *J.biortech*. **101**: 833-835.

Pereira, S. and Trindade, C. (2012). Aquatic macrophytes as indicators of water quality in subtropical shallow lakes, Southern Brazil. *Acta Limnol. Bras.* ***24**:* 52–63.

Piotrowicz, R., Kraska, M., Klimaszyk, P., Szyper, H. and Joniak, T. (2006). Vegetation Richness and Nutrient Loads in 16 Lakes of Drawieński National Park (Northern Poland). *Polish J. of Environ. Stud.* **15**: 467-478

Pompeo, M. and Moschini-Carlos, V. (1996). Seasonal variation of the density of the macrophyte *Scirpus cubensis* (Poepp and Kunth) (CYPERACEAE) in the Lagoa do Inferno, State of Sao Paulo, Brazil. *Limnetica.* **12**:17–23.

Poppe, L., Frankl, A., Poesen, J., Teshager Admasu, Mekete Dessie, Enyew Adgo, Deckers, J. and Nyssen, J. (2013) Geomorphological map of the Lake Tana basin. *Ethiopia. J Maps*. **9**: 431-437.

Powel, K. (2008). *Quantifying soil organic carbon (SOC) in wetlands impacted by groundwater withdrawals in west-central Florida*. MSc thesis, University of South Florida, USA, 113pp.

Prica, M., Dalmacija, B., Ronc˘ evic´, S., Krc˘ mar, D. and Bec˘ elic´ M. (2008). A comparisonof sediment quality results with acid volatile sulfide (AVS) and simultaneouslyextracted metals (SEM) ratio in Vojvodina (Serbia) sediments. *Sci Total Environ.* **389**: 235–244.

Rao, T., Yano, K., Iijima, M., Yamauchi, A. and Tatsumi, J. (2002). Regulation of rhizosphere acidification by photosynthetic activity in cowpea (*Vigna unguicukata* L. Walp.), Seedl. *Ann. Bot- London.* **89**:213–220.

Reddy K. (1984) Water hyacinth Eichhornia crassipes biomass production in Florida. *Biomass.* **6**: 167-181.

Rientjes, T., Perera, B., Haile, A., Reggiani, P. and Muthuwatta, L. (2011). Regionalisation for lake level simulation: the case of Lake Tana in the upper Blue Nile, Ethiopia. *HESS*. **15**: 1167–118.

Ruiz, M. and Velasco, J. (2010). Nutrient bioaccumulation in phragmites australis: Management tool for reduction of pollution in the mar menor. *Water Air Soil Pollut.* ***205****:* 173–185.

Rzóska, J. (1976). Lake Tana, headwaters of the Blue Nile. In: J. Rzóska (ed.), *The Nile, Biology of an Ancient River*. Dr W Junk, The Hague, pp. 223–232.

Sahu, O. and Seid Yimer. (2014).Treatment of Municipal Waste Water by Wetland. *Environ Microbiol*. **2**: 145–151.

Sánchez-Carrillo , S. Angeler, D., Álvarez-Cobelas, M. and Sánchez-Andrés R. (2011). Freshwater wetland eutrophication. In Abid A. Ansari , Sarvajeet Singh Gill , Guy R. Lanza , Walter Rast (Ed.), *Eutrophication: causes, consequences and control* (1st ed., pp. 195–210). Netherlands: Springer Netherlands. http://doi.org/10.1007/978-90-481-9625-8

Schallenberg, M and Waite, E. (2004).Survey of Aquatic macrophytes in Lake Waihola, Summer 2002-2003. Limnology Report No. 9, Department of Zoology, University of Otago.

Seifu Kebede, Travi Y, Taddesse Alemayehu and Marc V. (2006). Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile Basin, Ethiopia. *J. Hydrol.* **316**: 233–247.

Selome Mekonnen Tessema (2006). *Assessment of Temporal Hydrological Variations Due to Land Use Changes Using Remote Sensing/Gis KTH: A Case Study Of Lake Tana Basin*. TRITA LWR Masters Thesis.

Serag, M. and Khedr, A. (2001). “Vegetation-environment relationships along El-Salam Canal, Egypt”. *Environmetrics*. **12:** 219-232.

Shah, M., Hashmi, H., Ali, A. and Ghumman, A. (2014). Performance assessment of aquatic macrophytes for treatment of municipal wastewater. *J. Environ. Heal. Sci. Eng.* **12**: 1–12. doi:10.1186/2052-336X-12-106

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

Sheikh, J., Jeelani, G. and Gavali, R. (2011). Distribution of Emergent Macrophytes of Three Eutrophic Lakes from Jhansi, Bundelkhand Region, *J RES DEV.* **11**: 41–48.

