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Assessment of the Impact of Anthropogenic Activities on Water Quality, Biodiversity and Livelihood in Lake Tana, Northwestern Ethiopia

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DECLARATION

I Sisay Misganaw Tamiru hereby declare that this disertaion is my own work and that all sources that I have used or quoted have been indicated and acknowledged as references. The thesis has not been submitted to other institution or University for the award of a degree.

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Signed (Author)	**Date**

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DEDICATION

I dedicate this research work to my beloved family: my wife Tsehaynesh Serkalem and my kids Absalat Sisay and Loza Sisay.

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ACRONYMS

a.s.l	Above sea level
APHA	American public health association
ARARI	Amhara region agricultural institute
ARS	Amhara regional state
ASPT	Average score per taxon
BDU	Bahir Dar university
BI	Biotic index
BMI	Benthic macroinvertabrate metric index
BOD	Biological oxygen demand
BOD5	Biological oxygen demand of five days
CBOs	Community based organizations
CCME	Canadian council of ministers of the environment
CFU	Coli form unit
CLI	Community loss index
COD	Chemical oxygen demand
D	Dry season
DF	Dominant family
DO	Dissolved oxygen
DOC	Dissolved organic carbon
EC	Electrical conductivity
EPA	Environmental protection authority
EPLUA	Environmental protection land administration and use authority
EPT	Ephemeropterans, Plecopetrans and Trichopterans
EU	European union
FDREEPA	Federal democratic republic of Ethiopia environmental protection authority
FBI	Family biotic index
FGD	Focus group discussion
GPS	Global positioning system
HBI	Hilsenhoff biotic index
IBAs	Important bird areas
IBI	Index of biological integrity
IBMWP	Index biological monitoring working party

ID	Impacted sites in the dry season
IT	Total number of organisms collected in the impacted sites
IW	Impacted sites in the wet season
Imp	Impacted site/s
IQ	Intelligent quotient
KI	Key informant
KII	Key informant interview
LT	Lake Tana
LTMI	Lake Tana metric index
MF	Membrane filtration tests
MIBI	Macroinvertebrate index of biotic integrity
MI	Metric index
MPN	Most probable number test
NBI	Nile basin initiative
NGOs	Non government organizations
No. wet	Number of organisms in the wet season
No. dry	Number of organisms in the dry season
No. T	Total number of organisms collected in the study time
PMA	Percent model affinity
RDA	Redundency analysis
Ref	Reference Site
SD	Standard deviation
SE	Standard error
T	Total in the sampling year
TDS	Total dissolved solides
T dry	Total number of organisms collected in the dry season
T wet	Total number of organisms collected in the wet season
TLT	Total number of organisms collected in Lake Tana
Temp	Water temperature
TSS	Total suspended solides
TR	Taxa richness
UNIDO	United Nations industrial development organization
USEPA	United states environmental protection agency

UV/Vis	Ultraviolet per visibility
WHO	World health organization
W	Wet season
WQI	Water quality index

ABSTRACT

Lake Tana is a biodiversity and natural reservoir for fresh water supply contributing significantly to the economy of Ethiopia and downstream recipient countries, namely: Sudan and Egypt. The Lake Tana Ecosystem provides a variety of goods and services such as: provisioning, regulating, amenity and supporting services. These services are affected by high human activities which threaten the water quality and biodiversity of the lake. Hence, this study aims to assess the impact of human activities on water quality, biodiversity and livelihood of Lake Tana and its shore sides.To assess the impact of anthropogenic activities of Lake Tana; physicochemical parameters, macroinvertebrates, macrophytes and livelihood of the Lake side communities were collected in the year 2014/2015 during dry and wet seasons for 11 sampling sites as indicated in Figure 1.1 and Table 1.1. The variations of physicochemical, metals and bacterial parameters were investigated. The overall water quality parameters (mean analytical results) of Lake Tana were found to be: Temp (Temperature)23.0^{O}C, pH 7.5, EC (Electrical conductivity)180.1 µS/cm, BOD$_5$ (Biological oxygen demand in 5 days)37.3 mg/l, COD (Chemical oxygen demand)316.5 mg/l, TSS 0.3 mg/l, TDS 93.1 mg/l, SO_4^{2-} 11.0 mg/l, PO_4^{3-} 42.4 mg/l, Cr (0.08 mg/l), (Mn (0.01 mg/l), E. Coli (13.4 Cell/ml), F. Coliform (82.5 Cell/ml), T. Coliform (113.0 Cell/ml), etc. These parameters did not show significant variation among the sites but were significantly different between wet and dry seasons ($P<0.05$). The highest concentration values were recorded during the wet season. However, most of the parameters under investigation were within the Ethiopian EPA (Environmental protection agency) permissible range except PO_4^{3-}, S^{2-}, E. Coli (Cell/ml), F. Coliform (Cell/ml) and T. Coliform (Cell/ml). Based on the analysis of the water quality index (WQI), Lake Tana water was unfit for drinking purpose and needs treatment. For the Macroinvertebrates analysis, a total number of 629 macroinvertebrate individuals are belonging to 9 orders and 38 families were found. In the study year impacted areas number of identified macroinvertebrates were 478 (76%); of this, 233 (37%) were in the wet season and 245 (39%) in the dry season and the total number of individuals identified in the reference area was 151 (24% of the total) in the wet season 61 (9.7%) and in the dry season 90 (14.3%) individuals. The diversity was more in the dry season. The dominant orders were Odonata (156 individuals), Coleoptera (153 individuals) and Hemiptera (141 individuals). The literature indicated that the presence of more Odonata, Coleptera and Hemipteran larvae is an indication of water quality deterioration due to pollution. From the collected samples, the total number of tolerant individuals was 303 (48.2%) and facultative individuals were 243 (38.7%) while intolerant *individuals were 80 (12.7%). Most of the taxa (48.2%) had tolerance scores ranging from 7 to 10. The analysis of different forms of indices showed poor water quality. The water quality of Lake Tana was also determined by developing the LTMI (Lake Tana Metric Index). The index indicated the impairment levels of the study sites. Seven of the sites were in the category of poor (disturbed) and the other three were very poor (highly disturbed). The study on macrophytes recorded 43 species and 18 families during the two seasons (wet and dry), throughout the study year. 2687 individual macrophytes were collected; 1756 in the wet season and 931 in the dry season. Poaceae (15 species) with abundance mean 215.40 ± 421.7 was the most dominant family, followed by Cyperaceae (5 species) 35.40 ± 68.3. Sacciolepis africana was the dominant macrophyte species in Lake Tana. But in the study area Ambobahir, the dominant species was Cyperus papyrus while the Megech study area was invaded by the nuisance exotic weed Eichhornia crassipes. In the present study, the low macrophyte diversity values of Shannon Wiener index (2.90), Simpson Diversity Index (1-D) (0.90), Simpson Dominance Index (D) (0.10), Margalef's index (M') richness index (5.32) and Evenness Index (E) (0.77) throughout the study year indicate moderate water quality status while the presence of certain bio-indicator species like Eichhornia, Potamogeton and Cyperus in the lake also confirm pollution. Because of the effect of human activities on water quality and biodiversity, the livelihood of the riparian community is affected indirectly. Hence, to recommend mitigation and remediation actions, this study also focused on the assessment of the change of livelihoods of people living in the study area using qualitative research methods (key informant interview, focus group discussion (FGD), observations, published and unpublished materials and photographes). Lake Tana is a home to different flora and fauna including endemic species. The flora such as macrophytes and forest resources are used mainly for traditional medicine, fuel wood, rope, pole, habitat for birds, animal feed, etc. and the fauna includes fish, hippos, crocodiles, invertebrates, etc. Further, the Lake Tana area is a good habitat for indigenous cattle breeds (Fogera breed) and field crops gene center. The major resources around Lake Tana are land (the major source of livelihood), vegetation resources (macrophytes and forest resources), wildlife resources (fish, the other important source of livelihood) and cultural landscapes (churches and monasteries). Lake Tana is exposed to a set of interrelated environmental problems induced by human influence such as deforestation, erosion, sedimentation, water level reduction, erratic rainfall, flood, and competition for water resources, pollution and introduction of alien species. The causes to these problems were overgrazing, farmland expansion, cultivation of marginal lands (shorelines), encroachment of communal land, pollution and vegetation removal to meet demand for food and* *fuel wood. It is observed that alteration of Lake Tana and its fringe wetlands has affected the whole dynamics of the Lake's ecosystem and the livelihood of the surrounding community. Ecosystem components are interlinked; hence correlation analysis was done between physicochemical parameters and macroinvertebrates of Lake Tana. Thus, correlations among many of the physicochemical parameters and macroinvertebrates families have been observed. To mention some of the correlations, the changes in the physical, chemical and biological characteristic of the lake affected the aquatic life forms and significantly affect economic activities that the lake supports. The RDA(Canonical redundency analysis) ordination of the species-environmental variable association indicated that pH, Cd, Pb and* $SO4^{2-}$ *and Velidae, Chironomidae, Physidae, Gerridae, Corixidae, Dytiscidae, Caenidae, Coenogrionidae Simuliidae and Psephenidae were negatively correlated while Mussidae positively correlated with these environmental variables. This study concludes that the main threat to aquatic ecosystems in Lake Tana arises from agricultural activities, urbanization and industrialization that deteriorated water quality and biodiversity. Thus, it is recommended that proper management of Lake Tana should be put in place to prevent further deterioration of water quality and biodiversity of the lake for its sustainable development.*

CHAPTER 1

INTRODUCTION

Lake Tana feeds the Blue Nile, which in turn, provides about two-thirds of the water supply to the Sudan and Egypt through the Nile system. It also provides some of the water supply for Bahir Dar (Ethiopia) and is a significant water supply for the rural population around the lake (Howell and Allan, 1994).

Currently, Lake Tana faces huge ecological pressure because of different services. It renders to the surrounding community and even downstream countries, such as Sudan and Egypt. Some of these services include transportation, fishery, hydro electric power supply, irrigation, water supply, heritage/religious practices, tourism and livelihood for marginalized and poor people (e.g. the Woito Tribe and some other fisher men), and sand mining. The lake shore is increasingly populated by urban encroachments from residents of Bahir Dar city and Gorgora town. It also has scientific and educational value due to its unique fish species. The shallowness of the lake gives the region or the catchment area of the lake, a “Wetland” characteristic. There are swamps on all sides of the lake resulting from hydrological and land use changes. The Dembia Plain to the North, Bahir Dar City to the South, the Fogera Plain to the East and the Kunzila Plain to the West are low areas bordering the lake. These are often flooded during the rainy season, forming an extensive wetland which is a precursor for the rice belt land. As a result of over flooding during the rainy season, tons of soils are loaded to the lake increasing sedimentation (Teshale *et al*., 2001).

1.1 BACKGROUND OF THE STUDY

Water is very essential for life on earth. As water is important for human life, the pattern of human settlement has been determined by its availability. The fertile land areas and the abundant water were beginning of civilizations. Demand for water has increased dramatically and its uses have become varied as used in agriculture, industry, recreation and non-ingested personal consumptions. Each of these uses required a different level of quality and quantity (Omer, 2007; Carlos *et al.*, 2012).

Ethiopia has abundant water resources in East Africa with a number of lakes and rivers (Negash *et al*., 2011; Gizachew, 2015). Ethiopia with its different geological formations and climatic conditions is endowed with considerable water resources and water ecosystems; including twelve river basins, some 14 major lakes, swamps, floodplains and manmade reservoirs. Approximately 123 billion cubic meters of water runs off annually from these sources to the neighboring countries. For this reason, Ethiopia is often referred as a "*water tower*" of north-eastern African countries (NBI, 2005; Negash *et al*., 2011).

The water resources of Ethiopia are the cradles of biodiversity and natural reservoirs for freshwater supply. It is contributing significant part to the macro-economy of the country and downstream recipient countries. Most of these freshwater resources are concentrated in lakes. The country's water bodies cover 0.7% of the total land mass of the country and comprise more than 10 lakes. Lake Tana is the largest freshwater lake in Ethiopia. It is the source of the Blue Nile (Abbay) with a catchment of approximately 300,000 km^2 and drains to Sudan and Egypt (NBI, 2005) and Lake Tana catchment area of 15,054 km^2 (Fanny, 2012). Lake Tana accounts for 50% of the total lakes' area in Ethiopia with a surface area of 3200 km^2 (Eshete, 2003). Most of the water of Lake Tana is collected from the Ethiopian highlands of many tributaries (NBI, 2005).

Ethiopia depends largely on inland water resources such as ponds, lakes, rivers, reservoirs and wetlands because of its land locked nature (Dereje, 2014). The Lake Tana ecosystem provides a variety of goods and services (Bergström *et al*., 2011). These services are provisioning, regulating, amenity and supporting services (Friedrich, 2012). Provisioning services are supplies of products that people harvest from the lake and wetlands such as reeds, wild fruits, fish and water. Regulating services are benefits from the regulation of ecosystem processes including air quality maintenance, water regulation, erosion control, water purification and waste treatment, regulation of human diseases and storm protection (Gemechu, 2010). Cultural and amenity services include spiritual, recreational and aesthetic values that people obtained from the lake and wetlands. Supporting services are services that are necessary for the production processes of soil formation, nutrient cycling and biodiversity availability (Bergström *et al*., 2011).

Despite, water is vital for life; on a global scale the availability in quantity and quality of the fresh water is a problem. Water scarcity is considered as one of the major challenges for livelihoods and the environment in sub-Saharan Africa. In Ethiopia water availability is erratic in space and time due to the seasonal variation in rainfall and a lack of structures regulating the water flow. But also the water quality is changed. The water quality of Ethiopian lakes showed dramatic changes in the last few decades (Mulugeta, 2013; Sisay, 2013).

Lakes are subjected to multiple interacting stressors, such as atmospheric, meteorological, geological, hydrological and astronomical influences. The human-induced changes are also affecting the hydrology of lakes in many parts of the world (Mulugeta, 2013). Anthropogenic activities are sources of pressure on natural ecosystem specially the aquatic ecosystem. Rapid population growth, agricultural activities, mining, urbanization and industrial activities have been degrading the environment and pollution has reached burning issue. All these activities are causes for the increasing of organic matter, silt, nutrients and other wastes in water resources resulting in the alteration of the ecological functioning of aquatic ecosystems (Temesgen, 2009; Habiba, 2010).

The major consequences of man's activities on the environment are habitat degradation and water pollution that deteriorates the aquatic ecosystem and resulting in the alteration of the ecological functioning of aquatic ecosystems (Mekonnen, 2008). Until recently, the environmental degradation and deterioration of water quality with pollution was not a serious problem, because human population was small and people were living in scattered communities in this regard the quantity and complexity of wastes were much below the assimilative capacity of the environment and hence, wastes dumped into surface water were subject to dilution and natural self purification (Baye, 2006). But today, as human population, agricultural activities and industrialization increased, the water pollution problem becomes more critical, since these things result in habitat loss and the excessive addition of pollutants into the water bodies; and all these affect the use and the natural balance of the aquatic ecosystem (Baye, 2006; Habiba, 2010). Water pollution is a big consequence that can poison both terrestrial and aquatic life. It may cause disease due to the presence of hazardous substances, may distort water quality and significantly hinder economic activities. The causes and forms of water pollution include sewage, infectious agents, organic chemicals, hazardous chemicals, mineral substances, sediments, radioactive substances and thermal pollution (Habiba, 2010; Temesgen, 2009). Due to human activities today surface water show a significant degree of pollution in Ethiopia. The rain washes much of the surface pollutants into the surface waters during wet seasons but in the dry seasons the flow towards reciving waters is minimal (Temesgen, 2009).

In the catchment areas of Lake Tana, human activities have been much more intense than many years before. Thus it is possible to conclude that human interference in the lake basin is a major cause of water quality changes in the lake (Habiba, 2010). Of the many cities and towns found in the catchment of Lake Tana, the fast-growing cities that are affecting the lake are Bahir Dar, Gondar and Debretabor. The growing population and industrialization of these cities can have potentially serious consequences on the lake. It is possible that domestic and industrial wastes find ways into the lake (Stave *et al.*, 2017). The waste discharged from these urban centers and agricultural areas has contributed to the decrease in the water quality and the increase in the concentrations of ions (Habiba, 2010). These ions determine the physicochemical characteristics of the water known by water quality that has a relation with biodiversity. The water quality is also determined by seasonal variation due to dilution factor (Stave *et al.*, 2017)

Degradation of Lakes water is one of the most series problems affecting the health of the utilizing population (Temesgen, 2009). The level of water pollution tends to rise with increasing human population and low level economic development in the Ethiopian community (Mekonnen, 2008). In developing countries, sources of pollution from domestic, agricultural, industrial activities are unregulated. Likewise, Lake Tana, where there is gap in effective environmental management practice, there are a number of pollution sources that continuously deteriorate its water quality (Temesgen, 2009). Lake Tana has suffered much from pollution resulting from silt deposition, organic and inorganic chemicals load from the catchment and it has been invaded by water hyacinth (*Echhornia crassipes)*. Both of these factors have severely affected the ecosystem of Lake Tana (Habiba, 2010). As a result of deterioration of the ecosystem, the water quality and biodiversity of Lake Tana degraded and livelihoods of the vicinity community who are dependent on its resources for their day to day life are affected. Thus, to restore and maintain the factors (chemical, physical, and biological integrity of the Lake Tana) these parameters should be monitored (Baye, 2006). So, the water quality analysis and the biological communities can provide an ideal indicator response serving as a pertinent measure for water quality goals and resource use of Lake Tana. Therefore, evaluation of Lake Tana water quality and Biodiversity conditions are of great importance to meet the ecosystem function goals and livelihood requirements.

1.2 STATEMENT OF THE PROBLEM

The world development practices have been centered on freshwater habitats (Reddy, 2014). It is generally understood that freshwater and wetlands play an important role in ecological, economic, social and cultural functions. Aquatic ecosystems have been the heart of human civilization. Thus, lakes and their wetland systems have played a key role in the development and survival of human beings (Stearner, 2013).

Ethiopia possesses a great diversity of aquatic ecosystems (shallow lakes, rivers and streams, swamps/marshes, flood plains, reservoirs and ponds and high mountain lakes) as a result of the formation of diverse landscapes. Lake Tana is the largest fresh water lake in Ethiopia. The Lake Tana and its wetland systems have immense environmental, socio-economic services as well as sustenance of local community livelihoods. But, these functions/opportunities of wetlands are under threats from a wide range of sources (Stearner, 2013) or anthropogenic activities, such as: intensive agricultural irrigation, the expansion of human settlements including urbanization, industrial pollution, agricultural pollution by pesticides and fertilizers, water diversion for drainage and the construction of dams (Negash *et al*., 2011; Phul, 2016). Freshwater ecosystems are seriously threatened today (Reddy, 2014). Lakes suffer high rates of degradation when there is habitat modification (such as dam construction) or exotic species introduction (Reddy, 2014; Lamsal *et al.*, 2015). Other factors contributing to the decline of freshwater ecosystems and their native biota are chemical and thermal pollution and overharvesting. These factors have affected water body ecosystems in both industrialized and developing regions (Bergström *et al*., 2011). High growth rates of both the economy and the population produces environmental stress pronounced by rising resource demands and increasing waste disposal. Thus, the current socio-economic development is degrading the fresh water quality. The water quality degradation proceeds at a level that is not sustainable for domestic, agricultural and recreational uses. Agricultural and industrial activities and domestic pollutant discharges lead to water quality deterioration. In addition to this, climate change impacts on water quality, too (Steve *et al*., 2015).

Poor water quality has been the most challenging global threat to the quality of our lakes as a result of excess nutrients load through run off during rainy seasons. This process of excess nutrient enrichment, dissolved and particulate inorganic and organic materials to lakes and reservoirs affects the lake water quality. Water bodies are experiencing water quality deterioration due to nutrient loading (that leads to rapid eutrophication), sedimentation, acidification and the introduction of toxic contaminants as a result of water runoff from the watersheds of lakes dominated by agricultural production, urbanization and industrialization. These activities combined with highly erodible soils and locally intense rainfall events create high potential for nonpoint source pollution to the water bodies. The amounts of nutrient load in water also play a significant role in the physical and chemistry of water. Pollution of these aquatic environments including lakes is a significant global water quality management concern; because, Physicochemical factors affect the whole aquatic environments (Steve *et al*., 2015).

Water is exposed to innumerous natural and/or anthropogenic influence in the form of compounds, such as sulfides, nitrates, chlorides, metals e.g. toxic metals (Lead, cadmium, chromium, etc), carbon components, pathogens: such as bacteria and viruses. These all could be harmful to the human when present at high concentarations. The sources of these water pollutants are determined by human activities, which include farming, constructing, mining and disposing of waste. With intensive agriculture, the leaching of nutrients and pesticides into the water affects the physicochemical parameters. There is also a growing concern of pollution caused by the leaching of industrial wastes into the aquifers (Omer, 2007; Negash *et al*., 2011). In India about 70% of the available water is polluted. The chief source of the pollution is sewage which constitutes 84 to 92% of the waste water (Agrawal and Rajwar 2010; Khan *et al.* 2013).

There is a great deal of human activities that have negative impacts on Lake Tana that needs to be corrected. Some of the largest contributors to the pollution are domestic sewage, agricultural inputs and outputs, industrial inputs and outputs, silt from the agricultural activity, etc. In addition to the chemical pollution, bacterial pollution (*Escherichia coli (E. coli)*, *Salmonella*, Hepatitis A virus, *Cryptosporidium*, and others) is documented. The pollution has endangered not only human being but also the wildlife (fish, birds and animals) found in the lake and threatens the clean water source. Additionally, recreational, fishing, boating and swimming activities are affected due to the pollution (Eshete, 2003).

Anthropogenic activities drastically influence aquatic ecosystems, resulting in modified biological communities and loss of species and alteration of ecosystem services (Roque, 2013). Freshwater environments are among the most affected environmental systems on Earth that requires great effort to conserve and restore. This is because: *i*) freshwaters declines in biodiversity are more greater than in the most affected terrestrial ecosystems; and *ii*) freshwaters have been strongly affected by changes in climate, invasive species, habitat alteration and overexploitation (Mariadoss and Ricardo, 2015).

Availability of safe and reliable resources including water is an essential prerequisite for sustainable development. Though water pollution is an old phenomenon, the rate of industrialization and urbanization has exacerbated its effects on the environment in an alarming rate (Temesgen, 2009). The physicochemical parameters of lakes, ponds and rivers have considerable effect on the aquatic life. These Parameters determine the productivity of a water body (Akaahan *et al*., 2014). Thus, a change in the physicochemical variables of a water body brings about a corresponding change in the relative composition and abundance of the organisms in that water (Tapan *et al*., 2014). All the same chemical and physical measurements used in evaluating water quality provide data that primarily reflect conditions that exist when the water sample was taken (Akaahan *et al*., 2014). However, physicochemical and biomonitoring are not mutually exclusive, an optimal limnological study involves both approach (Akaahan *et al*., 2014). This is because the biological community gives an indication of past conditions as well as the current situation of the aquatic ecosystem (Kiran, 2015). Therefore, any negative effect caused by pollution in the community structure can in turn affect trophic relationship (Akaahan *et al*., 2014). Apart from this, the water quality is also determinant for the well being of the fisheries and any other water resources is of paramount importance. Similarly macroinvertebrates and macrophytes show a long-term response to changes in environmental conditions (Mirosław, 2014). The occurrence of species is more likely determined by biological and stochastic factors than by simple environmental determinism (Akaahan *et al*., 2014). Assessing patterns of variability or change in ecological communities is important, because different communities provide different ecosystem services as well as for conservation and assessing the resilience of natural communities. Changes in macroinvertebrate community composition and abundance may dramatically affect the structure and function of ecosystems including trophic interactions, nutrient dynamics, responses and susceptibility to disturbance (Patrick *et al.*, 2014). Aquatic vegetation (macrophytes) are also important component of aquatic ecosystems and indicators for different specific water stress (Janauer *et al*., 2006). The main environmental factors affecting macrophyte abundance in lakes are general water chemistry, the trophic status of a lake and light availability (Mirosław, 2014). Macrophytes affect the physical, chemical and biological parameters of lakes and they reflect the impact of various environmental factors such as lake water chemistry and biotic interactions (Akaahan *et al*., 2014). The structure of aquatic vegetation can be used to determine the diversity of flora and lake habitats. The combined, long-term effects of those factors diversify aquatic vegetation along the environmental gradient (Mirosław, 2014).

Water chemistry changes lead to decreased abundance and diversity of macroinvertebtares and macrophytes as lakes become enriched and can trigger a switch from clear water to a turbid water stable state (Christopher *et al*., 2004). Another factor that can mediate the dominance and structure of macrophyte communities is water level alteration resulting from anthropogenic modulation of hydrology and transversely affecting macroinvertebrates. As water level decreases, macrophytes may overcome light limitation. Light can reach the sediment and germinate seeds and permit photosynthetically active radiation to penetrate to new areas in the water column (Nirmal *et al*., 2007). Both can lead to altered growth and distribution of macrophyte species (Christopher *et al*., 2004; Nirmal *et al*., 2007).

Macrophytes play an important role in providing a stable habitat structure to the aquatic ecosystems (Gaskill, 2014). The structural and functional significance of macrophytes can be demonstrated vis-àvis their diverse role in primary productivity, global nutrient cycling improvement of water quality, erosion prevention and in providing food, shelter and oxygen to fish fauna and macroinvertebrates (Shazia, 2015).

Water quality affect macroinvertebrates and macrophytes population and aquatic macrophytes affect the macroinvertebrate community structure by influencing both physical and biotic characteristics (Gaskill, 2014). This association with macrophytes can either be trophic, spatial or both (Shazia, 2015).

Different aquatic species are able to survive different conditions and therefore can act as indicators to water quality (Akaahan *et al*., 2014). Furthermore, as stressors (such as Physcochemical or changing habitat) increase and the environment becomes less habitable, diversity decreases (Gaskill, 2014). Many believe that an ecosystem's health is directly related to the biodiversity it supports (relative to the ecosystem if it were undisturbed) (Baye, 2006*)*. Thus, it is possible to assess the health of similar ecosystems based on macroinvertabrate and macrophyte diversity. A decrease in macroinvertebrate diversity also has a great potential to affect higher taxonomic levels negatively (Gaskill, 2014).

Pollution is thought to be major contributors to the decline of macroinvertebrates and macrophytes community (Baye, 2006*)*. Sediment also affects the macroinvertebrates and macrophytes community by altering water movement, food quality and interstitial spacing (Akaahan *et al*., 2014). Water quality and food availability affect biodiversity since the suspended solids absorb heat from sunlight, causing temperature increase, ultimately reduction in dissolved oxygen and unavailability of food enforce life forms to death (Baye, 2006). Hence, aquatic environment deterioration affects taxa richness and diversity with a drastic change in overall taxonomic composition (Younes and Nafea, 2012). Therefore, studies have shown that there is entwining relationship between surface water quality, macrophytes and macro invertebrate diversity and at the same time the livelihood of the dependent communities on the environmental resources (Christopher *et al*., 2004; Akaahan *et al*., 2014). Consequently, this has been adversely affecting the use and management practices of the lakes and its wetlands which in turn have affected the local communities' livelihoods (Seyoum, 2011). Therefore, it is important to note the costs on the environment and the community who depend on it should not be underestimated. Because, inadequate care to today‘s environment would lead to an environment that doesn‘t provide enough support to fulfill the needs of the present and future generation.

Lack of integrated water management, ecologically oriented scientific research and wise resource utilization of the lake are essential unforeseen impacts to the problem (US EPA, 2003). These situations of degradation of lakes water quality in the country due to human activities need to be properly identified, targeted and proper mitigation measures put in place. The first-approach to tackle the issue would be assessing the water quality of Lake Tana by identifying the types of impacts and their severity that would initiate appropriate mitigation measures to achieve the national water quality standard. In this study the degradation level of Lake Tana has been evaluated with respect to the assessment of physico-chemical characteristics, macroinvertebrate and macrophyte structure composition and diversity as well as livelihood of the vicinity community. This study is fundamental for the understanding of the ecological status and water quality of Lake Tana. The study shows to what extent the Lake water quality is affected. This lake was chosen for this study due to its diverse biotic organisms compared with other Lakes in Ethiopia but with very high human impact.

1.3 SIGNIFICANCE OF THE STUDY

This study seeks to investigate major issues raised on the Lake Tana degradation and the status of livelihoods of the local communities that may help to the mitigation and management action that would be undertaken by the stakeholders.

Lake Tana and its wetlands are under severe pressure from water and land based human activities, jeopardizing the natural services that they provide. Most of the wetlands around the lake are already modified and threatened by different causes. Unless conservation action will be undertaken, they will be lost, having tremendous effects on the whole Lake Tana resources. Major threats to the long-term ecological integrity of Lake Tana and its associated wetlands are alteration of ecosystems, loss of species, loss of genetic diversity and invasion of exotic species and reduced water quality and food production. There is overutilization and unregulated management like changes in land use practices, heavy cattle grazing, clearing of the vegetation, construction of dams and irrigation channels, overfishing, water hyacinth invasion, which can eventually lead to ecosystem collapse. Lake Tana community livelihoods have been negatively impacted, especially the youth remain vulnerable to poverty and loss of income as they may neither be able to secure employment nor get suitable alternatives for livelihoods. Therefore, wetlands have to be utilized sustainably using wise use principles to enhance any environmental friendly and sustainable development in the study area to succeed the livelihood of the surrounding community. In general, Lake Tana has been affected by anthropogenic activities that impact on the water quality, flora and fauna. All these mentioned reports indicated that the need for immediate actions for development and application of restoration measures aiming to improve the environmental conditions and achieve the “Good” ecological potential of Lake Tana.

The information generated in this study can assist local authorities to gain further insight into the state of the lake within the community and set remediation action. Furthermore, the information can be utilized to revise the established water quality assessment procedures and treatment systems and national standards thereby assisting water resource managers and regulatory bodies in restoring this impaired water resource. But also this study is expected to be helpful in designing a plan for the sustainable management of Lake Tana.

1.4 THE RESEARCH (STUDY) LIMITATIONS

This study aimed to investigate the impact of anthropogenic activities on water quality, Biodiversity of Lake Tana and the livelihood of the vicinity community. The analysis of the study largely focused on water quality and biodiversity which needs intensive financial cost and that needs full-fledged laboratory facilities. The limited financial capacity posed financial strain toconduct the study well. The othe challenge was full-fledged laboratory facilities to water quality parameter analysis. However, limitation in such resources made it difficult to do so and much of the data was collected in a period covering part of the year based seasons, i.e. dry and wet seasons rather than collected on a monthly interval. Thus, the study was carried out with some of the physicochemical parameters and limited water samples that need future studies to the remaining water quality parameters by pursuing scholarships and full-fledged access of laboratory facilities to adequately cover a lot more parameters for water analyses. Despite the limitations faced, efforts were made to compare the two extreme seasons that can confirm and clarify the research issues; hence, the impact of the stated weaknesses on the conclusion made was minimized.

Availability of livelihood information was a key consideration to achieve the objective of livelihood assessment. Some of the focus group discussants were reluctant to disclose information for fear of political implications, but it was solved with repeated contact and intimacy. Secondary data on local level information had to be sourced directly through many physical visits to state government offices and communities, but many of the stakeholder government offices do not have enough data repositories. Likewise, a plan to collect secondary data on livelihood of the vicinity community households for comparison to the outcomes of the primary data could not be realized due to lack of recorded data at household level; hence only qualitative data and literature data were used for analysis.

1.5 ETHICAL CONSIDERATIONS

Prior to the commencement of this study, ethical approval was obtained from the Research Ethics Committee of the College of Agriculture and Environmental Sciences at the University of South Africa. Furthermore, permission was requested and obtained from relevant authorities and institutions for laboratory facilities and utilization of the environmental variables for this research purpose. Permission Letter was obtained from University of Gondar, Biology Department to use its laboratory facilities and consent letter was obtained from Amahara National Regional State Bureau of Environmental Protection, Land Administration and Use to utilize environmental variables for the research output based on the UNISA research ethics policy. In conducting the key informant interviews and FGDs, the ethical standards in social sciences research were strictly adhered to. Participants were intimated of the purpose of the study and their involvement. Participants were also informed that they could withdraw from the study at any point in time, should they had felt uncomfortable and the materials collected from them would be destroyed by the researcher. The researcher also promised to protect the confidentiality of all information gathered in the course of the fieldwork. Participants were adequately informed of the need to record the interview through note taking and audio recording. The risks associated with the research were minimized by the researcher and maximized the expected benefits that would accrue to participants. In order to keep research ethical principles the researcher explained the purpose, risk and benefit, confidentiality in Amharic based on prepared guiding questions (information sheet) and shown approval of the study. On the basis of the mentioned ethical standards written consents were also taken from some of the focus group discussants and key informants to take part in the study. None of the study participants' names were included in the report. All contributors to research were acknowledged.

1.6 SCOPE AND DELIMITATION OF THE STUDY

The study focuses on analyses of selected physicochemical parameters and on the identification of impact indicator species (macroinvertebrates and macrophytes) as well as the kinds of pollution encountered in the different areas. This study employed quantitative and qualitative research techniques to study the impact of human activities on Lake Tana. Selected physicochemical parameters and bioindicators of the impact level helped the study to have a broader view on the impact of anthropogenic activities on the natural environment because the study focused on assessment of physicochemical parameters, identification of macroinvertebrates and macrophytes including the situation of the Lake Tana vicinity livelihood.

The scope of the study was restricted to Lake Tana and its vicinity up to 5 km distance from the shore line of Lake Tana. All the study areas were selected on the basis of the relative anthropogenic influence that they experience, as well as kinds of pollution the areas were experiencing. In this basis, the areas were classified into three categories, i.e., areas less impacted, moderately impacted and highly impacted by the urban, industrial and agricultural activities. The selected study areas where highly impacted urban area was Bahir Dar and rural area Megech and modestly impacted urban area was Gorgora and rural area Tana Kirkos where as less impacted area Ambobahir was used as a reference for comparison of impact levels. The sampling sites for the selected study areas were Kuriftu, Tana transport and Tana hotel in Bahir Dar study area; Gorgora hotel, Gorgora transport and Debresina in Gorgora study area; Tana Kirkos and Gumara in Tana Kirkos study area; Megech inlet and Megech east in Megech study area and Ambobahir as a reference site in Ambobahir study area.

1.7 RESEARCH SETTING (THE STUDY AREA)

1.7.1 Location and Characteristics of Lake Tana

The study was conducted in Lake Tana. It is located between 37^{0} 00'-37^{0} 20' East Longitude and 11^{0} 37'-12^{0}00' North Latitude (Shimelis *et al*., 2011). It is situated in the north-western highlands of Ethiopia (Eshete, 2003; Misganaw and Getu, 2016). The rocky bottom of Lake Tana is volcanic in its origin. The lake is believed to have been formed because of damming by lava flow during the Pliocene, but the formation of the depression itself started in the Miocene (Goraw, 2010). The lake is shallow, oligotrophic and freshwater with weak seasonal stratification (Shimelis *et al*., 2011). Its bottom is volcanic basalt mostly covered with a thin layer of organic matter (Dereje, 2014). It is turbid, well-mixed Lake (Berhan *et al*., 2016). Lake Tana is found in the Tana sub basin with a watershed of 16,500 km^2, of which about 20% is covered by the lake water (Dessalegn *et al.,* 2013; Stave *et al*., 2017). The Tana sub-basin is found in the Amhara Regional State, bordering West Gojam, North Gondar and South Gondar (Gebremedhin *et al.*, 2013). It is the largest lake in Ethiopia and the third largest in the Nile Basin with a surface area of 3200 km^2, accounting for 50% of the total inland water (Mohammed *et al*, 2011). The lake has a coastline of 385 km, with harbours towns of Gorgora, Delgi, Kunzila and Bahir Dar. It is a shallow lake with a mean depth of 8 m and the maximum depth of 14 m, at an altitude of about 1,830 m above sea level (Dereje, 2014). It is approximately 84 km long (North to south) and 66 km wide (East to West) (Gizachew *et al*., 2015). There are 37 islands in the lake, many of which are with ancient churches and some with colonies of birds. These islands form the craddle of the Ethiopian Orthodox Church. In their churches and monasteries beautiful old scriptures and scrolls are kept. Unfortunately only men can admire these treasures, because women are not allowed to set foot on these islands (Misganaw and Getu, 2016).

The Lake shares common border with woredas: Bahirdar Zuria, Dera, Fogera, Libokemkem, Gondar Zuria, Dembia, Alafa-Takusa and Achefer (Eshete, 2003). Lake Tana forms the head waters of the Blue Nile (Abay), which contributes more than 80% of the total water of the Nile River (Gizachew *et al*., 2015). The Blue Nile (Abay) River annual flow volume is 4 billion cubic meters measured at Bahir Dar gauge station (Shimelis *et al*, 2008). It contains large areas of wetlands (Shimelis *et al*., 2011). Lake Tana is rich in biodiversity with many endemic species and a home to many cultural and archeological sites. The lake trophy level is based on macroinvertebrate community structure (Shimelis *et al*., 2011). It is endowed with Dry Evergreen Montane Forest, Fauna Diversity, Mammals, Birds, Fish, Reptiles, Amphibians and Invertebrates (Eshete, 2003). The lake is surrounded by dry montane forest as well as permanent and seasonal wetlands. The predominant macrophytes of Lake Tana are *Cyperus papyrus, Typha latifolia, Phragmites karka, Persicaria senegalensis, Vossia spp., Scirpus spp*., and *Nymphaea lotus* (Vijverberg *et al*., 2009). The average annual precipitation at Lake Tana was 1410 mm. The Precipitation occurs almost during May to October months (Kassandra *et al*., 2014). The mean annual inflow to the lake is estimated to be 158 m^3/s (i.e. 4,986 Mm^3/y). The mean annual outflow is estimated to be 119 m^3/s (i.e. 3,753 Mm^3/y (Dessalegn *et al.,* 2013). Lake Tana area has a warm temperature and mean annual temperature of 13.5 to 27.7 ^oC and the mean annual rainfall is about 1500 mm of which 54% falls in the months of July and August when the rainfall reach 250 to 300 mm per month (Goraw, 2010; Dessalegn *et al.,* 2013). The seasonal rains cause the lake level to fluctuate regularly with an average difference about 1.5 m, the minimum from May to June and maximum from September to October (Goraw, 2010; Stave *et al*., 2017).

The lake is fed by more than 60 small seasonal tributaries and seven big perennial rivers: Gumara, Ribb, Megech, Gilgel Abbay, Gelda, Arno-Garno and Dirma supplying 95% of the lake's inflow (Shewit *et al.*, 2012; Gizachew *et al*., 2015; Berhan *et al*., 2016). But the main tributaries of the Lake Tana are Gilgel Abay, Gumera, Ribb and Megech rivers that contribute more than 90% of the inflow (Shimelis *et al*., 2011). Hydrologic balance is maintained mainly through evaporation (64% of water loss) and outflow via the Blue Nile (Vijverberg *et al*., 2009). These days, the rivers are becoming seasonal due to upstream water pumping for irrigation activities and catchment degradation (Gebremedhin *et al*., 2013*)*. The Lake is experiencing changes in the environmental balance due to climate change, but mostly by the persistence of unsustainable production and consumption systems (Teshale *et al.,* 2001; Goraw *et al.*, 2010).

1.7.2 Socio-Economic and Biological Conditions of LakeTana

1.7.2.1 Socio-Economy

The population in the lake catchment was estimated to about 3 million in 2007 (Ajala, 2008; Dessalegn *et al.,* 2013). The largest city on the lake shore is Bahir Dar with a population of over 200,000 and more than 15,000 people are believed to live on the 37 islands in the lake. Most islands in Lake Tana are small but two of them are larger (Daga Estifanos and Dek) which were used to be the seat of Ethiopian emperors (Matseliso, 2006; Ajala, 2008; Seyoum, 2011; Dessalegn *et al.,* 2013). Majority of the population in the catchment depends for their livelihoods largely on rain-fed agriculture. Fishery is also an essential part of their livelihood both for household consumption and income generation (Seyoum, 2011; Dessalegn *et al.,* 2013). Lake Tana and its adjacent wetlands provide directly and indirectly a livelihood for more than 500,000 people, of which about three million lives in the catchment (Goraw *et al*, 2010; Dessalegn *et al.,* 2013). Population density is high in the north, east and south areas of Lake Tana with the highest in the north and in some parts of Fogera plain to the east (151-200 persons/km^2) and about 101 - 150 persons per km^2 the more fertile lowland areas to the east and south west (Goraw *et al*, 2010; Seyoum, 2011).

Agriculture activities are dependent on the single *kiremt* rainy season from June to September. Fertile clay and clay loam soils present the basis for good harvests of barley, rice, finger millet, maize, teff, chickpea and vetch, whilst there is widespread rice production by smallholders on irrigated land a highly unusual crop for Ethiopia, introduced in the zone by schemes in recent decades. Maize, barley and millet are the main food crops, while rice, vetch and chickpea are the main cash crops. There are pocket areas with irrigated vegetable market-gardens (growing for example garlic, spices, pepper) (Goraw, 2010).

Livestock holdings in sheep and cattle are relatively modest, but livestock and butter sales make a substantial compliment to the dominant crop sales. Sheep are sold more often to earn income for regular expenses through the year and peaks during religious festivals in April (*Fasika*/Easter), September (*Enkutatash*/New Year) and January (*Genna*/Christmas and *Timket*/Epiphany), when community members individually or collectively purchase animals for slaughter and there is peak demand in town markets. Cattle are high value assets mostly owned by middle and better off households and they are sold sparingly, especially fertile females. Livestock condition is promoted by the relatively good availability of pasture and water. Pasture is supplemented by the purchase of crop residues after the harvest season. It is mainly children who are responsible for looking after livestock day to day (Hughes and Hughes, 1992; Tesfaye, 1998).

Paid work gives a supplement to crop sales in the income of poorer households, but some of the hired labors are provided to men migrating seasonally into the zone from less productive neighboring areas, especially for weeding and harvesting. Nevertheless local men also travel to Metemma and Humera to work, attracted by the high wages during the sesame and cotton harvests. Fishing in Lake Tana using nets and hooks is an additional income source for those living nearby, peaking in February and March (Dereje, 2014).

Pests and diseases are the main hazards to crop production. Common pests and diseases are stalk borer, bollworm, shoot fly, grasshopper aphids, cut worm, and rust. Aphids attack the teff, vetch, chickpea, and rice. Bollworm mainly attacks chickpea and vetch, while the stalk borer attacks maize and chickpea. Hailstorm and uneven distribution of rainfall are the common weather related hazards. Both hazards are intermittent and occur on average once every three years. Localized flooding occurs in some woredas (Ayele, 2011).

Livestock diseases also occur once every three years. The main diseases are anthrax, trypanosomiasis, pasteurellosis and black leg. Anthrax and black leg affect both cattle and sheep, while trypanosomiasis and pasteurellosis affect only cattle. Vaccination is available from the bureau of agriculture and rural development both for cash and free (Getaneh, 2011).

Poor household's first response to bad times is to intensify the sale of high value staples (eg. rice in some areas) which otherwise might be consumed at home and increase the purchase and consumption of cheaper staples (eg. maize). Even wealthier people do this. The search for paid work is also intensified and spreads to more distant areas. The sale of livestock is a last resort for the poorer, whilst the sale of an ox or cow by a wealthier farmer might be a reluctant last response. Increased sales of eucalyptus are also a source of extra money (Getaneh, 2011).

1.7.3 Flora and Fauna

1.7.3.1 Macrophytes

Emergent macrophytes fringe the flat swampy parts of the shoreline; the dominant species in Lake Tana are *Cyperus papyrus,* with *Echinochloa pyramidalis, E. stagnina, Polygonum barbatum, P. senegalense* and *Typha doiningensis.* Floating leaved aquatics include *Nymphaea caerulea, N. lotus* and *Pistia stratiotes,* while the most important submerged species are *Ceratophyllum demersunt* and *Vallisneria spiralis* (Eshete, 2003).

1.7.3.2 Fishing

Among the fishes in Lake Tana, cyprinids are best represented, with 14 species of *Barbus* (of which *B. affinis* and *B. intermedius* are the most numerous), *Discognathus quadriinaculatus* and *Varicorhinus beso.* There are three clariids, *Clarias anguillaris, C. mossanzbicus* and the endemic *C. tsanensis. Oreochromis niloticus* is the only cichlid (Goraw, 2010).

Until 1998 fish production was about 1000 tons/yr which amounts to an average productivity of less than 4 kg/ha/yr, even though the lake is estimated to have a potential of 13000 ton/year; Large ‘Barbus species stocks are highly vulnerable to increased fishing pressure, especially during aggregation of the ripe fish in the spawning season in the river mouths (Esthete, 2003). Due to ecological degradation of the lake and the region around it, the livelihood of the indigenous people has been threatened.

Fish breeding generally take place in vegetated areas about the edge of the lake. However, excess sediment loading makes it more and more difficult for fish species to breed. This suggests that depletion of fish stocks have accelerated in recent years as largely attributable to the expansion of unsustainable social and economic activities in the region (Eshete, 2003).

There are artisanal fisheries on the lake, with *Barbus* and *Clarias* spp. contributing 90% of the catch. Parts of the lakeshore are cultivated and urbanized that influences the lake ecosystem (Hughes and Hughes, 1992).

1.7.3.3 Avifauna

Lake Tana qualifies as an IBA (Important Bird Area) because it possesses globally threatened species such as Wattled Crane (*Bugeranus carunculatus*), Lesser Flamingo (*Phoeniconaias minor*), Rouget's Rail (*Rougetius rougetti*), Pallid Harrier (*Circus macrourus*) and Greater Spotted Eagle (*Aquila clanga*). Recent estimates on the birds of Lake Tana suggested that 43,000 wetland birds are found in the area. There are 214 Palaearctic migrants in Ethiopia and among these, 45 species have been found to over summer within the boundaries of the country. A large number of these birds have breeding population in Ethiopia. A wide spectrum of aquatic birds is found here with *Alopochen aegyptiaca, Bubulcus ibis, Egretta internzedia, Larus ichthyaetus, Plectropterus gambensis, Sarkidiornis melanota* and *Threskiornis aethiopica* among the most numerous (Getaneh, 2011).

Bird inventory around the lake shows 1. Globally threatened spp.: *Wattled Crane* and *Greater Spotted Eagle* (rare), 2. Near threatened spp: *Pallied Harrier*, *Lesser Flamingo* and *Rouget's Rail,* 3. Birds found particularly in high number: *White breasted Cormorante, African Darter, Yellow billed Egret, Scared Ibis, Fulvous and white faced Whistling Duc* and *4.* Those found in substantial no's: *Common Crane and Open billed Strock.* The area is important for wintering migrants. Species wintering in the area include; *Stone Curlew and Blue throat* birds (EWNHS, 1996). Due to the anthropogenic effect the avifauna are threatened.

1.7.3.4 Crocodiles and Hippopotamus

In the past decades, poachers kill crocodiles and hippos. Crocodiles killed for teir skin to sell and to make belts. Hippos killed to sell for their skin particularly for making whip used to drive or galloping horses. Hippos in respect to their large size need very rich grass land. At the moment most of the vegetations have nearly cleared and all the arable land is tilled up to the banks of the lake and the river. What is virtually left to hippos are rocks and barrier gorges. This may lead them to starvation like the local cattle or even extinction from the lake (Eshete, 2003). In the same while, the habitat of crocodiles, the vegetations cleared. This leads barier for survival of crocodiles (Eshete, 2003).

Hence, in the context of the future Biosphere Reserve Lake Tana the existing wetlands considered worthy of protection should be zoned as core and buffer zones. They offer important services for the whole region and are of great importance for the existence of the ecosystem of Lake Tana.

1.7.4 Physicochemical Characteristics of Lake Tana

Average water temperature varies with in the range of 21^{o}C to 26^{o}C and dissolved O_2 concentration ranges form 5-7 mg/l to 6.9 mg/l. The water is almost alkaline, with bicarbonate levels ranging from 48 to 75 mg/l and a pH range level is 7.3 to 8.1. Rooted macrophytes obtain their nutrient demand from the sediment, their tissue P and N content is important to the nutrient economy of the lake. It favors growth of macrophytes. But there is a fear that after constant death and deposition of plants, the case may lead to the accumulation of organic debris and the subsequent ecological degradation of the lake through acidification. There is a fear that excess growth of macrophytes and increase in the phosphorous level coupled with continued pollution of the lake be a predisposing factor for eutrophication in the foreseeable future (Teshale *et al.*, 2001). According to Goraw (2010) the physico-chemical characteristics of lake Tana is 12 mg/1 NH_3, 0.366 mg/l NO_2^-, 3.6 mg/l NO_3^-, 0.42 mg/l TDS, 34 mg/l TSS, 9.0 pH and 1200 μS/cm EC. And 20–24 ^{o}C Lake temperature, 220 μS/cm Electrical conductivity, 8.1 pH, 7–9 mg/l Na^+, 1 mg/l K^+, 14 mg/l Ca^{2+}, 12 mg/l Mg^{2+}, 91 mg/l HCO_3^-+ CO_3^{2-}, 1.25 mg/l Cl^- and 150 mg/l TDS (Kebedea *et al.*, 2005; Teshale *et al.*, 2001). This indicated that the impact of the lake is increasing with time, hence the current human impact will be studied by copmaring the water quality parameters of impacted sites versus reference sites.

1.7.5 Environmental Changes in Lake Tana

The quality of the lake water is also being increasingly affected by pollution from point and non-point sources in the region. Solid waste and effluent discharges from the domestic, commercial and industrial quarters of Bahir Dar and the surrounding urban and rural areas pass untreated into the lake. Already, with the growth of Bahir Dar, the amount of domestic, municipal and industrial waste discharged to the lake is increasing. At present the gulf area of the lake, however, appears to have high levels of silt and waste materials most of which originates from activities in the city. The use of agrochemicals, to promote agricultural productivity and pesticides, like DDT, to control malaria, are washed to the lake by runoff. The disposal of waste into the lake has implication for the fish population and for the sustainability of the livelihood of local communities (Tesfaye, 1998).

The four important constituents of the waste entering the lake from non-point sources are: total dissolved solids, high organic derivative wastes (agrochemicals and pesticide), nutrient rich wastes (total N and total P) and pathogenic bacteria. In addition to these, the urban runoff washing into the lake contains heavy metals from garages, factories, hospital etc. DDT and other chemicals also released to the lake (Teshale *et al.*, 2001). These chemicals affect the water quality parameters. The water quality parameters affect the biotic integrity of the lake. Therefore, by integrating the water quality parameters with the biological community assessment the lake ecosystem status can be provided. Assessment of water quality parameters and biological community is an ideal indication serving as a pertinent measure for water quality monitoring (Barbour *et al.*, 1996). The lake ecosystem monitoring can be assessed by comparison of the reference site with test sites that are impacted by these factors. Comparing water quality and coliform conditions and biological communities between the reference and test sites, can provide scientific evidence of tangible effects of human activities on the lake biotic integrity.

1.7.6 The Study Areas and Sampling Sites

This study was conducted in five study areas. Two urban areas: Bahir Dar study area and Gorgora study area. Bahir Dar study area is expected to be highly impacted and Gorgora town minimally impacted. The other category is two agricultural areas: Megech study area that was expected to be highly impacted and Tana Kirkos study area expected to be minimally impacted. Ambobahir study area is a reference site with likely to be less impacted and used for comparison of impacted areas with less impacted areas. Sampling areas are in the region bounded by latitudes 11°35'42.24"N to 12°16'51.68"N and by longitudes 37°19'23.14"E to37°29'37.31"E and ranging in altitude from 1,784 to 1,791 mas. This was measured using Global Positioning System (GPS) (Table 1.1and Figure 1.1).

For this study, all study areas were selected on the basis of the relative anthropogenic influence that they experience, as well as the relatively different kinds of pollution that they presented to the lake. In this regard, the areas were stratified into three categories, i.e., areas with less impacted, moderately impacted and highly impacted by the urban, industrial and agricultural activities of the lake.

The study areas were selected based on the impact levels. The study areas anthropogenically highly influenced were Bahir Dar, Gorgora, Megech and Tana kirkos and Ambobahir was relatively less influenced by human activities. In addition, they were selected in such a way they reflected livelihood of the community. The livelihood data collection considered up to the 5 km from the shoreline of Lake Tana. Study areas were located on map by using GPS coordinates.

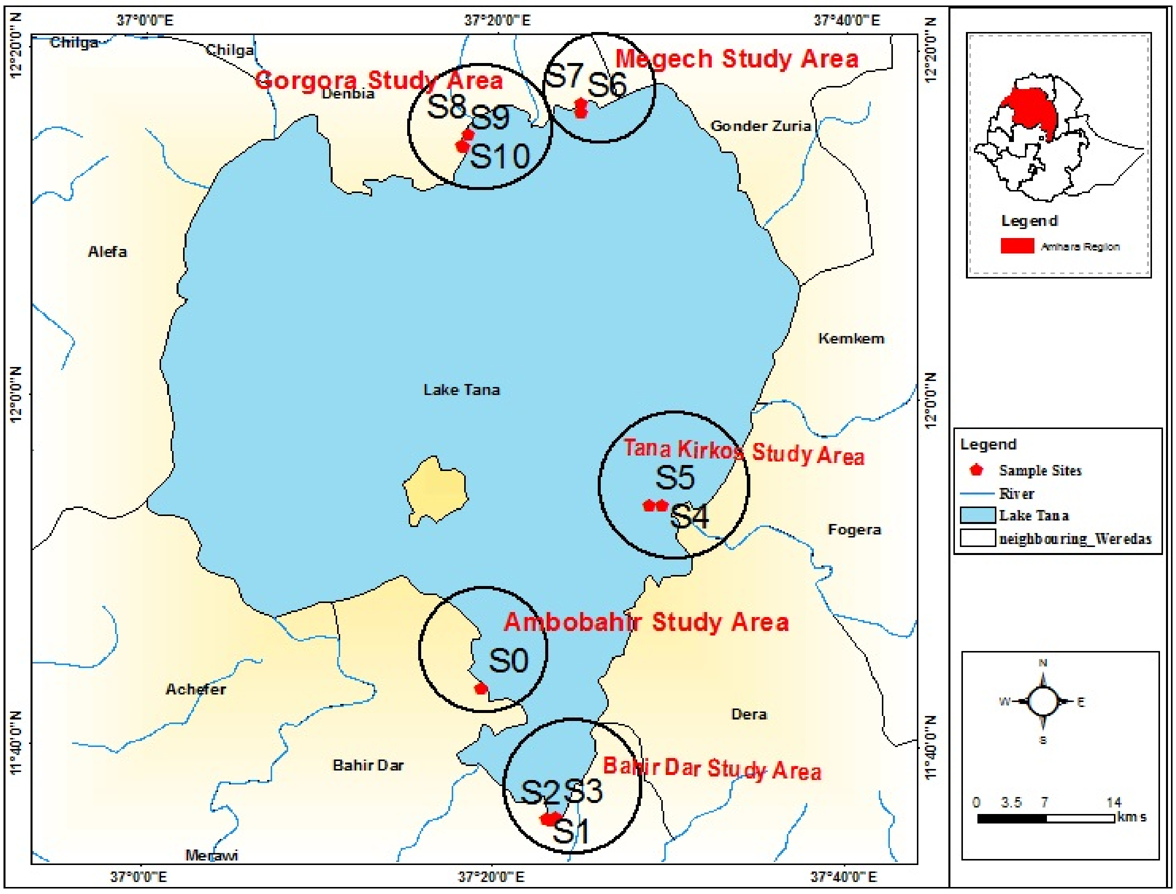


Figure 1.1: Map of Lake Tana showing study areas (Source: Field Survey Coordinate Data)

For this study, samples were taken from Lake Tana in Bahir Dar study area sampling sites: Kuriftu, Tana Transport and Tana Hotel; Gorgora study area sampling sites: Gorgora hotel, Gorgora Transport and Debresina; Tana Kirkos study area sampling sites are Tana kirkos and Gumara; Megech study area sampling sites: Megech inlet and Megech east and Ambobahir study area a reference site with a sampling site Ambobahir.

Table 1.1: The study areas and sampling sites of Lake Tana

Study Area	Code name	Site name	Altitude(m)	Latitude	Longitude
Ambobahir	S_0	Ambobahir	1789	11°43'15.60"N	37°19'23.14"E
Bahir Dar	S_1	Kuriftu	1788	11°35'47.71"N	37°23'3.16"E
	S_2	Tana Transport	1784	11°35'42.24"N	37°23'19.73"E
	S_3	Tana Hotel	1780	11°35'50.98"N	37°23'40.65"E
Tana Kirkos	S_4	Tana Kirkos	1790	11°53'49.92"N	37°29'37.31"E
	S_5	Gumara	1791	11°53'49.81"N	37°28'51.31"E
Megech	S_6	Megech Inlet	1788	12°16'20.90"N	37°24'49.49"E
	S_7	Megech East	1786	12°16'51.68"N	37°24'48.87"E
Gorgora	S_8	Debresina	1785	12°15'3.22"N	37°18'23.37"E
	S_9	Gorgora Transport	1774	12°14'25.33"N	37°18'5.68"E
	S_{10}	Gorgora Hotel	1773	12°14'21.47"N	37°18'7.96"E
Average to the lake			1786 masl		

Source: Measured at the field survey using GPS

Site Selection in the Study Area

All sample sites were selected with expected impacted categories. The categories are those areas expected to be less polluted, moderately polluted and highly polluted. The other categories are influenced by urban and agricultural activities of the lake. The criteria in the selection of sites were also dependent on pollution load of the lake.

Sampling sites were selected and located for human influenced sites along the shore lines of Lake Tana in Bahir Dar study area, Gorgora study area, Tana Kirkos study area and Megech study area. Reference site was fixed at Ambobahir study area. Sampling points were located on map by using GPS coordinates.

Samples for physicochemical, macroinvertebrate and macrophytes were collected two times at each site seasonally at wet season and dry season but for physicochemical analysis two replicate samples were collected per site per sampling date with the water sampler at different depth intervals and homogenized before being sub sampled. Samples were taken at 6 months regular intervals seasonally in wet and dry seasons and 11 sampling points (sites) were determined in Lake Tana at five study areas to determine site and seasonal variation based on the criteria APHA, (2005) and used by Peter *et al.* (2014), Selcuk *et al.* (2014) and Manjunath *et al.* (2016). In other way, the livelihood data was collected once in the study time.

1.7.7 Reference Conditions

To address levels of impact to any part of Lake Tana, understanding of the inherent physicochemical, biological variability's and natural potentials of the lake is necessary. This is accomplished using a reference approach used by Hughes (1995), which is based on minimal human impact. The objective of the reference is to collect and summarize data from least disturbed site used as a framework in order to develop appropriate criteria for the impacted sites (Barbour *et al.*, 2002; APHA, 2005).

The reference condition collectively refers to the range of quantifiable ecological elements (i.e., chemistry, habitat and biology) that are found in minimally disturbed environments. Finding reference site in the lake is a difficult task, because no region is entirely without human disturbance. Therefore, the reference site has been selected based on minimally or least disturbed attributes (Gregory *et al.*, 1991) as cited by Baye (2006) and Blanca *et al.* (2014).

Selection of Reference Area

According to Barbour *et al.,* (1999) as cited by Baye (2006), reference site for any location must meet 11 criteria:

1) pH $\geq$ 6 if black water stream, then pH<6 and DOC$\geq$8 mg/l

2) DO $\geq$ 0.000004 mg/l

3) Nitrate $\leq$ 300 mg/l

4) Urban land use $\leq$ 20% catchment area

5) Forest land use $\geq$ 25% catchment area

6) Remoteness rating: optimal or suboptimal

7) Aesthetics rating: optimal or suboptimal

8) In stream habitat rating: optimal or suboptimal

9) Riparian buffer width $\geq$15 m

10) No channelization

11) No point source discharge

However, as there is a problem getting a reference site that fulfils all the above criteria; the reference of this study was identified based on the following criteria as indicated by Jennifer *et al.* (2003):

1) Same water body type, size and chemical characteristics as treated sites,

2) Within same watershed as treated sites,

3) Minimal impacts within the last few years, and

4) Limited anthropogenical inputs.

A reference site was selected to compare against the highly human influenced sites in all impacted sites. Physicochemical measures, macroinvertebrates and macrophytes were taken in highly human influenced sites to compare with the reference site. The reference site was selected in an area with less human influence.

1.8 THE STRUCTURE OF THE STUDY

This is an outline of the chapters of the thesis.

Chapter One: *Introduction* - This chapter discussed the general overview of the study which includes background to the study, statement of problem, significance of the study, research limitations, ethical considerations, scope and delimitation of the study, research setting (the study area), the structure of the study, research hypothesis and the research objective.

Chapter Two: *The impact of anthropogenic activities on physicochemical, metals and bacterial characteristics of Lake Tana*. This chapter discuss with the impact level of Lake Tana using selected physicochemical parameters based on the national and international standards and indices. It also includes Introduction to the chapter, objectives, materials and methods that included the principal methods of data collection and result and discussion.

Chapter Three: *Assessment of the impact of anthropogenic activities on Lake Tana using macroinvertebrates metric index*. It has general overview of the macroinvertebrate assessment in the form of introduction, objectives to this specific study, materials and methods used to accomplish this study and finally result and discussion of the study.

Chapter Four: *Assessment of the impact of anthropogenic activities on Lake Tana using macrophytes as bioindicator*. Introduction discusses the use of macrophytes as bioindicator, objectives of the study, materials and methods to achieve the result and finally result and discussion of the study.

Chapter Five: *The impact of anthropogenic activities on livelihood of Lake Tana shore side community*. It has introduction as overview of livelihood assessment, research questions as the reflection of objectives, objectives that are going to be achieved, materials and methods used to get the result and result and discussion as a final output of the study.

Chapter Six: *Conclusion and Recommendations* - This chapter provides concluding remarks of the findings and evaluation of the study. It discusses the theoretical implications of the findings and set as knowledge. The chapter also recommended necessary steps to tackle and improve the problem including further research.

1.9 RESEARCH HYPOTHESIS

1. Long-term human activities due to agriculture, urbanization and industrialization have affected the water physicochemical characteristics, biotic integrity and livelihood support systems of Lake Tana, which has resulted in reduced water quality and degraded aquatic biodiversity.
2. Monitoring tools and mitigation measures are needed to rehabilitate ecosystem services and continue livelihood support for resident and riparian communities.

1.10 THE RESEARCH OBJECTIVE

This research aims to assess the impact of human activities on Water quality, Biodiversity and Livelihood of Lake Tana and its shore sides.

CHAPTER 2

THE IMPACT OF ANTHROPOGENIC ACTIVITIES ON PHYSICOCHEMICAL, METALS AND BACTERIAL CHARACTERISTICS OF LAKE TANA

2.1 INTRODUCTION

In recent years, much concern has been arising regarding environmental pollution due to toxic chemicals resulting from domestic, agricultural, mining and industrial activities. Pollution by nutrient load, disease causing agents, metals and other toxic chemicals has been of considerable public concern (Elsayed and Alaa, 2013). These situations are the result of point source and non point source pollution which causes change in physicochemical parameters of Ethiopian lakes. These are clear alarms and indications of water quality degradation of lakes in the country (FDRE EPA, 2004). These problems also apply to Lake Tana. So, the water quality analysis (physicochemical, metals and bacterial characteristics) can provide an ideal indicator response serving as a pertinent measure for water quality goals of Lake Tana. Therefore, this chapter evaluates Lake Tana water quality on the basis of its great importance to Ethiopia, in particular to the study area.

2.2 OBJECTIVES

1. Analyze long-term impacts of agricultural, industrial and urban activities on Lake Tana.
2. Assess human impacts on water quality using physico-chemical measurements (EC, BOD_5, pH, TSS, TDS, COD, and T^o), inorganic pollutants (NO_3^-, NO_2^-, PO_4^{3-}, SO_4^{2-}, S^{2-} and NH_3), metals (Cr, Cu, Pb, Mn, As, Fe and Cd) and bacteria (*Escherichia coli, Fecal coliform and Total coliform)*

2.3 MATERIALS AND METHODS

2.3.1 Water Quality Sampling and Analysis

2.3.1.1 Sample Collection

Water samples from the lake were collected along the shorelines of the lake in Bahir Dar study area, Gorgora study area, Tana Kirkos study area, Megech study area for human influenced sites and Ambobahir study area as a reference site at all sampling sites seasonally in wet and dry seasons which were used for comparison for one year (June 2014 to May 2015). Water samples were collected in plastic bottles from each site two times a year with six months interval and water quality parameters were tested. One liter polyethylene cans which were previously cleaned, rinsed and washed with deionised water and then rinsed with sample water several times were used for collection of samples. After sampling, samples were put in a cooler box containing ice packs to preserve the sample matrix during transportation to the laboratory in 48 hours. Water samples were taken based on water sampling technique (Procedure of APHA) (APHA, 2005).

Surface water samples were collected seasonally in selected sampling zones 10cm below the surface of the lake water as used by Das and Acharya (2003). The samples were brought to Dashen brewery and Bahir Dar university water analysis laboratories within 48 hours and analyzed following the protocols used for water sample analysis (APHA, 2005).

2.3.1.2 Physicochemical, Metal and Bacteria Analyses

Water samples were collected for analysis of Sulphate (SO_4^{2-}), nitrate (NO_3^-), ammonia (NH_3), orthophosphate (PO_4^{3-}), sulphide (S^{2-}), chemical oxygen demand (COD) and biological oxygen demand (BOD_5) as chemical variables and temperature, pH and electrical conductivity included as physical variables were measured following water quality assessment protocols.
Water temperature was measured by using a glass thermometer (China), pH was measured using pH meter and electrical conductivity was measured using conductivity meter (HACH DR/2010, USA) according to HACH instructions.

NH_3, NO_2^-, PO_4^{3-}, S^{2-}, $SO_4^{2-,}$ TSS, TDS and COD were determined with spectrophotometer (HACH DR/2010, USA) according to HACH instructions that uses standard chemicals and instruments. BOD_5 and nitrate were determined using standard methods for examination of wastewater manual that uses standard chemicals and instruments, Jenway Model 6305 UV/Vis. Spectrophotometer (APHA, 2005 and as used by Mohamed *et al*., 2009).

Metals: Cr, Cu, Mn, As, Pb, Fe and Cd were determined using atomic absorption Spectrophotometer (Buck Scientific Model 210 VGP, USA) according to standard methods (APHA, 2005).

Coliforms were tested by the Most Probable Number test (MPN) and Membrane Filtration tests (MF). The MPN technique, referred to as the Multiple Tube Fermentation Technique, is a technique based on serial dilution of the sample in test tubes containing a selective liquid media. At the end of the incubation, the analyst counts the number of positive test tubes to estimate the number of coliforms in the sample. The MF test refers to a technique where 100 ml of the sample is filtered onto a membrane. The membrane is placed on a growth selective media for coliforms. After incubation, colonies were counted as used by Rhonda *et al.* (2006).

Table 2.1: Water quality parameters determination methods and instruments used (Adapted from Rhonda *et al*, 2006)

Parameter for analysis	**Unit**	**Method**
Temperature	°C	Mercury-in-glass thermometer
EC	µS/cm	Conductivity meter
pH	-	Digital pH meter
TSS	mg/l	Ion selective method
TDS	mg/l	Spectrophotometric method
Ammonia (NH_3)	mg/l	Spectrophotometric method
Nitrate (NO_3^-)	mg/l	Spectrophotometric method
Nitrite (NO_2^-)	mg/l	Spectrophotometric method
Sulphate (SO_4^{2-})	mg/l	Spectrophotometric method
Sulphide (S^{2-})	mg/l	Spectrophotometric method
Phosphate (PO_4^{3-})	mg/l	Spectrophotometric method
BOD_5	mg/l	Modified Winkler-Azide dilution technique
COD	mg/l	Determined by dichromate reflux method through oxidation of the sample with potassium dichromate in sulphuric acid solution followed by titration
Cr, Cd, Cu, Mn, As, Pb & Fe	mg/l	Determined by atomic absorption spectrometer (APHA, 1995).
E.coli, F.coliform and T.coliform	Cfu/100 ml	Most probable number method (CFU/100 ml)

2.4 DATA ANALYSIS

Basic statistical measurement was done and results were expressed as mean ± SE. One-way ANOVA was used to study the difference among sites, where significant values ($P < 0.05$) were obtained and least significant difference test was subsequently applied to detect the specific point of difference among variables and correlation among physicochemical, metals and bacterial variables ($n = 23$) was conducted. Graphs were used to evaluate differences in physicochemical, heavy metal and biological parameters among the reference and impacted sites as well as the wet and dry seasons. All statistical analyses were performed using the SPSS statistical software Version 23 (SPSS Inc, 2016) and Excel spreadsheet, 2007.

2.5 RESULT AND DISCUSSION

In this study, the average results for the 23 physicochemical, metal and bacterial parameters that differentiate impacted from less impacted sites and wet and dry seasons were given in Table 2.2. and Appendix 1: EC, COD, BOD_5, PO_4^{3-} and NO_3^- have high significant difference between the reference site and the impacted sites. And all physcochemical variables have significant difference between the wet and the dry season. Physicochemical variables that are modified by habitat disturbances show a short-term pollution effect with impacted sites. Green *et al*., (2000) and Pond and McMurray (2002) reported that conductivity, dissolved oxygen, pH and organic load (which can be expressed in the form of COD and BOD_5) in degraded habitat were significant factors to compare reference and impacted sites in streams. In this study, of the 23 variables EC, COD, BOD_5, SO_4^{2-} and PO_4^{3-} showed habitat degradation in impacted sites compared to the reference site.

The environmental processes: physical, chemical and biological interactions at ecosystem scale affect the Lake ecosystem including algae and invertebrates which are food for fish and other aquatic organisms. Therefore, it is logical to examine the physical, chemical and contaminants as potentially influencing the Lake Tana ecosystem.

Table 2.2: Physicochemical, metal and bacterial parameters values (Mean± SE, n= 23) of the eleven study sites.

	Season		
n=Parameter	**Wet Mean ± SE**	**Dry Mean ± SE**	**Mean ± SE**
Temp (^oC)	21.9 ± 0.4	24.073 ± 0.2054	23.000 ± 0.3177
pH	7.3 ± 0.1	7.7009 ± 0.11235	7.5055 ± 0.08396
EC (µS/cm)	157.009 ± 14.0482	203.236 ± 25.5691	180.123 ± 15.1027
BOD5 (mg/l)	22.30 ± 4.252	52.36 ± 9.879	37.33 ± 6.189
COD (mg/l)	311.18 ± 54.985	321.73 ± 68.969	316.45 ± 43.055
TSS (mg/l)	0.45± 0.13	0.21945± 0.049280	0.33959 ± 0.073287
TDS (mg/l)	78.5 ± 5.9	107.573 ± 21.3000	93.082 ± 11.2411
NO_3^- (mg/l)	0.57± 0.12	0.40873 ± 0.062584	0.49227 ± 0.070565
NO_2^- (mg/l)	0.03618 ± 0.006769	0.07155 ± 0.039571	0.05386 ± 0.019966
NH_3 (mg/l)	0.3136 ± 0.09182	0.3364 ± 0.11625	0.3250± 0.07233
PO_4 (mg/l)	76.573 ± 46.7510	8.200 ± 2.2271	42.386 ± 24.0256
SO_4 (mg/l)	18.273 ± 2.4498	3.636 ± 0.6219	10.955 ± 2.0178
S^{2-} (mg/l)	23.0 ± 2.0	3.409 ± 0.7224	13.205 ± 2.3697
Cr (mg/l)	0.08 ± 0.01	0.00391 ± 0.001928	0.03973 ± 0.009339
Mn (mg/l)	0.00618 ± 0.003811	0.00509 ± 0.001504	0.00564 ± 0.002003
As (mg/l)	0.00555 ± 0.002986	0.00018 ± 0.000122	0.00286 ± 0.001571
Cd (mg/l)	0.00405 ± 0.001063	0.00082 ± 0.000263	0.00243 ± 0.000640
Cu (mg/l)	0.04 ± 0.02	0.19000 ± 0.066428	0.12273 ± 0.037545
Pb (mg/l)	0.07636 ± 0.026086	0.02473 ± 0.009133	0.05055 ± 0.014616
Fe (mg/l)	0.61818 ± 0.245067	0.09636 ± 0.035221	0.35727 ± 0.133553
E. Coli (Cell/ml)	13 ± 5	7 ± 1	10 ± 3
F. Coliform (Cell/ml)	83 ± 24	27 ± 9	55 ± 14
T. Coliform (Cell/ml)	113 ± 25	48 ± 11	80 ± 15

The frequencies of different physicochemical, metal and bacterial parameters are represented in Figure 2.1 to Figure 2.23 and the correlation coefficient matrix between each two pairs of parameters were estimated to conclude the relationships between different physicochemical, metal and bacterial parameters value as indicated in Table 2.3.

Table 2.3: Correlation coefficient matrix between different physicochemical, heavy metal and bacterial parameters of Lake Tana

	Temp	pH	EC	DO	BOD5	COD	TSS	TDS	NO3	NO2	NH3	PO4	SO4	S2	Cr	Mn	As	Cd	Cu	Pb	Fe	EColi	FColi	TColi
Temp	1																							
pH	.417	1	.																					
EC	**.625****	**.451***	1																					
DO	**-.699****	**-.471***	**-.791****	1																				
BOD_5	**.670****	.296	**.718****	**-.648****	1																			
COD	.264	.422	**.715****	**-.711****	**.539****	1																		
TSS	-.056	-.004	.033	-.168	-.098	.141	1																	
TDS	.309	.412	**.751****	**-.487***	**.601****	**.433***	.063	1																
NO_3^-	.120	-.004	.299	-.234	-.120	.082	.235	.027	1															
NO_2^-	.266	.314	**.793****	**-.438***	**.602****	**.538****	.048	**.884****	.070	1														
NH_3	.117	.305	.383	-.234	.060	.077	-.031	.340	**.430***	.415	1													
PO_4^{3-}	-.069	.186	.221	-.179	-.210	.094	.291	.161	**.660****	.053	**.563****	1												
SO_4^{2-}	**-.594****	**-.485***	-.393	.367	-.358	-.065	.250	-.349	-.146	-.252	-.308	-.074	1											
S^{2-}	**-.476***	**-.519***	-.175	.085	-.375	.030	.273	-.247	.384	-.204	.060	**.432***	**.702****	1										
Cr	**-.576****	-.353	-.119	.171	**-.455***	.024	.264	-.085	.374	-.064	.124	**.515***	**.533***	**.769****	1									
Mn	.061	-.113	.150	.175	.227	-.129	.061	.252	-.160	.297	-.006	-.104	.400	-.013	.050	1								
As	-.041	-.369	.007	-.076	-.094	.019	-.049	-.135	**.505***	-.119	-.129	-.008	.216	**.449***	.381	-.034	1							
Cd	-.072	-	.165	-	-	.230	.021	-	**.584**	-	.297	**.637**	.214	**.762**	**.636**	-	**.492**	1						

		.160		.241	.191			.060	**	.080		**		**	**	.171	*							
Cu	.368	.084	.218	-.163	.248	-.057	-.085	.319	.017	.279	.283	-.010	-.389	-.304	-.250	.111	-.193	-.085	1					
Pb	-.225	-.181	-.131	.023	-.223	.011	.020	-.245	-.066	-.218	-.211	-.103	.287	.342	.291	-.072	.247	.339	-.255	1				
Fe	-.207	.045	.156	-.141	-.304	.083	.364	.114	**.618** **	.006	**.423** *	**.945** **	.056	**.523** *	**.604** **	-.122	.040	**.617** **	-.052	.035	1			
EColi	-.310	.202	-.005	-.080	-.124	.366	-.167	-.012	.189	-.022	.258	.318	.101	.280	.236	-.221	.202	**.501** *	.016	.198	.311	1		
FColi	-.226	-.108	-.009	-.196	-.128	.200	-.071	-.004	-.006	-.020	.308	.353	.261	**.604** **	**.441** *	-.211	.007	**.689** **	.086	.415	.380	**.529** *	1	.
TColi	-.243	-.102	-.008	-.214	-.129	.223	-.096	-.011	.005	-.014	.262	.239	.300	**.625** **	.401	-.246	.180	**.664** **	-.015	**.490** *	.300	**.549** **	**.948** **	1

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

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

Parameters that have strong positive correlations at the 0.01 level (2-tailed) are: Temperature with EC and BOD_5, EC with BOD_5, COD, TDS and NO_2^-, BOD_5 with COD, TDS and NO_2^-, COD with NO_2^-, TDS with NO_2^-, NO_3^- with PO_4^{3-}, Cd and Fe, NH_3 with PO_4^{3-}, NH_3 with PO_4^{3-}, PO_4^{3-} with Cd and Fe, SO_4^{2-} with S^{2-}, S^{2-} with Cr, Cd, F. Coliform and T.Coliform, Cr with Cd and Fe, Cd with Fe, F. coliform and T.Coliform, *E.Coli* with T.Coliform and F.Coliform with T. Coliform. While Parameters that have strong negative correlations at the 0.01 level (2-tailed) are: Temperature with SO_4^{2-} and Cr.

The relative concentration of ammonia is pH and temperature dependent. Higher the pH, the more of ammonia will be present (Deepa *et al*, 2016). In contaminated water, dissolved Cd levels are mainly dependent upon pH. High concentration of cadmium occurs at neutral and alkali pH (Tirkey *et al.*, 2012). The low EC value recorded could be related to the adsorption of dissolved salts in the surface of suspended particles which coming with water runoff and discharged waste, where EC is positively correlated with total dissolved solids (Mohamed *et al*., 2009). The electrical conductivity of water is the capacity to transport an electrical current. The transport of electricity is ensured by the presence of ions. The measure gives an indication of the total amount of ionizable salts in solution. Similarly TDS by definition are the inorganic salts, organic matter and other dissolved materials in water. Hence, EC is correlated with TDS (Muthulakshmi *et al*., 2015; Wondie, 2015).

2.5.1 Physicochemical Parameters

2.5.1.1 Temperature

The temperature showed no significant mean variation ($P < 0.05$) between the reference site and impacted sites (Table 2.2). But there was significant variation of temperature between the wet season and the dry season Appendix 1. However, the lowest value was recorded in the reference site and the highest value was recorded in Megech inlet sampling site of the lake (Figure 2.1).

The highest temperature was recorded during dry season (winter) and lowest during wet season (summer) which is a normal feature in fresh water bodies (Deepa *et al*., 2016). The climate of the Lake region is 'tropical highland monsoon' with one rainy season between June and September. The air temperature shows large diurnal but small seasonal changes with an annual average of 21 ^{o}C. The seasonal distribution of rainfall is controlled by the northward and southward movement of the inter-tropical convergence zone (ITCZ). Moist air masses are driven from the Atlantic and Indian Oceans during summer (June–September). During the rest of the year the ITCZ shifts southwards and dry conditions persists in the region between October and May. Generally, the southern part of the Lake Tana basin is wetter than the western and the northern parts (Kebede *et al*., 205). Temperature is an important limiting factor, which regulates the chemical and biological activities in the aquatic environment. Water temperature in Lake Tana water ranged between 20- 24 and 23-25 °C during wet and dry seasons, respectively (Figure 2.1). The lowest 20°C is at the reference site in wet season and the highest temperature 25°C at the sampling site Megech inlet where there is loss of riparian vegetation cover and all discharges of Gondar town and the surrounding area is flowing towards river Megech. The higher temperature in dry season was probably due to the increased load of suspended solids, soil particles and decomposed organic matter in the lake; because they absorb more heat (Phul, 2016). And also the surface water temperature is influenced by the intensity of solar radiation, evaporation and fresh water influx (Dhinamala *et al*, 2015). Temperature affects distribution and survival of aquatic organisms. This is because temperature influences the amount of dissolved oxygen that is available to aquatic organisms and also the metabolic rate because increasing in temperature decreases the DO (APHA, 2005; WHO, 2006, Vincy *et al.*, 2012; Deepa *et al.*, 2016). Temperature plays also an important role in the physical and chemical characteristics of the Lake Tana environment; it has a pronounced effect on the rate of CO_2 fixation by phytoplankton (primary productivity). In addition, temperature is responsible for the decomposition of organic matter and nutrient recycling by the bacterial activities. Hence, it may affect the food chain of aquatic organisms (APHA, 2005; Mohamed *et al*., 2009).

According to FDREEPA and UNIDO (2003) standard, the temperatures of inland (Surface waters) generally range from 5 - 30 °C for the protection of the aquatic species. Therefore the water temperature range of 20-25 °C at the sampling sites of Lake Tana was within this range. But the variation of temperature among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas Appendix 1.

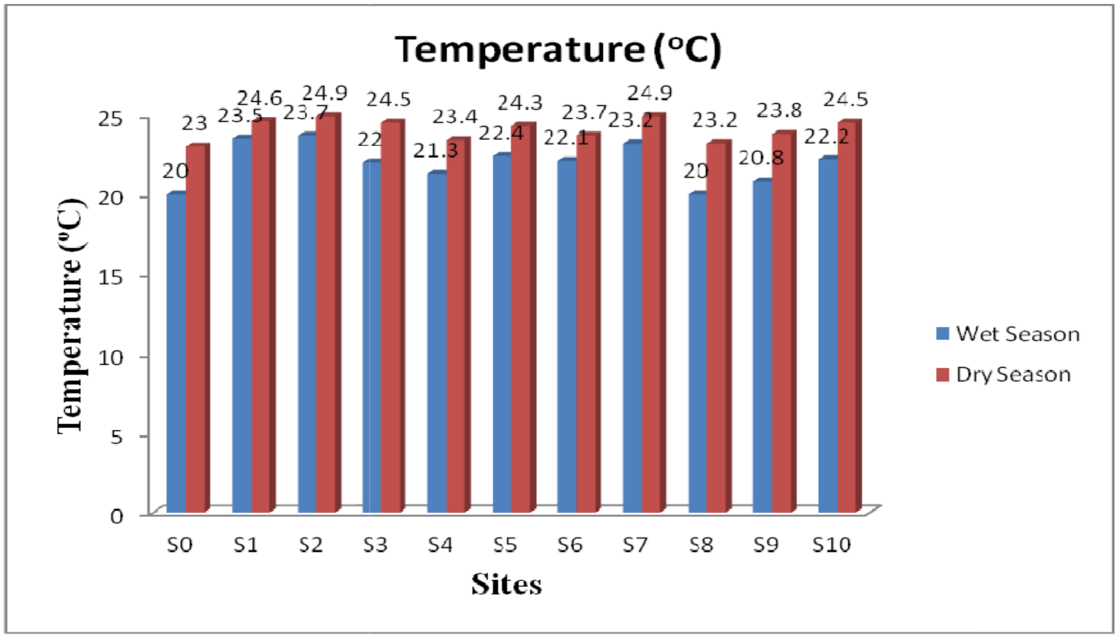


Figure 2.1: Water temperature (°C) in Lake Tana Water

2.5.1.2 pH (Power of Hydrogen)

In this study the pH difference between the reference and impacted sites was not significant ($P < 0.05$). But there was significant difference in pH value between the wet season and the dry season. pH showed neutrality in the reference site (S_0) and impacted sites S_1, S_2, S_4, S_5 and to S_6 (Figure 2.2). Moderate alkalinity peaks were recorded in S_3, S_6, S_7, S_8, S_9 and S_{10} from pH value 7.84 to 8.4 in the dry season. The reference site pH value was recorded as 6.99 in the wet season and 7.35 in the dry season while impacted sites S_2 6.93 at wet season is increasing to S_3 8.4. The maximum pH value was 8.4 recorded at S_3 in the dry season as compared with the minimum value 6.9 at S_2 during the wet season. Both the maximum and the minimum records were at Bahir Dar study area in the southern part of Lake Tana (Figure 2.2) where there are high human activities. But in all sites the wet season pH value was less than the dry season Appendix 1. Rainwater, which has a slightly acidic pH, as well as dilution effect, could be responsible for the decreased pH values in the wet season (Ghana EPA, 2002). Increased pH appears to be associated with increased use of alkaline detergents in residential areas and alkaline material from wastewater in industrial areas, pesticides and fertilizers from agricultural activities (FDREEPA and UNIDO, 2003; Chang, 2008).

Generally, temporal fluctuations in pH could be attributed to factors like removal of carbon dioxide by photosynthesis through bicarbonate degradation and low primary productivity besides decomposition of organic matter (Paramasivam and Kannan, 2005). The recorded high pH values during dry season might be due to the influence of light penetration and high biological activity as a result of organisms' respiration (Kumar *et al.,* 2010; Buttner *et al.,* 2015; Wondie, 2015; Phul, 2016). pH is an important parameter in water quality assessment because it influences the biological and chemical processes in the water body and all processes associated with water supply and treatment(George *et al*., 2012; Wondie, 2015). It is an important environmental factor and is generally considered as an index for suitability of the aquatic environment to life (FDREEPA and UNIDO, 2003; Chang, 2008). The pH of water is also very important because it affects the solubility and availability of nutrients and their utilization by aquatic organisms (Osman and Kloas, 2010).

Naturally occurring fresh waters have a pH range between 6.0 and 8.0 suitable for aquatic organisms (Osman and Kloas, 2010). The largest varieties of aquatic animals prefer a range of 6.5 to 8.0. A standard for priority of surface water pollutants with regard to protection of aquatic species, pH is 6.0 – 9.0 (FDREEPA and UNIDO, 2003). When pH is outside this range, diversity within the water body may decrease due to physiological stress and result in reduced reproduction. Extremes in pH can produce conditions that are toxic to aquatic life, alterations in the ionic and osmotic balance of individual organisms and change in community structure (FDREEPA and UNIDO, 2003; Boman *et al.,* 2008). Lethal effects of pH on aquatic organisms occur below pH 4.5 and above pH 9.5 (WHO, 2006).

In general, it can be concluded that the pH value of Lake Tana water lies within the permissible range of standards indicated in Table 2.4 suitable to human, livestock consumption and fisheries (Ghana EPA, 2002). But the difference in pH among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas (Appendix 1).

Table 2.4: pH standards of surface water as cited by Boman *et al.* (2008) and Osman and Kloas (2010)

pH values	Reference
7.0 – 8.0	WHO (2006)
6.5 – 8.5	Law 25 (1967)
6.5– 9.0	CCME (2007)
6.5 – 8.5	WHO (2008)
6.5 – 8.5	USEPA (2008)
6.5 – 9.5	EU (1998)
6.5 – 8.5	Iranian (1997)
6.5 – 8.5	Australian (1996)
6.5 – 9.2	Indian (2005)
7.0 – 8.5	New Zealand (2008)
6.0 – 9.0	FDREEPA and UNIDO (2003)

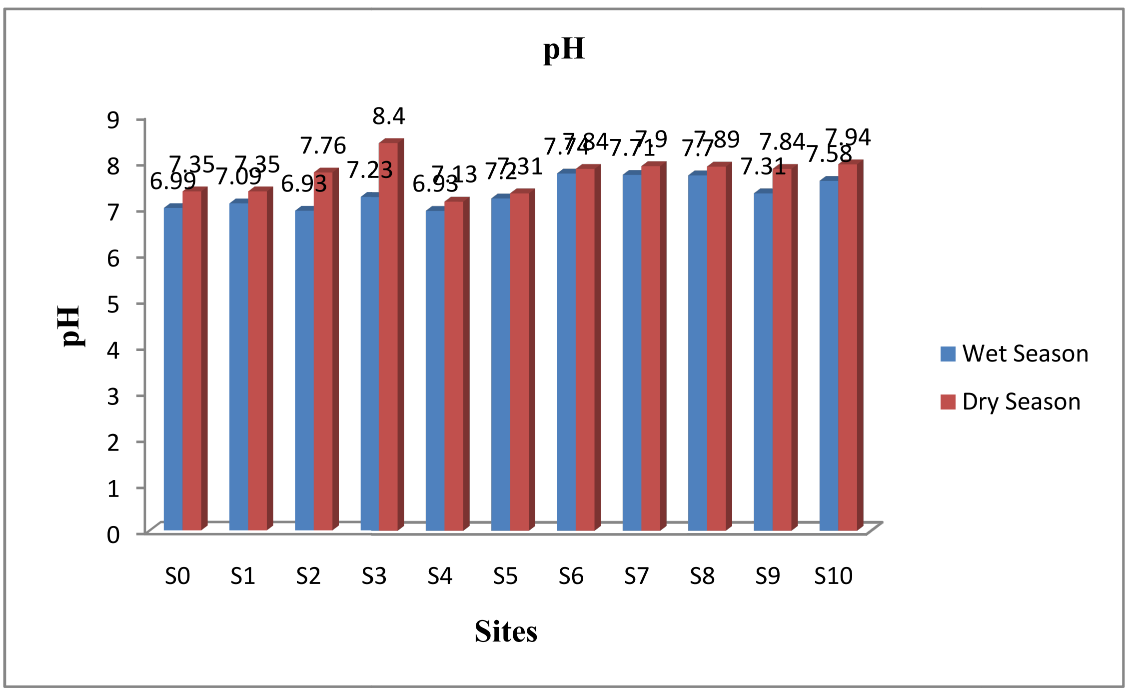


Figure 2.2: Hydrogen ion concentration (pH) in Lake Tana.

2.5.1.3 EC (Electrical Conductivity)

Electrical conductivity (EC) showed significant difference between the reference and impacted sites as well as between the wet season and the dry season ($P < 0.05$) (Figure 2.3). Highly significant differences in conductivity were observed between Megech study area sites and the rest of the study area sampling sites ($P < 0.05$). Electrical conductivity values in Lake water varied between 78-242 and 89-393 µS/cm during wet season and dry season respectively (Appendix 1). The lowest mean value was recorded in the reference site (Eastern part of Lake Tana) in the wet season and the highest mean value was in S_7 (Northern part of Lake Tana) in the dry season where every effluent of Gondar town and upstream agricultural wastes were discharged to Megech and reached at the study area with stipend run off (Figure 2.3, Table 1.1 and Appendix 1).

EC is a useful indicator of the mineralization in a water sample. EC of the water is the sum of ionic conductance of the ionic constituents. It depends on the dissolved nutrients of the water samples. The EC is an indication of the total amount of ionizable salts in solution (Muthulakshmi *et al*., 2015; Wondie, 2015). As Balakrishna *et al.,* (2013) stated that any rise in the electrical conductivity of water indicates pollution (Tekade *et al*., 2011; Srinivas *et al*., 2015).