Shilla D. and Dativa ,J. (2008). Biomass dynamics of charophyte-dominated submerged macrophyte communities in Myall Lake, NSW. - *Australia, Chem. Ecol*. **24**: 367-377.

Shimelis Aynalem (2007). *Species Composition, Distribution, Relative Abundance & Habitat Association of the Bird Fauna of Bahir Dar, Zegie Peninsula and the Nearby Islands of Lake Tana, Bahir Dar.* M.Sc. Thesis. Addis Ababa University, Ethiopia.

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. *Trop. Ecol*. **49**: 199-209.

Shimelis Gebriye, Srinivasan, R., Dargahi, B. and Assefa Melesse (2009). Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. *Hydrol. Processes.* **23**:1-13

Shimelis Setegn, Srinivasan, R., Assefa Melesse and Dargahi, B. (2010). SWAT model application and prediction uncertainty analysis in the Lake Tana Basin, Ethiopia. *Hydrol. Processes.* **24**: 357-367.

Shrestha, S. and Kazama, F. (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environ. *Model.* **22**: 464-475.

Shuman, L. (1994). Mineral nutrition. **In**: *Plant- Environment Interactions,* pp 149-182, (Wilkinson, R. E. ed). Marcel Dekker, Inc., New York, 612pp.

Silva, T., Costa, M. and Melack, J. (2010). Assessment of two biomass estimation methods for aquatic vegetation growing on the Amazon floodplain. *Aquat. Bot*. **92**:161–167.

Sim C., Eikaas H., Chan S. and Gan J. (2011). Nutrient removal and plant biomass of 5 wetland plant species in Singapore. *Water Pract. Technol*. **6:** 3.

Singh, K., Sharma, B. and Usha, K. (2013). Inventory of the Aquatic Macrophytes in Lake Kharungpat, India. *Journal of Energy Technologies and Policy*. ***3****:* 64–75.

Singh. K Sharma, B. and Usha, K. (2010). Biomass dynamics of the macrophytic species of kharungpat lake, manipur, india. *Bioscan*. **2**: 373-382

Sizo, A., Noble, B. and Bell, S. (2015). Futures analysis of urban land use and wetland change in Saskatoon, Canada: An application in strategic environmental assessment. *Sustainability*. ***7****:* 811–830. http://doi.org/10.3390/su7010811

Soto -Jim enez, M., Paez-Osuna, F and Bojorquez- Leyva, H. (2003). Nutrient cycling at the sediment –water interface and in sediments at Chiricahueto marsh: A subtropical ecosystem associated with agricultural land uses. *Water Res.* **37**: 719 -728.

Stanković, Ţ., Pajević, S., Vučković, M. and Stojanović, S. (2000). Concentrations of trace metals in dominant aquatic plants of Lake Provala (Vojvodina, Yugoslavia). *Biologia Plant*. **43**: 583 – 585

Stefanakis, A. I. and Tsihrintzis, V. (2012). Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of a pilot-scalevertical flow constructed wetlands. *Chemical Engineering Journal*. **181**: 416-430.

Straub, K. Benz, M. and Schink, B. (2001). Iron metabolism in anoxic environments at near neutral pH. *FEMS Microbiol. Ecol.* **34**:181-186

Sushil, M. (2012). Performance Evaluation of Reed Grass (*Phragmites karka*) in Constructed Reed Bed System (CRBs) on domestic sludge, Ujjain city, India. *Res.J.Recent.Sci.* **1:**41–46.

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

Tadesse Alemayehu, McCartney, M. and Seifu Kebede (2010). The water resource implications of planned development in the Lake Tana catchment, Ethiopia. *Ecohydrol. Hydrobiol*. **104**: 211- 222.

Tadesse Alemu, Seyoum Leta and Alemayehu Mengistu (2012). Phytoremediation Potential of Plants in Tannery wastewater Treatment. LAP Lambert Academic Publishing ISBN-13 978-3838391250https://www.lap-publishing.com/

Tenagne Addisu Wondie (2009). *The Impact of Urban Storm Water Runoff and Domestic Waste*. Msc. Thesis. Cornell University

Tenalem Ayenew and Dagnachew Legesse (2007). The changing face of the Ethiopian rift lakes and their environs: call of the time. *Lakes Reserv ResManag.* **12**: 149–165.

ter Braak, C. (1987). The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetatio.* **69**:69-77.

ter Braak, C. and Šmilauer P.(1998). CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4). Microcomputer Power, Ithaca, NY, USA.