EC is a numerical expression ability of an aqueous solution to carry electric current. This ability depends on the presence of ions, their total concentration, mobility, valence, relative concentrations and temperature of measurement. High value of EC in dry season could be due to inflow of high quantum of domestic sewage and low values might be due to higher temperature and stabilization of water due to sedimentation and increased concentration of salts (ions and ctions) because of discharged domestic sewage and organic matter in the lake (Gayathri *et al.*, 2013). It is generally known that organic loading (domestic and industrial wastes), fertilizers and pesticides increase the lake water ionic concentrations and subsequently conductivity (Deepa *et al*., 2016).

Wet season conductivity was lower than dry season conductivity at all sites (Figure 2.3). Because evaporation of water from the surface of a lake concentrates the dissolved solids in the remaining water and so it has a higher EC. High electrical conductivity is an indicator of saline conditions (Deepa *et al.,* 2016). On the the other hand, the large amounts of water received during the wet season contribute to dilution effects and a subsequent lowering of EC.

According to Fatoki and Awofolu (2003), health effects in human beings for consuming water with high EC may include disturbances of salt and water balance, adverse effect on certain mycocardic patients and individuals with high blood pressure.

A standard for priority of surface water pollutants with regard to protection of aquatic species, EC is 1000 mg/l at 20^{o}C (FDREEPA and UNIDO, 2003). The World Health Organization (WHO) limit for EC for drinking and potable water is 700 µS/cm (WHO, 2003). Based on this limit, the Lake Tana water is suitable for domestic use in relation to electrical conductivity recorded in this study. EC was below the permissible limit imposed by the Romanian legislation which is 2500 µS/cm (Oana *et al*., 2014).

Generally, EC is below the standard limits indicated in Table 2.5. But the varation of pH among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas (Appendix 1).

Table 2.5: EC standards of surface water as cited by Deepa *et al.* (2016)

EC (µS/cm)	**Reference**
1000	SON (2007)
2500	EU (1998)
700	WHO (2003)
2500	RL (2002)
1000	FDREEPA and UNIDO (2003)

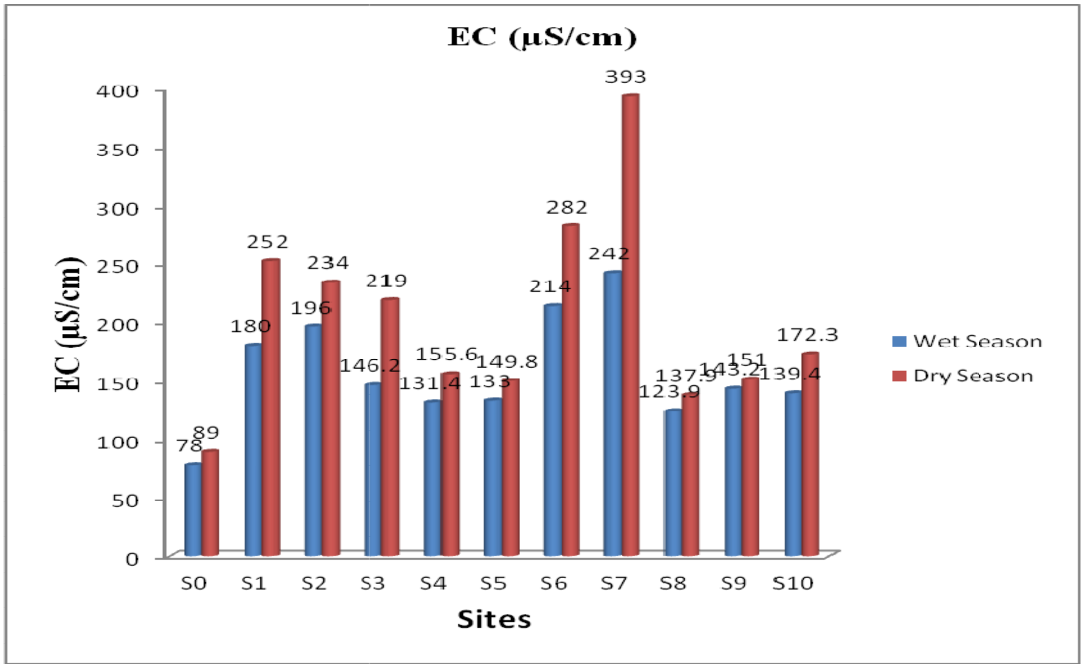


Figure 2.3: Electrical conductivity (EC, µS/cm) in Lake Tana.

2.5.1.4 BOD_5 (Biological Oxygen Demand)

BOD_5 (Biological Oxygen Demand) represents the amount of oxygen that microbes need to stabilize biologically oxidizable matter in five days. It is found to be more sensitive test for organic pollution (WHO, 2006). There were no significant differences in BOD_5 ($p<0.05$) between the reference site and impacted sites. But there was significant difference between the wet season and the dry season. BOD_5 ranges between 4.0-50.0 and 13-114 mg/l in the wet season and dry season respectively (Figure 2.4 and Table 2.2). The highest BOD_5 (12.2 mg/l.) was observed at S_7 in the dry season and lowest was in the reference site (4 mg/l) in the wet season (Appendix 1).

Large quantities of organic matter can reduce the chemical and biological quality of surface water and result in impacted biodiversity of aquatic communities and microbiological contamination that can affect the quality of water. Sources of organic matter include discharges from domestic activities, industrial effluents and agricultural runoff that can affect the water quality. Organic pollution leads to higher rates of metabolic processes that demand oxygen in the lake water which could result in lack of oxygen (anaerobic conditions). It indicates the amount of oxygen that aerobic aquatic organisms could consume in the process of metabolising all the organic matter available in the water. High BOD_5 is low levels of dissolved oxygen in affected water, resulting in aquatic organisms becoming stressed and in extreme cases, suffocating and dying (WHO, 2004). Therefore, Megech study area sampling sites are more suffocated when compared with others that it is affected by human activities in the upstream, Gondar city and its surroundings.

S_7 is with high BOD_5 (114 mg/l). A high oxygen demand indicates the potential for developing DO sag as the microbiota oxidizes the organic matter in the water (FDREEPA and UNIDO, 2003). In all sampling sites the dry season is with high BOD_5 compared with the wet season. This might be organic matter decomposition is appropriate with the dry season that would influence by temperature.

Generally, the BOD_5 levels recorded in the sampling points except the reference site in the wet season were higher than the EU guidelines of 3.0 to 6.0 mg/l (BOD_5) for the protection of fisheries and aquatic life and for domestic water supply (EU, 1998) as cited by (FDREEPA and UNIDO, 2003) and 5 mg/l standard limit of WHO and Ethiopian EPA to the protection of aquatic species (FDREEPA and UNIDO, 2003; WHO, 2007). According to Indian standards, desirable limit of BOD_5 is 4.0 mg/l and permissible limit is 6.0 mg/l. Biological oxygen demand below 3 mg/l or less is required for the best use in India (Phul, 2016). Lake Tana water is used for domestic, recreational and agricultural activities with no treatment especially in the surrounding rural areas. Hence, the BOD_5 levels were beyond the indicated permissible limits in most of the sampling sites.

Temperature and pH are limiting factors for the survival of bacteria in the environment for the decomposition process of organic matter that determine BOD_5 which is indicated in all the sampling sites except the reference site. In the dry season the reference site BOD_5 is 13 mg/l that might be due to leaf debris decomposition of the riparian vegetation that is highly vegetated. A high oxygen demand indicates the potential for developing DO sag (oxygen depletion) as the microbiota oxidizes the organic matter in the water (Igbinosa *et al*., 2012).

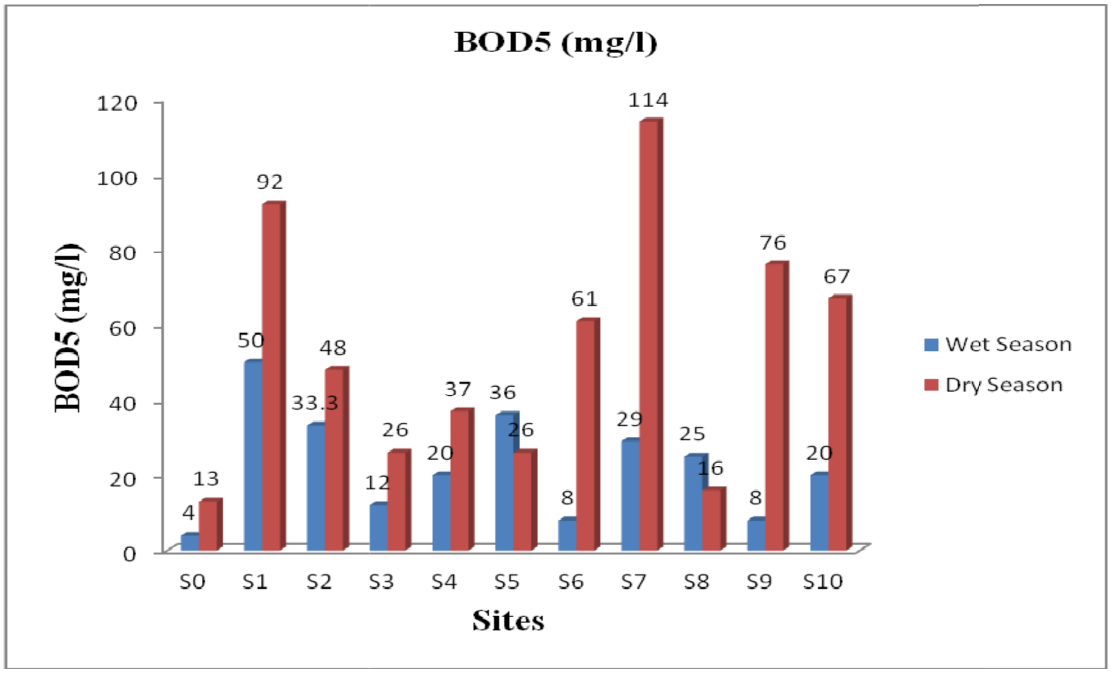


Figure 2.4: Biological Oxygen Demand BOD_5 (mg/l) in Lake Tana.

2.5.1.5 COD (Chemical Oxygen Demand)

There were significant differences in COD ($p<0.05$) between the reference site and impacted sites as well as the wet season and the dry season (Figure 2.5 and Table 2.2)**.** Within the reference site S_0 the COD is less compared with the impacted sites. S_0 is 44 mg/l and the impacted sites range from 72 mg/l (S_5) to 456 mg/l (S_7) and S_0 is 41 mg/l and the impacted sites range from 39 mg/l (S_8) to 680 mg/l (S_7) in the wet and dry seasons respectively (Appendix 1).

The high COD values observed in this study were alarming and suggests that both organic and inorganic contaminants from municipal and industrial sources are entering into the water system. This is undesirable as continuous discharge of untreated effluent can negatively impact the quality of the lake water and subsequently cause harm to aquatic life (Igbinosa *et al*., 2012).

BOD_5 and COD are indices of organic pollution. Since nearly all organic compounds are oxidized in the COD test, COD results are always higher than BOD_5. This was confirmed in this study with all the sampling sites (WHO, 2006).

The increasing trend in COD concentration in all the sampling sites except the reference site (44 and 41 mg/l) and impacted sites S_4 (102 and 156 mg/l) and S_5 (72 mg/l and 138 mg/l) in the wet and dry seasons respectively (Appendix 1) when compared to the WHO standard value (200 mg/l) and Ethiopian EPA 150 mg/l (to the protection of aquatic species) is an indication of pollution from domestic, agricultural and industrial sources (FDREEPA and UNIDO, 2003; WHO, 2004).

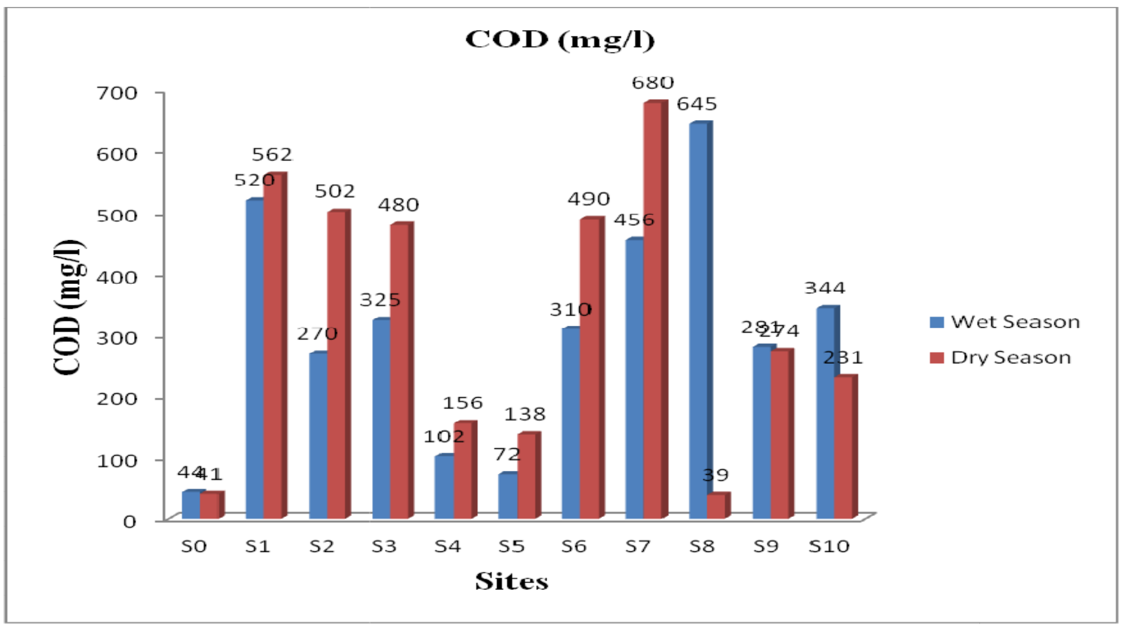


Figure 2.5: Variation in Chemical Oxygen Demand COD (mg/l) of Lake Tana.

2.5.1.6 TSS (Total Suspended Solids)

There were no significant differences in TSS ($p<0.05$) between the reference site and impacted sites. TSS values ranged in the reference site S_0 (0.105 mg/l) and impacted sites S_7 (0.115 mg/l) to S_6 (1.225 mg/l) in the wet season and S_0 (0.025 mg/l); S_7 (0.113 mg/l) to S_6 (0.514 mg/l) in the dry season (Figure 2.6, Appendix 1 and Table 2.2).

Total Suspended Solids (TSS) is known as non-filterable residue, solids (minerals and organic material) that remain trapped on a 1.2 µm filter. TSS elevated concentrations reduce water clarity which can inhibit the ability of aquatic organisms to find food, degrade habitats, clog fish gills, decrease photosynthetic activity, cause an increase in water temperatures, limit the ecological function of aquatic habitats, reduce light penetration, decrease in primary production and reduces food availability for aquatic organisms (USEPA and Environment Canada, 2002; FDREEPA and UNIDO, 2003; Toronto and Region Conservation, 2009). Suspended solids could enter Lake Tana through runoff from industrial, urban and agricultural areas (FDREEPA and UNIDO, 2003).

The TSS value in all sampling sites and seasons of Lake Tana was below the WHO and Ethiopian EPA maximum permissible limit of 20 mg/l and 25 mg/l for drinking water respectively. In addition, the levels of TSS in the entire sample points were below the WHO, USEPA and Ethiopian EPA guidelines of 50 mg/l for the protection of fisheries and aquatic life (FDREEPA and UNIDO, 2003; WHO, 2004). But the difference in TSS among the study areas and sampling sites was due to anthropogenic activities in the watershed and in the study areas (Appendix 1).

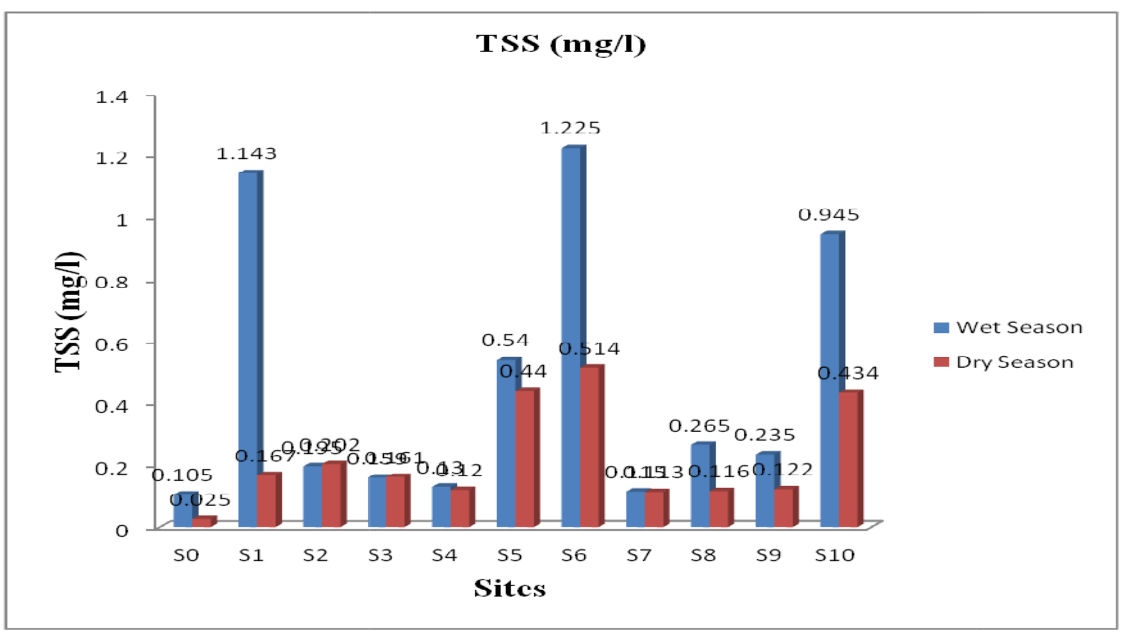


Figure 2.6: Variation in Total Suspended Solids TSS (mg/l) of Lake Tana.

2.5.1.7 TDS (Total Dissolved Solids)

There were no significant differences in TDS ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between wet and dry seasons. TDS values ranged from 66.7 to 119.0 mg/l at impacted sites (S_3 and S_7) respectively in the wet season and 39.0 to 252.0 mg/l at the reference site (S_0) and impacted site (S_6) respectively in the dry season (Figure 2.7). The average TDS value for the two seasons was 93.1 mg/l. The wet season mean value was 78.6 mg/l which is lower than the dry season mean value 107.6 mg/l (Table 2.2). The highest concentration of dissolved solid was 252.0 mg/1 measured at S_6 during the dry season while the lowest value was 39 mg/l at S_0 during the dry season. The data showed a wide variation in dissolved solids content along the whole of Lake Tana during dry season (Figure 2.7 and Appendix 1).

Variations in TDS may be due to the inflow of domestic and industrial effluent discharges, animal and agriculture wastes are examples of the types of sources that may contribute to increased TDS concentrations in the sampling sites. Evaporation also leads to an increase in the total salts (FDREEPA and UNIDO, 2003).

Water, the universal solvent has large number of salts dissolved in it, which largely influences the physicochemical properties and in turn have an indirect effect on aquatic life forms. Deepa *et al.*, (2016) observed that large amount of dissolved solids may result in high osmotic pressure in the organisms. Presence of excess TDS may cause gastrointestinal irritation (Anandhaparameswari *et al*, 2007), exert physiological effects on aquatic organisms, effects on, and adaptations of individual species, affect on community structure and affect microbial and ecological processes such as rates of metabolism and nutrient cycling. TDS has very important synergistic effects with water temperature on the total community composition and function in the water bodies (FDREEPA and UNIDO, 2003).

The total dissolved solids fluctuated in all sites of Lake Tana in the wet season as well as the dry season was in the tolerance limits indicated in Table 2.6. WHO has 500 mg/l as maximum tolerance limit for TDS to domestic water supply (BIS, 1991; Phul, 2016) and the TDS levels recorded in the entire sample points were below the WHO guideline of 1000 mg/l for the protection of fisheries and aquatic life (WHO, 2004). Ethiopian standard to TDS limit is 30 mg/l to the protection of aquatic species (FDREEPA and UNIDO, 2003). Hence the TDS range in Lake Tana water is indicating that Lake Tana has good water quality for drinking, fisheries and irrigation (Mohamed *et al*., 2009). Even though the TDS values of Lake Tana were below the desirable limit, it was affected by the human activities, because there is variation in TDS among the study areas and sampling sites and the wet and the dry seasons (Appendix 1).

Table 2.6: TDS standards of Surface water as cited by Phul (2016)

TDS (mg/l)	Reference
600	WHO (2008)
500	USEPA (2008)
500	Iranian (1997)
500	Australian (1996)
1500	Indian (2005)
100	New Zealand (2008)

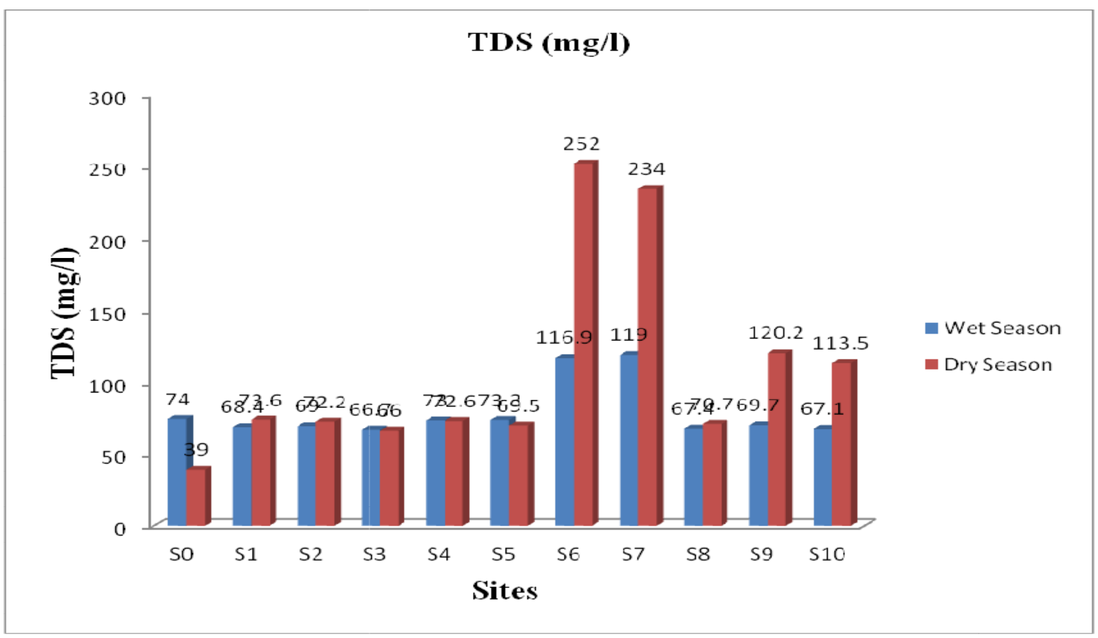


Figure 2.7: Total dissolved solids content TDS (mg/1) in Lake Tana.

2.5.1.8 NO_3^- (Nitrate)

There were no significant differences in NO_3^- value ($p<0.05$) between the reference site and impacted sites but there was a significant difference between wet season and the dry season (Appendix 1).

Nitrate values ranged from 0.151 to 1.230 mg/l at impacted sites (S_3 and S_2) respectively during the wet season and 0.084 to 0.700 mg/l at impacted sites (S_9 and S_7) respectively during the dry season (Figure 2.8). The mean nitrate value was 0.492 mg/l for all the two seasons (Table 2.2). The highest nitrate values were recorded in the wet season, the reason might be agricultural fertilizer runoff and sewage from the watershed in the rainy season (Appendix 1).

Nitrate is the oxidized form of nitrogen compounds commonly present in natural waters, because it is a product of aerobic decomposition of organic nitrogenous matter. Significant sources of nitrates are fertilizers, decayed vegetable and animal matter, domestic and industrial effluents (Gayathri *et al.*, 2013).

Ammonia, nitrate and phosphate are essential nutrients to plant life, but when found in excessive quantities can stimulate undesirable plant growth such as algal blooms. Eutrophication could adversely affect the use of water bodies for different purposes as it deplete oxygen and the covering of large areas by blue green algae and/or macrophytes that can release toxic substances (cyanotoxins) or cyanosis and toxic for human and animal life could prevent access to quality water (Igbinosa *et al*., 2012). Algal bloom is observed in some parts of the study areas. Excess amounts of nitrates in drinking water can result in serious health problems in humans. Nitrates can change normal haemoglobin to methaemoglobin that reduces the ability of blood to transport oxygen to cells. This oxygen starvation can lead to a bluish tint of the lips, ears and nose (known as blue-baby syndrome in infants). It is reported that nitrate concentration above the permissible value 45 mg/l is dangerous to pregnant women and poses a serious health threat to infants less than three to six months of age (WHO, 2006). In severe cases, it can lead to respiratory and heart problems. Infants are especially susceptible to the effects of nitrates in drinking water because of their high stomach pH that increases the conversion of nitrate to nitrite (Trivedi, 2008; WHO, 2011).

Nitrates have a high potential to percolate to ground water since they are very soluble and do not bind to soil (WHO, 2006).

In the sampling sites nitrate levels show seasonal fluctuations with increasing concentrations during the wet season compared with the dry season may be due to surface run off from agricultural activities and domestic sewage and specially washing activities. During the dry season, the reduction in nitrates could be due to algal assimilation and other biochemical mechanism (Rajashekhar *et al.*, 2007).

Nitrate concentration of Lake Tana water sample analysis was found to be below the permissible limits or standards. Water with nitrate levels exceeding 1.0 mg/l should not be used for feeding babies (Dodds, 2002). Expected levels are < 1.0 mg/l (Barbour *et al.*, 1999) and $\leq$ 10 mg/l (FDREEPA and UNIDO, 2003). The Nitrate water quality guideline established by CCME for the protection of aquatic life is 13 mg/l. The overall nitrate levels observed in the entire sampling points were below the WHO limit of 45 mg/l (WHO, 2004), 50 mg/l (WHO, 2008) and 50 mg/l NO_3^- for surface water (to the protection of aquatic species) (FDREEPA and UNIDO, 2003).

Even though the range and mean concentration values of nitrate are lower than the standards, fluctuations of values at the sampling sites were indicators of human influence on Lake Tana (Appendix 1).

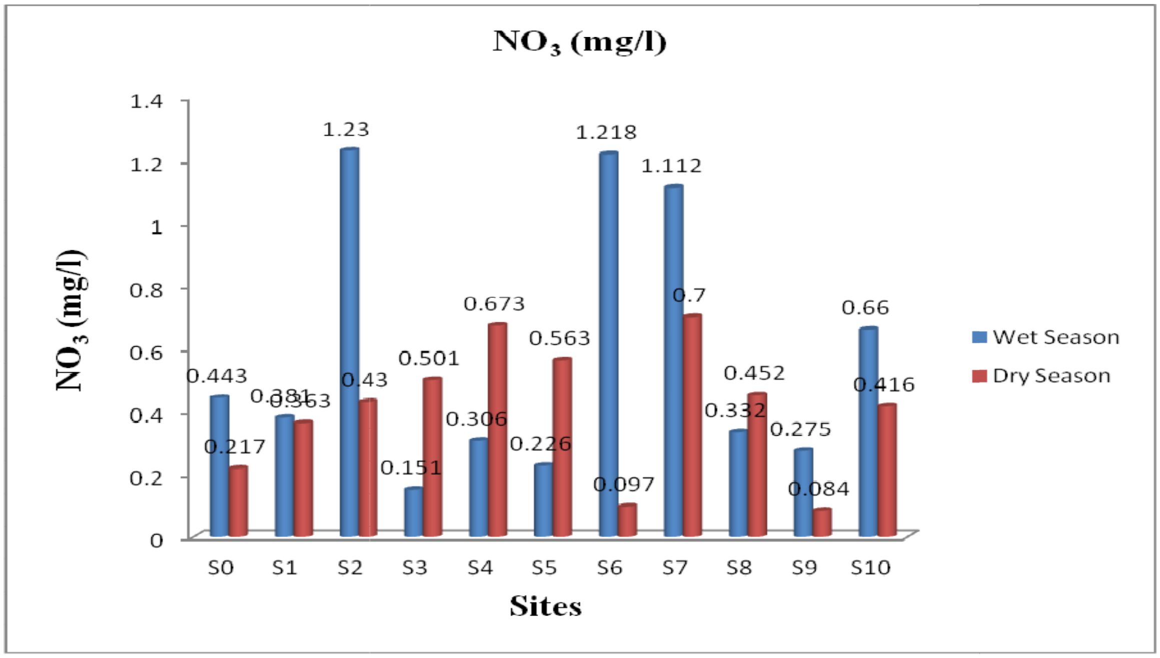


Figure 2.8: Nitrate NO_3^- (mg/1) in Lake Tana.

2.5.1.9 NO_2^- (Nitrite)

There were no significant differences in Nitrite ($p<0.05$) between the reference site and impacted sites. But there was significant difference between wet and dry seasons (Figure 2.9). Nitrite ranged from 0.003 mg/l at the reference site (S_0) to 0.410 mg/l at the affected site (S_7) in the dry season and in the impacted sites (S_2 and S_7) 0.007 to 0.072 mg/l respectively in the wet season (Appendix 1). The average nitrite value for all the two seasons was 0.054 mg/l (Table 2.2).

The very source of nitrite in the study areas might be fertilizers and sewage (untreated wastes). Nitrite is an intermediate in the oxidation of ammonia to nitrate. Many effluents, including sewage, are rich in ammonia, which in turn can lead to increased nitrite concentrations in receiving waters. Therefore high levels of nitrite in surface waters may indicate pollution. This form of nitrogen can be used as a source of nutrients for plants and its presence encourages plant proliferation. The higher concentration of nitrite and its seasonal variations could be attributed to the variation in phytoplankton, excretion and oxidation of ammonia and reduction of nitrate to nitrite. The low content of nitrite could be due to less freshwater input and also uptake by phytoplankton. Nitrites are relatively short lived because they are quickly converted to nitrates by bacteria (FDREEPA and UNIDO, 2003).

Nitrites are known with its carcinogenic effects (FDREEPA and UNIDO, 2003). It produces a serious illness called brown blood disease in fish. Nitrites also react directly with haemoglobin in human blood to produce methaemoglobin, which destroys the ability of blood cells to transport oxygen. This condition is especially serious in babies under three months of age as it causes a condition known as methaemoglobinemia or blue-baby disease. Excessive concentrations of nitrite can be harmful to humans and wildlife. Nitrite is also toxic to aquatic life at relatively low concentrations (Deepa *et al.,* 2016).

Water with nitrite levels exceeding 1.0 mg/l should not be given to babies and in unpolluted waters, nitrite levels are generally low (<0.01 mg/l N) (Deepa *et al.,* 2016). Nitrite concentration of Lake Tana was within the limits 0.1 mg/l to the protection of aquatic species and levels in unpolluted waters are normally low, below 0.03 mg/l NO_2, values greater than this may indicate sewage pollution (FDREEPA and UNIDO, 2003). But the difference in nitrite among the study areas and sampling sites and the wet and the dry seasons was due to anthropogenic activities in the watershed and in the study areas (Appendix 1).

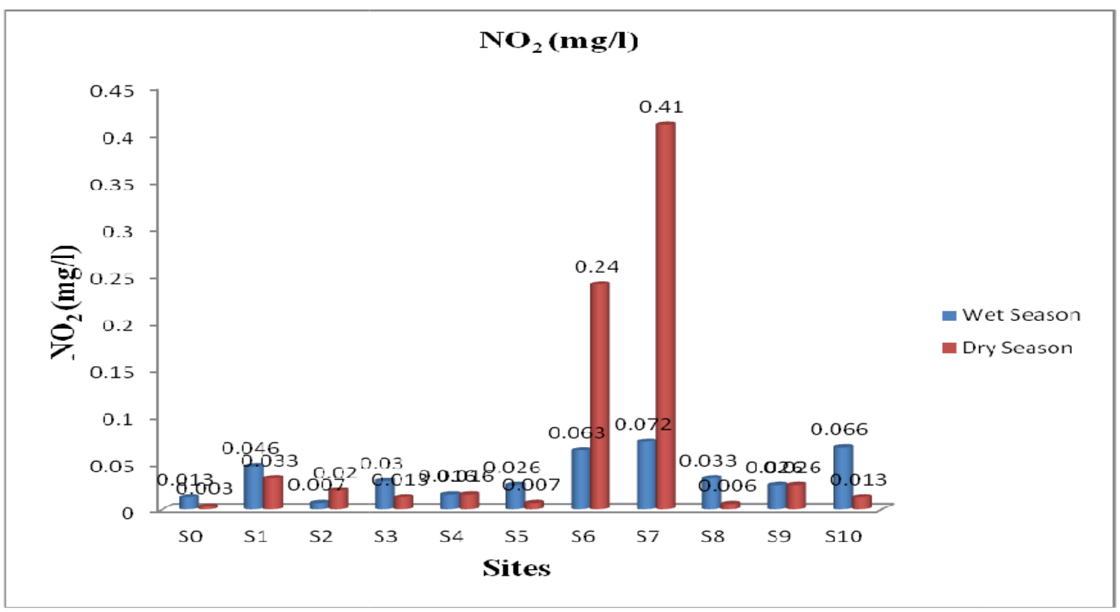


Figure 2.9: Variations of Nitrite NO_2^- (mg/1) in Lake Tana water.

2.5.1.10 NH_3 (Ammonia)

There were no significant differences in ammonia value ($p<0.05$) between the reference site and impaired sites. But there is significance difference between the wet and dry season. Ammonia ranged from 0.06 mg/l at S_{10} to 1.20 mg/l at S_8 during the dry season (Figure 2.10 and Appendix 1). The average value for all the two seasons (dry and wet) was 0.33 mg/l (Table 2.2). But the ammonia concentration of the wet season at each sampling sites exceeds the dry season. The source of ammonia in the study area might be application of fertilizer in the watershed, sewage discharge (from industries and domestic activities) and the biological degradation of manure. Ammonia may also be discharged directly into water bodies by some industrial processes or as a component of domestic sewage or animal slurry. It can also arise in waters from the decay of discharged organic waste. Ammonia occurs naturally in water bodies from the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion of biota, reduction of the nitrogen gas in water by microorganisms and from gas exchange with the atmosphere (FDREEPA and UNIDO, 2003). Ammonia (NH_3) a toxic pollutant often found in landfill leachate and in waste products, such as sewage, liquid manure and liquid organic wastes. It can be used as a measure of the health of water in natural bodies such as lakes (Manios *et al*., 2002; Aziz, 2004). Ammonia is rapidly oxidized by certain bacteria, in natural water systems to nitrite and nitrate. It occurs naturally in water bodies arising from the microbiological decomposition of organic matter. Fish and other aquatic organisms also excrete ammonia (Deepa *et al.,* 2016).

Ammonia, being a source of nitrogen is also a nutrient for algae and other forms of plant life in overloading of natural systems and causing pollution (Deepa *et al.,* 2016). High concentrations of ammonia (NH_3) are toxic to aquatic life. Therefore, it is essential to the ecological balance of water bodies. The acute toxicity of ammonia to fish increases as dissolved oxygen decreases. It can be a cause to pathological changes in tissue of gills, liver, kidneys and respiratory system of fish (FDREEPA and UNIDO, 2003). Ammonia can block oxygen transfer in the gills of fish thereby causing immediate and long term gill damage. Fish suffering from ammonia poisoning will appear sluggish and come to the surface as if gasping for air (Deepa *et al*, 2016).

Natural (unpolluted) waters contain relatively small amounts of ammonia, usually <0.02 mg/l (FDREEPA and UNIDO, 2003). The USEPA (2003) recommends a limit of 0.02 mg/l as ammonia in freshwater environments. And also, Ethiopian EPA water standard guideline recommended 0.02 mg/l of ammonia in fresh water to the protection of aquatic species (FDREEPA and UNIDO, 2003). From the study investigation, ammonia was found to be in excess in the water of Lake Tana compared with the standards. But there is fluctuation of ammonia in the sampling sites and seasons which indicated human influence (Appendix 1).

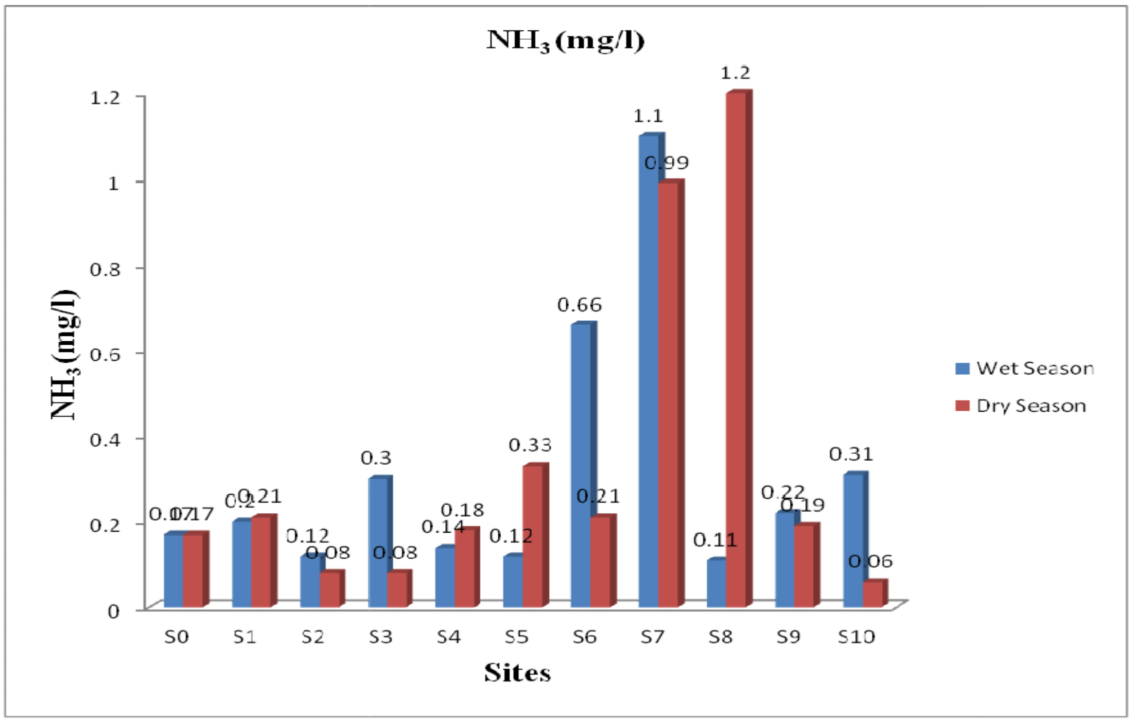


Figure 2.10: Concentrations of Ammonia NH_3 (mg/1) in Lake Tana water.

2.5.1.11 PO_4^{3-} (Phosphate)

There were no significant differences in phosphate ($p<0.05$) between the reference site and impacted sites (Figure 2.11). But there was a significant difference between wet and dry seasons. Phosphate values ranged from 2.6 mg/l at S_8 to 400.0 mg/l at S_7 in the wet season and 1.9 mg/l at S_1 to 28.5 mg/l at S_8 in the dry season (Appendix 1). The average phosphate value for all the two seasons was 42.4 mg/l (Table 2.2).

Phosphate is a nutrient for plant growth and a fundamental element in the metabolic reaction of plants and animals. Phosphate is a major pollutant that causes Eutrophication in surface waters. It is also essential nutrient for life. However, human activities have resulted in excessive loading of phosphorus into many freshwater. The source of phosphate to Lake Tana might be the decomposition of organic matter, atmospheric precipitation, urban runoff, and drainage from agricultural land, in particular from land on which fertilizers have been applied (FDREEPA and UNIDO, 2003).

Phosphate is a nutrient that is natural parts of aquatic ecosystems. Phosphate support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water. But when excess phosphate enters the environment, usually from a wide range of human activities, including the water that can polluted. Phosphate enter Lake Tana and its water sources from human, animal waste and other sources like phosphorus rich bedrock, industrial effluents, fertilizer runoff, laundry and cleaning activities. Phosphates in water increase the tendency of troublesome algae to grow in the water. This causes eutrophication or over fertilization as it chokes up the water ways and uses up large amounts of oxygen (WHO, 2006). Lake Eutrification is being seen around the edge of Lake Tana. Lakes that appear relatively clear in spring can resemble green soup in winter in the tropics due to algae blooms fueled by phosphate. Water quality can be further impaired when bacteria consume dead algae and use up dissolved oxygen, suffocating fish and other aquatic life (Gayathri *et al*., 2013). Significant increase in algae negatively affects water quality, food resources and habitats and decreases the oxygen that fish and other aquatic life need to survive. Some algal blooms are harmful to humans because they produce elevated toxins and bacterial growth that can make people sick if they come into contact with polluted water, consume tainted fish or shellfish, or drink contaminated water (US EPA, 2016). It is also toxic to man, livestock and wildlife (FDREEPA and UNIDO, 2003).

In the most of Lake Tana sampling sites maximum phosphate values were detected during wet season (Appendix 1). This might be due to the entry of agricultural fertilizers from the watershed to the lake.

Phosphate in many of Lake Tana sampling sites was above the limits of 2.2 mg/l (WHO, 2003) standard for drinking water**,** WHO maximum permissible limit of 5 mg/l for fresh water (WHO, 2004). Additionally, the phosphate levels obtained in this study are exceedingly higher than 0.03 mg/l Ethiopian EPA for aquatic life, irrigation purposes, livestock watering and recreational activities (FDREEPA and UNIDO, 2003; Igbinosa *et al*., 2012). This is because of human activities.

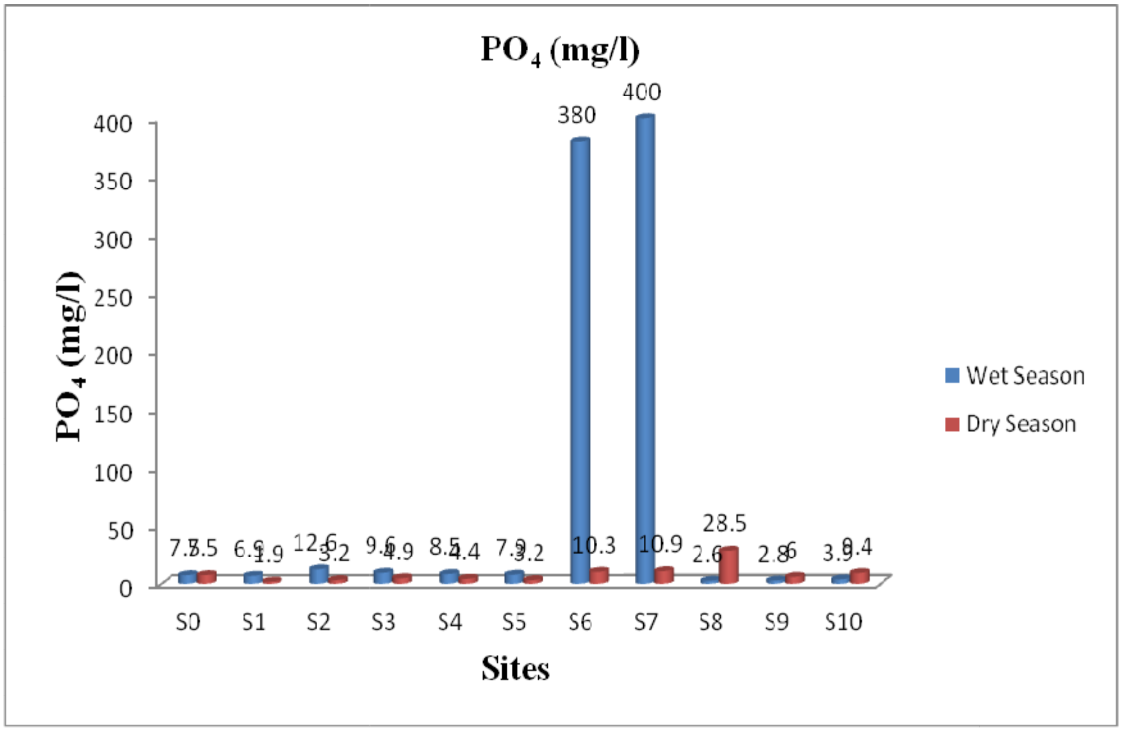


Figure 2.11: Concentrations of Phosphate PO_4^{3-} (mg/1) in Lake Tana water.

2.5.1.12 SO_4^{2-} (Sulphate)

There were no significant differences in sulphate values ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between the wet season and the dry season. Sulphate values ranged from 0 mg/l at S_7 to 8 mg/l at S_2 during the dry season and 8 mg/l at S_6 to 35 mg/l at S_5 during the wet season (Appendix 1). The average sulphate value was 11 mg/l for all the two seasons (Table 2.2). Seasonal variation of sulphate content exhibits high values during wet season and as compared with the low value measured in the dry season (Figure 2.12).

The high sulfate content probably may be due to decay of phytoplankton and aquatic macrophytes or due to the oxidation of sulphide or sulphite to sulphate in the presence of photosynthetic sulphur bacteria (Mohamed *et al*., 2009). Sulphate is present in fertilizers and contributes to water pollution and increases sulphate concentration in water body. They also come from runoff water that contains relatively large quantities of organic and mineral sulphur compounds. The supply of sulphate ions in surface water under natural conditions are due to the reactions of water with sulphate containing soil and with the biochemical and chemical oxidation of sulphides and other compounds of sulphur. Atmospheric sulphur dioxide, formed by the combustion of fossil fuels and in metallurgical processes, may contribute to the sulphate content of surface waters. Levels of sulphate in rainwater and surface water correlate with emissions of sulphur dioxide from anthropogenic sources (Deepa *et al,* 2016).

Excess sulphate in water imparts an offensive taste and noxious odours. SO_4^{2-} and its byproducts are toxic to plants, animals and microorganisms. Sulphate doses 14 to 29 mg/kg have effect on humans, resulting in disturbance of the alimentary canal. Water containing magnesium sulphate at a concentration of 1000 mg/l can cause human nausea (FDREEPA and UNIDO, 2003; Deepa *et al.,* 2016). Cathartic effects are commonly reported to be experienced by people consuming drinking water containing sulphate in concentrations exceeding 600 mg/l. Dehydration has also been reported as a common side effect following the ingestion of large amounts of magnesium or sodium sulphate (Deepa *et al.,* 2016).

The relative low sulphate content was recorded in the Nothern area of Lake Tana during dry season. The low sulphate value measured during dry season may be due to its uptake and accumulation by plankton and aquatic macrophytes as well as bacteria which are able to reduce sulphate to a form which can be incorporated into organic compounds (Toufeek and Korium, 2008).

Sulphate concentration ranges from 0-35 mg/l with a mean value of 11 mg/l (Table 3). This is lower than the maximum permissible limit of 250 mg/l set by WHO (WHO, 2006). In India the desirable amount of sulphate in drinking water is 200 mg/l (BIS, 1991). The levels of sulphate in the water samples in the entire sampling points were below the 200 mg/l WHO maximum permissible levels (WHO, 2004) and 200 mg/l of Ethiopian EPA standard to the protection of aquatic species (FDREEPA and UNIDO, 2003). Eventhogh the variation of sulphate value among the sites and between seasons is an indication of human influence on Lake Tana, the Lake water is very high quality for drinking, irrigation and fish culture (Mohamed *et al*., 2009).

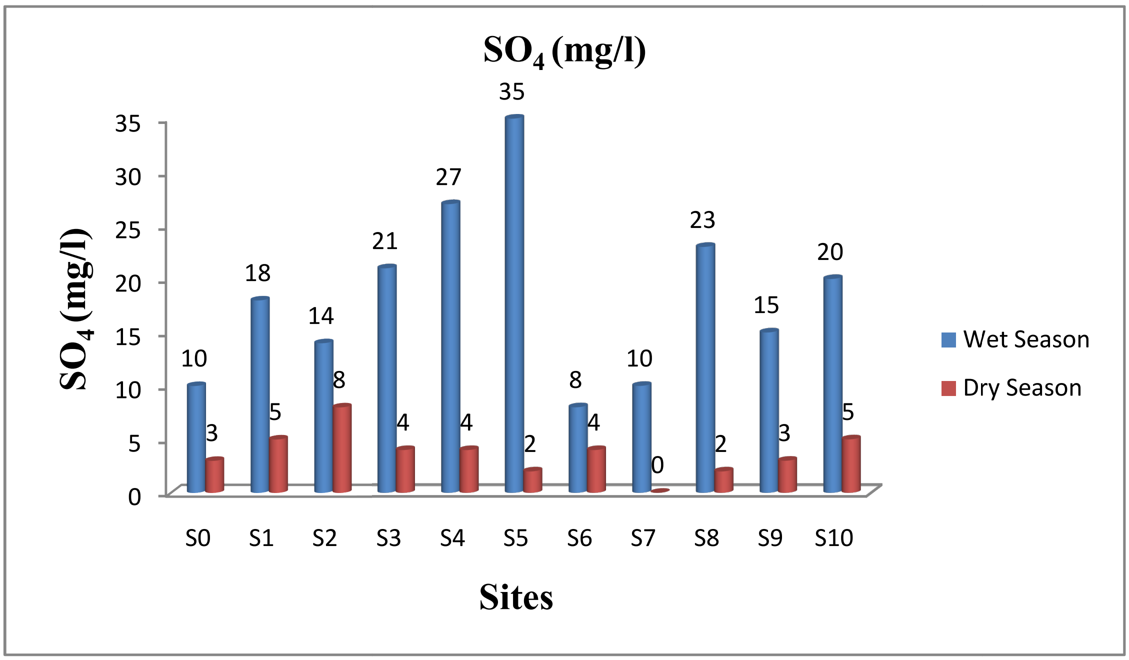


Figure 2.12: Concentrations of sulphate SO_4^{2-} (mg/1) in Lake Tana water.

2.5.1.13 S^{2-} (Sulphide)

There were no significant differences in the sulphide values ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between the wet and dry seasons (Figure 2.13).

A higher level (14 mg/l) of sulphide was recorded at the reference site the wet season compared to the impacted sites in the dry season. It was 0 at S_3 to 7 mg/l at S_1 in the dry season. This might be due to the conversion process of S^{2-} to SO_4^{2-} in the polluted sites by the consortia of sulphure oxidizing microorganisms and no run off in the dry season (Appendix 1).

We found sulfide at all sampling points in both seasons except site S_3, but were not deep enough to result in anoxic conditions.

Sulfide in the lake is formed through anaerobic respiration and levels tend to decrease in the presence of Fe(II) because sulfide and Fe(II) combine to form pyrite precipitates. Therefore, Fe(II) concentrations are limited in the hypolimnion of Lake Tana where sulfide exists in large concentrations.

The high sulphide may be due to decomposition portenious organic matter and aquatic organisms (Mohamed *et al*., 2009). Sulphide can result from fertilizers and contributes to water pollution. It also comes from runoff water that contains relatively large quantities of organic and mineral sulphur compounds. Atmospheric sulphur dioxide, formed by the combustion of fossil fuels and in metallurgical processes contributes to the sulphide in surface waters. Levels of sulphide and sulphate in rainwater and surface water correlate with emissions of sulphur dioxide from anthropogenic sources (Deepa *et al.,* 2016).

Sulphide gives bad odour, is toxic to many aquatic organisms and animals. It is a cause to loss of consciousness, respiratory symptoms (irritation and cough), increased headache, depression, tiredness and nausea. It also affects skin and integumentary system, cardiovascular system, kidney, liver, gastrointestinal system, hematopoietic system and immunological system (Trivedi, 2008).

Except S_3 in the dry season the levels of sulphate in the water samples of the entire sampling points were above the optimum S^{2-} for surface water $\leq$ 0.005 mg/l (US EPA, 2003). Hence Lake Tana was highly influenced by anthropogenic activities.

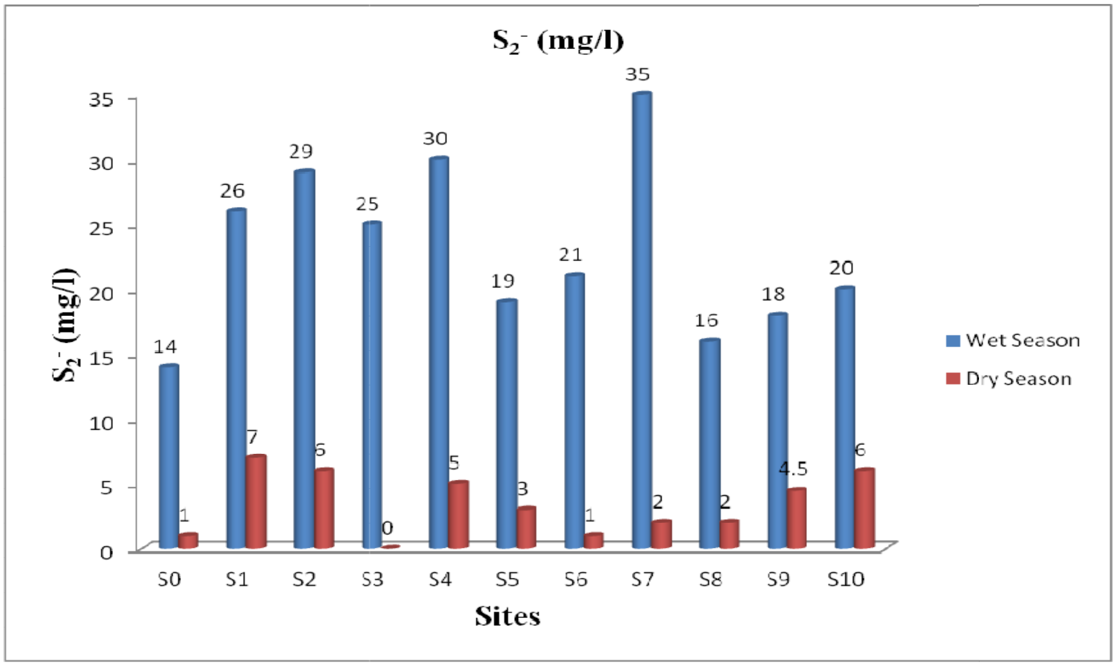


Figure 2.13: Concentrations of Sulphide S^{2-} (mg/1) in Lake Tana water.

2.5.2 Metals

Toxic metals can bioaccumulate in the body and in the food chain. Metal toxicity or metal poisoning is the toxic effect of certain metals in certain forms and doses on life (Raja and Namburu, 2014). Metals can accumulate in the human body system and causing damage to nervous system and internal organs (Lohani *et al*., 2008). The health implications of excess consumption of these non essential metals have been known to result in neurological, bone and cardiovascular diseases, renal dysfunction and various cancers, even at low levels (Igbinosa *et al*., 2012). Metals "can bind to vital cellular components such as structural proteins, enzymes and nucleic acids that interfere with their functioning." Long term exposure to heavy metals can have carcinogenic, central and peripheral nervous system and circulatory effects. Metals have properties of toxicity and non degradability in nature (Raja and Namburu, 2014). Agricultural runoff, urban centers and industrial discards and wastes, sewage, electronic wastes were the main anthropogenic source of the below mentioned toxic metals of Lake Tana (WHO, 2004).

2.5.2.1 Cr (Chromium)

There were no significant differences in Cr values ($p<0.05$) between the reference site and impacted sites; but showed significant difference between the wet season and the dry season (Figure 2.14).

Chromium was not detected at the sites S_0, S_8 and S_9 in the dry season and its maximum value at this season was 0.02 mg/l at S_7. The range of chromium was 0.02 mg/l at S_{10} to 0.13 S_3, S_6 in the wet seasons (Appendix 1). Chromium mean level in Lake Tana was 0.04 mg/l (Table 2.2). This value of chromium could be due to industrial wastes and sewage from the towns located within the catchment. It could be also from photography and corrosion inhibitor sources (FDREEPA and UNIDO, 2003), because there is little variation among the sites and the seasons. The study revealed that during the rainy seasons the levels of Cr were higher than the dry season because during the rainy season, a lot of industrial and urban wastes get into water channels through surface run off causing elevated levels. Sources of Cr in aquatic ecosystems are attributed to industrial and urban wastes and sewage (Akan *et al.,* 2010). It was reported that industrial activities such as metal plating, dyes, pigments, ceramic, glues, tanning, wood preserving are reported to contribute Cr (Krishna *et al.,* 2014). It is also used in a variety of applications such as leather tanning, chromium plating, timber preservation, corrosion protection, textiles, etc. The main sources of Cr are industrial wastes such as Cr pigment, tannery wastes, leather manufacturing wastes, electroplating and municipal sewage (Rahman *et al.,* 2012; Darshan *et al.*, 2014).

Chromium is mobile in the environment and highly toxic to all forms of organisms including microorganisms. It penetrates cell membrane and badly affects central nervous system. It causes irritation to respiratory system and risk of serious damage to eyes (Darrie, 2001). Chromium and its compounds are known to cause cancer of the lung, nasal cavity and suspected to cause cancer of the stomach and larynx (Akan *et al.,* 2010). It also causes mutagenic, anuria, nephritis, gastro-intestinal ulceration, perforation in partition of nose, hepatic, renal, neuronal damage and heritable genetic damage. It is very harmful in contact with skin and also toxic if swallowed and inhaled. It causes respiratory trouble and lung tumors when inhaled and may cause complications during pregnancy (Trivedi, 2008, Sundar *et al*., 2010; Raja and Namburu, 2014). Low exposure to chromium can irritate the skin and cause ulceration but long term exposure can cause kidney, liver, circulatory and nerve tissues damage (Raja and Namburu, 2014). It is also very toxic to aquatic organisms and the aquatic environment (Darrie, 2001). Fish are usually more resistant to Cr than other aquatic organisms (Krishna *et al.,* 2014).

Generally the natural content of chromium in drinking water is very low ranging 0.01 to 0.05 mg/l except for regions with substantial chromium deposits (Krishna *et al.,* 2014). The maximum limit of Cr is 0.05 mg/l by the Ethiopian EPA standard. This is with consideration of aquatic species protection (FDREEPA and UNIDO, 2003). Cr levels obtained in this study did not exceed the recommended limit of 0.05 mg/1 in drinking water (WHO, 2008) and the permissible limits of 0.1 mg/l set by WHO (WHO, 2004) in the dry season but in the wet season it exceeded the limit at S_0, S_3, S_6, S_7 and S_8 in the wet season. Lake Tana is used for drinkink purpose by the surrounding rural and monstry communities. It is below the standards indicated in Table 2.7. Therefore the water of Lake Tana is no safe in all of the sites and seaons to be used for domestic and agricultural activities and survival of aquatic life. The variation among the study areas and sampling sites as well as the sampling seasons is due to human activities in the catchments (Appendix 1).

Table 2.7: Cr standards of Surface water as cited by Gebrekidan and Samuel (2011)

Cr (mg/l)	Purpose	Reference
0.05	Drinking	WHO (1982); WHO (2003); WHO (2008); WHO (2011); Law 25 (1967); SON (2007); EU (1998); Iranian (1997); Australian (1996); Indian (2005); New Zealand (2008); New Zealand (2008); FDREEPA and UNIDO (2003)
0.1	Irrigation	FAO (1992); FAO (2007); US EPA (1998); US EPA (2008); WHO (2011)
12.0-13	Fishery	FAO (2007); USEPA (1998)

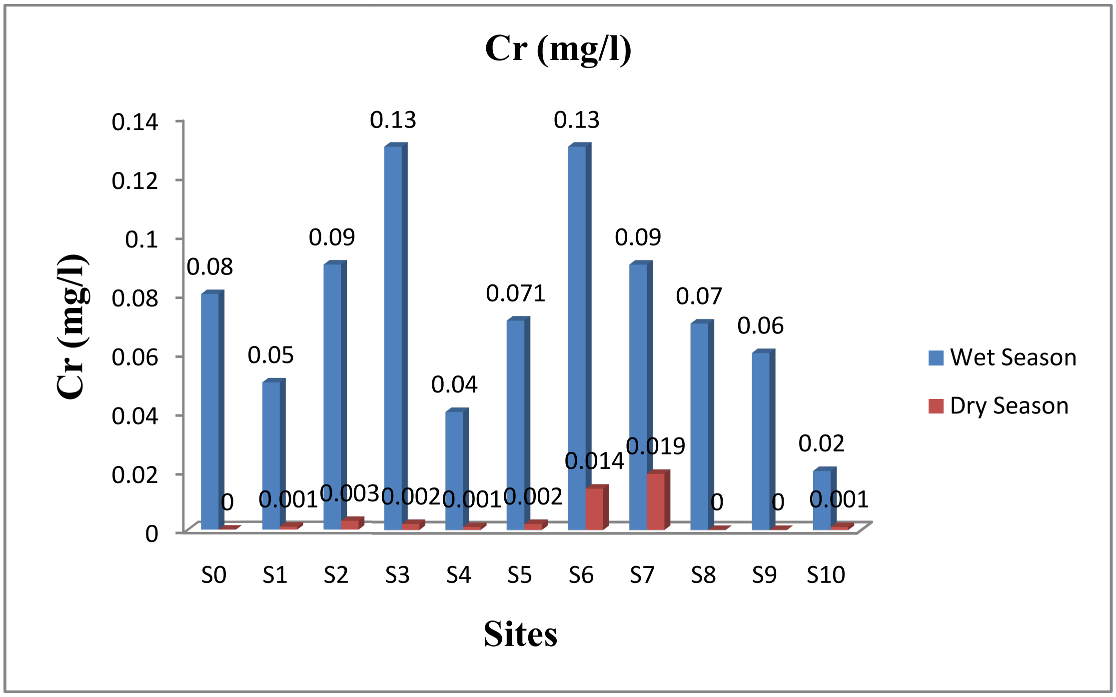


Figure 2.14: Chromium Cr (mg/1) in Lake Tana water.

2.5.2.2 Mn (Manganese)

There were no significant differences in Mn values ($p<0.05$) between the reference site and impacted sites as well as the wet season and the dry season. But there is some variation among the sites (Figure 2.15).

Mn showed the range of 0.001 to 0.044 mg/l from the reference site to the impacted sites in the two seasons (Appendix 1). The variation is minimal. The mean Mn level observed in this study was 0.006 mg/l (Table 2.2). This value of chromium could be due to industrial wastes, agricultural wastes and sewage from the towns located within the catchment.

Manganese is used as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate) and as an ingredient in various products that might be the source of pollution. It is used in the manufacturing of iron and steel alloys and as an ingredient in various products. It gets into the aquatic ecosystems from industries manufacturing dry cell batteries, glass, fertilizer and leather and textile industries (WHO, 2011). It is also released through agricultural activities, building activities and quarry processes (Akan *et al.,* 2010) which are the very phenomena of watershed of Lake Tana.

Manganese is known to block calcium channels and with chronic exposure results in central nervous system dopamine depletion that leads to Parkinson's disease (Raja and Namburu, 2014). In humans, it has been implicated with diseases such as diabetes, nervous instability and bone disorders in babies. Mn is a metal with low toxicity but has a considerable biological significance and seems to accumulate in fish (Krishna *et al.,* 2014). According to Krishna *et al.* (2014), high Mn concentration interferes with central nervous system of vertebrates; hence consumption of Mn contaminated fish could result to health risks to the consumers. High concentration of Mn causes liver cirrhosis and also produces a poisoning called Manganese or Parkinson disease. It also causes acute and chronic toxicity effects to algae, invertebrates and vertebrates (FDREEPA and UNIDO, 2003).

Mn is essential for mammals but in concentration greater than 100 ppm, is toxic and causes growth retardation, fever, sexual impotence, muscles fatigue and eye blindness (Trivedi, 2008).

In all the sampling sites the mean Mn concentration levels in surface water was found to be lower than the recommended limit of 0.40 mg/1 for Mn in drinking water (WHO, 2008). Ethiopian EPA water standard guideline recommended 0.3 mg/l of Mn in fresh water to the protection of aquatic species (FDREEPA and UNIDO, 2003). The mean Mn levels observed in this study were lower compared to the standards indicated in Table 2.8 that would be used for domestic and agricultural activities and survival of aquatic life. But the variation among study areas and sampling sites as well as the sampling seasons was the result of anthropogenic activities.

Table 2.8: Mn standards of surface water as cited by Gebrekidan and Samuel (2011)

Mn (mg/l)	Purpose	Reference
0.1	Drinking	WHO (2008); WHO (2011); Law 25 (1967); EU (1998); Indian (2005); USEPA (2008)
0.5	Drinking	Iranian (1997); Australian (1996)
0.4	Drinking	New Zealand (2008)
0.3	Drinking	FDREEPA and UNIDO (2003)
0.2	Irrigation	FAO (1992)
1	Fishery	FAO (2007); USEPA (1998)

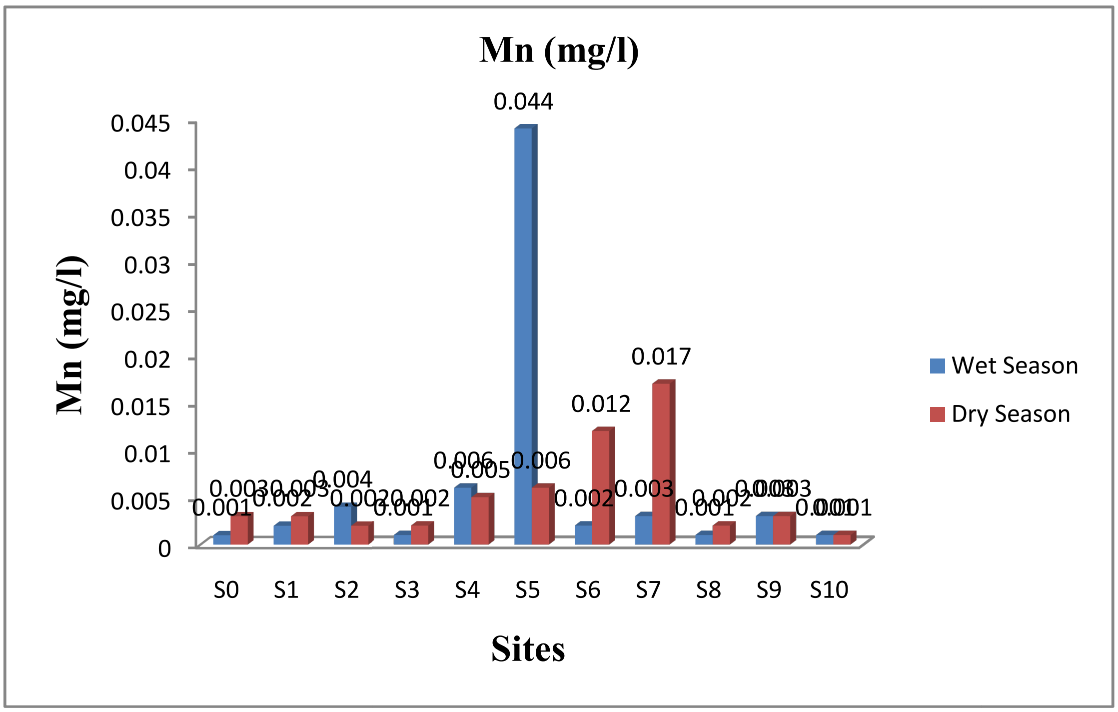


Figure 2.15: Concentrations of Manganese Mn (mg/1) in Lake Tana water.

2.5.2.3 As (Arsenic)

There were no significant differences in As values ($p<0.05$) between the reference site and impacted sites but a significant difference was observed between the wet and dry season (Figure 2.16).

As was absent in almost all of the sampling sites except S_5 and S_7 in the dry season but in the range 0.001 at S_0 and S_{10} to 0.035 mg/l S_2 (Appendix 1). The mean As level observed in this study was 0.003 mg/l (Table 2.2). The study area source of As in the wet season was runoff from agricultural activities and urban centers in the catchment.

As can be discharged from industrial pollution, pesticides and fertilizers, glass and ceramics production discharge, tanneries, dye, wood preservation products, chemical industry and in the production of detergents (FDREEPA and UNIDO, 2003). The processes of energy production from fossil fuel and the smelting of metals are the major anthropogenic activities that result in arsenic contamination of air, water and soil (Ravenscroft *et al.*, 2011; Pius and Orish, 2013).

Different studies have revealed that As is toxic to human cells at very low concentrations. This includes mutagenesis and carcinogenesis through alterations in cell differentiation and proliferation associated with uncontrolled cell growth (Liu and Lu, 2010; Flora, 2011). Arsenic is poisonous to fishes, animals and humans. Greater than 25 mg of arsenic causes vomiting, diarrhoea, nausea, irritation of nose and throat, abdominal pain, skin eruptions inflammations and even death. It may cause cancer of skin, lungs and liver, chromosomal aberration and damage, gangrene, loss of hearing, injury to nerve tissue, liver and kidney damage. Minor symptoms of As poisoning are weight loss, hair loss, nausea, depression, fatigue, white lines across toe nails and finger nails (Trivedi, 2008). Exposure to high levels of arsenic can cause death. All types of arsenic exposure can cause kidney and liver damage and in the most severe exposure there is erythrocyte hemolysis (Raja and Namburu, 2014). It has adverse effects on both vertebrate and invertebrate of aquatic organisms. It affects aquatic organisms by reducing migration, growth and reproduction, disrupting endocrine system and can be bioconcentrated in aquatic organisms (FDREEPA and UNIDO, 2003)

Ethiopian EPA water standard guideline recommended 0.05 mg/l of As in fresh water to the protection of aquatic species (FDREEPA and UNIDO, 2003). The concentration of arsenic in the study area is generally below the standards indicated in Table 2.9. But the variation of As among study areas, sampling sites and sampling seasons was the result of human activities in the catchments areas. Because, in one study area but the different sites in different seasons, the geologic formation is the same but the variation is due to human activities.

Table 2.9: As standards of surface water as cited by Pius and Orish (2013) and Gebrekidan and Samuel (2011)

As (mg/l)	Purpose	Reference
0.01	Drinking	WHO (2003); WHO (2008); WHO (2011); EU (1998); USEPA (1998), USEPA (2008); New Zealand (2008); Iranian (1997)
0.05	Drinking	Iranian (1997); Indian (2005); FDREEPA and UNIDO (2003)
0.007	Drinking	Australian (1996)
0.5	Fishery	FAO (2007); USEPA (1998)

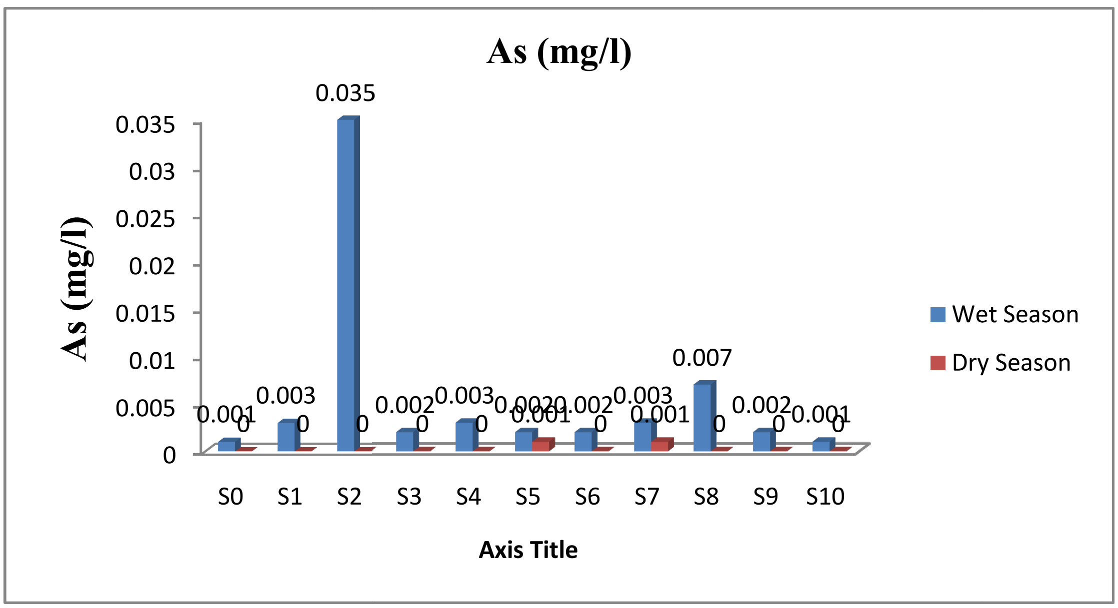


Figure 2.16: Concentrations of Arsenic As (mg/1) in Lake Tana water.

2.5.2.4 Cd (Cadmium)

There were no significant differences in Cd values ($p<0.05$) between the reference site and impacted sites. But there was a small variation between the wet and dry season (Figure 2.17). Cd in Lake Tana water ranged between 0 at S_0, S_4, S_6, S_8 to 0.003 mg/l at S_2 in the dry season while in the wet season ranged between 0.001 mg/l at S_0, S_5, S_{10} and to 0.013 mg/l at S_7 (Appendix 1). The mean Cd concentration of Lake Tana was 0.002 mg/l (Table 2.2). This value of Cd could be due to industrial wastes, agricultural wastes and sewage from the towns located within the catchment and the watershed agricultural areas. The highest Cd value was recorded at Megech inlet sampling site where there is discharge of Gondar town waste to Megech River and run off from the nearby agriculture sites.

Cd can be a source of environmental problem driving from Television Phosphors, fertilizers, pesticides, detergents and refined petroleum products (Darshan *et al.,* 2014). Cadmium is used in electroplating, in pigments and as stabilizer for plastics. Further environmental sources are smelting of other metals like Zn, burning of fossil fuels and waste materials, use of sewage sludge fertilizers. Cadmium is used industrially as an anti-friction agent, rust inhibitor, in plastic manufacturing, orange colouring agent and in paints and in alkaline batteries (nickel cadmium dry cell batteries). Cadmium is also released from cadmium fungicides, cadmium pigments, phosphates fertilizers and pesticides, burning of fossil, deterioration of galvanized materials and cadmium-plated containers (FDREEPA and UNIDO, 2003). It is also released into the environment from power stations, heating systems, metal working industries or urban traffic, run-off from waste batteries and paints (Aboud and Nandini, 2009). Hence disposal of industrial and agricultural wastes are sources of Cd.

Cd is a toxic metal with environmental decomposition process half-life time of 10-30 years, accumulating in the body especially in the kidneys (Su *et al*., 2011). Kidney is its major target organ; the first manifestation of Cd toxicity is tubular dysfunction with increased urinary excretion of calcium and low molecular weight proteins (Fujiwara *et al*., 2012). It is a major cause of renal disease. Long term exposure has been associated with bone diseases (such as osteomalacia and osteoporosis), alteration in lung function, lung cancer, prostate cancer and renal cancer in exposed individuals (Nair *et al*., 2013). The experimental and epidemiological evidence of Cd in its carcinogenicity to man has been proven (Templeton and Liu, 2010). It induces single strand DNA breaks, exerts inhibitory effects on DNA repair system, disrupts cell adhesion (Pius and Orish, 2013; Raja and Namburu, 2014). Cadmium causes high blood pressure and interferes with enzymes and causes a painful disease (Rajappa *et al*., 2010). Cd concentaration is also responsible to liver damage, renal dysfunction, gastrointestinal damage, inhibit bone repair mechanisms, mutagenic and carcinogenic (FDREEPA and UNIDO, 2003; Darshan *et al*., 2014). Cadmium causes reduced plant growth and complete failure (FDREEPA and UNIDO, 2003).

Above 50 mg/l Cd may cause vomiting, diarrhoea, abdominal pains, loss of consciousness. It takes 5–10 years for chronic Cd intoxication. During first phase, discolouration of teeth, loss of sense of smell, mouth dryness occurs. Afterwards it may cause decrease of red blood cells, impairment of bone marrow, disturbance in calcium metabolism, softening of bones, fractures, skeletal deformations, damage of kidney, hypertension, tumor formation, heart disease, impaired reproductive function, genetic mutation, etc with 50mg and above concentration (Trivedi, 2008).

Ethiopian EPA water standard guideline recommended 0.005 mg/l of Cd in fresh water for the protection of aquatic species (FDREEPA and UNIDO, 2003). All the samples in the study area showed concentrations below the maximum acceptable concentration for drinking water (0.003 mg/l) (WHO, 2008) except at S_7 0.0125 mg/l. At all the sampling sites except S_7 Cd level range was within the stipulated tolerance limit for water bodies as indicated in Table 2.10. But the difference in Cd values among the study areas, sampling sites and sampling seasons is human activities. Because value difference in one study area that has the same geologic formation, the variation with the sampling sites and seasonal was human activities.

Table 2.10: Cd standards of surface water as cited by Pius and Orish (2013) and Gebrekidan and Samuel (2011)

Cd (mg/l)	**Purpose**	**Reference**
0.01	Drinking	WHO (2011); Iranian (1997); Indian (2005)
0.005	Drinking	FDREEPA and UNIDO (2003); USEPA (2008); FAO (2007); USEPA (1998)
0.003	Drinking	WHO (2008)
0.002	Drinking	Australian (1996)
0.004	Drinking	New Zealand (2008)
1	Fishery	FAO (2007); USEPA (1998)

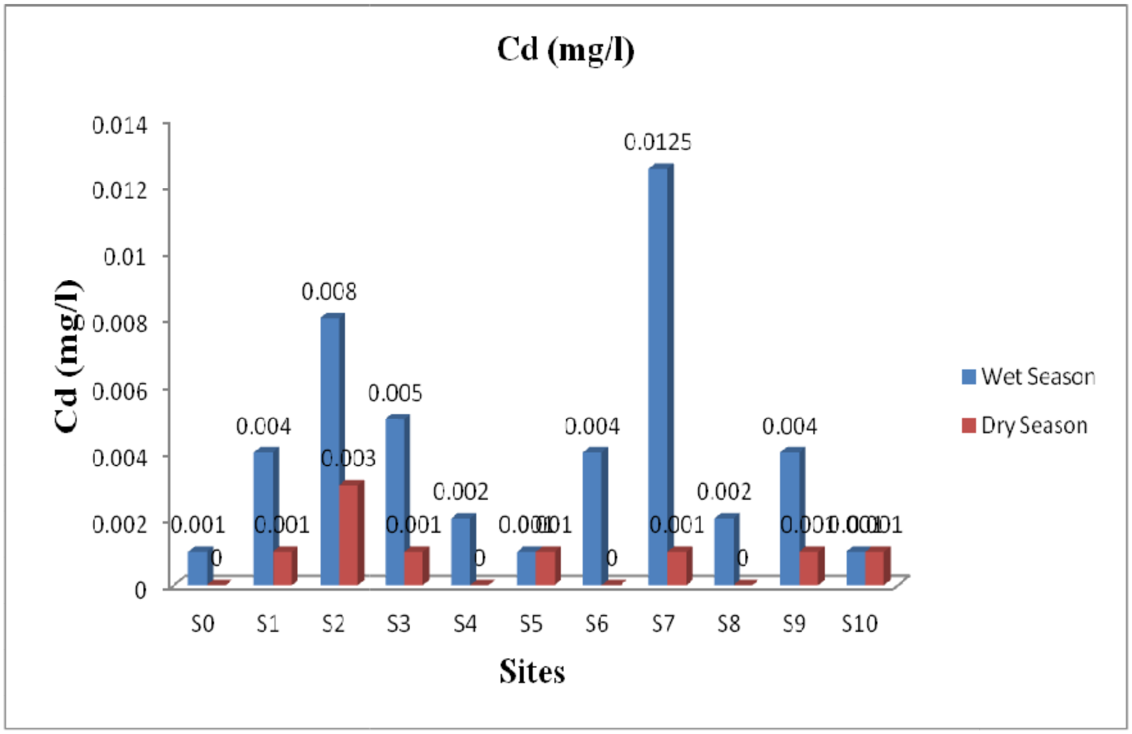


Figure 2.17: Concentrations of Cadmium Cd (mg/1) in Lake Tana.

2.5.2.5 Cu (Copper)

There were no significant differences in Cu values ($p<0.05$) between the reference site and impacted sites but there was a significance difference between the dry and wet seasons (Figure 2.18).

Minimum concentrations of copper detected were 0 and maximum concentration was 0.76 mg/l at S_5 from the results obtained after water analysis of Lake Tana (Appendix 1). The mean Cu in study area water was 0.12 mg/l (Table 2.2). The variation of Cu levels in sampling sites of Lake Tana could be attributed to agricultural activities in the catchment especially the use of fertilizers, fungicides and insecticides. Therefore, during the rainy season Cu compounds added in fertilizers and animal feeds get into Lake Tana through surface runoff.

Major Sources of Copper are Electroplating and Pesticide Production (Darshan *et al*., 2014). Copper can get into aquatic ecosystems from use of fungicides, algicides, insecticides, wood preservatives, electroplating, azo dye manufacture and plumbing materials that contain lead, copper, or galvanized steel (FDREEPA and UNIDO, 2003; Chaitali and Jayashree, 2013). Also, from fertilizers and animal feeds as a nutrient to support plant and animal growth (Akan *et al.,* 2010). Copper compounds are also used in food additives and copper salts in water supply systems to control biological growths in reservoirs (WHO, 2008). Copper reaches the aquatic environment through wet and dry depositions, mining activities, industrial (copper plating, pulp and paper mills), domestic (e-waste and sewage) and agricultural waste disposal and other forms of waste waters (Aboud and Nandini, 2009)

Contamination of drinking water with high level of copper (more than 470 mg/l) may lead to chronic anaemia, brain damage, coronary heart diseases and high blood pressures (hypertension) although coronary heart diseases have also been linked to copper deficiency (FDREEPA and UNIDO, 2003; Trivedi, 2008; Chaitali and Jayashree, 2013). High doses of copper can cause liver and kidney damage and stomach and intestinal irritation, disease of the bone, nausea, vomiting, abdominal pain and diarrhea (Darshan et al., 2014 and Raja and Namburu, 2014). Excess of copper in human body is toxic and produces pathological changes in brain tissues. Copper is highly toxic to invertebrates and moderately to mammals in trace amounts (Tirkey *et al*., 2012).

Ethiopian EPA water standard guideline recommended 0.05 mg/l of Cu in fresh water to the protection of aquatic species (FDREEPA and UNIDO, 2003). Copper has the maximum acceptable concentration of (0.l mg/l) (WHO, 2008). S_4, S_5, S_6, S_7, S_8, S_9 and S_{10} of the water samples in the dry season contained copper above the specified maximum acceptable concentration indicated in Table 2.11. However, copper was not detected in some of the water samples. The detection in some of the sampling sites is due to human activities in the catchments.

Table 2.11: Cu standards of Surface water as cited by Chaitali and Jayashree (2013) and Babagana *et al*. (2014)

Cu (mg/l)	Purpose	Reference
0.05	Drinking	WHO (2006)
0.005	Drinking	FDREEPA and UNIDO (2003)
0.2	Irrigation	FAO (1992)
30	Fishery	FAO (2007); USEPA (1998)

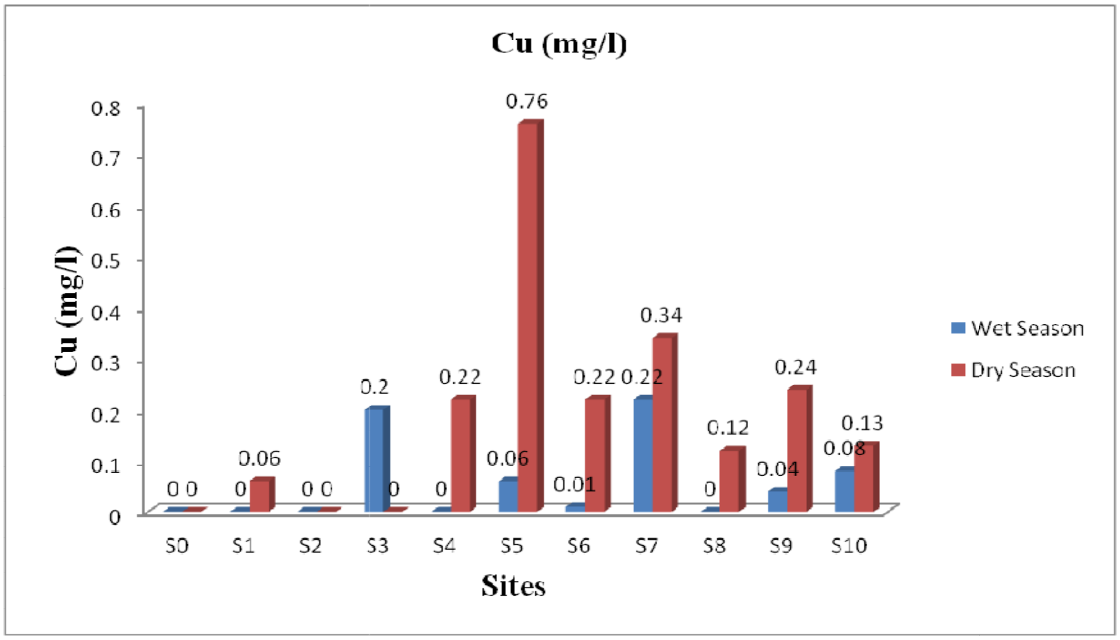


Figure 2.18: Concentrations of Copper Cu (mg/1) in Lake Tana water.

2.5.2.6 Pb (Led)

There were no significant differences in Pb values ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between the wet and dry seasons (Figure 2.19).

Pb in Lake Tana water ranged between 0 at S_5 and S_7 to 0.08 mg/l at S_3 and S_{10} in the dry season while in the wet season ranged between 0.01 mg/l at S_0 and S_8 to 0.31 mg/l at S_9 (Appendix 1). The mean Pb concentration of Lake Tana was 0.05 (Table 2.2). This value of Pb could be due to industrial wastes and sewage from the towns located within the catchment. The highest Pb value was recorded at S_9 and S_2 sampling sites (Gorgora Transport and Tana Transport) where there is discharge from boat stations.

Major Sources of lead are paint, pesticide, batteries, glass preparation, metal plating, e-waste, electrical equipment, textile mills, dye and pigments, paper mills, chemical and fertilizer industries (Darshan *et al*., 2014). Exposure occurs through contaminated food and water. Occupationally, exposure occurs in lead smelting and refining, in lead battery waste, gasoline additive and in many other industrial processes (Chandran and Cataldo, 2010). The sources include burning of lead based petroleum fuels, organic and inorganic lead compounds in plastics, bearing alloys, insecticides, ceramics, cable sheathings, paints, lead acid batteries, solder, alloys, pigments, rust inhibitors and plastic stabilizers (WHO, 2008; Akan *et al.,* 2010) The sources of Pb in water include lead emissions from combustion of fossil fuels, industrial and municipal wastewater discharge and agricultural runoff (FDREEPA and UNIDO, 2003; Akan *et al.,* 2010).

Higher concentrations are more likely to be found in leafy vegetables and fruits like tomatoes, squash, strawberries and apples (Raja and Namburu, 2014).

Recent experimental and epidemiological studies showed that inorganic lead compounds are associated with increased risk of carcinogenesis. Lead carcinogenicity includes direct DNA damage and inhibition of DNA synthesis. Lead is known to be toxic to the peripheral system, reproductive system, immune system, causes blood and brain disorders, gastrointestinal tract, kidney, liver, blood vessels, central nervous system and potent neurotoxin that accumulates in soft tissues and bone over time (Chandran and Cataldo, 2010). The pathological effects of lead are observed in three organ systems: the nervous system, kidney and haematopietic system. Lead accumulates in the bones and soft tissues, particularly in the brain, resulting in its reduced functioning (Omwenga, 2003).

Lead toxicity leads to anaemia both by impairment of haemoglobin biosynthesis and acceleration of red blood cell destruction in human beings and inhibits some of the enzymes involved in energy metabolism, spinal deformities (FDREEPA and UNIDO, 2003). Lead also depresses sperm count (Aboud and Nandini, 2009; Chaitali and Jayashree, 2013). Lead is a systemic agent affecting the brain. The toxicity of lead is based on the fact that it is a potent enzyme inhibitor. Lead is observed to lower IQ levels in children, hyperactivity and mental deterioration with children under the age of six (Omwenga, 2003; Tirkey *et al*., 2012; Raja and Namburu, 2014). The consequences of excess lead in the human body range from low intelligent quotient in children and high blood pressure in adults (WHO, 2008). Health Effects of lead are cognitive impairment and developmental delay in children and peripheral neuropathy in adults (Darshan *et al*., 2014).

More than 400 mg of lead in human body can cause brain damage, vomiting, loss of appetite, uncoordinated body movements, affects skin, respiratory system, damages kidney, liver, brain cells, disturbs endocrine system, causes anaemia, and long term exposure may cause even death (Trivedi, 2008).

Ethiopian EPA water standard guideline recommended 0.05 mg/l of Pb in fresh water for the protection of aquatic species (FDREEPA and UNIDO, 2003). The lead value in many of the sampling sites is higher than the maximum permissible limit as indicated in Table 2.12. The exceeded permissible limit concentration of Pb in Lake Tana water could be due to anthropogenic activities taking place in the catchments.