Terer, T., Ludwig, T. and Muasya, A. (2012). Effects of harvesting Cyperus papyrus in undisturbed wetland, Lake Naivasha, Kenya. *Hydrobiologia*. **680**:135–148

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

Thenya, T. 2006. *Analysis of macrophyte biomass productivity, utilization and its impact on various eco-types of Yala Swamp, Lake Victoria Basin, Kenya*. Ecology and Development Series No. 48,

Thomaz, S., Chambers, P., Pierini S. and Pereira, G. (2007). Effects of phosphorous and nitrogen amendment on the growth of Egeria najas. *Aquat.Bot.* **86**: 191-196.

Thomaz, S., Esteves, F., Murphy, K. dos Santos, A., Caliman, A. and Guariento, R. (2008). Aquatic macrophytes in the tropics: ecology of populations and communities, impacts of invasions and use by man. Trpoical Biology and Conservation Management – IV. UNESCO, pp.1252-1280

Titus, J. and Stone, W. (1982). Photosynthetic response of two submersed macrophytes to dissolved inorganic carbon concentration and pH. *Limnol. Oceanogr.* **27**:151-160.

Tjandraatmadja, G., Diaper, C., Gozukara, Y., Burch, L., Sheedy, C. and Price, G. (2008). Sources of priority contaminants in domestic wastewater: Contaminant contribution from household products. CSIRO: Water for a Healthy Country National Research Flagship.

Trepanier, C., Parent, S., Comeau, Y. and Bouvrette, J. (2002). Phosphorous budget as a water quality management tool for closed aquatic mesocosms. *Water Res*. **36**:1007–1017.

Udomsri, C., Premcharoen, S., Thawatphan, C., Vidthayanon, C. and Vajrodaya, S. (2004). Community structure of aquatic plants in Bung Khong Long, Nongkhai province, a Ramsar site of Thailand. *Witthayasan Kasetsat.* **39**: 64-75

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

United States Environmental Protection Agency (USEPA) (1986). *Quality Criteria for Water. Office of Water*. EPA-440-5-86-001

United States Environmental Protection Agency (USEPA) (1993). Drinking Water Regulations and Health Advisories. Health and Ecological Criteria Division, United States Environmental Protection Agency, Washington D.C.

United States Environmental Protection Agency (USEPA) (1994). Method 200.7, “Determination of Metals and Trace Metals in Water and Wastes by Inductively

Coupled PlasmaAtomic Emission Spectrometry," http://www.epa.gov/ waterscience/methods/method/files/200_7.pdf

United States Environmental Protection Agency (USEPA) (1999). Free water surface wetlands for wastewater treatment: a technology assessment. *U.S. Environmental Protection Agency.* EPA 832– S–99–002.

United States Environmental Protection Agency (USEPA) (2000). *Manual Constructed Wetlands Treatment of Municipal*. Wastewaters Office of Research and Development Cincinnati, Ohio. Retrieved January 15, 2012, from: http://www.epa.gov/ORD/NRMRL

Vanek, V. (19991). Riparian zone as a source of phosphorus for a groundwater dominated lake. *water Res*. **25:** 409-418

Varol, M. (2011). Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. *J Hazard Mater.* **195**: 355–364

Verhoeven, J., Arheimer, B., Yin, C. and Hefting, M. (2006). Regional and global concerns over wetlands and water quality. *Trends Ecol. Evol*. **21:** 96–103. doi:10.1016/j.tree.2005.11.015

Vijverberg, J., Sibbing, F. and Dejen, E. (2009). Lake Tana: Source of the Blue Nile. In H. J. Dumont, The Nile: Origin, Environments, Limnology and Human Use (p. 818). Dordrecht: Springer Netherlands.

Vymazal, J. (2002). The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. *Ecol. Eng.* **18**:633–646.

Vymazal, J. (2009). The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecol. Eng*. **35**: 1-17. doi:10.1016/j.ecoleng.2008.08.016

Vymazal, J. (2011). Plants used in constructed wetlands with horizontal subsurface flow: A review. *Hydrobiologia.* **674**: 133–156.

Wang, B., Wang, Y. and Wang, W. (2014). Retention and mitigation of metals in sediment, soil, water, and plant of a newly constructed root-channel wetland (China) from slightly polluted source water. *Springerplus*. **3***:* 326. doi:10.1186/2193-1801-3-326

Wassie Anteneh, Abebe Getahun and Eshete Dejen (2008). The lacustrine species of *Labeobarbus* of Lake Tana (Ethiopia) spawning at Megech and Dirma Tributary Rivers. *SINET Ethiop.J.Sci*. **31**: 21–28.

Wassie Anteneh, Minwuyelet Mengist, Ayalew Wondie, Dereje Tewabe, Woldegebrael W/Kidan, Addisalem Assefa and Wondie Engida (2014). Water hyacinth coverage survey report on Lake Tana, Technical Report Series 1, 1 – 29.

Wetzel, R. (2001). *Limnology: Lake and River Ecosystems*. Academic Press, U.S.A. 1006pp.