Table 2.12: Pb standards of surface water as cited by Chaitali and Jayashree (2013) and Babagana *et al*. (2014)

Pb (mg/l)	**Purpose**	**Reference**
0	Drinking	USEPA (2007)
0.05	Drinking	WHO (2006); WHO (2011); FDREEPA and UNIDO (2003); USEPA (1998); Iranian (1997); USEPA (2002)
0.01	Drinking	Australian (1996); New Zealand (2008); WHO (2008)
5	Irrigation	FAO (1992)
1.5	Fishery	FAO (2007); USEPA (1998)

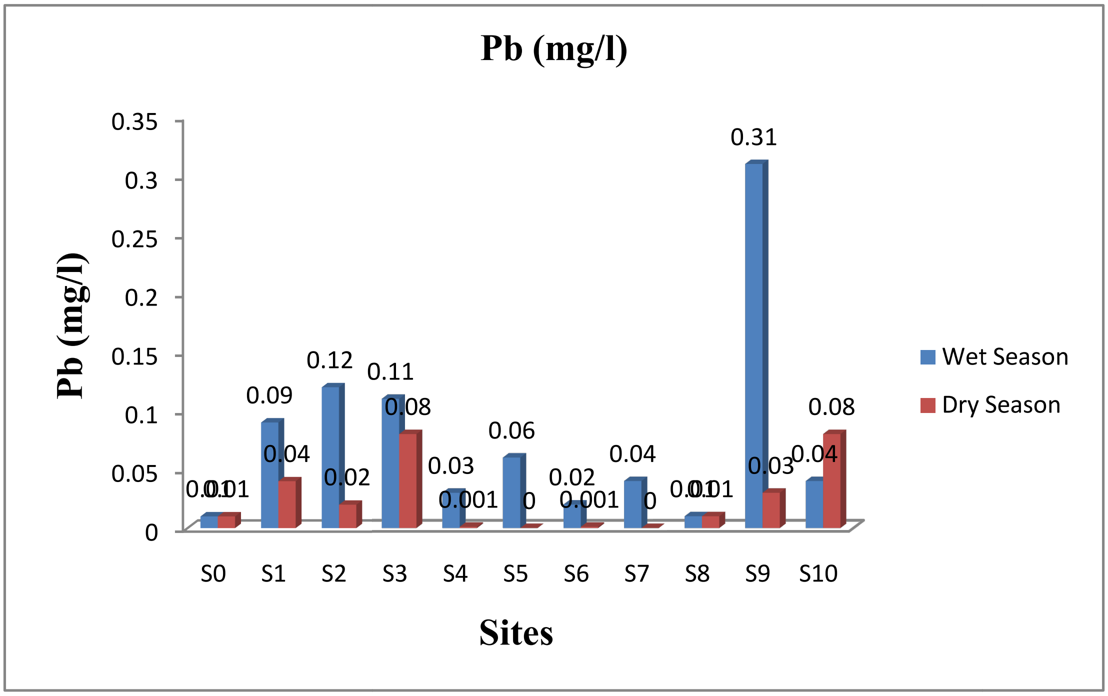


Figure 2.19: Lead Pd (mg/l) in Lake Tana water.

2.5.2.7 Fe (Iron)

There were no significant differences in Fe values ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between the dry and wet season (Figure 2.20).

Fe in Lake Tana water ranged between 0 at S_0 in both the wet and dry seasons to 0.35 mg/l in the dry season at S_4 to 2.45 mg/l at S_6 in the wet season (Appendix 1). The mean Fe concentration of Lake Tana was 0.36 mg/l (Table 2.2).

The source of iron for the high concentration of Fe in the study area are human activities, mainly from sewage, landfill leachates and the corrosion of iron (fungicide industry, petro-chemical industry) (FDREEPA and UNIDO, 2003).

Iron (Fe) is one of the essential mineral for humans and animals. Degree of absorption depends upon solubility and stability of compound. It is a component of blood cells and liveral metalloenzymes. However, more than 10 mg/kg of body weight causes rapid respiration and pulse rates, congestion of blood vessels and hypertension. It increases hazard of pathogenic organisms, as many of them require Fe for their growth (Trivedi, 2008).

It is the most abundant metal in the earth's crust. In fresh water, iron content depends on location and may vary from 0.01 to 1 mg/l, with low values in rural areas, intermediate in urban and highest in areas close to iron foundries. The daily intake of iron in diet is about 9-35 mg, and this may also vary depending on the source of the diet as agricultural products mining areas contain higher iron contents (Pius and Orish, 2013).

Iron has been shown to be mutagenic, and carcinogenic at high concentration (Pius and Orish, 2013). Due to Fe concentration acute and chronic toxicity to both invertebrates and vertebrates are rather limited (FDREEPA and UNIDO, 2003).

According to WHO guideline value and maximum contaminant levels of 0.30 mg/l (water) for Fe is acceptable (WHO, 2004). Above 0.3 mg/l might lead to pollution of the aquatic environment. Ethiopian EPA water standard guideline recommended 1 mg/l of Fe in fresh water for the protection of aquatic species (FDREEPA and UNIDO, 2003). From the result of this study, the concentrations of iron in water samples exceeded the standard limits in Table 2.13 indicating pollution at S_6 and S_7 sampling points of Lake Tana sourced from catchments (WHO, 2004; USEPA, 2009).

Table 2.13: Fe standards of surface water as cited by Gebrekidan and Samuel (2011)

Fe (mg/l)	Purpose	Reference
1	Drinking	FDREEPA and UNIDO (2003); USEPA (1998); Iranian (1997)
0.2	Drinking	New Zealand (2008); EU (1998)
0.3	Drinking	Indian (2005); Australian (1996) ;USEPA (2008); WHO (2008)
5	Irrigation	FAO (1992); WHO (2011)
0.1	Fishery	FAO (2007); USEPA (1998)

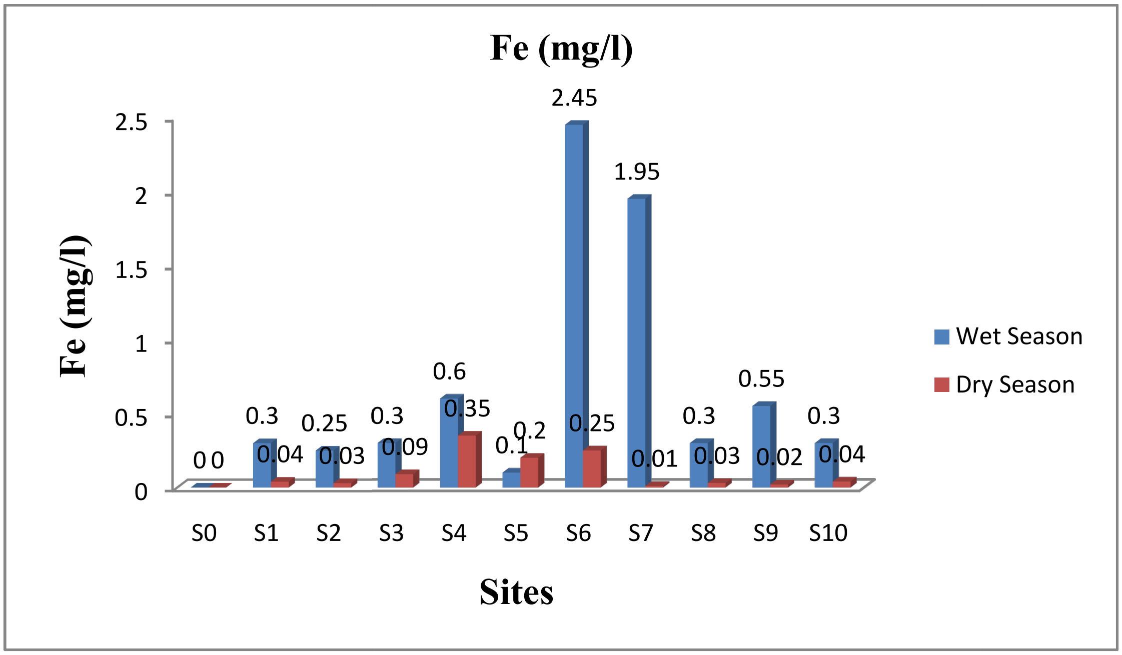


Figure 2.20: Concentrations of Iron Fe (mg/1) in Lake Tana water.

2.5.3 Bacteria

2.5.3.1 *E. Coli*

There were no significant differences in *E. Coli* values ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between dry and wet season (Figure 2.21).

The amount of *E.coli* was highest at S_8 (40 cfu/100 ml) and S_7 (48 cfu/100 ml), while at S_0, S_4 and S_5 (0 cfu/100 ml) in the wet season and it increased in the dry season in the range of 2 cfu/100 ml (S_0 and S_1) to 14 cfu/100 ml (S_9) (Appendix 1). In the wet season sewage from urban areas, animal fecal materials and agricultural wastes enter through runoff and the increased *E.coli* level might be due to the wastes drain in to the lake (Table 2.2 and Appendix 1).

E. coli is a species within the fecal coliform bacteria which originates from the waste of warm-blooded animals (US EPA, 2009) and is estimated to be about 60 – 80% of the fecal coliform value (Annie *et al*, 2002; Rivera and Rock, 2011). *E. coli* is considered to be the species of coliform bacteria and the best indicator of fecal pollution shows the possible presence of pathogens (US EPA, 2009).

The presence of *E. coli* in water is a strong indication of sewage or animal waste contamination. Sewage may contain different types of disease causing organisms. *E.coli* in water may originate from the waste of both humans and other warm-blooded animals, such as dogs, cats, livestock and wildlife. Human sources include failing septic tanks, leaking sewer lines, wastewater treatment plants, sewer overflows, land application of biosolids, boat discharges, recreational activities, local land use practices (manure used as fertilizers, livestock, concentrated feeding operations) and urban sewage runoff (US EPA, 2009).

In circumstances where the contact or ingestion of the water is higher (swimming) the concentration of the *E. coli* has to be in acceptable limit. In situations where the contact with the water is low (irrigation) the levels of *E. coli* considered may be higher than the acceptable limit because there is a lower risk of a person becoming sick (Channah and Berenise, 2014). This microorganism spreads through "fecal-oral" route of transmission. Contaminated food and water are the most common transition ways of *E. coli* (Channah and Berenise, 2014). Therefore, introduction of animal or human waste in the water is a concern for the introduction of pathogenic organisms. Although not all *E. coli* bacteria are pathogenic, studies have shown that *E. coli* concentrations are the best indicators of swimming-associated gastrointestinal illness (diarrhea). The presence of *E. coli* may be indicative of contamination with other bacteria, viruses or protozoa that can cause sickness. Detection of these bacteria in water means that fecal contamination has occurred and suggests the presence of pathogens. Therefore, humans and animals should not come into contact with the contaminated water until the presence of *E. coli* is no longer detected and the water is safe (Channah and Berenise, 2014). Source of *E. coli* bacterial include illegal sewer connections and inputs from wildlife and domestic animals (USEPA and Environment Canada, 2002; Toronto and Region Conservation, 2009).

Elevated levels can result in restrictions on the recreational and domestic use of water bodies (USEPA and Environment Canada, 2002). *E. coli* is related more with swimming related gastrointestinal illnesses compared to fecal coliforms, the US EPA has recommended *E. coli* as an appropriate indicator species for assessing potential health risks of recreational waters (USEPA and Environment Canada, 2002).

Most *E. coli* do not cause illness but if a person becomes sick from *E. coli,* the primary site of infection is the gastrointestinal tract and symptoms are nausea, vomiting, diarrhea and fever. Naturally *E. coli* bacterium lives and grows in the gastrointestinal tract of humans and animals but if it gets in the kidneys or blood, it can cause illness. According to Ingerson and Reid (2011), the infection may spread within the body (to blood, liver and nervous system). In addition to gastrointestinal illness, eye infections, skin irritations, ear, nose, throat infections and respiratory illness are also *E. coli* related problems. These serious health effects are higher in swimmers than non-swimmers (Channah and Berenise, 2014).

E. coli is the most reliable indicator of fecal bacterial contamination of surface waters in the U.S. according to water quality standards of USEPA. For partial-body contact, *E. coli* levels cannot exceed 575 colony forming units (cfu) per 100 ml of water (US EPA, 2009). For full-body contact, *E. coli* levels cannot exceed 235 cfu per 100 ml of water. Full-body contact refers to the human body being completely underwater in activities such as swimming or other recreational activity. A cfu refers to the number of living bacterial cells in a water sample. Therefore, cfu is used to tell us the degree of contamination in samples of water or the degree of the infection in humans and animals (US EPA, 2009; Channah and Berenise, 2014).

Table 2.14: Level of *E. coli* permitted for different types of water (US EPA, 2009)

Purpose	**Level of *E. coli***
Drinking Water	Zero
Fresh water (Recreation Water) Ambient Water Quality Criteria	126 cfu/100 ml
Surface Water Full-Body Contact (swimming)	235 cfu/100 ml
Surface Water Partial-Body Contact (Fishing, boating, etc…)	575 cfu/100 ml
Wastewater	< 2.2 cfu/100 ml
Irrigation or discharge	< 1.0 cfu/100 mL

According to the United States Environmental Protection Agency (US EPA) criteria for *E. coli* density is (<33 cfu/ 100 ml for freshwater) (US EPA, 2004; Igbinosa *et al*., 2012). Concentration of *E.coli* in stream water is 10 cfu/100 ml (USEPA, 2002).

A number of environmental factors will affect bacteria survival in water bodies. *E.coli* counts are often higher during the wet season compared to the dry season. In the study area the highest count is found in the wet season where there is water runoff from different waste water sources (Appendix 1). Higher *E. coli* counts may be found in warmer waters because *E.coli* survives longer at its optimal growth temperatures (*E. coli* are adapted to living in the warm environment of the intestines of warm-blooded animals). However, ultraviolet light from the sun can kill bacteria in clear streams, rivers or lakes (US EPA, 2002). The *E.coli* concentration of Lake Tana water is above the recommended limit for drinking water as it is indicated in Table 2.14. According to Rhonda *et al*., (2006) *E.coli* dependent water quality rating of Lake Tana water in the dry season is in the category of fair (2) but in the wet season Sites, S_7, S_8 and S_9 were in the rating of poor water quality as referred in Table 2.15. Hence, the water quality of Lake Tana is affected by waste discharges.

Table 2.15: Water quality rating on the basis of *E. coli* colony (Rhonda *et al*., 2006)

4 – Best	3 – Good	2 – Fair	1 – Poor
None detected. (For drinking water, this is the only acceptable level).	*E. coli* detected, but less than 2 colony forming units per plate. (Safe for contact recreation, such as swimming).	*E. coli* between 2 and 20 colony forming units per plate. (Not safe for contact recreation, but acceptable for noncontact recreation, such as boating).	*E. coli* greater than 20 colony forming units per plate. (Not considered safe for non contact recreation).

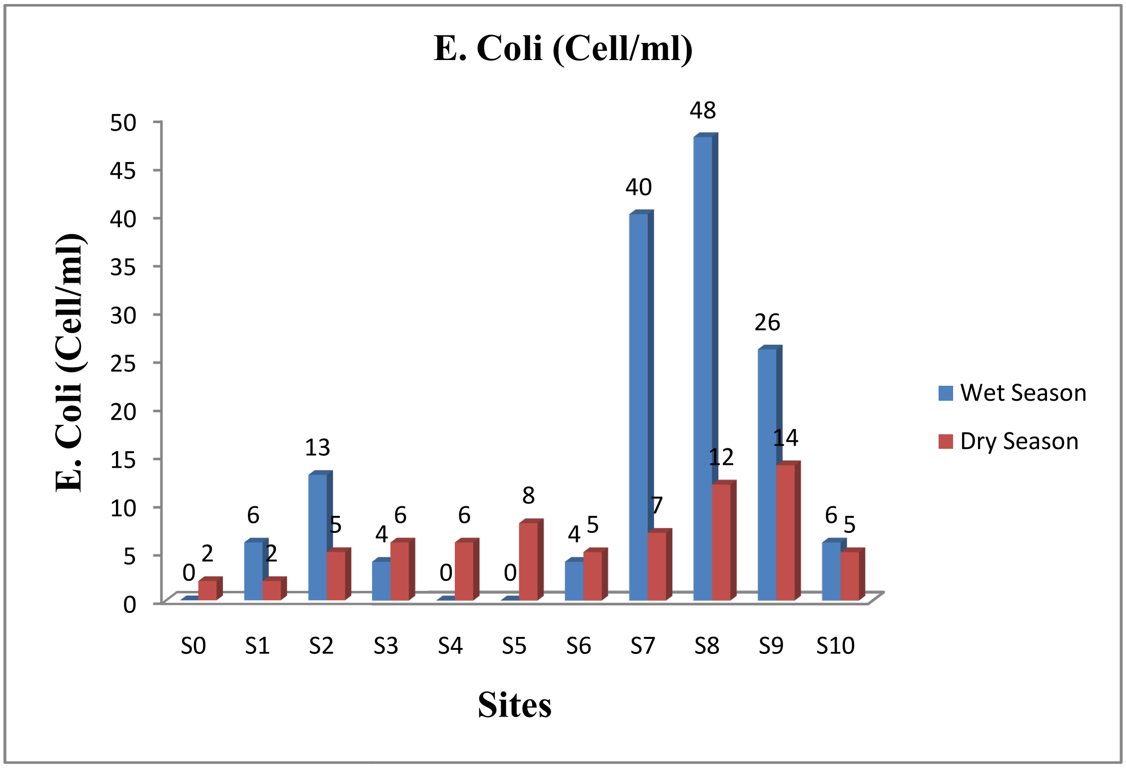


Figure 2.21: Escherichia coli, *E. coli* (cfu/100ml) in Lake Tana water.

2.5.3.2 F. Coliform

There were no significant differences in F. coliform values ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between the wet and dry season. It showed 0 cfu/100 ml at the reference site (S_0) and the highest at the impacted site S_7 (232 cfu/100 ml) in the wet season while in the dry season 0 cfu/100 ml was detected at S_0 and S_3 and 103 cfu/100 ml detected at S_9 (Figure 2.22 and Appendix 1). This indicates that the number of F. Coliform in Lake Tana was higher in the wet season than the dry season in many of the impacted sites (from S_1 to S_{10}).

Fecal Coliforms are a form of coliform bacteria; it originates from fecal matter (Annie *et al*, 2002). Fecal Coliforms are the group of the total coliforms that are considered to be present in feces of warm-blooded animals, because the origins of Fecal Coliforms are more specific than the origins of Total Coliform bacteria. Fecal Coliforms are more accurate indicators of animal or human waste than the Total coliforms (Rivera and Rock, 2011).

The presence of Fecal Coliforms is indicator of fecal contamination. However, the absence of fecal coliforms does not mean the absence of fecal contamination. The source of the fecal contamination could be animal excreta, wastewater, sludge, septage, or biosolids. Each of these wastes is derived from the feces and urine of warm-blooded animals. Since pathogens and Fecal Coliforms are excreted by warm-blooded animals, detection of Fecal Coliforms indicates the potential presence of pathogens (Channah and Berenise, 2014).

Possible sources of Fecal Coliform bacteria include human and animal wastes: land application of animal waste, dairy operations, poultry operations, horse farms, dog and cat waste from parks, lawns, streets and wildlife such as geese, pigeons, ducks and deer (USEPA and Environment Canada, 2002). During rainfalls, fecal bacteria may be washed into rivers, streams, lakes, or ground water. When these waters are used as sources of drinking water without treatment (inadequately treated), fecal bacteria may be taken into the body. Human and animal sources of fecal pollution represent a serious health risks because of the high likelihood of the existence of pathogens (USEPA and Environment Canada, 2002).

Water pollution caused by fecal contamination is a serious health problem due to the potential for contracting diseases from pathogens (Rhonda *et al*., 2006). The presence of pathogens is determined by testing of "indicator" organisms such as coliforms. Coliforms are sourced from the same sources as pathogenic organisms. Coliforms are relatively easy to identify than pathogens. They are usually present in larger numbers than more dangerous pathogens (US EPA, 2009).

Fecal bacteria, in addition to the health risk associated with the presence of elevated levels, they can also cause cloudy water, unpleasant odors and an increased oxygen demand which may result in oxygen depleted water (Annie *et al.*, 2002).

Table 2.16: F. coliform limits (Annie *et al*, 2002)

Water use	**Desired level (cfu/100 ml)**	**Permissible level (cfu/100 ml)**
Drinking	0	0
Swimming	<200	<1,000
boating or fishing	<1,000	<5,000

The USEPA recommended conversion factor between fecal coliform and *E. coli* is 126/200 that results in an *E. coli/*Fecal Coliform (EC/FC) ratio of 0.63 (USEPA and Environment Canada, 2002). USEPA and Environment Canada Fecal Coliform standard is (200 col/100 ml) (USEPA and Environment Canada, 2002). According to Igbinosa *et al*. (2012), the maximum limit for no risk (domestic and recreational use) for Fecal Coliform is 0 cfu/100 ml. The reasonable margin of safety, the recommended bathing water criteria based on a Fecal Coliform concentration of 200 cfu/100 ml (U.S. EPA, 2002) and according to Awuah, (2006) infectious dose of F. Coliform organisms in water is 106-1010 cfu/100 ml.

An extremely large range of sample values exists for S_1, S_2, S_7 and S_9 locations; however, the geometric mean standard of 200 cfu/100 ml for Fecal Coliform was exceeded only at S_7 location in the wet season (USEPA and Environment Canada, 2002) that was above the disered limit but below the permissible limit as indicated in Table 2.16. Therefore, variation in F. Coliform colony among study areas, sampling sites and sampling seasons is the result of fecal contamination.

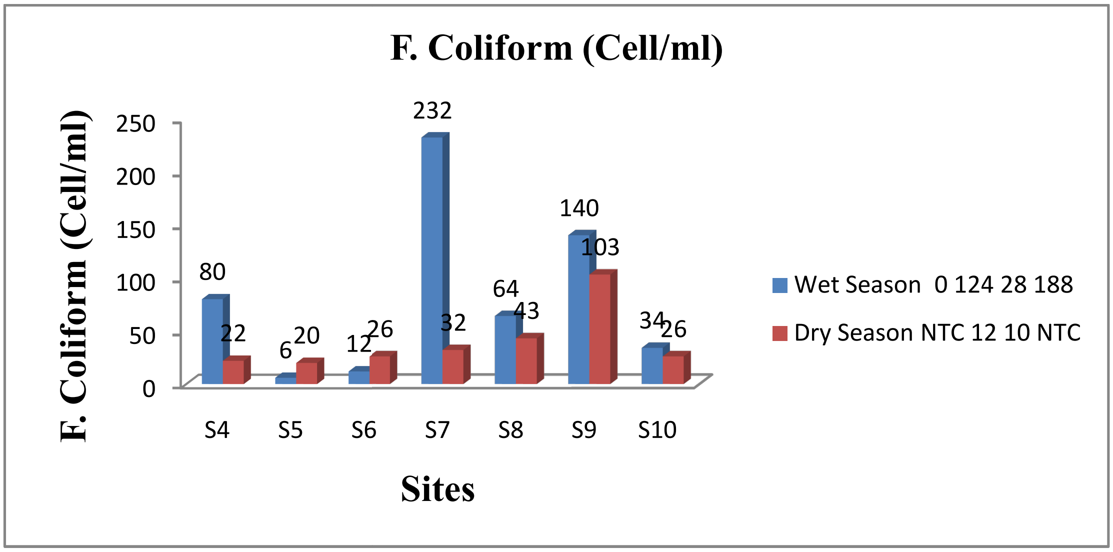


Figure 2.22: Fecal Bacteria, F. *Coliform* (Cell/ml) in Lake Tana water.

2.5.3.3 T. Coliform

There were no significant differences in T.coliform values ($p<0.05$) between the reference site and impacted sites. But there was a significant difference between the wet and the dry season. The results of analysis for Total Coliform (TC) bacteria ranges from 2 cfu/100 ml (S_0) to 240 cfu/100 ml (S_7) in the wet season and 13 cfu/100 ml (S_2) to 136 cfu/100 ml (S_9) in the dry season, with an average of 54.6364 cfu/100 ml which indicates the presence of contamination (Figure 2.23, Table 2.2 and Appendix 1)

About 18 percent of Total Coliforms are found to be fecal coliforms (US EPA, 2009). For recreational waters, Total Coliforms are no longer recommended as an indicator. For drinking water, Total Coliforms are still the standard test because their presence indicates contamination of water by an outside source (Rhonda *et al*., 2006).

Table 2.17: Water quality rating on the basis of Total Coliform colony (Rhonda *et al*., 2006)

4 – Best	3 – Good	2 – Fair	1 – Poor
None detected. (For drinking water, this is the only acceptable level).	Less than 20 colonies per plate.	20 to 200 colonies per plate.	More than 200 colonies or too many to count.

In all sampling sites the value is beyond the recommended maximum permissible limits of WHO (2006), and Adimasu (2015), zero/100 ml for the drinking uses. Therefore, the lake water was contaminated by T.coliform and it does not fit for drinking purposes as rated in Table 2.16.

According to Igbinosa *et al*. (2012), the maximum limit for no risk (domestic and recreational use) for total coliform is 10 cfu/100 ml. Concentration of T. Coliform in stream water is 400 cfu/100 ml (USEP, 2002). Many of the water samples analysed were contaminated (Appendix 1). The Lake Tana water is rated as good according to Rhonda *et al*., (2006) water quality rating on the basis of Total Coliform colony (Table 2.17).

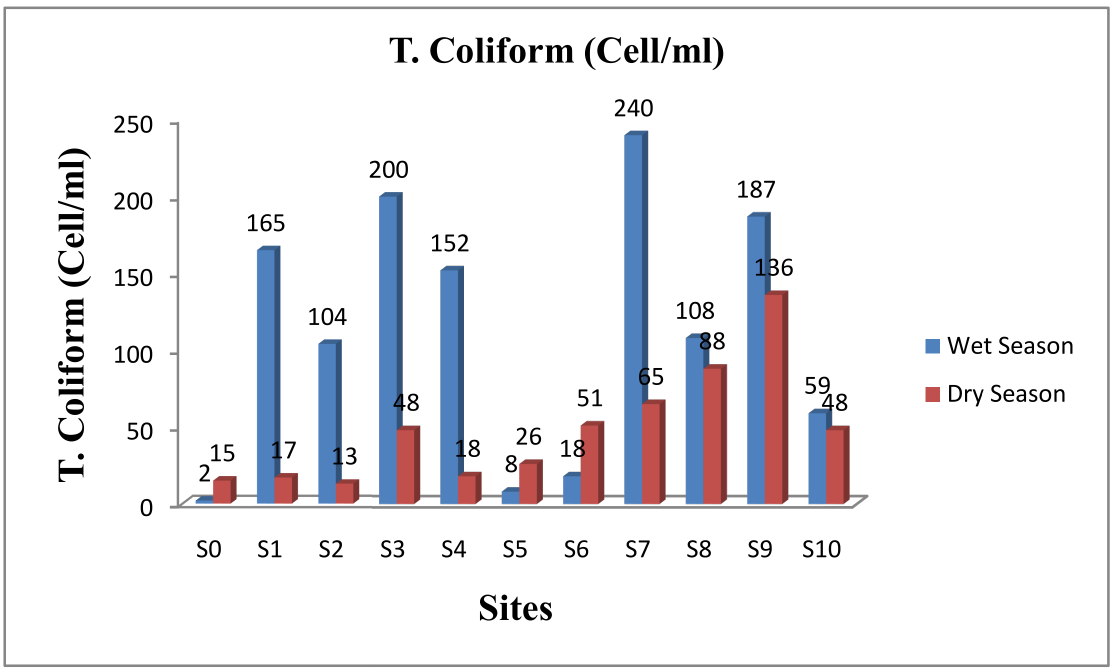


Figure 2.23: Total Coliform, T. Coliform (Cell/ml) in Lake Tana water.

2.5.4 WATER QUALITY INDEX OF LAKE TANA

Accurate information on the quality of water is very essential to form a public policy and to implement the water quality management programmes. Water quality index (WQI) provides information on the quality of water in a single value. WQI is commonly used for the evaluation of water pollution and defined as a reflection of composite influence of different water quality parameters on the overall quality of the water (Horton, 1965) as cited by (NIS, 2007).

A. WQI Calculation

Calculation of WQI was carried out in this study by Horton's or APHA method (APHA, American Public Health Association, 1995). The WQI is calculated by using the expression given in Equation (1).

$$WQI = \sum_{n=1}^{n} qnWn \,/\, \sum_{n=1}^{n} Wn \quad (1)$$

Where, qn = Quality rating of n^{th} water quality parameter.

Wn= Unit weight of n^{th} water quality parameter.

B. Quality rating (qn)

The quality rating (qn) is calculated using the Equation given in (2).

$$qn = [\,(V_n - V_{id}) / (S_n - V_{id})\,] \times 100 \quad (2)$$

Where,

V_n = Estimated value of n^{th} water quality parameter at a given sample location.

V_{id} = Ideal value for n^{th} parameter in pure water.

(V_{id} for pH = 7, Do=14.6 and 0 for all other parameters) (All the ideal values (Vio) are taken as zero for drinking water except for pH=7.0 and DO=14.6mg/L (Trivedi and Pathak, 2007).

Sn = Standard permissible value of n^{th} water quality parameter.

C. Unit weight

The unit weight (Wn) is calculated using the expression given in Equation (3).

$$Wn = k / Sn \quad (3)$$

Where,

Sn = Standard permissible value of n^{th} water quality parameter.

k = Constant of proportionality and it is calculated by using the given Equation (4).

D. k = Constant of proportionality

$$k = [\,1 / (\sum_{n=1}^{n} 1/ S_{n = 1,2,..n})] \quad (4).$$

E. WQI and status

The ranges of WQI with the corresponding status of water quality and their possible use are indicated in Table 2.18.

Table 2.18: WQI and corresponding water quality status (Trivedi and Pathak, 2007)

S.No	WQI	Status	Possible usages
A	0 – 25	Excellent	Drinking, Irrigation and Industrial
B	25 – 50	Good	Domestic, Irrigation and Industrial
C	51 -75	Fair	Irrigation and Industrial
D	76 – 100	Poor	Irrigation
E	101 -150	Very Poor	Restricted use for Irrigation
F	Above 150	Unfit for Drinking	Proper treatment required before use.

2.5.4.1 Standard values and unit weights of water quality parameters of the Lake Tana

The water quality parameters are selected based on its direct involvement in deteriorating water quality. The standards for the water quality were used as recommended by Ethiopian EPA for the computation of quality rating (qn) and unit weights (Wn).

Nineteen water quality parameters have been selected for the purpose of calculation of WQI of Lake Tana. They were Temperature, pH, EC, BOD_5, COD, TSS, TDS, NO_3^-, NO_2^-, NH_3, PO_4^{3-}, SO_4^{2-}, Cr, Mn, As, Cd, Cu, Pb and Fe. Four paremeters (S^{2-} (mg/l), *E. Coli* (Cell/ml), F. Coliform (Cell/ml) and T. Coliform (Cell/ml)) were rejected from the water quality index calculation as they did not have Ethiopian standard. The values of these parameters are found high above the permissible limits in some of the samples of Lake Tana. The higher values of these parameters increased the WQI value. The Ethiopian EPA standard values of water quality parameters and their corresponding ideal values and unit weights are given in Table 2.19.

Table 2.19: Standard values of water quality parameters and their corresponding ideal values and unit weights

S. No	Parameters	Sn	Recommending Agency for Sn	Ideal Value (V id)	(S_n- V_{id})	$1/S_n$	K Value	Unit Weight Wn= k / Sn
1	Temp (°C)	5 - 30 °C	Ethiopia standard	0	30.00	0.030	0.00264	0.00009
2	PH	6.0 – 9.0	Ethiopia Standard	7	2.00	0.110	0.00264	0.00029
3	EC(µS/cm)	1000	Ethiopia Standard	0	1000.00	0.001	0.00264	0.000003
4	BOD5(mg/l)	5.00	Ethiopia Standard	0	5.00	0.200	0.00264	0.00053
5	COD(mg/l)	150.0	Ethiopia Standard	0	150.00	0.007	0.00264	0.00002
6	TSS (mg/l)	50.00	Ethiopia Standard	0	50.00	0.020	0.00264	0.00005
7	TDS (mg/l)	30.00	Ethiopia Standard	0	30.00	0.030	0.00264	0.00009
8	NO_3^- (mg/l)	50.00	Ethiopia Standard	0	50.00	0.020	0.00264	0.00005
9	NO_2^- (mg/l)	0.10	Ethiopia Standard	0	0.10	10.000	0.00264	0.02640
10	NH_3 (mg/l)	0.02	Ethiopia Standard	0	0.02	50.000	0.00264	0.13200
11	PO_4^{3-}(mg/l)	0.03	Ethiopia Standard	0	0.03	33.33	0.00264	0.08800
12	SO_4^{2-}(mg/l)	200.0	Ethiopia Standard	0	200.00	0.005	0.00264	0.00001
13	Cr (mg/l)	0.05	Ethiopia Standard	0	0.05	20.000	0.00264	0.05280
14	Mn (mg/l)	0.30	Ethiopia Standard	0	0.30	3.330	0.00264	0.00880
15	As (mg/l)	0.05	Ethiopia Standard	0	0.05	20.000	0.00264	0.05280
16	Cd (mg/l)	0.005	Ethiopia Standard	0	0.005	200.00	0.00264	0.52800
17	Cu (mg/l)	0.05	Ethiopia Standard	0	0.05	20.000	0.00264	0.05280
18	Pb (mg/l)	0.05	Ethiopia Standard	0	0.05	20.000	0.00264	0.05280
19	Fe (mg/l)	1.00	Ethiopia Standard	0	1.00	1.000	0.00264	0.00264
$\sum_{n=1}^{n} 1/\,S_{n\,=\,1,2,..n}$						378.08		
k = [1 / ($\sum_{n=1}^{n} 1/\,S_{n\,=\,1,2,..n}$)]						0.0026		
$\sum_{n=1}^{n} Wn$								0.99818

2.5.4.2 WQI of Lake Tana

The WQI values of Lake Tana for wet season, dry season and Lake Tana mean water samples were calculated separately. WQI has been calculated based on nineteen selected physicochemical parameters given in Table 2.19 for the all the four hundred eighteen samples.

2.5.4.2.1 WQI of Wet Season Water Samples

The WQI values of the wet season samples were summarized in Table 2.20. WQI of the wet season was 22775.29. 209 water samples of Lake Tana were taken for this wet season analysis. This indicated that samples of the study area in the wet season were very poor to unfit for drinking and the water from these locations require proper water treatment before use. NH_3 and PO_4^{3-} values in the wet season were very high and above the permissible limit which makes the Lake water quality very poor to unfit for drinking. The sources of these variables were fertilizers in the catchment. When the seasonal values of these variables were compared the wet season is more than the dry season, because the fertilizer application in the watershed is high in the wet season and it is discharged to Lake Tana through the run off.

Table 2.20: WQI values of wet season mean water samples

Parameter	V_n	V_{id}	$(V_n - V_{id})$	S_n	$(S_n - V_{id})$	qn = [$(V_n - V_{id})$ / $(S_n - V_{id})$] x 100	Unit Weight (Wn= k/Sn)	qnWn
Temp (°C)	21.93	0	21.93	5 - 30 °C	30.00	73.500	0.00009	0.00647
PH	7.310	7	0.31	6.0 – 9.0	2.00	15.500	0.00029	0.00455
EC (µS/cm)	157.0	0	157.00	1000	1000.00	15.700	0.000003	0.00004
BOD_5 (mg/l)	22.30	0	22.30	5.00	5.00	446.000	0.00053	0.23549
COD (mg/l)	311.2	0	311.20	150.00	150.00	207.470	0.00002	0.00365
TSS (mg/l)	0.460	0	0.46	50.00	50.00	0.920	0.00005	0.00005
TDS (mg/l)	78.590	0	78.59	30.00	30.00	261.970	0.00009	0.02305
NO_3^- (mg/l)	0.576	0	0.58	50.00	50.00	1.152	0.00005	0.00006
NO_2^- (mg/l)	0.036	0	0.04	0.10	0.10	36.000	0.02640	0.95040
NH_3 (mg/l)	0.314	0	0.31	0.02	0.02	1570.000	0.13200	207.240
PO_4^{3-} (mg/l)	76.570	0	76.57	0.03	0.03	255233.000	0.08800	22460.53
SO_4^{2-} (mg/l)	18.270	0	18.27	200.00	200.00	9.135	0.00001	0.00012
Cr (mg/l)	0.076	0	0.08	0.05	0.05	152.000	0.05280	8.02560
Mn (mg/l)	0.006	0	0.01	0.30	0.30	2.000	0.00880	0.01760
As (mg/l)	0.006	0	0.01	0.05	0.05	12.000	0.05280	0.63360
Cd (mg/l)	0.004	0	0.01	0.005	0.005	80.000	0.52800	42.2400
Cu (mg/l)	0.055	0	0.06	0.05	0.05	110.000	0.05280	5.80800
Pb (mg/l)	0.076	0	0.08	0.05	0.05	152.000	0.05280	8.02560
Fe (mg/l)	0.618	0	0.62	1.00	1.00	0.618	0.00264	0.00163
$\sum_{n=1}^{n}$ Wn							0.99818	
$\sum_{n=1}^{n}$ qnWn								22733.75
WQI = $\sum_{n=1}^{n}$ qnWn / $\sum_{n=1}^{n}$ Wn								22775.288

All the sampling sites of the wet season water sample results showed in Table 2.21 revealed that the WQI was in the range of bad water quality. All the sampling sites were unfit for drinking purpose. Hence to use the water of Lake Tana for domestic purpose there is a need for proper treatment.

Table 2.21: WQI values of all sampling sites in the wet season

Sampling Sites	WQI		Status
S_0	2337.048	F	Unfit for Drinking
S_1	2219.250	F	Unfit for Drinking
S_2	3893.296	F	Unfit for Drinking
S_3	3120.200	F	Unfit for Drinking
S_4	2620.178	F	Unfit for Drinking
S_5	2433.166	F	Unfit for Drinking
S_6	112168.620	F	Unfit for Drinking
S_7	118447.400	F	Unfit for Drinking
S_8	868.419	F	Unfit for Drinking
S_9	1055.164	F	Unfit for Drinking
S_{10}	1378.639	F	Unfit for Drinking
F = S. No. taken from Table 2.18.			

2.5.4.2.2 WQI of Dry Season Water Samples

The WQI values of the dry season water samples were summarized in Table 2.22. WQI of the wet season was 2666.48. 209 water samples of Lake Tana were taken for this dry season analysis. Samples of the study area in the dry season were very poor to unfit for drinking and the water require proper treatment before use. NH_3 and PO_4^{3-} values in the wet season were very high and above the permissible limit which makes the Lake water quality very poor to unfit for drinking. The sources of these variables were fertilizers in the catchment but the values were less in the dry season than the wet season and the quality of the water is better in the dry season.

Table 2.22: WQI values of dry season mean water samples

Parameter	V_n	V_{id}	($V_n - V_{id}$)	S_n	(S_n- V_{id})	qn = [($V_n - V_{id}$) / (S_n- V_{id})] x 100	Unit Weight (Wn= k / Sn)	qnWn
Temp (°C)	24.0730	0	24.0730	5 - 30 °C	30.00	80.24	0.00009	0.00706
PH	7.7010	7	0.7000	6.0 – 9.0	2.00	35.00	0.00029	0.01027
EC (µS/cm)	203.236	0	203.2360	1000.00	1000.00	20.32	0.00001	0.00005
BOD_5 (mg/l)	52.3600	0	52.3600	5.00	5.00	1047.20	0.00053	0.55292
COD (mg/l)	321.730	0	321.7300	150.00	150.00	214.49	0.00002	0.00378
TSS (mg/l)	0.2190	0	0.2195	50.00	50.00	0.44	0.00005	0.00002
TDS (mg/l)	107.573	0	107.5730	30.00	30.00	358.58	0.00009	0.02276
NO_3^- (mg/l)	0.4090	0	0.4087	50.00	50.00	0.82	0.00005	0.00004
NO_2^- (mg/l)	0.0720	0	0.0716	0.10	0.10	71.55	0.02640	1.88892
NH_3 (mg/l)	0.3360	0	0.3364	0.02	0.02	1682.00	0.13200	222.024
PO_4^{3-} (mg/l)	8.2000	0	8.2000	0.03	0.03	27333.33	0.08800	2405.33
SO_4^{2-} (mg/l)	3.6360	0	3.636 0	200.00	200.00	1.82	0.00001	0.00002
Cr (mg/l)	0.0040	0	0.0039	0.05	0.05	7.82	0.05280	0.41290
Mn (mg/l)	0.0050	0	0.0051	0.30	0.30	1.70	0.00880	0.01493
As (mg/l)	0.0002	0	0.0002	0.05	0.05	0.36	0.05280	0.01901
Cd (mg/l)	0.0008	0	0.0008	0.01	0.01	16.40	0.52800	8.65920
Cu (mg/l)	0.1900	0	0.1900	0.05	0.05	380.00	0.05280	20.0640
Pb (mg/l)	0.0250	0	0.0247	0.05	0.05	49.46	0.05280	2.61149
Fe (mg/l)	0.0960	0	0.0964	1.00	1.00	0.10	0.00264	0.00025
$\sum_{n=1}^{n} \mathrm{Wn}$							0.9982	
$\sum_{n=1}^{n} \mathrm{qnWn}$								2661.625
WQI = $\sum_{n=1}^{n} \mathrm{qnWn} / \sum_{n=1}^{n} \mathrm{Wn}$								2666.48834

The overall WQI in all the sampling sites of the dry season showen in Table 2.23 revealed that no sampling site was fitted for drinking purpose. All sampling sites quality index is in the range of bad quality that required proper treatment.

Table 2.23: WQI values of all sampling sites in the dry season

Sampling Sites	WQI		Status
S_0	2317.732	F	Unfit for Drinking
S_1	720.3754	F	Unfit for Drinking
S_2	1028.546	F	Unfit for Drinking
S_3	1512.812	F	Unfit for Drinking
S_4	1436.482	F	Unfit for Drinking
S_5	1250.443	F	Unfit for Drinking
S_6	3197.761	F	Unfit for Drinking
S_7	3918.633	F	Unfit for Drinking
S_8	9182.856	F	Unfit for Drinking
S_9	1929.552	F	Unfit for Drinking
S_{10}	2836.068	F	Unfit for Drinking
F = S. No. Taken from Table 2.18.			

2.5.4.2.3 WQI of Lake Tana mean water samples

The WQI values of Lake Tana mean water samples were summarized in Table 2.24. WQI of Lake Tana was 12721.36. 418 water samples of Lake Tana were taken for this mean analysis. Water Samples of the study area were very poor to unfit for drinking and the water locations require proper water treatment before use. The mean values of NH_3 and PO_4^{3-} were very high and above the permissible limit which makes the Lake water quality very poor to unfit for drinking and require treatment before use.

Table 2.24: WQI values of Lake Tana mean water samples

Parameter	V_n	V_{id}	($V_n - V_{id}$)	S_n	(S_n- V_{id})	qn = [($V_n - V_{id}$) / (S_n- V_{id})] x 100	Unit Weight (Wn= k / Sn)	qnWn
Temp (°C)	23.000	0	23	5 - 30 °C	30	76.670	0.00009	0.00675
PH	7.5056	7	0.506	6.0 – 9.0	2	25.300	0.00029	0.00742
EC (µS/cm)	180.123	0	180.123	1000	1000	18.012	0.00001	0.00005
BOD_5 (mg/l)	37.33 0	0	37.330	5	5	746.600	0.00053	0.39421
COD (mg/l)	316.45	0	316.450	150	150	210.970	0.00002	0.00371
TSS (mg/l)	0.340	0	0.340	50	50	0.679	0.00005	0.00004
TDS (mg/l)	93.082	0	93.082	30	30	310.270	0.00009	0.02730
NO_3^- (mg/l)	0.492	0	0.492	50	50	0.985	0.00005	0.00005
NO_2^- (mg/l)	0.054	0	0.054	0.10	0.10	53.860	0.02640	1.42190
NH_3 (mg/l)	0.325	0	0.325	0.02	0.02	1625	0.13200	214.500
PO_4^{3-} (mg/l)	42.386	0	42.386	0.03	0.03	141286.670	0.08800	12433.227
SO_4^{2-} (mg/l)	10.955	0	10.955	200	200	5.478	0.00001	0.00007
Cr (mg/l)	0.040	0	0.040	0.05	0.05	79.460	0.05280	4.19549
Mn (mg/l)	0.006	0	0.006	0.30	0.30	1.880	0.00880	0.01654
As (mg/l)	0.003	0	0.003	0.05	0.05	5.720	0.05280	0.30202
Cd (mg/l)	0.002	0	0.002	0.01	0.01	48.600	0.52800	25.6608
Cu (mg/l)	0.123	0	0.123	0.05	0.05	245.460	0.05280	12.9603
Pb (mg/l)	0.051	0	0.051	0.05	0.05	101.100	0.05280	5.33808
Fe (mg/l)	0.357	0	0.357	1	1	35.727	0.00264	0.09432
$\sum_{n=1}^{n} \mathrm{Wn}$							0.9982	
$\sum_{n=1}^{n} \mathrm{qnWn}$								12698.16
WQI = $\sum_{n=1}^{n} \mathrm{qnWn} / \sum_{n=1}^{n} \mathrm{Wn}$								12721.359

Generally the rating of water quality showed that the water of the Lake Tana was not suitable for drinking and pollution load is comparatively high during the wet season. Fertilizers were suspected to make the water quality unfit for drinking purpose because the two parameters (NH_3 and PO_4^{3-}) are majorly sourced from fertilizers which were the highest values.

CHAPTER 3

ASSESSMENT OF THE IMPACT OF ANTHROPOGENIC ACTIVITIES ON LAKE TANA USING MACROINVERTEBRATE INDEX

3.1 INTRODUCTION

The water resources of Ethiopia are rich in biodiversity with many endemic species (NBI, 2005). The biological resources of any water system can be studied using biological organisms in order to understand the quality of the water based on the organisms present, abundance and distribution patterns and other meaningful attributes of the biotic community. Many of aquatic species live in fresh water habitat around the world; along the edges, on the surface or at the bottom of shallow lakes. Aquatic organisms normally grow in association with both standing and flowing water at or above the surface of the soil (Keddy, 2010).

Aquatic macroinvertebrates are ubiquitous and sensitive to environmental changes that make them good indicators of water condition. Macroinvertebrates are used to describe the health of water bodies based on the biological integrity of their fauna. Macroinvertebrates analysis is cost effective and widely accepted tool in water quality monitoring (Sanz *et al.*, 2014). Anthropogenic activities (domestic, industrial and agricultural) strongly affect and change the species richness and abundance of aquatic macroinvertebrates. Biotic indices are common tools for the assessment and sustainable management of water resources (Sanz *et al.*, 2014). The evaluation provides information about environmental stresses (Couceiro *et al.*, 2012). Each macroinvertebrate species is unique and possesses different tolerance to change in environmental stress. Hence, aquatic macroinvertebrates are very sensitive to measure environmental changes and stress of aquatic ecosystem. Therfore, the use of macroinverterates as a biomonitoring tool has been well accepted throughout the world for effective water quality monitoring (Blanca *et al.*, 2014). They are very essential tools to provide a coherent classification of water quality and systematic evaluation of water quality degradation that can be used to set improvement strategies using mitigation or rehabilitation measures (Mariadoss and Ricardo, 2015). On the basis of this justification chapter three relied on the assessment of the impact of anthropogenic activities on Lake Tana using macroinvertebrates.

3.2 OBJECTIVES

1. To evaluate macroinvertebrate diversity, distribution and varations within the wet and dry seasons and among the sampling sites.
2. Evaluate the biotic integrity of the lake, its ability to support macroinvertebrates by comparing biological diversity and abundance between the reference and impacted sites (taxa richness, abundance, evenness, etc).
3. Develop bio-monitoring tool (Metric Index) for Lake Tana using macroinvertebrate metric indices as biological indicator.

3.3 MATERIALS AND METHODS

3.3.1 Macroinvertebrate Sampling

3.3.1.1. Materials Used in Macroinvertebrate Sampling

1. For collection of macroinvertebrates: aquatic scoop net, brush, bucket, markers or labels, forceps, 4% formalin, 70% alcohol, boats, trappers and gloves.
2. For macroinvertebrate identification: Enamel trays for sorting, dissecting microscopes, forceps, droppers, vials, petridish, manuals for identification of aquatic macroinvertebrate (Gerber and Gabriel, 2002; Bouchard, 2004; Javier *et al.*, 2011).

3.3.1.2. Sample Collection

Macroinvertebrates were collected to provide a quantitative and qualitative description of the community composition of Lake Tana at Bahir Dar study area, Gorgora study area, Tana Kirkos study area, Megech study area and Ambobahir study area at all sampling sites in wet and dry seasons for one year (June 2014 to May 2015) based on macroinvertebrates field guide (Gerber and Gabriel, 2002, Bouchard, 2004 and Javier *et al.*, 2011). Macroinvertebrate kick net samples were collected in the wet and dry seasons, once in a season for one year.

Samples were collected once in the wet season and once in the dry season from 11 sampling sites. Sampling sites were along the shorelines of Lake Tana in Bahir Dar (Kuriftu, Tana Transport and Tana Hotel), Gorgora (Debresina, Gorgora Transport and Gorgora Hotel), Tana Kirkos (Tana Kirkos and Gumara) and Megech study areas (Megech East and Megech Inlet) for human influenced sites and Ambobahir study area (Ambobahir) as a reference site. The samplings were conducted in wet and dry seasons which were used for comparison.
Macroinvertebrate samples were taken in the wet and dry seasons for one year (June 2014 to May 2015) by using a kick net (standard aquatic Scoop net) with 500 μm mesh size and sampling area = 0.9 m^2). The samples were collected from an area of nearly 100 m^2 at different riparian areas in order to include all possible microhabitats for thirty minutes in each sampling site as used by Carlos *et al*. (2012). Moreover, the macroinvertebrate samples on macrophytes were collected by using sieves. All collected samples were immediately fixed (preserved) in 4% formaldehyde in the field and then transferred to 70% ethyl alcohol. The specimens were transferred in to 250 ml containers on site. The hand picking method (using forceps) was used for the collection of macroinvertebrates. In the laboratory, collected macroinvertebrates were sorted, identified to the family level by using a binocular microscope and counted as done in Teodora *et al.,* (2013).

3.3.1.3. Identification

The samples were sorted at the laboratory of ARARI (Amhara Region Agricultural Institute, Fishery laboratory) and University of Gondar (Biology Department laboratory) on the day following the collections. Macroinvertebrate samples were cleaned (debris and mud removed) and the samples were transferred to plastic tray and a small amount of the sample was randomly placed in a Petri dish to be identified. Using a dissecting microscope and identification keys, aquatic insects were identified, counted, organized and analyzed to family level and placed in vials containing 70% ethyl alcohol as done in Teodora *et al.,* (2013).

3.3.1.4. Biodiversity Analysis

Only the organisms from the sweep were used to estimate the macroinvertebrate richness and composition based on relative abundances of macroinvertebrate. The collected macroinvertebrates tolerance was valued based on Hisenhoff tolerance value. All collected samples were used to calculate the metric and biological indices (FBI, Family Biotic Index, Shannon-Wiener Diversity Index, Simpson's Diversity Index (D), Biological Monitoring Working Party (IBMWP), Average Score Per Taxon (ASPT), Taxa Richness (TR), EPT Index, Percent Contribution of Dominant Family (% DF), Community Loss Index (CLI) and Percent Model Affinity (PMA)), Metric Index Development for Lake Tana, Index development for the study sites based on taxon richness and composition. These analyses were chosen because they are cost effective to use and have been used widely in the past.
Metrics were reviewed based on description in the Hilsenhoff (1988) and Barbour *et al.*, (1999) from the data. Then Lake Tana water quality (aquatic community health) at each site was assessed based on the diversity (richness and abundance), metrics, tolerance values and biological indices.

Composition and relative abundance, tolerance values and biological indices were used to evaluate differences in biological parameters among the reference and impacted sites. Metrics of macroinvertebrate community structure was used to see the environmental stress at reference and impacted sites.

3.3.2 Data Analysis

Basic statistical measurement was done and results were expressed as mean ± SE. One way ANOVA was used to study the difference among sites, where significant values ($P < 0.05$) were obtained and least significant difference test was subsequently applied to detect the specific point of difference among variables and correlation among metrics ($n = 21$) was conducted using SPSS version 23. Graphs were used to evaluate richness, composition and abundance of macroinvertebrates; metrics developed among the sampling sites, the reference and impacted sites as well as the sampling seasons (wet and dry season of the sample period). Biotic indices were developed for the study area to evaluate the Lake Tana water quality level. All statistical analyses were performed using the SPSS statistical software version 23 (SPSS Inc, 2016) and Excel spreadsheet, 2007.

3.3.3 Macroinvertebrate Metric Selection

Biological integrity approach consists of four steps: 1) defining biological condition in a minimally disturbed area, what the natural condition in the area should be, 2) defining biological attributes that change along the gradient of human influence, 3) associating those changes with specific human impacts and 4) identifying management practices for improving biological integrity (Couceiro *et al.*, 2012).

3.3.3.1 Metrics

Metric is a characteristic of the biota that changes in some predictable way with increased human influence. Metrics are various attributes of the benthic macroinvertebrate community that have been characterizing in the form of quantitative measures. The attributes of the community measured by the metrics fall into several categories of benthic community characteristics and the specific metrics of the categories can indicate different aspects of the community condition (Joel, 2003). For example, metrics dealing with species richness or diversity or total taxa can be used as indicator of community health. Ecologically healthy system is expected to support a more diverse community of fauna than ecologically impacted area. The identifications and counts of organisms collected provide the information to calculate suitable metrics for water quality evaluation (Joel, 2003; Mariadoss and Ricardo, 2015).

Metrics evaluated for use with macroinvertebrate data in a typical macroinvertebrate index of biotic integrity (MIBI) are represented in four categories (Hilsenhoff, 1988) as cited by Mariadoss and Ricardo (2015). These metric categories are:

1) Richness measures (such as total taxa),
2) Tolerance measures (such as percent tolerant taxa),
3) Composition measures (such as percent dominant taxa), and

4) Trophic structure measure (such as percent shredders) (Hilsenhoff, 1988; Joel, 2003)

3.3.3.2 Index

Index of biological integrity (IBI) is a synthesis of different biological information that numerically depicts associations between human influence and biological attributes. Hence, index is a compilation of information on the health of aquatic ecosystems. Index of biological integrity (IBI) is a single score value measuring societal goals of biological integrity and cumulative site assessment. The IBI is a multi-metric analytical approach to biological assessment (Masese *et al.*, 2009). IBI is made of a combination of several biological indicators (metrics) into a summary index that measure the condition of a water body and its stressors damaging the organisms living in the water. Thus, the information can be used to minimize the negative impacts and improve the health of the water and the surrounding habitat (Davis and Simon, 1995) as cited by Patrick *et al.* (2014). IBI is based on empirically defined metrics because: (1) such metrics are biologically and ecologically meaningful; (2) they increase or decrease as human influence increases; (3) they are sensitive to a range of stresses; (4) they distinguish stress-induced variation from natural and sampling variation; (5) they are relevant to societal concerns; and (6) they are easy to measure and interpret. IBI metrics evaluate species richness; indicator taxa (stress intolerant and tolerant); relative abundances of trophic guilds and other species groups; the incidence of hybridization, disease, and anomalies such as lesions, tumors, or fin erosion (fish) and head capsule abnormality (stream insects) (Patrick *et al.*, 2014).

3.3.3.3 Multimetric Index

Multimetric index comprise metrics that integrates information from ecosystem, community, population and individual levels (Joel, 2003). Multimetric indexes are generally dominated by metrics of taxa richness (number of taxa) because a biota's structure, including which taxa are present and their relative abundance. The best and most comprehensive and accurate multimetric indexes embrace several attributes of the sampled assemblage (taxa richness, indicator taxa (e.g., tolerant and intolerant groups), health of individual organisms and assessment of processes (e.g., trophic structure). Multiple metrics evaluate the overall indication of ecological situation (Patrick *et al.*, 2014).

Individual species of BMIs reside in the aquatic environment for periods of months to several years are sensitive in varying degrees to environmental attributes (temperature, dissolved oxygen, sedimentation, nutrient enrichment and chemical and organic pollution). Finally, aquatic invertebrates represent a significant aquatic environmental change since they provide a wealth of evolutionary, ecological and biogeographical information (Carlos *et al.*, 2012). In this study, benthic macroinvertebrate metrics index was used.

For index development, a set of metrics or community attributes that are known to be responsive to aquatic degradation were used. Each of the metrics index were calculated from the sample data (Karr, 1996; Carlos *et al.*, 2012).

Seventeen metrics representing richness, composition and tolerance/intolerance measures were considered for the index development (Table 3.1). During development of index, a metric has to:

1) Show habitat degradation (differentiate between reference and impacted sites),
2) Represent some aspects of the community (species composition, richness, tolerance, feeding groups, and etc), and
3) Minimize redundancy of metrics (provide unique information) i.e. not be linearly correlated with another metric or no overlap of information (Karr, 1996) as cited by Sisay (2017).

Metric scoring was based on the continuous scoring method as outlined in Blocksom (2003) and used in Solomon (2006). Each metric was scored on a continuous scale from 0 (poor) to 10 (good) using the upper and lower threshold of the distribution in the reference and impacted sites. The range of numbers that might be observed for each of these characteristics is representing values expected from most stressed (impacted) to least stressed (reference) sites.

Metric scores were calculated using the following formula:

$$\text{Metric score} = \frac{(\text{observed} - \text{lower threshold}^{a}) * 10}{\text{Upper}^{b} - \text{lower threshold}^{a}}$$

[a]Lower treshold for metrics that decrease (increase) with perturbation is 25th (75th) percentile of impacted.

[b] upper threshold for metrics that decrease (increase) with perturbation is 75th (25th) percentile of the reference.

Source: Blocksom (2003)

For positive metrics (i.e., those that increased with improving conditions), the upper expectation (ceiling) was the 75th percentile of the distribution of reference site while the lower expectation (floor) was the 25th percentile of the distribution of impacted sites. And for negative metrics, those that decreased with improving condition, the ceiling was the 75th percentile of the distribution of impacted reaches and the floor was the 25th percentile of the distribution of reference reaches. Negative metrics with a value above the ceiling scored 0, while those below the floor scored 10.

Metrics with a value above the ceiling (upper expectation) receive a score of 10, while those below the floor (lower expectation) scored 0. All other values were linearly scaled along the range between the high and the low ranges for positive and negative metrics. By using the above procedures to calculate the Lake Tana macroinvertebrate index metric scores were added together, multiplied by 10 and divided by the number of metrics scored to produce a range of 0-100.

Table 3.1: Candidate metrics and expected direction of metric response to increasing perturbation (Barbour *et al.*, 1999) as cited by (Sisay, 2017).

Category	Metrics	Description(Definition)	Expected response to Increasing impact
Taxonomic Richness	No. taxa	Measures the overall variety of the macroinvertebrate assemblages	Decrease
	No. Odonata taxa	Number of dragonflies and damselflies taxa	Decrease
	No. Hemiptera taxa	Number of water or true bugs taxa	Decrease
	No. Diptera taxa	Number of "true" fly taxa, which includes midges	Decrease
	No. Chironomidae taxa	Number of taxa of chironomid (midge) larvae	Decrease
	No. Coleoptera taxa	Number of beetle taxa (adult or larva)	Decrease
	No. Mollusca	Number of taxa of Mollusca	Increase
	No. Physidae taxa	Number of taxa of Physidae	Increase
	No. Planorbidae taxa	Number of taxa of Planorbidae	Decrease
Taxonomic composition	% Odonata	Percent of mayfly nymphs	Decrease
	% Hemiptera	Percent of caddisfly larvae	Decrease
	% Diptera	Percent of dipterans	Decrease
	% Chironomidae	Percent of midge larvae	Decrease
	% Coleoptera	Percent of beetle larvae and aquatic adults	Decrease
	% Mollusca	Percent of Mollusca	Increase
	% Physidae	Percent of aquatic Mollusca	Increase
Tolerance/ Intolerance	% Dominant taxon	Percent of the most abundant taxon	Increase

3.4 RESULT AND DISCUSSION

3.4.1 Macroinvertebrate Richness

A total of six hundred twenty nine macroinvertebrate individuals falling in nine orders and thirty eight families were identified from all eleven sites in the study year (Table 1.1 and Appendix 2). But in the wet season a total of two hundred ninety four macroinvertebrate individuals (two hundred thirty three impacted sites while sixty one in the reference site) in nine orders and twenty six families (twenty in impacted sites, thirteen in the reference site) and during the dry season a total of three hundred thirty five macroinvertebrate individuals (two hundred forty five in the impacted sites while ninety in the reference site) in nine orders and thirty five families (thirty two in the impacted and twenty four in the reference sites) were identified from all eleven sites in the study year (Table 3.2 and Table 3.3 and Appendix 2).

The study area represented by Ephemeroptera three families, Plecopetra one family, Trichoptera two families, Arachnid one family, Odonata five families, Coleoptera six families, Diptera eight families, Hemiptera nine families and Mollusca three families. Total number of families collected over the sample period was thirty eight (Table 3.2 and Appendix 2). A decrease in the diversity of Ephemeropterans, Plecopetrans and Trichopterans is a decrease in the EPT index while an increase in hemiptera is an indicator of environmental stress (Patrick *et al.*, 2014). This stress was due to an increase in land use-land cover change due to intensive agriculture activities in the catchment and a dramatic increase in the application of fertilizers, pesticides and herbicides as well as urbanization as it was reported in Marius *et al*. (2014).

Table 3.2: Total number of Orders collected and orders abundance over the sample period at all sites of Lake Tana

Taxa	Orders		Ephemeroptera	Plecopetra	Trichoptera	Arachnid	Odonata	Coleoptera	Diptera	Hemiptera	Mollusca	Total number of Families Collected over the sample period	Total Abundance
	No. of Families		3	1	2	1	5	6	8	9	3	38	
Ambo bahir	Wet	**S_0**	2	0	1	0	46	7	0	5	0	13	61
	Dry	**S_0**	19	10	1	1	34	5	5	15	0	24	90
Bahir Dar Study Area (S.A)	Wet	**S_1**	0	0	0	0	4	11	1	0	0	3	16
	Dry	**S_1**	1	2	0	0	3	4	5	2	2	12	19
	Wet	**S_2**	2	0	0	0	20	13	12	17	0	6	64
	Dry	**S_2**	21	0	0	0	3	0	3	0	2	8	29
	Wet	**S_3**	5	0	0	0	9	16	0	2	0	7	32
	Dry	**S_3**	3	3	0	0	10	3	8	1	32	16	60
Tana Kirkos S.A	Wet	**S_4**	2	3	0	0	6	7	1	4	0	7	23
	Dry	**S_4**	0	0	0	0	0	0	0	0	0	0	0
	Wet	**S_5**	0	0	0	0	0	0	0	0	0	0	0
	Dry	**S_5**	0	0	0	0	0	0	0	0	0	0	0
Megech S.A	Wet	**S_6**	0	0	0	0	0	6	0	0	0	2	6
	Dry	**S_6**	0	0	0	0	0	0	2	0	0	1	2
	Wet	**S_7**	0	0	0	0	0	0	0	0	0	0	0
	Dry	**S_7**	0	0	0	0	0	5	0	0	0	2	5
Gorgora S. A	Wet	**S_8**	0	0	0	0	5	6	0	3	3	5	17
	Dry	**S_8**	3	3	0	0	7	13	1	28	0	12	55
	Wet	**S_9**	0	0	0	0	3	12	0	30	2	6	47
	Dry	**S_9**	0	0	0	0	2	31	7	4	4	10	48
	Wet	**S_{10}**	2	0	0	0	0	12	0	14	0	6	28
	Dry	**S_{10}**	0	0	0	1	4	2	0	16	4	10	27
Total Indiv.	Wet	LT	13	3	1	0	93	90	14	75	5	26	294
	Dry	LT	49	18	1	2	63	63	31	66	44	35	335
	T	LT	60	21	2	2	156	153	45	141	49	38	629

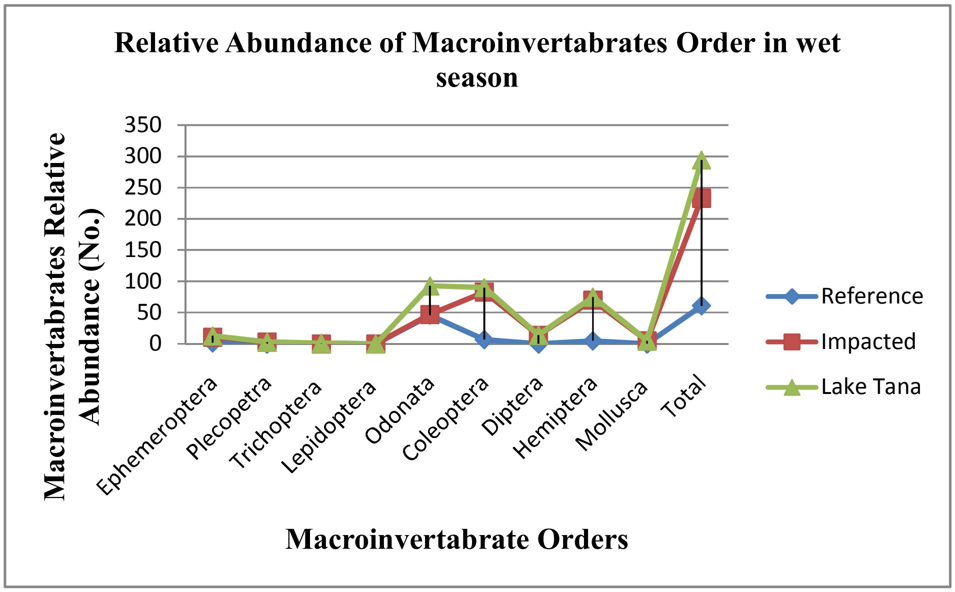


Figure 3.1: Relative abundance of macroinvertebrates order in the wet season

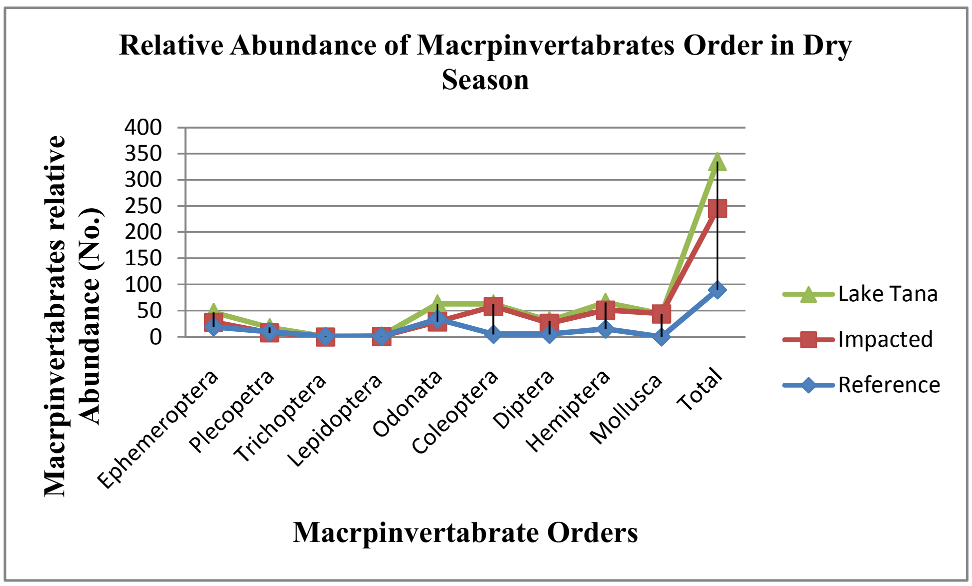


Figure 3.2: Relative abundance of macroinvertebrates order in the dry season

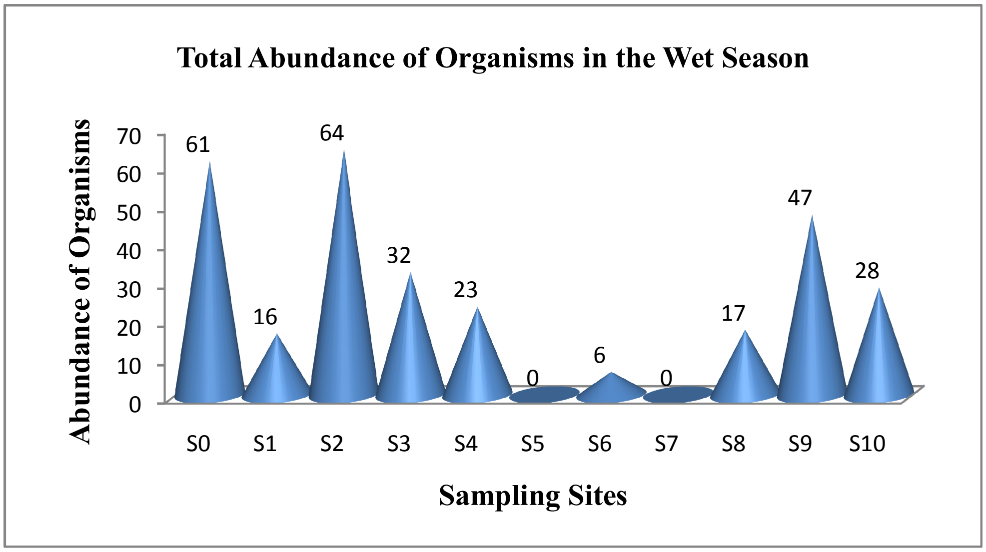


Figure 3.3: Total abundance of organisms in the sampling sites in the wet season

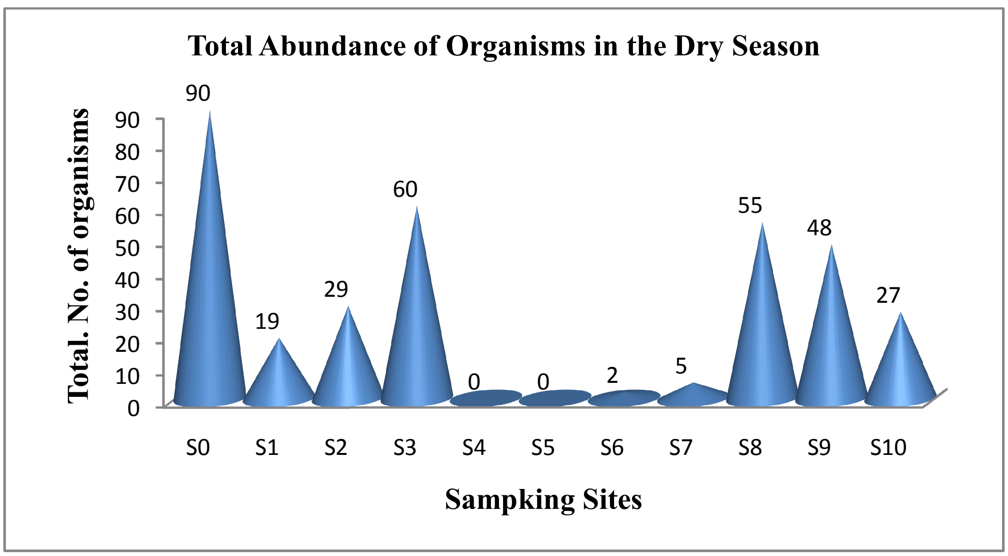


Figure 3.4: Total abundance of organisms in the sampling sites in the dry season

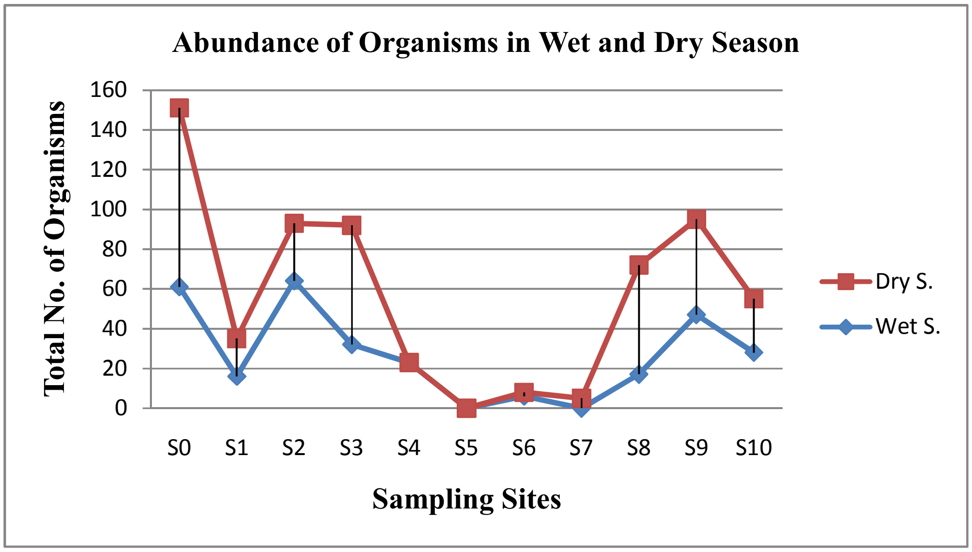


Figure 3.5: Abundance of macroinvertebrates order in Lake Tana

In the wet and dry seasons of 2014/2015, 38 taxa of macroinvertebrates were identified. The most abundant taxa were from the order Coleoptera, Odonata and Hemipetera. Also they were the most dominant in the lake. The most frequent taxa found in both seasons were Coleoptera. The abundance is more in the dry season compared with the wet season (Figure 3.1, 3.2, 3.3 and 3.4). Abundance of organisms in the study area is more in the dry season than the wet season as indicated in Figure 3.5. The number of organisms and Taxa identified was almost negligible at S_5, S_6 and S_7 as indicated in Figure 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.12 and 3.13. This indicated that these impacted sites S_5, S_6 and S_7 were much degraded areas.

Most of the taxa collected from the study sites of Lake Tana are moderately tolerant such as Coleoptera as reported in Bouchard (2004). Therefore, higher number of coleopteran taxa can be an indicator of less impact, whereas low number of coleopteran taxa shows severe impact (Amanuel, 2011). Percent ephemeroptera also well discriminated the reference site from the impacted sites. Percent ephemeroptera generally tends to decrease with decreasing water quality for healthy ecosystem since mayflies are among sensitive to moderately tolerant taxa (Bouchard, 2004).

Odonatas and Coleopterans are able to withstand the pollution impact. Its abundant presence in the sampling sites might be due to the water quality is polluted. The presence of more Odonata, Coleptera and Hemipteran larvae is the indication of water quality deterioration due pollution (Mariadoss and Ricardo, 2015). Therefore, the ecological potential of the Lake Tana was assessed as "Moderate". The low diversity of macroinvertebrate taxa in some sites for instance S_5 and S_7 other than the pollution effect might be the absecence of riparian vegetation cover but site S_6 is 100% covered by water hyacinth (Teodora *et al.,* 2013).

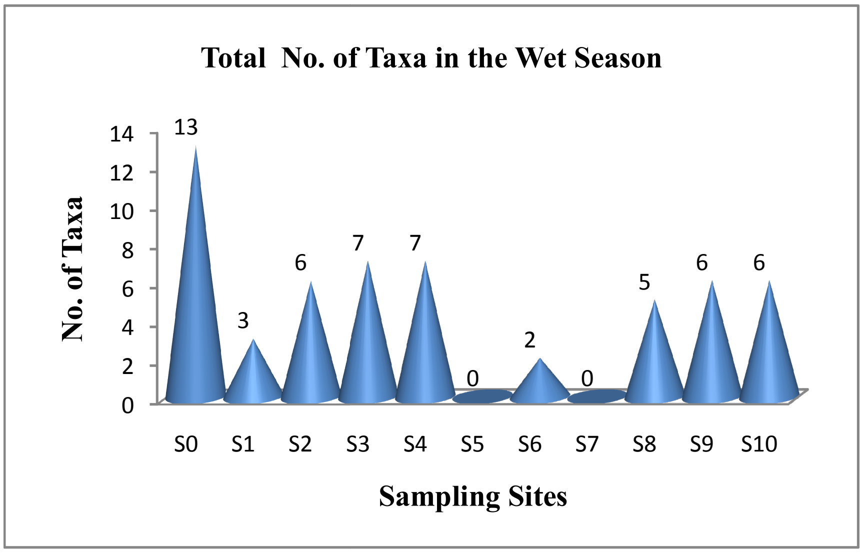


Figure 3.6: Total No. of Taxa in sampling sites in the wet season

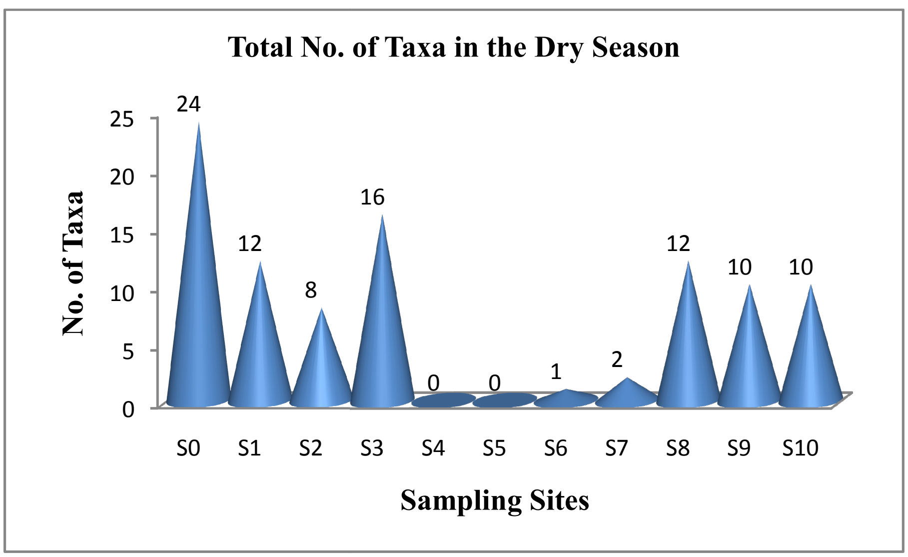


Figure 3.7: Total No. of Taxa in sampling sites in the dry season

Through out the sampling Period in the dry season sites S_3 (sixteen Taxa), S_1 and S_8 (twelve taxa) and S_9 and S_{10} (ten taxa) were characterized by the highest total abundance of taxa other than the reference site in descending order while in the wet season S_3 and S_4 (seven Taxa) and S_9 and S_{10} (six taxa) collected (Table 3.2, Appendix 2 and Figure 3.6 and 3.7). The taxonomic composition of the lake was dominated by odoata and coleopetera larvae. The site areas S_1 and S_2 (Bahir Dar study area) and S_6 and S_7 (Megech sudy area) were known with urban pollutant discharges. S_4 and S_5 (Tana kirkos sudy area) and S_6 and S_7 (Megech sudy area) were used for intensive agricultuareal activities (fertilizers and pesticides applied) most likely had some adverse impact on the benthic macroinvertebrates as reported in Teodora *et al.* (2013).

A shift from rich macroinvertebrates fauna in the reference site to relatively less macroinvertebrates in the impacted sites is very clear indication of water quality effect. Gastropods and Dipterans also have more capability to adapt to varied aquatic habitats due to their extra ordinary structural organization which are abundant taxa next to Odonata, Coleoptera and Hemiptera in the study area. Similar observations were also made by Mariadoss and Ricardo (2015). According to Mariadoss and Ricardo (2015) the biota organizes itself in response to environmental circumstances. Accurate bioassessment of lakes depends on having a good knowledge of the natural variation in the structure of the assemblage with environmental impact or stress being deviated from the reference sites (Tujuba, 2010). It is apparent from the study that the quality of the Lake water deteriorated as one moved to the north (Megech study area). This was mainly because of different types of anthropogenic activities. Seasonal changes can modify the value of environmental variable such as temperature, organic matter availability, riparian vegetation cover and other factors that can influence macroinvertebrate fauna (Figure 3.1 and 3.2) a similar result by Mariadoss and Ricardo (2015) was observed.

Table 3.3: Total number of Taxa collected and taxa abundance over the sample period at all sites of Lake Tana

Taxa	Ambobahir		Bahir Dar Study area (S.A)						Tana Kirkos S.A				Megech S.A				Gorgora S. A					
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Families	S_0	S_0	S_1	S_1	S_2	S_2	S_3	S_3	S_4	S_4	S_5	S_5	S_6	S_6	S_7	S_7	S_8	S_8	S_9	S_9	S_{10}	S_{10}
Baetidae	1	16	0	1	0	17	0	2	2	0	0	0	0	0	0	0	0	2	0	0	2	0
Caenidae	1	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Heptageniidae	0	2	0	0	2	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perlidae	0	1	0	2	0	0	0	3	3	0	0	0	0	0	0	0	0	3	0	0	0	0
Capniidae	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropsychidae	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracarina	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aeshinidae	0	3	0	2	0	2	0	5	5	0	0	0	0	0	0	0	5	0	0	0	0	0
Calopterygidae	8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenogrionidae	42	22	4	0	20	0	9	3	1	0	0	0	0	0	0	0	0	1	3	1	0	1
Gomphidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lestidae	3	1	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	2
Dytiscidae	1	1	0	2	13	0	10	2	0	0	0	0	0	0	0	2	6	0	12	23	9	0
Elimidae	0	1	0	2	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	3	0	0
Gyrinidae	2	1	11	0	0	0	2	1	7	0	0	0	0	0	0	3	0	11	0	0	1	0
Haliplidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Hydrophilidae	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Psephenidae	4	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	2
Ceratopogonidae	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	0	0	0	3	12	1	0	1	0	0	0	0	0	0	0	0	0	0	0	6	0	0
Culicidae	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0
Muscidae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Psychodidae	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simuliidae	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tabanidae	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tipulidae	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Belostomatidae	0	8	0	0	8	0	0	0	4	0	0	0	0	0	0	0	0	27	0	0	0	0

Corixidae	0	3	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2	8	10
Gerridae	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	2
Hydrometridae	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoridae	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Nepidae	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notenoctidae	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	16	2	6	0
Pleidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Velidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Physidae	0	0	1	0	2	0	2	0	0	0	0	0	0	0	0	0	3	0	2	4	0	3
Planorbidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Corbiculidae	0	0	0	1	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Taxa	13	24	3	12	6	8	7	16	7	0	0	0	2	1	0	2	5	12	6	10	6	10
Total Abundance	61	90	16	19	64	29	32	60	23	0	0	0	6	2	0	5	17	55	47	48	28	27
Total Individual Organisms																						629

3.4.2 Macroinvertebrate Composition

In the study year collected impacted sites macroinvertebrate sample size was four hundred seventy eight (76% of the total). From four hundred seventy eight collected individuals, two hundred thirty three (37% of the total) were collected in the wet season and two hundred forty five (39% of the total) in the dry season. But the reference area macroinvertebrate sample size was one hundred fifty one (24% of the total); from this sixty one (9.7% of the total) was in the wet season and ninety (14.3% of the total) in the dry season individuals identified. The diversity was more in the dry season. The reason might be less water disturbance and more reproductive interval in the dry season. More diversity was in site S_0 (thirteen and twenty four families in the wet and dry seasons respectively); Reference site, Ambobahir study area, where the expected impact was less. Less diversity was obsedved in sites S_6 and S_7 (Megech East and Megech inlet, Megech study area) (maximum two and minimum zero families in wet and dry seasons) where high expected impact in the watershed or catchment (Table 3.3 and Figure 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.12 and 3.13). Coenogrionidae (Odonata) was the most abundant family collected (forty two individuals at S_0 in the wet season, twenty two individuals at S_0 in the dry season and twenty at S_2 in the wet season), followed by Corbiculidae thirty individuals (Mollusca, at S_3 in the dry season), Belostomatidae (Hemiptera, twenty seven individuals at S_8 in the dry season), Dytiscidae (Coleoptera, twenty three individuals at S_9 in the dry season), Baetidae (Ephemeroptera, seventeen individuals at S_2 and sixteen individuals at S_0 in the dry season), Notenoctidae (Hemiptera, sixteen individuals at S_9 in the wet season), others are below fifteen individuals (Table 3.3 and Appendix 2). The macroinvertebrates community in the study area had the highest diversity in the dry season compared with the wet season and the reference site diversity was more among all the lake sampling sites. This was justified by the study of Marius *et al*. (2014). The abundance was more in sites where the impact was high and less abundance in sites where the expected impact was less. It was true in the study area sites as indicated in (Table 3.3 and Appendix 2). This may be a result of the complementary influence of several factors.

Table 3.4 (A-C): Common macroinvertebrate families at reference and impacted sites

(A) Taxa very common at the reference site

Taxa		**Abundance**		**% ***	
Order	**Family**	Wet	Dry	Wet	Dry
Ephemeroptera (Mayflies)	Caenidae (Small square –gill Mayflies)	1	-	100	-
Plecopetra (Stoneflies)	Capniidae (Small Winter Stoneflies)	-	9	-	100
Trichoptera (Caddisflies)	Hydropsychidae (Common Net - Spinner Caddisflies)	1	1	100	100
Odonata (Damselflies &Dragonflies)	Calopterygidae (Broad-Winged)	-	8	-	88.9
	Coenogrionidae (Damselflies)	-	22	-	78.6
	Gomphidae (Club-Tail Dragonflies)	1	-	100	-
Diptera (Two winged or "True flies")	Psychodidae (Moth Flies)	-	3	-	100
Hemiptera (Water or true bugs)	Hydrometridae (Marsh treaders)	2	-	100	-
	Naucoridae (Creeping Water Bugs)	-	1	-	100
	Pleidae (Pigmy backswimmers)	1	-	100	-

* Percent of the total family

(B) Taxa common in impacted sites

Taxa		Abundance		% *	
Order	**Family**	Wet	Dry	Wet	Dry
Ephemeroptera (Mayflies)	Heptageniidae (Flathead Mayflies)	7	-	100	-
Plecopetra (Stoneflies)	Perlidae (Common Stoneflies)	-	8	-	88.9
Odonata (Damselflies &Dragonflies)	Aeshinidae (Darner Dragonflies)	10	16	100	84.2
	Lestidae (Damselflies)	3	6	-	85.7
Coleoptera (Beetles)	Dytiscidae (Predaceous Diving Beetles)	50	29	98	96.7
	Elimidae (Riffle Beetles)	-	6	-	85.7
	Gyrinidae (Whirligig Beetles)	21	15	91.3	93.8
Diptera (Two winged or"True flies")	Chironomidae ((Non-Biting) (Midges))	12	11	100	100
Hemiptera (Water or true bugs)	Belostomatidae (Giant water bugs)	12	27	100	77.1
	Corixidae (waterboatmen)	26	12	100	80
	Gerridae (water Striders)	6	-	85.7	-
	Notonectidae (Waterscorpion)	22	-	100	-
Mollusca (Snails)	Physidae (Pouch snails)	5	12	100	100
	Corbiculidae	-	31	-	100

* Percent of the total family

(C) Taxa common to reference and impacted sites

Taxa		**Abundance**				**% ***			
		Ref		Imp		Ref		Imp	
Order	**Family**	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Ephemeroptera (Mayflies)	Baetidae (Small Minnow Mayflies)	---	16	---	22	---	42.1	---	57.9
Odonata (Damselflies &Dragonflies)	Coenogrionidae (Damselflies)	42	---	37	---	53.2	---	46.8	----
Coleoptera (Beetles)	Psephenidae (Water penny beetles)	4	---	4	---	50	---	50	---

***** Percent of the total family

The abundance of organisms in Table 3.4(A-C) to be considered, the total sum of reference and impacted sites individual organisms has to be more than five but if the individual organisms found only in the reference site are less than five in number it has been considered with recognition of the reference site is only one and the impacted sites were ten. On the basis of this abundance was determined, most of the families' common in the reference site tolerance level was in the intermediate range and common to the impacted sites tolerance range was in the tolerant and organisms' common to the reference and the impacted sites tolerance range was intermediate.

Dytiscidae (Coleoptera (Beetles) was the most abundant family collected (eighty one individuals, 12.9%) in all of the sites, followed by Belostomatidae (Hemiptera (Water or true bugs) (forty seven individuals, 7.5%), Baetidae (Ephemeroptera (Mayflies), forty three individuals, 6.8%), Corixidae (Hemiptera (Water or true bugs), forty one individuals, 6.5%), Corbiculidae (Mollusca (Snails)), thirty one individuals, 4.9%), others were below thirty individuals (Table 3.6). Among the thirty eight families collected in wet and dry seasons (Appendix 2), eleven were found common in the reference site, fourteen were commonly found in impacted sites and three were common in impacted and the reference site. The abundance of organisms is given in Table 3.4 (A-C).