Wetzel, R. and Likens, G. (2000). *Limnological analyses*. 3rd ed.Springer Verlag, New York, 430pp.

Willby, N., Pulford, I., and Flowers, T. (2001). Tissue nutrient signatures predict herbaceous-wetland community responses to nutrient availability. *New Phytol.* **152**: 463- 481.

Woldegabriel G/kidan and Solomon Teka (2006). Ecological Significances, Threats and Management Options of Lake Tana-Associated Wetlands. Analysis of the Biophysical and Cultural Resources, and Socioeconomic Factors. Amhara National Regional State, Environmental Protection Land Administration and Use Authority, Bahir Dar.

Wood, A., Afework Hailu, Abbot, P. and Dixon, A. (2002). Sustainable management of wetlands in Ethiopia: Local knowledge versus government policy. **In**: *Strategies for wise use of wetlands: Best practices in participatory management,* (Gawler, M. ed), p 81-88, IUCN, Gland, Switzerland, 116pp.

Wu, H., Zhang, J., Li, P., Zhang, J., Xie, H. and Zhang, B. (2011). Nutrient removal in constructed microcosm wetlands for treating polluted river water in northern China. *Ecol. Eng*. **37**: 560–568

Xu, Z., Yin, X. and Yang, Z. (2014). An optimisation approach for shallow lake restoration through macrophyte management. *HYDROL EARTH SYST SC*. ***18:*** 2167–2176. http://doi.org/10.5194/hess-18-2167-2014

Yang J, Skogley E, Schaff B and Kim J.(1998). A simple spectrophotometric determination of nitrate in water. *Soil Sci. Soci. American J.* **62:**1108 – 1115

Yang, L., Chang, H. and Huang, M. (2001). Nutrient removal in gravel and soil-based wetland microcosms with and without vegetation. *Ecol. Eng.* **18**:91–105.

Yirga Kebede Wondim and Hassen Muhabaw Mosa (2015). Spatial Variation of Sediment Physicochemical Characteristics of Lake Tana Ethiopia. *Journal of Environment and earth science.* ***5:*** 95–110.

Yirgalem Chebud and Ayalew Melesse (2009). Modeling lake stage and water balance of Lake Tana, Ethiopia. *Hydrol. Processes.* **23**: 3534–3544.

Yu, S., Chen, W., He, X., Liu, Z., Song, H., Ye, Y., …and Jia, L. (2014). A Comparative Study on Nitrogen and Phosphorus Concentration Characteristics of Twelve Riparian Zone Species from Upstream of Hunhe River. *CLEAN - Soil Air Water pollu*. ***42***: 408–414.

Zedler, J. and Kercher, S. (2004). Causes and Consequences of Invasive Plants in Wetlands: Opportunities, Opportunists, and Outcomes. *Critical Rev. Plant Sci.* **23**: 431–452.

Zerihun Woldu and Kumulachew Yeshitila (2003). Wetland plants in Ethiopia with examples from Illubabor, south-western Ethiopia. **In**: Wetlands *of Ethiopia, Proceedings of a seminar on the resources and status of Ethiopia's wetlands* (Yilma Abebe and Kim Geheb eds), pp 49-57, IUCN, 123pp.

Zhanglu, L. (2014). The Response of Macrophytes to Nutrients and Implications for the Control of Phytoplankton Blooms in East Taihu Lake, China. *J. Pollut. Eff. Control* . **2**: 2–6. doi:10.4172/2375-4397.1000113

Zhang, Y., Wang, J. and Qui, J. (2010). Effectiveness of a sub-surface constructed wetland on the treatment of saline wastewater. *Environ. Sci. Eng*. **4**:9–13.

Zhu B., Mayer, C. and Rudstam, G. (2008). A comparison of irradiance and phosphorus effects on the growth of three submerged macrophytes. – *Aquat.Bot*. **88**: 358–362.

Zhu, L., Li, Z. and Ketola, T. (2011). Biomass accumulations and nutrient uptake of plants cultivated on artificial floating beds in China's rural area. *Ecol. Eng.* **37**:1460–1466

Zhuang, W. and Gao, X. (2014). Integrated assessment of heavy metal pollution in the surface sediments of the Laizhou Bay and the coastal waters of the Zhangzi Island, China: Comparison among typical marine sediment quality indices. *PLoS One.* **9**: e94145. doi:10.1371/journal.pone.0094145

Zinabu Gebre-Mariam (2002). The Ethiopian rift valley lakes: major threats and strategies for conservation. **In**: *Ethiopian rift valley lakes*, pp.259-271, (Tudorancea, C. and Taylor, W.D. eds), Backhuys publishers, Leiden, The Netherlands.