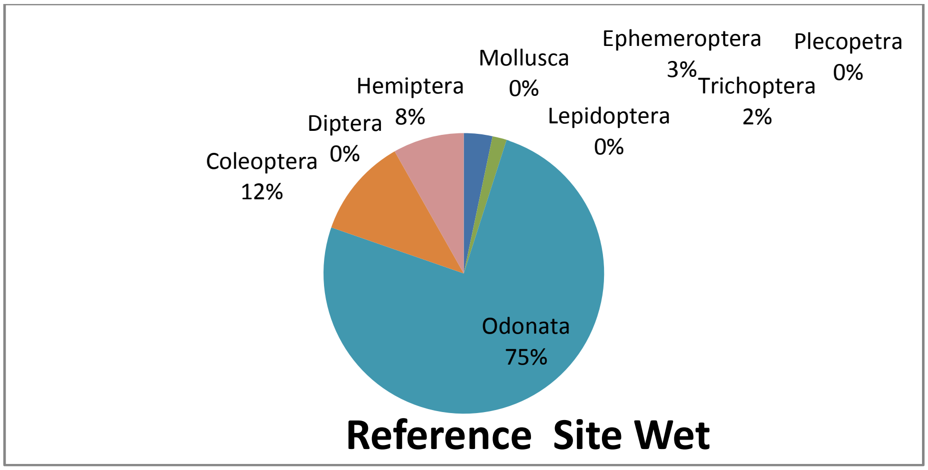


Figure 3.8: Composition of Lake Tana organisms order in the wet season

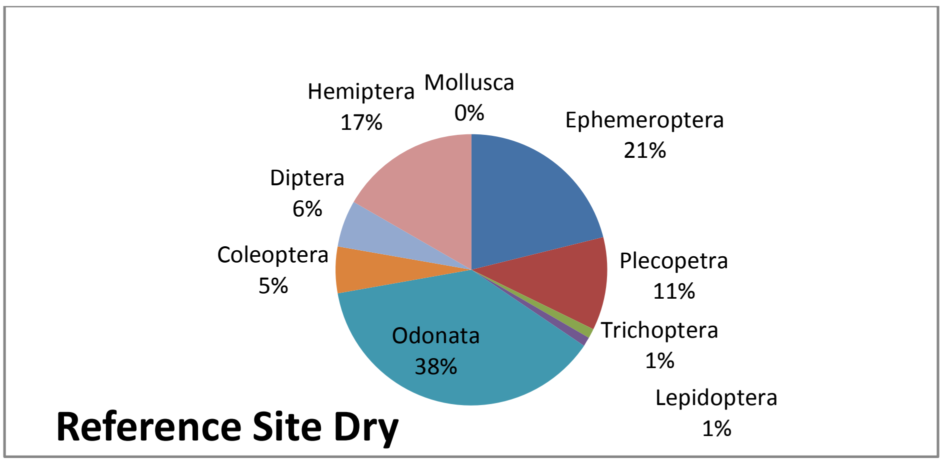


Figure 3.9: Composition of Lake Tana organisms order in the dry season

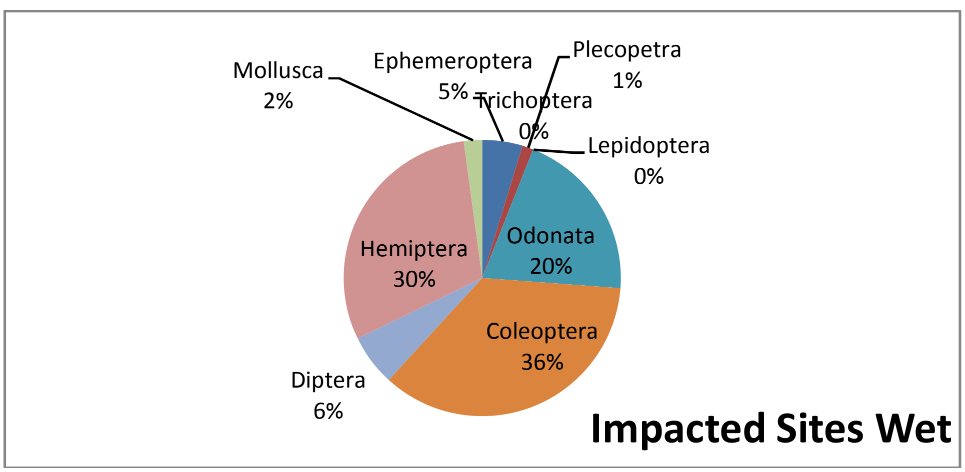


Figure 3.10: Composition of Lake Tana organisms order in the wet season in the impacted sites

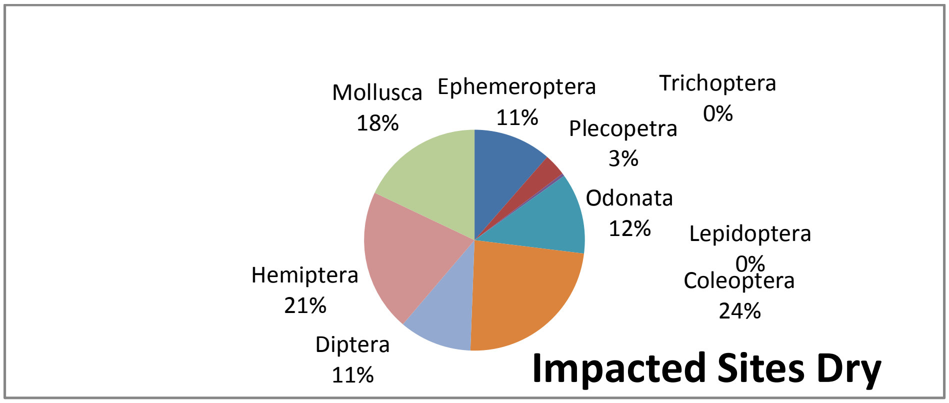


Figure 3.11: Composition of Lake Tana organisms order in the dry season in the impacted sites

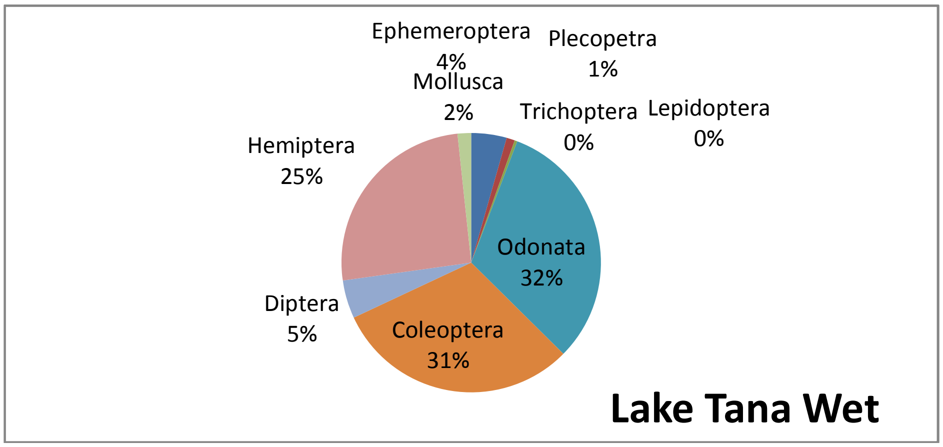


Figure 3.12: Percentage composition of macroinvertebrate orders in the wet season of Lake Tana

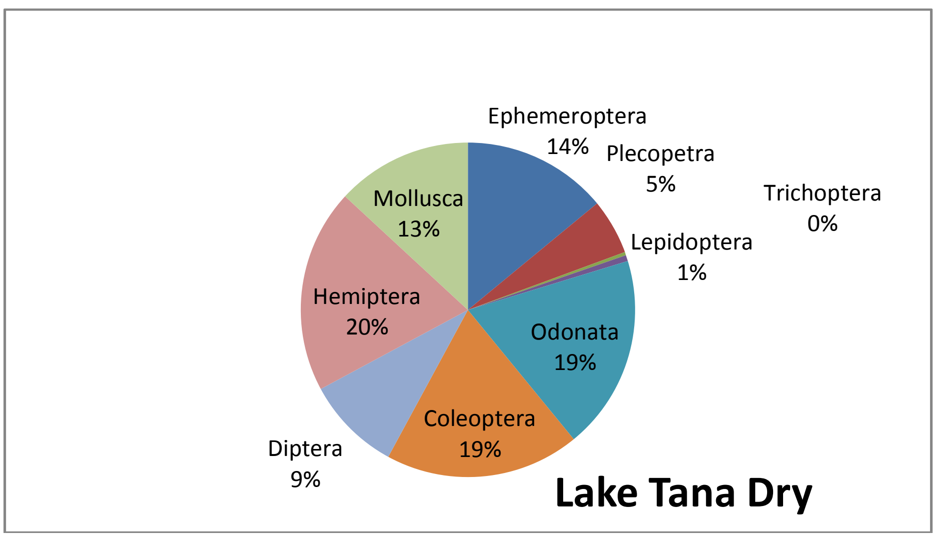


Figure 3.13: Percentage composition of macroinvertebrate orders in the dry season of Lake Tana

Ephemeroptera, plecoptera and trichoptera (EPT) (intolerant families) richness was highest in the reference site at the dry season (21%, 11% and 1% respectively) and at the impacted sites (composition rate of 11%, 3% and 0% in the dry season, but relatively low in the wet season at the reference site (3%, 0% and 2% while 21%, 11% and 1% in the dry season) (Figure 3.8, 3.9, 3.10, 3.11, 3.12 and 3.13).

The order Odonata was the most dominant accounting for over 24.8% of the total abundance followed by Coleoptera with a relative abundance of 24.3% and Order Hemiptera 22.4 %. All the remaining orders had proportions less than 10% while orders Trichoptera and Lepidopetra had the lowest relative abundance of 0.3% each Figure 3.1, 3.2 and Table 3.6 as the study of Patrick *et al*. (2014). As shown in Table 3.6 Odonata, Coleoptera and Hemiptera were abundant in the reference and impacted sites of Lake Tana almost in the same proportion except Ephemeroptera exceeded coleopteran in the reference site at the dry season 21% by 5%. Therfore, the Odonata, Coleoptera and Hemiptera (three) order taxas were the dominat groups in the study areas. Most larval and adult aquatic Coleoptera (Beetles) are tolerant of wide changes in environmental conditions (Such as: pH and dissolved oxygen concentration). Adults must rise to the surface to respire atmospheric oxygen. Beetles are recognized as indicator organisms of environmental health (Mariadoss and Ricardo, 2015). Hemipterans are all air breathers and are more tolerant of environmental extremes than most other insects. The water boatman, Gerridae (water strider) are among the few insects that can tolerate pH values less than 4.5 and are among the last to disappear when water bodies are affectd by acidity (Mandaville, 2002).

This result indicates existence of several organisms in terms of diversity and abundance in the study area. The high diversity of macroinvertebrate taxa is an indication of less stressed environment in Lake Tana (the reference site) promoting coexistence of different taxa but abundance of macroinvertebrate taxa is an indication of stressed environment. Higher taxa diversity has been attributed to good ecosystem condition and ability of the resident taxa to adapt to the prevailing conditions (Patrick *et al*., 2014). Past studies (Mustafa and Gurcay, 2011) have attributed dominance of taxa to suitable abiotic factors such as availability of sufficient food, lack of competition and predation. Baetis and Pulmonata (Mollusks) are scrapers; therefore abundance in food items could enhance the abundance of the Mollusks. Baetis are mostly controlled by predation from Hemiptera and Odonata while molluscks probably lack predators (Patrick *et al*., 2014). Corbiculidae (basket clams) was dominant of the Mollusca group in the study area (Table 3.3). Molluscks have been reported by Tanya *et al*., (2014) to be a major food item for African lung fish, in Lake Baringo, Kenya and thus affects its abundance in a system. Abundance of African lung fish significantly reduces abundance of molluscks in an aquatic system (Couceiro *et al.*, 2012; Patrick *et al*., 2014).

3.4.3. Macroinvertebrates Tolerance

Benthic macroinvertebrate species are differentially sensitive to many biotic and abiotic factors in their environment. Consequently, macroinvertebrate community structure has commonly been used as an indicator of the condition of an aquatic system called tolerance (Mandaville, 2002). Such organisms have specific requirements in physical and chemical conditions. Changes in presence/absence, numbers, morphology, physiology or behaviour of these organisms can indicate the physical and/or chemical conditions outside their preferred limits. Presence of numerous (abundant) families of highly tolerant organisms usually indicates poor water quality (Jake *et al.*, 2012). Seasonal variability highly affects community structure and productivity because many species of macroinvertebrates have annual (or shorter) life cycles, which culminate in an adult phase during the open-water period. Thus, the presence of mature larvae, pupae or adults (the life stages most useful for taxonomic work) may be short-lived and easily missed if seasonal development rates differ from year to year. In this regard, mid-summer survey dates are chosen (Mandaville, 2002). The study area result is justified by this literature (Table 3.3, 3.4(A-C) and 3.6).

According to Bouchard (2004) macroinvertebrates used to evaluate water quality are often given a number to represent their tolerance or intolerance to pollution; lower numbers represent intolerance while higher numbers represent increased tolerance**.** In this regard, values of 0 to 3 are considered indicative of a low tolerance to stress (impairment), value of 4 to 6 a moderate tolerance and values of 7 to 10 a high tolerance **(**Table 3.5**).** The pollution tolerance values might be based on only one or a few types of impacts (Hilsonhoff, 1988; Bouchard, 2004)**.** Tolerance values of the macroinvertebrates in Appendix1of the study area is shown in Table 3.5. Therefore, we can evaluate the water quality of the study area based on the tolerance values of the organisms.

The less number of individuals presence of EPT taxa (Ephemeroptera, Plecopetra and Trichoptera) in most of the impacted sites showed indication of water and habitat quality impairment as indicated by (Aura *et al.*, 2010). At the same time those Ephemeroptera groups found in the study area were with tolerance value 4 and 5 (that shows moderate water quality). The taxa that were found in the impacted sites were in the category of tolerance value more than 4 (water quality moderate to bad, many of the impacted sites were within the category of moderate while the Megech study area (sampling sites) were in the category of worst. However, in this study taxa richness was observed in the reference site while in the impacted sites, lower taxa were observed (Table 3.4 (A-C) and Appendix 2).

Plecoptera (stone fly) was represented by two families, Capniidae (nine individuals) only found at S_0 in the wet season and Perlidae found at S_0 (one individual), S_1 (two individuals), S_3 (three individuals) and S_8 (three individuals) in the dry season and at S_4 (three individuals) in the wet season but absent in the other sites (Table 3.3 and Appendix 2). These families are sensitive as represented by Hilsonhoff tolerance value of one. This showed more credence to the perturbed nature of many of the sampling sites. It has been also reported that plecoptera are very sensitive aquatic insect groups (Blanca *et al.*, 2014). Coleoptera was represented by six families (taxa). The presences of some species of dytiscidae have been reported to indicate moderate water quality with 5 tolerance values as it was studied by (Patrick *et al*., 2014). From this, the highest representation of Coleoptera families' composition and their tolerance value rated in the moderate water quality in the study area showed gross pollution effect on Lake Tana.

The more direct evidence to pollution in the study area was the fact that all families of diptera collected were pollution tolerant; especially pollution tolerant family Chironomidae, the most abundant were recorded in site S_2 during the wet season and S_9, S_1, S_2 and S_3 during the dry seasons, with decreasing rate. In view of this, this group can be used as pollution tolerant order owing to the fact that they were highly abundant and represented of this study area (Table 3.5 and 3.6).

Table 3.5: Tolerance values of macroinvertebrate families collected at all sites of Lake Tana as cited by Sisay (2017)

Order	Family	Tolerance	Reference
Coleoptera (Beetles)	Dytiscidae (Predaceous Diving Beetles)	5	Bode *et al*. (1996)
	Elimidae (Riffle Beetles)	5	Hauer & Lamberti (1996) Bouchard *et al (* 2004)
	Gyrinidae (Whirligig Beetles)	4	Bode *et al*. (1996)
	Haliplidae (Crawling Water Beetles)	5	Hilsenhoff (1988) Bode *et al*. (1996)
	Hydrophilidae (Water Scavenger Beetles)	5	Hilsenhoff (1988) Bode *et al*. (2002)
	Psephenidae (Water penny beetles)	4	Hauer & Lamberti (1996)
Diptera (Two winged or"True flies")	Ceratopogonidae (Biting Midges)	6	Hilsenhoff (1988) Bouchard *et al*. (2004)
	Chironomidae (Blood-red, including pink)	8	Hilsenhoff (1988)
	Chironomidae (Non-Biting)	6,1,2,4	Bode *et al*. (1996)
	Culicidae (mosquitoes)	8	Hilsenhoff (1988)
	Muscidae (House Flies)	6	Hilsenhoff (1988)
	Psychodidae (Moth Flies)	10	Hilsenhoff (1988) Hauer & Lamberti (1996)
	Simuliidae(black flies)	6	Hilsenhoff (1988) Hauer & Lamberti (1996)
	Tabanidae (Horse Flies, Deer Flies)	6	Hilsenhoff (1988) Hauer & Lamberti (1996)
	Tipulidae (Crane flies)	3	Hauer & Lamberti (1996)
Ephemeroptera (Mayflies)	Baetidae (Small Minnow Mayflies)	4	Hilsenhoff (1988) Hauer & Lamberti (1996)
	Caenidae (small square –gill Mayflies)	7	Hilsenhoff (1988) Bouchard *et al*. (2004)
	Heptageniidae (Flathead Mayflies)	4	Hilsenhoff (1988) Hauer & Lamberti (1996)
Hemiptera (Water or true bugs)	Belostomatidae	10	Bode *et al*. (1999)
	Corixidae (water boatmen)	9	Hilsenhoff (1988)

	Gerridae (water Striders)	8	Hilsenhoff (1988)
	Hydrometridae (Marsh treaders)	5	Barbour *et al*. (1999)
	Naucoridae (Creeping Water Bugs)	5	Barbour *et al*. (1999)
	Nepidae (Water scorpion)	8	Barbour *et al*. (1999)
	Notenoctidae (back swimmers)	2	Tanya *et al.* (2014)
	Pleidae (Pigmy backswimmers)	Undetermined	Barbour *et al*. (1999)
	Velidae (Broab-Shouldered Water Striders)	6	Barbour *et al*. (1999)
	Physidae	8	Barbour *et al*. (1999)
	Planorbidae	6	Hilsenhoff (1988)
Mollusca (Snails)	Corbiculidae (**basket clams)**	8	Bode *et al*. (1996)
	Aeshinidae (Darner Dragonflies)	3	Hilsenhoff (1988) Hauer & Lamberti (1996)
	Calopterygidae (Broad-Winged Damselflies)	5	Hilsenhoff (1988) Hauer & Lamberti (1996)
	Coenogrionidae (Narrow- Winged Damselflies)	9	Hilsenhoff (1988) Hauer & Lamberti (1996)
	Cordulegastridae (Spke-Tail Dragonflies)	3	Hilsenhoff (1988) Bouchard *et al.* (2004)
	Gomphidae (Club-Tail Dragonflies)	1	Hilsenhoff (1988) Hauer & Lamberti (1996)
Odonata (Damselflies &Dragonflies)	Lestidae (Damselflies)	9	Hauer & Lamberti (1996)
	Perlidae (Common Stoneflies)	1	Hilsenhoff (1988)
Plecopetra (Stoneflies)	Capniidae (Small Winter Stoneflies)	1	Hauer & Lamberti (1996)
Trichoptera (Caddisflies)	Hydropsychidae (Common Net -Spinner Caddisflies)	4	Hilsenhoff (1988)
Lepidoptera	Hydracarina (Water mites)		

Table 3.6: Composition of macroInvertebrates and family Tolerance values collected at all sites of Lake Tana

Order	Family	Tolerance	No. of Individuals	% of Composition
Coleoptera (Beetles)	Dytiscidae (Predaceous Diving Beetles)	5	81	12.9
	Elimidae (Riffle Beetles)	5	11	1.8
	Gyrinidae (Whirligig Beetles)	4	39	6.2
	Haliplidae (Crawling Water Beetles)	5	5	0.8
	Hydrophilidae (Water Scavenger Beetles)	5	6	1
	Psephenidae (Water penny beetles)	4	11	1.8
Diptera (Two winged or"True flies")	Ceratopogonidae (Biting Midges)	6	4	0.6
	Chironomidae ((Non-Biting, Blood-red, including pink)	8	23	3.7
	Culicidae (mosquitoes)	8	4	0.6
	Muscidae (House Flies)	6	2	0.3
	Psychodidae (Moth Flies)	10	3	0.5
	Simuliidae(black flies)	6	5	0.8
	Tabanidae (Horse Flies, Deer Flies)	6	2	0.3
	Tipulidae (Crane flies)	3	2	0.3
Ephemeroptera (Mayflies)	Baetidae (Small Minnow Mayflies)	4	43	6.8
	Caenidae (small square –gill Mayflies)	7	7	1.1
	Heptageniidae (Flathead Mayflies)	4	10	1.6
Hemiptera (Water or true bugs)	Belostomatidae	10	47	7.5
	Corixidae (water boatmen)	9	41	6.5
	Gerridae (water Striders)	8	10	1.6
	Hydrometridae (Marsh treaders)	5	2	0.3
	Naucoridae (Creeping Water Bugs)	5	4	0.6
	Nepidae (Water scorpion)	8	3	0.5
	Notenoctidae (back swimmers)	2	27	4.3

	Pleidae (Pigmy backswimmers)	---------	1	0.2
	Velidae (Broab-Shouldered Water Striders)	6	6	1
Mollusca (Snails)	Physidae	8	17	2.7
	Planorbidae	6	1	0.2
	Corbiculidae (basket clams)	8	31	4.9
Odonata (Damselflies &Dragonflies)	Aeshinidae (Darner Dragonflies)	3	29	4.6
	Calopterygidae (Broad-Winged Damselflies)	5	9	1.4
	Coenogrionidae (Narrow- Winged Damselflies)	9	107	17
	Gomphidae (Club-Tail Dragonflies)	1	1	0.2
	Lestidae (Damselflies)	9	10	1.6
Plecopetra (Stoneflies)	Perlidae (Common Stoneflies)	1	12	1.9
	Capniidae (Small Winter Stoneflies)	1	9	1.4
Trichoptera (Caddisflies)	Hydropsychidae (Common Net -Spinner Caddisflies)	4	2	0.3
Lepidoptera	Hydracarina (Water mites)		2	0.3
		Total	629	100

Total numbers of tolerant individuals were 303 (48.2%) and intermediate or facultative individuals were 243 (38.7%) while intolerant individual organisms were 80 (12.7%). Most of the taxa (48.2%) had tolerance scores ranging from 7 to 10, while 38.7% of taxa had intermediate/ Facultative tolerance scores between 4 and 6 and 12.7% taxa had tolerance scores of less than 4 (Table 3.6). This showed that Lake Tana is polluted including the reference site.

The less abundance of intolerant EPT taxa (Ephemeroptera, Plecopetra and Trichoptera) in impacted sites showed that there is indication of water and habitat quality impairment or degradation (Marius *et al.*, 2014). However, in this study the reference site taxa richness is proportional with the summation of impacted sites that showed impairment at the reference site (13 taxa and 20 taxa in the wet season and 24 taxa and 32 taxa in the dry season respectively). Seasonal variations are important in macroinvertebrate community composition (Gabriels, 2007). This was the realty in the study area. The dry season composition was more than the wet season. Consequently, the period of sampling might affect the evaluation of sampling sites as indicated by Tujuba (2010).

The family Baetidae (mayfly) taxon collected in this study is moderately tolerant. This family is known to increase with moderate pollution as reported by Tanya *et al*., (2014). Therefore, the low scores at the impacted sites could indicate highly impaired ecological condition (at S5, S6 and S7). Higher percent mayflies at the reference sites indicated moderate pollution known by moderately tolerant. Chironomidae is among the tolerant families of dipteran taxa being more tolerant (Amanuel, 2011).

Higher scores of percentage tolerant organisms at the reference site testify the presence of few tolerant organisms. The impacted sites scores show higher proportion of tolerant organisms, which in turn testify higher ecological impairment since percent tolerant organisms tend to increase with perturbation (Barbour *et al.,* 1999; Amanuel, 2011).

3.4.4. Biological Indices

Both pollution sensitive and tolerant organisms are present in "clean" waters; but it is the absence of the sensitive coupled with the presence of the tolerant which may indicate damage. This is the basis for the Biotic Index development (Mandaville, 2002).

Aquatic macroinvertebrates have been used to develop biotic water quality indices based on sensitive taxa, tolerant taxa or other metrics that can represent macroinvertebrates assemblages (Mariadoss and Ricardo, 2015). The total number of different taxa of macroinvertebrates collected in the eleven sites is presented in the Table 3.3 and Appendix 1 that can be used for biotic index development. Hence, based on litratures and guidelines the following indices were computed as biotic index (Mandaville, 2002).

3.4.4.1. FBI (Family Biotic Index)

One of the most comprehensive of the biotic indexes is the one proposed by the Hilsenhoff (1977) formula or FBI. It was calculated as:

$$FBI = \frac{\sum ni\ ai}{N}$$

Where (n) is the number of individuals in each taxonomic group (i), (a) is the pollution tolerance score ranging from 0 to 10 for that taxonomic group (i) and N is the total number of organisms in the sample (Hilsenhoff, 1988 as cited by Mandaville, 2002). By using the FBI score Lake Tana water quality was evaluated (Table 3.7 (A-C)).

Biotic index systems have been developed by giving numerical scores (values) to indicator organisms at a particular taxonomic level (Mandaville, 2002). The Biotic Index (BI) is based on categorizing macroinvertebrates into categories depending on their response to pollution (based on the tolerance levels) as shown in Table 3.6 which was justified by (Mandaville, 2002; Blanca *et al*., 2014).

The Biotic Index was originally developed by Hilsenhoff (1977) as cited by Mandaville (2002) to provide a single 'tolerance value' which is the average of the tolerance values of all families within the macroinvertabrate community. The Biotic Index was developed by using the family level tolerance values ranging from 0 (very intolerant) to 10 (highly tolerant) based on their tolerance to pollution (Plafkin *et al.,* 1989 and Bode *et al*., 1991 as cited by Blanca *et al*., 2014). A problem with the application of this form of the biotic index (BI) for general use is the requirement to identify the organisms belonging to family or species (Mandaville, 2002; Blanca *et al*., 2014).

Table 3.7(A-C) summarizes the family pollution tolerance scores (ai) for a variety of macroinvertebrates and ranges of FBI scores for Lake Tana sampling sites water quality interpretation as proposed by Hilsenhoff (1977, 1982, 1988 and 1988) (Mandaville, 2002).

Table 3.7 (A-C). Lake Tana water quality testing using the family biotic index (FBI) for macroinvertebrates

A. The whole Lake Tana water quality testing using the family biotic index (FBI) for macroinvertebrates

Order	Family	T Value	S_0 (T)	S_1 (T)	S_2 (T)	S_3 (T)	S_4 (T)	S_5 (T)	S_6 (T)	S_7 (T)	S_8 (T)	S_9 (T)	S_{10} (T)	T Wet	T Dry	T LT	IW	ID	IT
Ephemeroptera	Baetidae	4	0.45	0.1	0.7	0.1	0.3	0	0	0	0.1	0	0.1	0.1	0.5	0.3	0.1	0.4	0.2
	Caenidae	7	0.09	0	0.3	0	0	0	0	0	0.1	0	0	0	0.1	0.1	0	0.1	0.1
	Heptageniidae	4	0.05	0	0.1	0.3	0	0	0	0	0	0	0	0.1	0	0.1	0.1	0	0.1
Plecopetra	Perlidae	1	0.01	0.1	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
	Capniidae	1	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Hydropsychidae	4	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera	Hydracarina	----																	
Odonata	Aeshinidae	3	0.06	0.2	0.1	0.2	0.7	0	0	0	0.4	0	0.1	0.1	0.2	0.1	0.1	0.2	0.2
	Calopterygidae	5	0.26	0	0.1	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0
	Coenogrionidae	9	3.81	1	1.9	1.2	0.4	0	0	0	0.1	0.4	0.2	2.4	0.8	1.5	1.4	0.2	0.8
	Gomphidae	1	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lestidae	9	0.24	0.3	0	0.2	0	0	0	0	0.1	0	0.3	0.1	0.2	0.1	0	0.2	0.1
Coleoptera	Dytiscidae	5	0.07	0.3	0.7	0.7	0	0	0	2	0.4	1.8	0.8	0.9	0.4	0.6	1.1	0.6	0.8
	Elimidae	5	0.03	0.3	0	0	0	0	2.5	0	0.1	0.2	0	0.1	0.1	0.1	0.1	0.1	0.1
	Gyrinidae	4	0.08	1.3	0	0.1	1.2	0	0	2.4	0.6	0	0.1	0.3	0.2	0.2	0.4	0.2	0.3
	Haliplidae	5	0	0	0	0	0	0	0	0	0	0.3	0	0	0.1	0	0	0.1	0.1
	Hydrophilidae	5	0.03	0	0	0.2	0	0	0	0	0.1	0	0	0.1	0	0	0.1	0	0.1
	Psephenidae	4	0.13	0	0	0	0	0	1	0	0	0	0.3	0.1	0	0.1	0.1	0	0.1
Diptera	Ceratopogonidae	6	0.08	0.2	0	0.1	0	0	0	0	0	0	0	0	0.1	0	0	0	0
	Chironomidae	8	0	0.7	1.1	0.1	0	0	0	0	0	0.5	0	0.3	0.3	0.3	0.4	0.4	0.4
	Culicidae	8	0	0	0.1	0	0.3	0	0	0	0.1	0.1	0	0	0.1	0.1	0	0.1	0.1
	Muscidae	6	0	0	0	0	0	0	1.5	0	0	0	0	0	0	0	0	0	0
	Psychodidae	10	0.2	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
	Simuliidae	6	0	0	0.1	0.3	0	0	0	0	0	0	0	0	0.1	0	0	0.1	0.1
	Tabanidae	6	0	0.2	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tipulidae	3	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Belostomatidae	10	0.53	0	0.9	0	1.7	0	0	0	3.8	0	0	0.4	1	0.7	0.5	1.1	0.8
	Corixidae	9	0.18	0	0.9	0	0	0	0	0	0	1	2.9	0.8	0.4	0.6	1	0.4	0.7
	Gerridae	8	0.11	0	0	0.1	0	0	0	0	0	0.4	0.3	0.2	0.1	0.1	0.2	0.1	0.1
	Hydrometridae	5	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Naucoridae	5	0.07	0	0	0	0	0	0	0	0.1	0	0	0.1	0	0	0	0	0
	Nepidae	8	0.05	0.5	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0.1	0

	Notenoctidae	2	0.01	0	0	0	0	0	0	0	0	0.4	0.2	0.1	0	0.1	0.2	0	0.1
	Pleidae	-																	
	Velidae	6	0	0	0	0.1	0	0	0	0	0.1	0	0.4	0	0.1	0.1	0.1	0.1	0.1
Mollusca	Physidae	8	0	0.2	0.2	0.2	0	0	0	0	0.3	0.5	0.4	0.1	0.3	0.2	0.2	0.4	0.3
	Planorbidae	6	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
	Corbiculidae	8	0	0.2	0	2.6	0	0	0	0	0	0	0	0	0.7	0.4	0	1	0.5
FBI			6.74	5.5	7	6.4	4.8	0	5	4.4	6.5	5.6	6.3	6.4	6.2	6.3	6.1	6.3	6.2

B. Lake Tana reference site water quality testing using the family biotic index (FBI) for macroinvertebrates

Order	Family	Value	$S_0(W)$	$S_0(D)$	$S_0(T)$
Ephemeroptera	Baetidae	4	0.07	0.71	0.45
	Caenidae	7	0.11	0.08	0.09
	Heptageniidae	4	0	0.09	0.05
Plecopetra	Perlidae	1	0	0.01	0.01
	Capniidae	1	0	0.10	0.06
Trichoptera	Hydropsychidae	4	0.07	0.04	0.05
Lepidoptera	Hydracarina	-----			
Odonata	Aeshinidae	3	0	0.10	0.06
	Calopterygidae	5	0	0.44	0.26
	Coenogrionidae	9	6.20	2.20	3.81
	Gomphidae	1	0.02	0	0.01
	Lestidae	9	0.44	0.10	0.24
Coleoptera	Dytiscidae	5	0.08	0.06	0.07
	Elimidae	5	0	0.06	0.03
	Gyrinidae	4	0.13	0.04	0.08
	Haliplidae	5	0	0	0
	Hydrophilidae	5	0	0.06	0.03
	Psephenidae	4	0.26	0.04	0.13
Diptera	Ceratopogonidae	6	0	0.13	0.08
	Chironomidae	8	0	0	0
	Culicidae	8	0	0	0
	Muscidae	6	0	0	0
	Psychodidae	10	0	0.33	0.20
	Simuliidae	6	0	0	0
	Tabanidae	6	0	0	0
	Tipulidae	3	0	0	0
Hemiptera	Belostomatidae	10	0	0.89	0.53
	Corixidae	9	0	0.30	0.18
	Gerridae	8	0.13	0.09	0.11
	Hydrometridae	5	0.16	0	0.07
	Naucoridae	5	0.08	0.06	0.07
	Nepidae	8	0	0.09	0.05
	Notenoctidae	2	0	0.02	0.01
	Velidae	6	0	0	0
Mollusca	Physidae	8	0	0	0
	Planorbidae	6	0	0	0
	Corbiculidae	8	0	0	0
FBI			7.75	6.04	6.74

C. Lake Tana impacted sites water quality testing using the family biotic index (FBI) for macroinvertebrates

Order	Family	Value	S_1 (T)	S_2 (T)	S_3 (T)	S_4 (T)	S_5 (T)	S_6 (T)	S_7 (T)	S_8 (T)	S_9 (T)	S_{10} (T)	IW	ID	IT
Ephemeroptera	Baetidae	4	0.11	0.73	0.087	0.35	0	0	0	0.11	0	0.15	0.07	0.36	0.22
	Caenidae	7	0	0.30	0	0	0	0	0	0.1	0	0	0	0.14	0.07
	Heptageniidae	4	0	0.09	0.261	0	0	0	0	0	0	0	0.12	0.02	0.07
Plecopetra	Perlidae	1	0.06	0	0.033	0.13	0	0	0	0.04	0	0	0.01	0.03	0.02
	Capniidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Hydropsychidae	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera	Hydracarina	-----													
Odonata	Aeshinidae	3	0.17	0.06	0.163	0.65	0	0	0	0.42	0.03	0.05	0.13	0.20	0.16
	Calopterygidae	5	0	0.05	0	0	0	0	0	0	0	0	0	0.02	0.01
	Coenogrionidae	9	1.03	1.94	1.174	0.39	0	0	0	0.13	0.38	0.16	1.43	0.22	0.81
	Gomphidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lestidae	9	0.26	0	0.196	0	0	0	0	0.13	0	0.33	0	0.22	0.11
Coleoptera	Dytiscidae	5	0.29	0.70	0.652	0	0	0	2	0.42	1.84	0.82	1.07	0.59	0.83
	Elimidae	5	0.29	0	0	0	0	2.5	0	0.07	0.16	0	0.09	0.12	0.10
	Gyrinidae	4	1.26	0	0.130	1.22	0	0	2.4	0.61	0	0.07	0.36	0.24	0.30
	Haliplidae	5	0	0	0	0	0	0	0	0	0.26	0	0	0.10	0.05
	Hydrophilidae	5	0	0	0.217	0	0	0	0	0.07	0	0	0.09	0.02	0.05
	Psephenidae	4	0	0	0	0	0	1.0	0	0	0	0.29	0.07	0.03	0.05
Diptera	Ceratopogonidae	6	0.17	0	0.065	0	0	0	0	0	0	0	0	0.05	0.03
	Chironomidae	8	0.69	1.12	0.087	0	0	0	0	0	0.51	0	0.41	0.36	0.38
	Culicidae	8	0	0.09	0	0.35	0	0	0	0.11	0.08	0	0.03	0.10	0.07
	Muscidae	6	0	0	0	0	0	1.5	0	0	0	0	0	0.05	0.03
	Psychodidae	10	0	0	0	0	0	0	0	0	0	0	0	0	0
	Simuliidae	6	0	0.06	0.261	0	0	0	0	0	0	0	0	0.12	0.06
	Tabanidae	6	0.17	0	0.065	0	0	0	0	0	0	0	0.03	0.02	0.03
	Tipulidae	3	0.09	0	0.033	0	0	0	0	0	0	0	0	0.02	0.01

Hemiptera	Belostomatidae	10	0	0.86	0	1.74	0	0	0	3.75	0	0	0.52	1.10	0.82
	Corixidae	9	0	0.87	0	0	0	0	0	0	1.04	2.95	1.00	0.44	0.72
	Gerridae	8	0	0	0.087	0	0	0	0	0	0.42	0.29	0.21	0.07	0.13
	Hydrometridae	5	0	0	0	0	0	0	0	0	0	0	0	0	0
	Naucoridae	5	0	0	0	0	0	0	0	0.14	0	0	0.04	0	0.02
	Nepidae	8	0.46	0	0	0	0	0	0	0	0	0	0	0.07	0.03
	Notenoctidae	2	0	0	0.022	0	0	0	0	0.03	0.38	0.22	0.19	0.03	0.11
	Pleidae	-													
	Velidae	6	0	0	0.065	0	0	0	0	0.08	0	0.44	0.05	0.10	0.08
Mollusca	Physidae	8	0.23	0.17	0.174	0	0	0	0	0.33	0.51	0.44	0.17	0.39	0.28
	Planorbidae	6	0	0	0	0	0	0	0	0	0	0.11	0	0.02	0.01
	Corbiculidae	8	0.23	0	2.609	0	0	0	0	0	0	0	0	1.01	0.52
FBI			5.49	7.04	6.380	4.83	0	5.0	4.4	6.53	5.61	6.31	6.09	6.28	6.19

Table 3.8: Evaluation of water quality using the family level biotic index (adapted from Hilsenhoff, (1988) as cited by Mandaville (2002))

Family Biotic Index	Water quality	Degree of organic pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very poor	Severe organic pollution likely

The Lake Tana FBI Score (Appendix 3 (A-C)) in the wet season was 6.4, in the dry season 6.2 and yearly score was 6.3 in all cases it was in a range of fairly poor water quality implying that there is substantial pollution likely as shown in Table 3.8. The reference site (S_0) FBI score in the wet season was 7.75 in a range of very poor where there was severe organic pollution, in the dry season 6.04 in the range fairly poor (ther is substantial pollution) and yearly score was 6.74 in the range poor (in the degree of very substantial pollution) (Appendix 3 and Table 3.8). Cumulative impacted sites FBI score in the wet season was 6.09, in the dry season 6.28 and cumulative score from S_1 to S_{10} in all seasons 6.19, all scores are in a range of fairly poor water quality (Appendix 3 (A-C) and Table 3.8). But there is water quality difference in Lake Tana among the sampling sites as per the FBI yearly score. Those sites water quality in a range of poor were S_0 (6.74), S_2 (7.04) and S_8 (6.53), in a range fairly poor were S_3 (6.38), S_9 (5.61) and S_{10} (6.31), in a range fair S_1 (5.49) and in a range good were S_4 (4.83), S_6 (5.0) and S_7 (4.4). As per sampling seasons, in a wet season in a range very poor were S_0 (7.75) and S_2 (7.97), in a range fairly poor S_3 (6.03), in a range fair S_1 (5.38), S_9 (5.45) and S_{10} (5.32) and in a range good were S_4 (4.83), S_6 (4.67) and S_8 (5.0); in a dry season in in a range very poor was site S_{10} (7.33), in a range poor were S_3 (6.57) and S_8 (7.0), in a range fairly poor were S_0 (6.04), S_6 (6.0) and S_9 (5.77), in a range fair was S_1 (5.58) and in the range good were S_2 (5.0) and S_7 (4.4) (Table 3.7 (A-C), 3.8 and Appendix 3 (A-C)).

The scores for the family biotic index suggested that all sites were in a very poor condition to good where there is some pollution in all of the sites including the reference site. The refrence site showed very poor water quality in the wet season compared to the dry season. The reason might be due to fertilizers and pesticides runoff from the surrounding agricultural activities. The FBI narratives categorized sites with less pollution to a higher pollution. Therefore, it was good enough in discriminating between highly impacted sites to less impacted sites of Lake Tana and similar with the study of Amanuel (2011).

3.4.4.2. Shannon-Wiener Diversity Index (H′)

The Shannon-Wiener Index (H′) is currently one of the most widely used diversity measure. The Shannon-Wiener Diversity Index (H) is commonly used to calculate aquatic and terrestrial biodiversity (Used by the Gerritsen *et al* (1998) and cited by Patrick *et al*. (2014); Mariadoss and Ricardo (2015)). This index was calculated as:
The basic formula is:

$$H = -\sum_{i=1}^{S} \left(\frac{ni}{N}\right) \log\left(\frac{ni}{N}\right)$$

Where (ni) is the number of individuals in the (ith) families, N equals the total number of individuals in the sample, and s equals the total number of families in the sample. This index, which usually varies from 0 to 5, shows how successful one would be at guessing the next bit of information (i.e., families) after knowing the first (Mandaville, 2002).
Or

$$H = \sum_{i=1}^{s} -(P_i * \ln P_i)$$

where:
H = the Shannon diversity index
P_i = fraction of the entire population made up of species i or the proportion of individuals in the “ith” taxon of the community (ni/N)
S = numbers of species encountered (the total number of taxa in the community)
$\sum$ = sum from species 1 to species S

Note: The power to which the base e (e = 2.718281828.......) must be raised to obtain a number is called the natural logarithm (ln) of the number.

To calculate the index:

1. Divide the number of individuals of species #1 you found in your sample by the total number of individuals of all species. This is P_i
2. Multiply the fraction by its natural log ($P_1 * \ln P_1$)
3. Repeat this for all of the different species that you have. The last species is species "s"
4. Sum all the - ($P_i * \ln P_i$) products to get the value of H (Mandaville, 2002).

Hence, the biotic diversity of Lake Tana using Shannon-Weiner diversity index (H) ranged from 0.64 in S_6 to 1.75 in S_4 in the wet season and it was ranged from 0.67 in S_7 and 2.52 in S_0 in the dry season while in the study year in lake Tana the range was 0.67 at S_7 and 2.35 and 2.33 in S_1 and S_0 respectively. Lake Tana biotic diversity using Shannon-Weiner diversity index (H) was 3.07 in the dry season and 2.50 in the wet season. By using the index, the impacted sites biotic diversity was 2.94 in the dry season while in the wet season 2.49 (Appendix 4 (A-C)). Hence, diversity is more in the dry season as similar with the study of Patrick *et al*. (2014) and Mariadoss and Ricardo (2015).

As the number and distribution of taxa (biotic diversity) within the community increases, so does the value of "H" and the lowest value indicates abundance. The sites were observed with eveness, good water quality while with abundance, poor water quality (Gerritsen *et al.,* 1998) as cited by Mandaville (2002).

High values of H would be representative of more diverse communities. A community with only one species would have an H value of 0 because P_i would equal 1 and be multiplied by ln P_i which would equal zero. If the species are evenly distributed then the H value would be high. So the H value allows us to know not only the number of species but how the abundance of the species is distributed among all the species in the community (Mandaville, 2002; Tanya *et al*., 2014).

3.4.4.3. Simpson's Diversity Index (D)

Diversity within the macroinvertebrate community was described using the Simpson's diversity index ("D"). The Simpson Index (D), with values ranging from 0 to 1, is the probability that if two selections are made randomly from a collection of organisms, they will be individuals of the same families. This index is calculated as follows:

$$H = D - \sum_{i=1}^{S} (\mathrm{Pi})^2$$

Where "pi" is the proportion of individuals in the "ith" taxon of the community and "s" is the total number of taxa in the community. This index places relatively little weight on rare families and more weight on common families. Its values range from 0, indicating a low level of diversity, to a maximum of 1 for high level of diversity (Mandaville, 2002).

Or

$$\mathrm{D} = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right)$$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

The value of D ranges between 0 and 1. With this index, 0 represents infinite diversity and 1, no diversity.

The average family diversity indexes were determined using Simpson's diversity index ("1-D") for each site and compared (Appendix 5 (A-C)).Therefore the diversity level of Lake Tana was in the wet season ranged from the lowest 0.53 at S_6 (less diversity) to the highest 0.84 at S_4. In the dry season it ranged from 0.6 at S_7 to 0.95 and 0.89 at S_1 and S_0 respectively. In the study year the lowest value was 0.6 and 0.71 at S_7 and S_6 respectively while the highest value (high diversity) was 0.88 and 0.85 at S_1 and S_2 respectively. The over all Lake Tana 1-D value in the wet season was 0.87 and in the dry season 0.94; in the impacted sites the wet season 1-D value was 0.89 and in the wet season 0.93 (Apendix 5 (A-C)). In general the hihghest 1-D value was observed in the dry season that showed the highest organism diversity. The diversity was less in wet season. The reason might be agricultural run off, sedimentation drain to Lake Tana from rivers and tributaries and industrial effluent mix up by rain flood.

A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance. Simpson's Diversity Index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so diversity increases (Dipankar and Jayanta, 2015).

3.4.4.4. Index Biological Monitoring Working Party (IBMWP)

The Biological Monitoring Working Party score (IBMWP) provides single value at the family level, representative of the organisms' tolerance to pollution. The greater the tolerances towards pollution, the lower the IBMWP score. IBMWP was calculated by adding the individual scores of all families represented within the community (Friedrich *et al*., 1996) as cited by Mandaville, (2002).

The index analyzes the composition of aquatic macroinvertebrates family level according to their tolerance to pollution, assigning a score to each family according to their ability to survive at various levels of contamination: 10 to more sensitive or less tolerant and 1 to tolerant or resistant. The final score is obtained by summing the values of all components of each sample and determining the water quality (Mandaville, 2002; Mariadoss and Ricardo, 2015).

Families are graded according to the inverse of Bode *et al.* (1991) and Plafkin *et al.* (1989) tolerance values to correspond to BMWP scores (modified from Mackie, 2001 and cited by Mandaville, 2002; Mariadoss and Ricardo, 2015).

Table 3.9: Index Biological Monitoring Working Party (IBMWP) Score of Lake Tana

Taxon			BMWP scores
Order	**Family**	**Common name**	
Ephemeroptera (Mayflies)	Baetidae	Small Minnow Mayflies	4
	Caenidae	Small square –gill Mayflies	7
	Heptageniidae	Flathead Mayflies	10
Plecopetra (Stoneflies)	Perlidae	Common Stoneflies	10
	Capniidae	Small Winter Stoneflies	10
Trichoptera (Caddisflies)	Hydropsychidae	Common Net -Spinner Caddisflies	5
Lepidoptera (Aquatic caterpillars)	Hydracarina	Water mites	-
Odonata (Damselflies and Dragonflies)	Aeshinidae	Darner Dragonflies	8
	Calopterygidae	Broad-Winged Damselflies	-
	Coenogrionidae	Narrow- Winged Damselflies	6
	Gomphidae	Club-Tail Dragonflies	8
	Lestidae	Damselflies	-
Coleoptera (Beetles)	Dytiscidae	Predaceous Diving Beetles	5
	Elimidae	Riffle Beetles	5
	Gyrinidae	Whirligig Beetles	5
	Haliplidae	Crawling Water Beetles	5
	Hydrophilidae	Water Scavenger Beetles	5
	Psephenidae	Water penny beetles	-
Diptera (Two winged or "True flies")	Ceratopogonidae	Biting Midges	-
	Chironomidae	(Blood-red, including pink) (Non-Biting) (Midges)	2
	Culicidae	Mosquitoes	-
	Muscidae	House Flies	-
	Psychodidae	Moth Flies	8
	Simuliidae	Black flies	-
	Tabanidae	Horse Flies, Deer Flies	-
	Tipulidae	Crane flies	5
Hemiptera (Water or true bugs)	Belostomatidae	Giant water bugs	-
	Corixidae	Waterboatmen	5
	Gerridae	water Striders	5
	Hydrometridae	Marsh treaders	5
	Naucoridae	Creeping Water Bugs	5
	Nepidae	Waterscorpion	5
	Notenoctidae	Back swimmers	5
	Pleidae	Pigmy backswimmers	5

	Velidae	Broab-Shouldered Water Striders	-
Mollusca (Snails)	Physidae	Pouch snails	3
	Planorbidae	Orb snails	3
	Corbiculidae		-
IBMWP			149

The sudy area maximum IBMWP would be 260 but the calculated IBMWP was 149 (Table 3.9) which is above 50% which rated in Table 3.10 the water quality as good quality.

Table 3.10: IBMWP Water Quality Rate (Mariadoss and Ricardo, 2015)

IBMWP	**Water Quality Rated**
>75% (195-260)	Very good
50%-75% (130-195)	Good
25%-50% (65-130)	Fair
<25% (65)	Poor

3.4.4.5. Average Score Per Taxon (ASPT)

The Average Score Per Taxon (ASPT) represents the average tolerance score of all collected taxa and was calculated by dividing the BMWP by the number of families represented in the sample (Mandaville, 2002). From this value, the water quality of Lake Tana was assessed and ranked as Table 3.11.

From the 38 total collected familes in the study area 12 of them do not have IBMWP score. Hence, the 12 familes were rejected for Average Score Per Taxon (ASPT) calculation and only 26 families score was used. Therefore, ASPT of the study area was 149/26=5.73 that is in the category of ASPT value (5-6), Doubtful quality of water as per Table 3.11.

Table 3.11: Average Score Per Taxon (ASPT) of Lake Tana (Mackie, 2001) as cited by Mandaville (2002)

ASPT value	Water Quality Assessment
>6	Clean Water
5-6	Doubtful quality
4-5	Probable moderate pollution
<4	Probable severe pollution

3.4.4.6. Taxa Richness (TR)

Taxa Richness (TR) indicates the health of the community through its' diversity and increases with increasing habitat diversity, suitability and water quality (Plafkin *et al*., 1989) as cited by Mandaville (2002).

TR equals the total number of taxa represented within the sample. The healthier the community is, the greater the number of taxa found within that community (Mandaville, 2002; Tanya *et al*., 2014).

Hence, Sites S_0 and S_3 both in the dry season were rich with 24 and 16 taxa respectively and Sites S_5 and S_6 in the dry season were poor with 0 and 1 taxa respectively. Hence the poor taxa sites are poor in water quality. In general Lake Tana sites S_0 and S_3 were rich with 37 and 23 taxa respectively where as S_5 and S_7 sites were poor with taxa value 0 and 2 respectively.

3.4.4.7. EPT Index

The Ephemeroptera, Plecoptera and Trichoptera (EPT) index displays the taxa richness within the insect groups which are considered to be sensitive to pollution and therefore should increase with increasing water quality. This index is valid for use at the family level (Plafkin *et al*., 1989) as cited by Mandaville (2002). The EPT index is equal to the total number of families represented within these three orders in the sample (Mandaville, 2002).

$$\%EPT = \left(\frac{E + P + T}{N}\right)x100$$

E is the number of Ephemeroptera, P is the number of plecoptera and T is the number of trichoptera (EPT) and N is the total no. of individuals in the study area sampling.

In the sample, six hundred twenty nine organisms were identified to at least the level of nine order and thirty eight families. The Ephemeroptera, Plecoptera and Trichoptera made up 13.2% (eighty three) of the total sample. The three most dominant families were in the genera Ephemeropterans (Baetidae, Heptageniidae and Caenidae (n = 60, 9.5% of the sample collected), Plecoptera (Perlidae and capniidae (n = 21, 3.3%) and Trichoptera (Hydropsychidae) (n = 2, 0.3%). Ephemeroptera comprised about 9.5% of the maximum of EPT sample groups.

$$\%EPT = \left(\frac{60 + 21 + 2}{629}\right)x100$$

%EPT= 13.2% (83) of the total sample collected. Therfore, %EPT of Lake Tana showed water quality degradation (Table 3.12).

Tolerance levels were based on mean tolerance level for families within each order (Hilsenhoff, 1977; 1982; 1988) as cited by Mandaville (2002). Table 3.12 summarizes the abundances of EPT genera having those tolerances. Low tolerances were exhibited by the majority of EPTs present in the sample of Lake Tana. And it is also justified by Mandaville (2002).

The largest amount of variation was seen between seasons in the Ephemeroptera. The highest number of Ephemeroptera (3 families) at S_1 in the dry season was identified. Water quality values were affected slightly by this variation. S_1 and S_0 were assigned values of “excellent” water quality, while S_5, S_6, S_7 and S_9 were assigned a water quality value of “poor”.

Comparisons of EPT taxa richness also showed variation among the sampling sites (Table 3.3 and Table 3.12). Richness of EPT taxa is widely used to evaluate anthropogenic impacts in aquatic ecosystems. It has been reported by many authors that Ephemeroptera, Plecoptera and Trichoptera Taxa (EPT Index) are reliable index sensitive to change in water bodies. The number of EPT index decreases with increasing human impacts (Mariadoss and Ricardo, 2015). The highest EPT index was registered in Lake Tana at sampling sites of S_2 (24.7) and S0 (21.9) (Table 3.12). The reference site EPT index was lower than sampling site S_2 (Table 3.12). This showed that the reference site was also under the influence of anthropogenic activities. EPT index (taxa) with organic enrichment decreases (Mandaville, 2002).

Although the value for percent Ephemeroptera decreased at almost in all of the sampling sites, the percent E.P.T. (Ephemeroptera + Plecoptera + Trichoptera) remained high at S_2 24.7% (Table 3.12). This was due to the presence of families associated with the vegetation and many of the Ephemeroptera families collected tolerance value was 4 with the range of moderate water quality as was reported by Teodora *et al.* (2013).

Table 3.12: EPT Index of Lake Tana

Families		T.No. EPT	T.Organisms	EPT Index	% EPT
Season	**Sites**				
W	**S_0**	3	61	0.05	4.9
D	**S_0**	30	90	0.33	33.3
T	**S_0**	33	151	0.22	21.9
W	**S_1**	0	16	0	0
D	**S_1**	3	19	0.16	15.8
T	**S_1**	3	35	0.09	8.6
W	**S_2**	2	64	0.03	3.1
D	**S_2**	21	29	0.70	72.4
T	**S_2**	23	93	0.25	24.7
W	**S_3**	5	32	0.16	15.6
D	**S_3**	6	60	0.10	10.0
T	**S_3**	11	92	0.12	12.0
W	**S_4**	5	23	0.20	21.7
D	**S_4**	0	0	0	0
T	**S_4**	5	23	0.20	21.7
W	**S_5**	0	0	0	0
D	**S_5**	0	0	0	0
T	**S_5**	0	0	0	0
W	**S_6**	0	6	0	0
D	**S_6**	0	2	0	0
T	**S_6**	0	8	0	0
W	**S_7**	0	0	0	0
D	**S_7**	0	5	0	0
T	**S_7**	0	5	0	0
W	**S_8**	0	17	0	0
D	**S_8**	6	55	0.10	10.9
T	**S_8**	6	72	0.08	8.3
W	**S_9**	0	47	0	0
D	**S_9**	0	48	0	0
T	**S_9**	0	95	0	0
W	**S_{10}**	2	28	0.07	7.14
D	**S_{10}**	0	27	0	0
T	**S_{10}**	2	55	0.04	3.6
W	**LT**	17	294	0.06	5.8
D	**LT**	66	335	0.20	19.7
T	**LT**	83	629	0.13	13.2

3.4.4.8. Percent Contribution of Dominant Family (% DF)

The Percent Contribution of Dominant Family or percent dominance (%DF) equals the abundance of the numerically dominant family relative to the total number of organisms in the sample. This index indicates the present state of the community balance at the family level. For example, a community dominated by relatively few families would have a high %DF value, thus indicating the community is under the influence of environmental stress (Plafkin *et al*., 1989) as cited by Mandaville (2002).

The highest dominant taxons were Caenogrionidae with 68.9% (42) and Gyrinidae with 68.8% (11) at S_0 and S_1 respectively (Table 3.13). In general Lake Tana was with dominated by the taxon Caenogrionidae (26.9%, 79) during the wet season and Belostomatidae during the dry season 10.4% (35) while for the whole year Coenogrionidae with 17% (107) as presented in Table 3.13.

Table 3.13: Percent Contribution of Dominant Family (% DF) of Lake Tana

Families		Baetidae	Coenogrionidae	Gyrinidae	Chironomidae	Dytiscidae	Corbiculidae	Elimidae	Muscidae	Belostomatidae	Notenoctidae	Corixidae	T. Organisms	% DF
W	**S_0**	-	42	-	-	-	-	-	-	-	-	-	61	68.9
D	**S_0**	-	22	-	-	-	-	-	-	-	-	-	90	24.4
T	**S_0**	-	64	-	-	-	-	-	-	-	-	-	151	42.4
W	**S_1**	-	-	11	-	-	-	-	-	-	-	-	16	68.8
D	**S_1**	-	-	-	3	-	-	-	-	-	-	-	19	15.8
T	**S_1**	-	-	11	-	-	-	-	-	-	-	-	35	31.4
W	**S_2**	-	20	-	-	-	-	-	-	-	-	-	64	31.3
D	**S_2**	17	-	-	-	-	-	-	-	-	-	-	29	58.6
T	**S_2**	-	20	-	-	-	-	-	-	-	-	-	93	21.5
W	**S_3**	-	-	-	-	10	-	-	-	-	-	-	32	31.3
D	**S_3**	-	-	-	-	-	30	-	-	-	-	-	60	50.0
T	**S_3**	-	-	-	-	-	30	-	-	-	-	-	92	32.6
W	**S_4**	-	-	7	-	-	-	-	-	-	-	-	23	30.4
D	**S_4**	-	-	-	-	-	-	-	-	-	-	-	0	0
T	**S_4**	-	-	7	-	-	-	-	-	-	-	-	23	30.4
W	**S_5**	-	-	-	-	-	-	-	-	-	-	-	0	0
D	**S_5**	-	-	-	-	-	-	-	-	-	-	-	0	0
T	**S_5**	-	-	-	-	-	-	-	-	-	-	-	0	0
W	**S_6**	-	-	-	-	-	-	4	-	-	-	-	6	66.7
D	**S_6**	-	-	-	-	-	-	-	2	-	-	-	2	100.0
T	**S_6**	-	-	-	-	-	-	4	-	-	-	-	8	50.0
W	**S_7**	-	-	-	-	-	-	-	-	-	-	-	0	0.0
D	**S_7**	-	-	3	-	-	-	-	-	-	-	-	5	60.0
T	**S_7**	-	-	3	-	-	-	-	-	-	-	-	5	60.0
W	**S_8**	-	-	-	-	6	-	-	-	-	-	-	17	35.3
D	**S_8**	-	-	-	-	-	-	-	-	27	-	-	55	49.0
T	**S_8**	-	-	-	-	-	-	-	-	27	-	-	72	37.5
W	**S_9**	-	-	-	-	-	-	-	-	-	16	-	47	34.0
D	**S_9**	-	-	-	-	23	-	-	-	-	-	-	48	47.9
T	**S_9**	-	-	-	-	35	-	-	-	-	-	-	95	36.8
W	**S_{10}**	-	-	-	-	9	-	-	-	-	-	-	28	32.0
D	**S_{10}**	-	-	-	-	-	-	-	-	-	-	10	27	37.0
T	**S_{10}**	-	-	-	-	-	-	-	-	-	-	18	55	32.7

W	**LT**	-	79	-	-	-	-	-	-	-	-	-	294	26.9
D	**LT**	-	-	-	-	-	-	-	-	35	-	-	335	10.4
T	**LT**	-	107	-	-	-	-	-	-	-	-	-	629	17.0

3.4.4.9. Community Loss Index (CLI)

The Community Loss Index (CLI) measures the loss of benthic taxa in a study sites with respect to the reference site. Values range from 0 to "infinity" and increase as the degree of dissimilarity between the sites increases (Plafkin *et al*., 1989) as cited by Mandaville (2002). CLI was calculated as:

$$Community\ Loss = \frac{\mathrm{d} - \mathrm{a}}{e}$$

Where "a" is the number of taxa common to both sites (Refernec and Impacted), "d" is the total number of taxa present in the reference site, and "e" is the total number of taxa present in the study sites. In this study, CLI was determined by comparing the total number of taxa present in each study sites ("e") to the number of taxa present in the reference site ("d"). This was done to account for the variation that occurs under natural conditions (less impacted site) (Mandaville, 2002).

CLI= (10-3)/38=0.18. The data was taken from Table 3.2 and Table 3.4(A-C). Hence, the degree of similarity between the reference site and the impacted sites was high. This showed that the referece site was also influenced by human activities and the range of dissimilarity was very low.

3.4.4.10. Summary of Macroinvertebrate Community Biological Indices Attributes

Table 3.14: Summary of macroinvertebrate community Biological Indices attributes at each sampling station.

Attributes		No. of Families	FBI	H	D	EPT Index	% EPT	% DF
Sites	S_0	27	6.74	2.33	0.20	0.22	21.9	42.4
	S_1	15	5.50	2.35	0.12	0.09	8.60	31.4
	S_2	13	7.00	2.16	0.13	0.25	24.7	21.5
	S_3	19	6.40	2.32	0.15	0.12	12.0	32.6
	S_4	7	4.80	1.75	0.84	0.20	21.7	30.4
	S_5	0	0.00	0.00	0.00	0.00	0.0	0.0
	S_6	3	5.00	1.04	0.71	0.00	0.0	50.0
	S_7	2	4.40	0.67	0.60	0.00	0.0	60.0
	S_8	16	6.50	2.08	0.82	0.08	8.3	37.5
	S_9	11	5.60	1.93	0.81	0.00	0.0	36.8
	S_{10}	14	6.30	2.17	0.85	0.04	3.6	32.7
Lake Tana		38	6.4	2.98	0.07	0.13	13.2	17.0

3.4.5. Metric Index Development for Lake Tana

Macroinvertebrate metrics were selected from the biological data in Table 3.3 and Appendix 2 from the 11 sampling sites to evaluate the status of the water quality of Lake Tana.

Thirty one candidate metrics based on richness, composition and pollution tolerance measures were selected and calculated to discriminate between the reference and impacted sites as indicated in Table 3.15. The candidate metrics were chosen by reviewing the literature appropriate for freshwater (Barbour *et al*., 1999; Hayslip, 2007).

The EPT is one of metric that characterizes the community, representing the proportion between sensitive and tolerant taxa and providing consistent information about fauna and aquatic ecosyetem conditions. This EPT metric efficiently has shown this in the observation of Mariadoss and Ricardo (2015). According to Jacobsen *et al.* (2008) the biota organizes itself in response to environmental conditions. Accurate bioassessment of lakes depends on having a good knowledge of the natural variation in the structure of the macroinvertebrate assemblage with environmental impact or stress being indicated by deviation from the expected reference levels (Jacobsen *et al.*, 2008; Mariadoss and Ricardo, 2015). According to bioassessment, some biotic metrics can vary naturally with lake size. It is apparent from the study that the water quality of the Lake deteriorated as one moved to less impacted habitats and this was mainly because of different type of anthropogenic activities (Couceiro *et al.*, 2012; Mariadoss and Ricardo, 2015).

Table 3.15: Observed values of metrics thought to be applicable to Lake Tana with expected response to Pollution (Nutrient load)

Category	Metric	Description(Definition)	Predicted Response to Increasing Perturbation	Reference Site (S_0)	Impacted Sites (S_1 to S_{10})
Richness measures	No. Taxa	Indicates overall richness of the community	Decrease	27	31
	No. Ephemeroptera Taxa	Number of taxa within this group (mayflies)	Decrease	21	39
	No. Plecoptera Taxa	Number of taxa within this group (stoneflies)	Decrease	10	11
	No. Trichoptera Taxa	Number of taxa within this group (caddisflies)	Decrease	2	0
	No. EPT Taxa	Number of taxa in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)	Decrease	33	50
	No. Diptera taxa	Number of "true" fly taxa, which includes midges	Decrease	5	40
	No. Odonata taxa	Number of "Damselflies &Dragonflies" taxa	Decrease	80	69
	No. Coenogrionidae	Number of taxa of Coenogrionidae	Decrease	64	43
	No. Chironomidae taxa	Number of taxa of chironomid (midge) larvae	Decrease	0	23
	No. Coleoptera taxa	Number of beetle taxa (adult or larva)	Decrease	12	141
	No. Mollusca	Number of taxa of Mollusca	Increase	0	49
	No. Corbiculidae taxa	Number of taxa of Corbiculidae	Decrease	0	31
Composition measures	Total Abundance	Total number of organisms of all taxa	Increase	151	478
	% Ephemeroptera	Percent mayflies	Decrease	17.9	8.2
	%Plecoptera	Percent of stonefly nymphs	Decrease	13.9	2.3
	% Trichoptera	Percent of caddisfly larvae	Decrease	6.6	0
	% EPT	Percent of total abundance composed of mayflies, stoneflies, and caddisflies	Decrease	21.9	10.5
	% Diptera	Percent of all "true" fly larvae	Decrease	3.3	8.4
	% Odonata	Percent of "Damselflies &Dragonflies" taxa	Decrease	53	14.4
	% Coenogrionidae	Percent of Coenogrionidae	Decrease	42.4	9
	% Chironomidae	Percent of midge larvae	Decrease	0	4.8
	% Coleoptera	Percent of beetle larvae and aquatic adults	Decrease	8	29.5
	% Mollusca	Percent of Mollusca	Increase	0	10.3
	% Corbiculidae	Percent of aquatic Corbiculidae	Decrease	0	6.5
Tolerance/ intolerance measures	% Dominant Taxon	Percent of the most abundant taxon	Increase	64	42
	No. intolerant organisms	Number of present taxa individuals with tolerance score <4	Decrease	15	49
	No. facultative	Number of present taxa individuals with tolerance	Decrease	47	163

	organisms	score ≥4 to ≤6			
	No. tolerant organisms	Number of present taxa individuals with tolerance score >6	Increase	87	182
	% intolerant organisms	Percentage of present taxa individuals with tolerance score <4	Decrease	9.9	10.3
	% of facultative organisms	Percentage of present taxa individuals with tolerance score ≥4 to ≤6	Decrease	31.1	34.1
	% tolerant organisms	Percentage of present taxa individuals with tolerance score >6	Increase	57.6	38.1

The choice of metrics to compose biotic index based on macroinvertebrates data can lead to erroneous conclusions about the biological condition of the Lake ecosystem when the temporal variability of the metrics used to compose the index is not considered (Couceiro *et al.*, 2012). Some recommendations suggested including an effective and regular sampling during the year is important to understand the other ecological factors like rain fall and flooding. From the economic perspective there is a desire to minimize the frequency of sampling while biological studies need sampling for more than a year in order to understand the total condition of the water quality. Mariadoss and Ricardo (2015) has showed that combined season data enable better prediction of microinvertebrate communities than single season data in order to understand the role of macroinvertebrates in water quality assessment of lake water. Since seasonal changes are a natural phenomenon and it is not possible to determine the time period most suitable for sampling. For metric that show seasonal variation the best solution would be to carry out frequent sampling at least two times a year, so that we could generate more data on the quality of lake water by using various macroinvertebrates taxa (Mandaville, 2002; Mariadoss and Ricardo, 2015).

In three different metric types: richness, composition and tolerance measures showed significant response to the environmental stress and are known to discriminate for water quality assessment under various stresses (Hayslip, 2007). No. Ephemeroptera Taxa do not show a clear boundary between the reference and impacted sites. The reason might be the tolerant Ephemeroptera Taxa are available in the Lake and the lake reference condition is not free from human influence while No. Plecoptera Taxa is in the same proportion in the impacted and the reference sites but No. Trichoptera Taxa was 0 at the impacted sites. Generally, No. EPT Taxa do not show a decreased phenomenon in the impacted sites which were sensitive (intolerant) Taxa. The reason might be the EPT groups found in the reference and the impacted sites are facultative types. But No. Diptera taxa, No. Chironomidae taxa, No. Coleoptera taxa, No. Mollusca and No. Corbiculidae taxa increased in the impacted sites which were tolerant taxa to pollution (Table 3.15).

Taxa Richness increases with increasing water quality, habitat diversity and habitat suitability. The percent contribution of the dominant taxon to the total number of organisms uses abundance of the numerically dominant taxon relative to the rest of the population as an indication of community balance at the family level. A community dominated by relatively few families would indicate environmental stress (Hilsenhoff, 1988; Hayslip, 2007).

The metric result in Table 3.15 showed the impairment levels of the study sites, as the impacted sites were highly disturbed and the reference site was relatively less disturbed. This was justified by Sisay (2017). High richness is the higher the number of different kinds of invertebrates, the better the ecosystem condition and the better water quality. Number of taxa decreases with decreasing water quality. This showed diversity increased where human influence is less but abundance of individuals was higher in polluted sites (Table 3.3). This was also observed in Maryland water bodies (Dermott and Pachkevitch, 2012).

Increment in the total abundance shows disturbance because it may favor some tolerant, opportunistic and less competent taxa with reduction in sensitive taxa that means the community is dominated by few taxa. When aquatic environment is excessively acidic or alkaline, the change can adversely affect the biota. The biota is unable to tolerate the altered conditions decline, tolerant organisms increase in number due to lack of competition for food and habitat. This is a common phenomenon in unhealthy biological community dominated by a few tolerant taxa (Sanz *et al*., 20014). Mariadoss and Ricardo (2015) noted that the absence of intolerant taxa and moderate tolerant taxa are associated with toxicity or disturbance. Lake Tana is polluted with agricultural and industrial activities and it is justified by the characteristics of macroinvertebrates.

Most commonly known sensitive indicator organisms are Ephemeroptera (Mayflies), Plecoptera (Stoneflies) and Trichoptera (Caddis flies) (Couceiro *et al.*, 2012). They are often indicators of good water quality because most of them are intolerant of pollution. Plecoptera are the most sensitive order of aquatic insects and many of this species are restricted to habitats with high levels of dissolved oxygen**.** Percent Ephemeroptera is expected to decrease as the water quality declines (Bouchard, 2004; Mariadoss and Ricardo, 2015)**.** In Lake Tana intolerant Ephemeropterans were completely absent in the sites. The reference site had higher richness and this result indicated that many taxa would disappear in the presence of severe pollution.

3.4.6. Index development for Lake Tana

A total of 21 metrics that have good values in the reference sites thought to be applicable to the Lake Tana were used Table 3.16 and 3.17. A correlation analysis was performed on the candidate metrics (Table 3.18) to discriminate metrics for index development. Bivariate scatterplot was examined (Appendix 6) to reject metrics that showed a strong correlation (r> 0.9) (Table 3.19).

Table 3.16: Observed values of metrics thought to be applicable to the Lake Tana

Metric	Sites										
	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Total No. taxa	27	16	12	19	7	0	3	2	16	11	13
No. Ephemeroptera	21	1	23	8	2	0	0	0	3	0	2
No. Plecopetra	10	2	0	3	3	0	0	0	3	0	0
No. Odonata	80	7	23	19	6	0	0	0	12	5	4
No. Coenogrionidae	64	4	20	12	1	0	0	0	1	4	1
No.Coleoptera	12	15	13	19	7	0	6	5	19	43	14
No. Diptera	5	6	15	8	1	0	2	0	1	7	0
No. Hemiptera	20	2	17	3	4	0	0	0	31	34	30
No. Mollusca	0	2	2	32	0	0	0	0	3	6	4
No. Corbiculidae	0	2	2	30	0	0	0	0	0	4	4
No.Planorbidae	0	0	0	0	0	0	0	0	0	0	1
% Ephemeroptera	18.3	2.9	24.7	8.7	8.7	0	0	0	4.2	0	3.6
% Plecopetra	0.9	5.7	0	3.3	13.0	0	0	0	4.2	0	0
% Odonata	7.0	20.0	24.7	20.7	26.1	0	0	0	16.7	5.3	7.3
% Coenogrionidae	55.7	11.4	21.5	13.0	4.4	0	0	0	1.4	4.2	1.8
% Coleoptera	10.4	42.9	14.0	20.7	30.4	0	75.0	100.0	26.4	45.3	25.5
% Diptera	4.4	17.1	16.1	8.7	4.4	0	25.0	0	1.4	7.4	0
% Hemiptera	1.7	5.7	18.3	3.3	17.4	0	0	0	43.1	35.8	54.6
% Mollusca	0	5.7	2.2	34.8	0	0	0	0	4.2	6.3	7.3
% Corbiculidae	0	5.7	2.2	32.6	0	0	0	0	0	4.2	7.3
% Dominant taxon	55.7	11.4	21.5	13.0	4.4	0	0	0	1.4	4.2	1.8
Total Abundance	115	35	93	92	23	0	8	5	72	95	55

Table 3.17: Observed values of metrics thought to be applicable to sampling sites of Lake Tana in wet and dry seasons

Metric	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
	S_0	S_0	S_1	S_1	S_2	S_2	S_3	S_3	S_4	S_4	S_5	S_5	S_6	S_6	S_7	S_7	S_8	S_8	S_9	S_9	S_{10}	S_{10}
Total No. taxa	13	24	3	12	6	8	7	16	7	0	0	0	2	1	0	2	5	12	6	10	6	10
No. Ephemeroptera	2	19	0	1	2	21	5	3	2	0	0	0	0	0	0	0	0	3	0	0	2	0
No. Plecopetra	0	10	0	2	0	0	0	3	3	0	0	0	0	0	0	0	0	3	0	0	0	0
No. Odonata	46	34	4	3	20	3	9	10	6	0	0	0	0	0	0	0	5	7	3	2	0	4
No. Coenogrionidae	42	22	4	0	20	0	9	3	1	0	0	0	0	0	0	0	0	1	3	1	0	1
No.Coleoptera	7	5	11	4	13	0	16	3	7	0	0	0	6	0	0	5	6	13	12	31	12	2
No. Diptera	0	5	1	5	12	3	0	8	1	0	0	0	0	2	0	0	0	1	0	7	0	0
No. Hemiptera	5	15	0	2	17	0	2	1	4	0	0	0	0	0	0	0	3	28	30	4	14	16
No. Mollusca	0	0	0	2	0	2	0	32	0	0	0	0	0	0	0	0	3	0	2	4	0	4
No. Corbiculidae	0	0	0	2	0	2	0	30	0	0	0	0	0	0	0	0	0	0	0	4	0	4
No.Planorbidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
% Ephemeroptera	3.3	21.1	0	5.3	3.1	72.4	15.6	5.0	8.7	0	0	0	0	0	0	0	0	5.5	0	0	7.1	0
% Plecopetra	0	11.1	0	10.5	0	0	0	5.0	13.0	0	0	0	0	0	0	0	0	5.5	0	0	0	0
% Odonata	75.4	37.8	25.0	15.8	31.3	10.3	28.1	16.7	26.1	0	0	0	0	0	0	0	29.4	12.7	6.4	4.2	0	14.8
% Coenogrionidae	68.9	24.4	25.0	0	31.3	0	28.1	5.0	4.3	0	0	0	0	0	0	0	0	1.8	6.4	2.1	0	3.7
% Coleoptera	11.5	5.6	68.8	21.1	20.3	0	50.0	5.0	30.4	0	0	0	100	0	0	100	35.3	23.6	25.5	64.6	42.9	7.4
% Diptera	0	5.6	6.3	26.3	18.8	10.3	0	13.3	4.3	0	0	0	0	100	0	0	0	1.8	0	14.6	0	0
% Hemiptera	8.2	16.7	0	10.5	26.6	0	6.3	1.7	17.4	0	0	0	0	0	0	0	17.6	50.9	63.8	8.3	50.0	59.3
% Mollusca	0	0	0	10.5	0	6.9	0	53.3	0	0	0	0	0	0	0	0	17.6	0	4.3	8.3	0	14.8
% Corbiculidae	0	0	0	10.5	0	6.9	0	50.0	0	0	0	0	0	0	0	0	0	0	0	8.3	0	14.8
% Dominant taxon	68.9	24.4	25.0	0	31.3	0	28.1	5.0	4.3	0	0	0	0	0	0	0	0	1.8	6.4	2.1	0	3.7

Table 3.18: Pearson correlation matrix of all metrics data

	No. taxa	No.Ephemer	No.Plecop	No.Odon	No.Coenog	No.Coleopt	No.Dipt	No.Hemipt	No.Mollu	No.Corbicu	No.Planorb	% Ephemer	% Plecop	% Odon	% Coenog	% Coleopt	% Dipt	% Hemipt	% Mollu	% Corbicul	% Dom taxon
No. taxa	1																				
No.Ephemer	**.556** **	1																			
No.Plecop	**.768** **	**.570** **	1																		
No.Odon	**.659** **	.369	.467*	1																	
No.Coenog	.487 *	.247	.266	**.967** **	1																
No.Coleopt	.230	-.125	-.053	.091	.128	1															
No.Dipt	.451 *	.232	.294	.275	.233	.311	1														
No.Hemipt	.388	.070	.263	.222	.177	.337	.106	1													
No.Mollu	.374	.008	.162	.018	-.087	-.060	.423	-.097	1												
No.Corbicu	.383	.025	.175	.024	-.076	-.062	.445 *	-.124	**.994** **	1											
No.Planorb	.117	-.106	-.093	-.059	-.083	-.150	-.138	.230	.058	.073	1										
% Ephemer	.282	**.883** **	.183	.103	.035	-.144	.128	-.072	-.005	.012	-.095	1									
% Plecop	**.603** **	.309	**.792** **	.248	.064	-.060	.256	.134	.135	.151	-.110	.114	1								
% Odon	**.563** **	.240	.291	**.901** **	**.874** **	.140	.171	.121	.008	-.003	-.005	.092	.245	1							
% Coenog	.369	.139	.105	**.879** **	**.947** **	.212	.146	.104	-.104	-.093	-.072	.001	-.034	**.888** **	1						
% Coleopt	-.168	-.262	-.204	-.208	-.150	.501 *	-.119	-.107	-.160	-.163	-.145	-.218	-.153	-.113	-.034	1					
% Dipt	-.072	-.041	-.024	-.098	-.084	-.121	.283	-.164	.035	.050	-.095	-.024	.031	-.139	-.109	-.212	1				
% Hemipt	.275	-.077	.074	.035	-.002	.280	-.064	**.909** **	-.075	-.106	.464 *	-.121	.064	.033	-.037	-.073	-.199	1			
% Mollu	.385	.000	.122	-.020	-.141	-.085	.385	-.092	**.959** **	**.936** **	.178	.012	.133	.037	-.163	-.172	.022	-.008	1		
% Corbicul	.420	.044	.158	-.005	-.111	-.088	.449 *	-.110	**.967** **	**.978** **	.216	.055	.180	-.011	-.128	-.192	.061	-.050	**.947** **	1	
% Dom taxon	.369	.139	.105	**.879** **	**.947** **	.212	.146	.104	-.104	-.093	-.072	.001	-.034	**.888** **	**1.000** **	-.034	-.109	-.037	-.163	-.128	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 3.19: Highly correlated metrics

	No. taxa	**No.Ephemer**	**No.Plecop**	**No.Odon**	**No.Coenog**	**No.Hemipt**	**No.Mollu**	**No.Corbicu**	**% Odon**	**% Coenog**	**% Mollu**
No.Ephemer	.556 **										
No.Plecop	.768 **	.570 **									
No.Odon	.659 **										
No.Coenog				.967 **							
No.Corbicu							.994 **				
% Ephemer		.883 **									
% Plecop	.603 **		.792 **								
% Odon	.563 **			.901 **	.874 **						
% Coenog				.879 **	.947 **				.888 **		
% Hemipt						.909 **					
% Mollu							.959 **	.936 **			
% Corbicul							.967 **	.978 **			.947 **
% Dom taxon				.879 **	.947 **				.888 **	1.000 **	

The scatterplot (Appendix 6) metrics in Table 3.20 showed linear relationships.

Table 3.20: Linearly correlated metrics

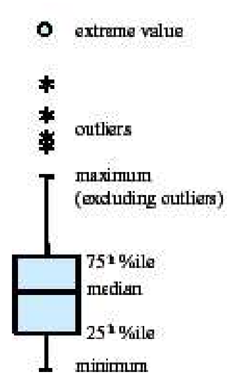
	No.Odon	No.Mollu	% Coenog
No.Coenog	✓		
No.Corbicu		✓	
% Dom taxon			✓

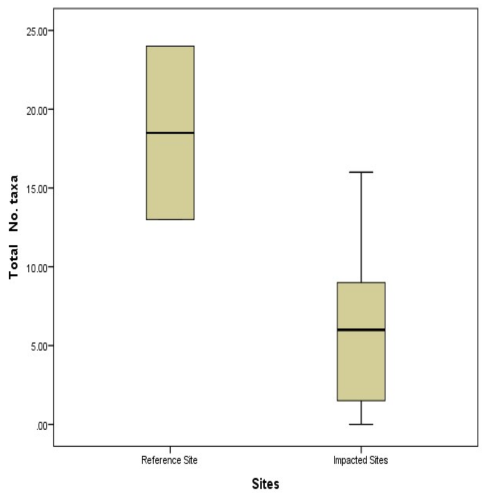
No. of Coleoptera, No. of Diptera, No. of Planorbidae, %Coleoptera and %Diptera had no strong correlation and Total No. of taxa, No. of Ephemeroptera, No. of Plecopetra, No. of Hemiptera, %Ephemeroptera, %Plecopetra, %Odonata, %Hemiptera, %Mollusca and %Corbiculidae had non-linear relationship. Based on the results of the Pearson correlation matrix and the bivariate scatterplot No. of Odonata, No. of Coenogrionidae, No. of Mollusca, No. of Corbiculidae, %Coenogrionidae, %Dominant taxon were rejected. As No. of Odonata, No. of Hemiptera, No. of Diptera, No. of Chironomidae, No. of Planrobidae, %Diptera and

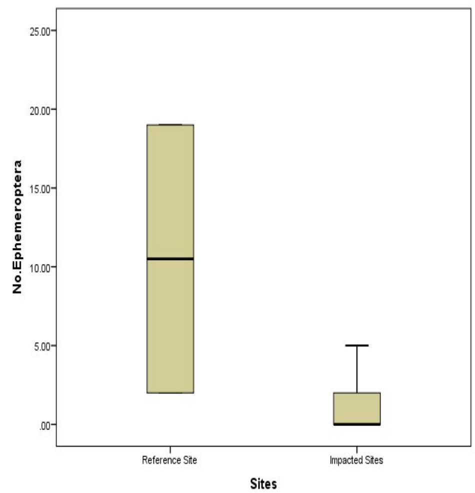
%Odonata were rejected %Hemiptera were retained; in the same way as No. of Hemiptera and %Diptera were rejected % Chironomidae was retained.

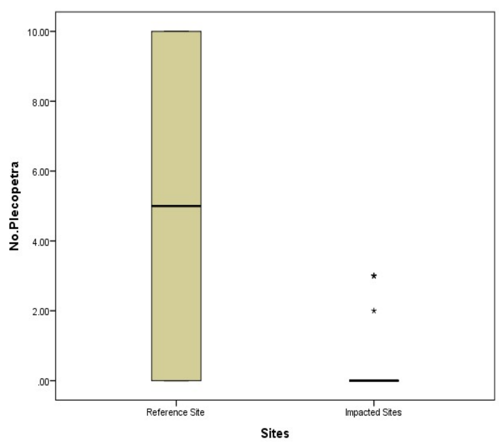
No. of Odonata and No. of Coenogrionidae, No. of Mollusca and No. of Corbiculidae and %Coenogrionidae and %Dominant taxon had strong correlation and linear relationship but No. of Odonata, No. of Mollusca and %Dominant taxon were retained because orders thought to provide better information than the individual families (Blocksom, 2003).

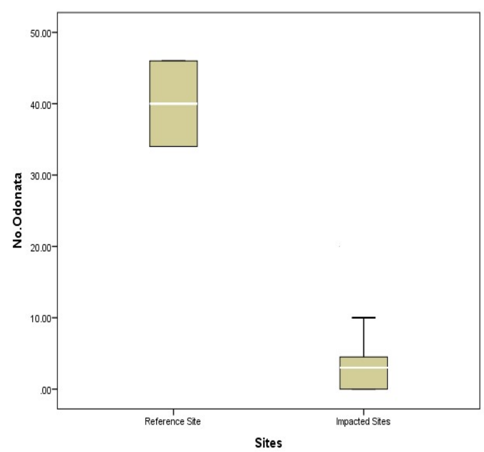
The remaining eighten metrics, which showed no strong correlation and non-linear relationship, were evaluated for their discriminatory power using box plots (Figure 3.14). The four metrics: Total No. of taxa, No. of Odonata, %Odonata, and %Dominant taxon had good discriminatory power between the reference and impcted sites; so that they were considered for the final index development. No. of Coleoptera, No. of Diptera, No. of Planorbidae, No. of Ephemeroptera, No. of Plecopetra, No. of Hemiptera, No. of Mollusca, %Ephemeroptera, %Plecopetra, %Coleoptera, %Diptera, %Hemiptera, %Mollusca and %Corbiculidae were rejected because they showed overlap in the Box and whisker plots of the candidate metrics in the reference and impacted sites.

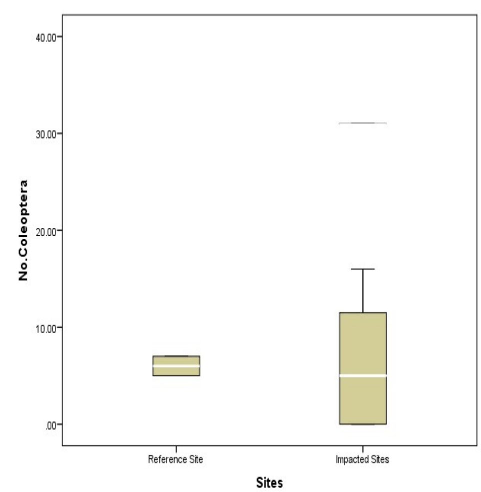


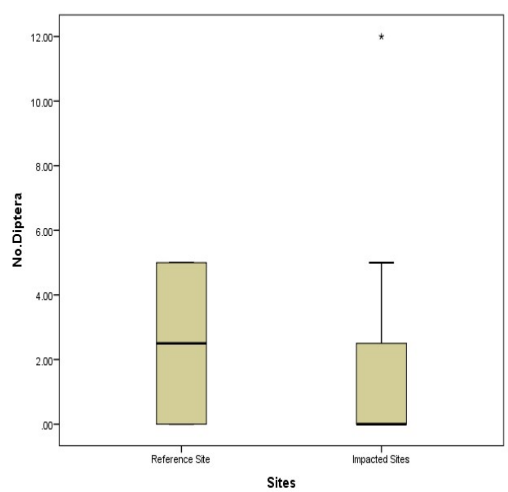

Total No. taxa
25.00
20.00
15.00
10.00
5.00
.00
Reference Site
Impacted Sites
Sites

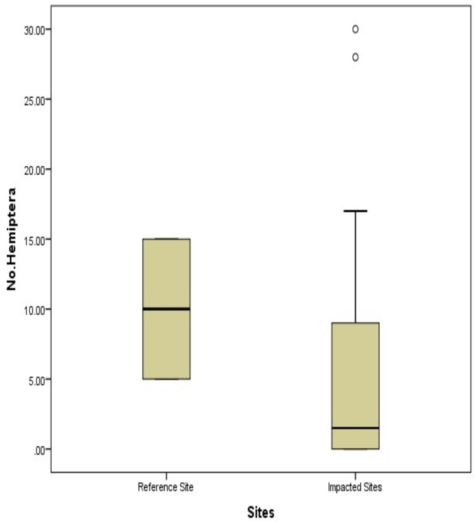

No.Ephemeroptera
25.00
20.00
15.00
10.00
5.00
.00
Reference Site
Impacted Sites
Sites

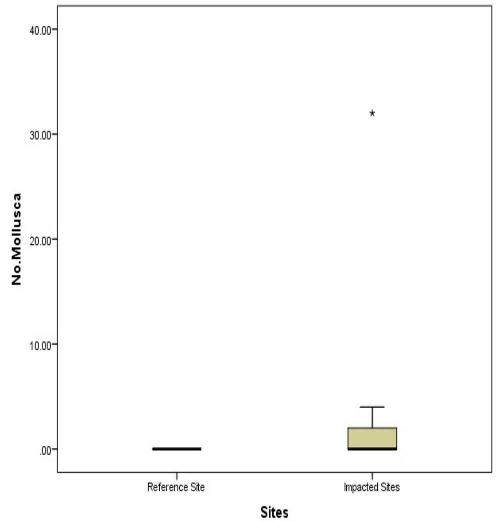

No.Plecopetra
10.00
8.00
6.00
4.00
2.00
.00
Reference Site
Impacted Sites
Sites

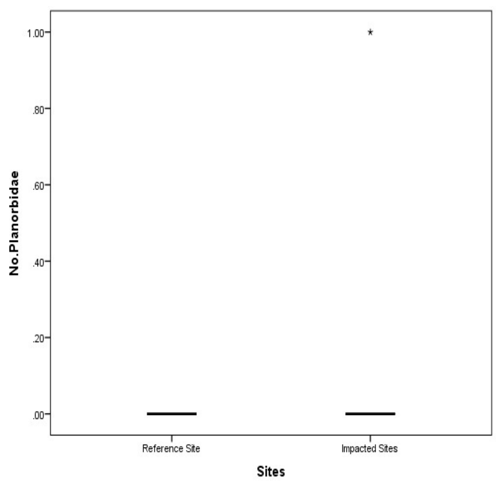

No.Odonata
50.00
40.00
30.00
20.00
10.00
.00
Reference Site
Impacted Sites
Sites

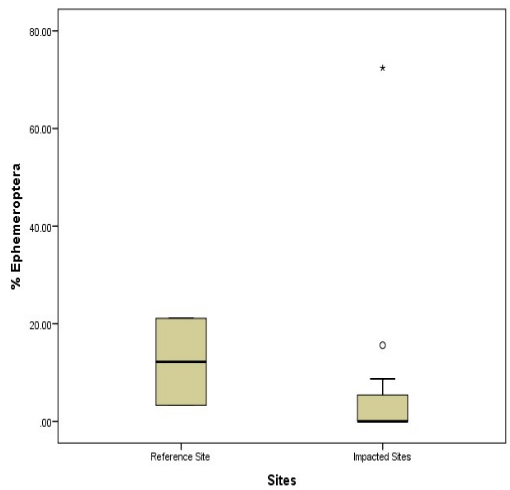

No.Coleoptera
40.00
30.00
20.00
10.00
.00
Reference Site
Impacted Sites
Sites

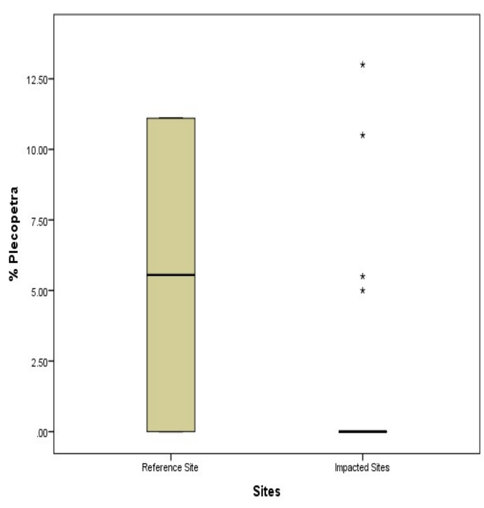

No.Diptera
12.00
10.00
8.00
6.00
4.00
2.00
.00
Reference Site
Impacted Sites
Sites

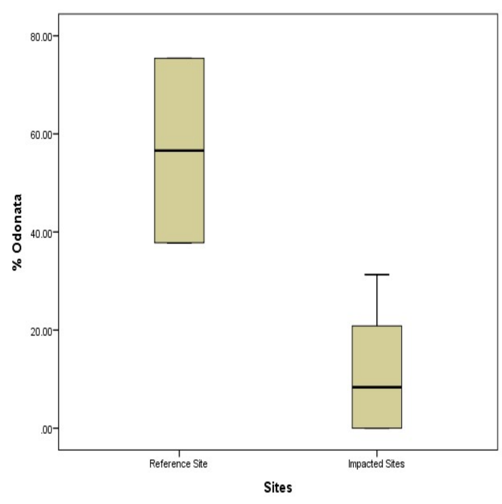

No.Hemiptera
30.00
25.00
20.00
15.00
10.00
5.00
.00
Reference Site
Impacted Sites
Sites


No.Mollusca
40.00
30.00
20.00
10.00
.00
Reference Site
Impacted Sites
Sites


No.Planorbidae
1.00
.80
.60
.40
.20
.00
Reference Site
Impacted Sites
Sites


% Ephemeroptera
80.00
60.00
40.00
20.00
.00
Reference Site
Impacted Sites
Sites


% Plecopetra
12.50
10.00
7.50
5.00
2.50
.00
Reference Site
Impacted Sites
Sites


% Odonata
80.00
60.00
40.00
20.00
.00
Reference Site
Impacted Sites
Sites

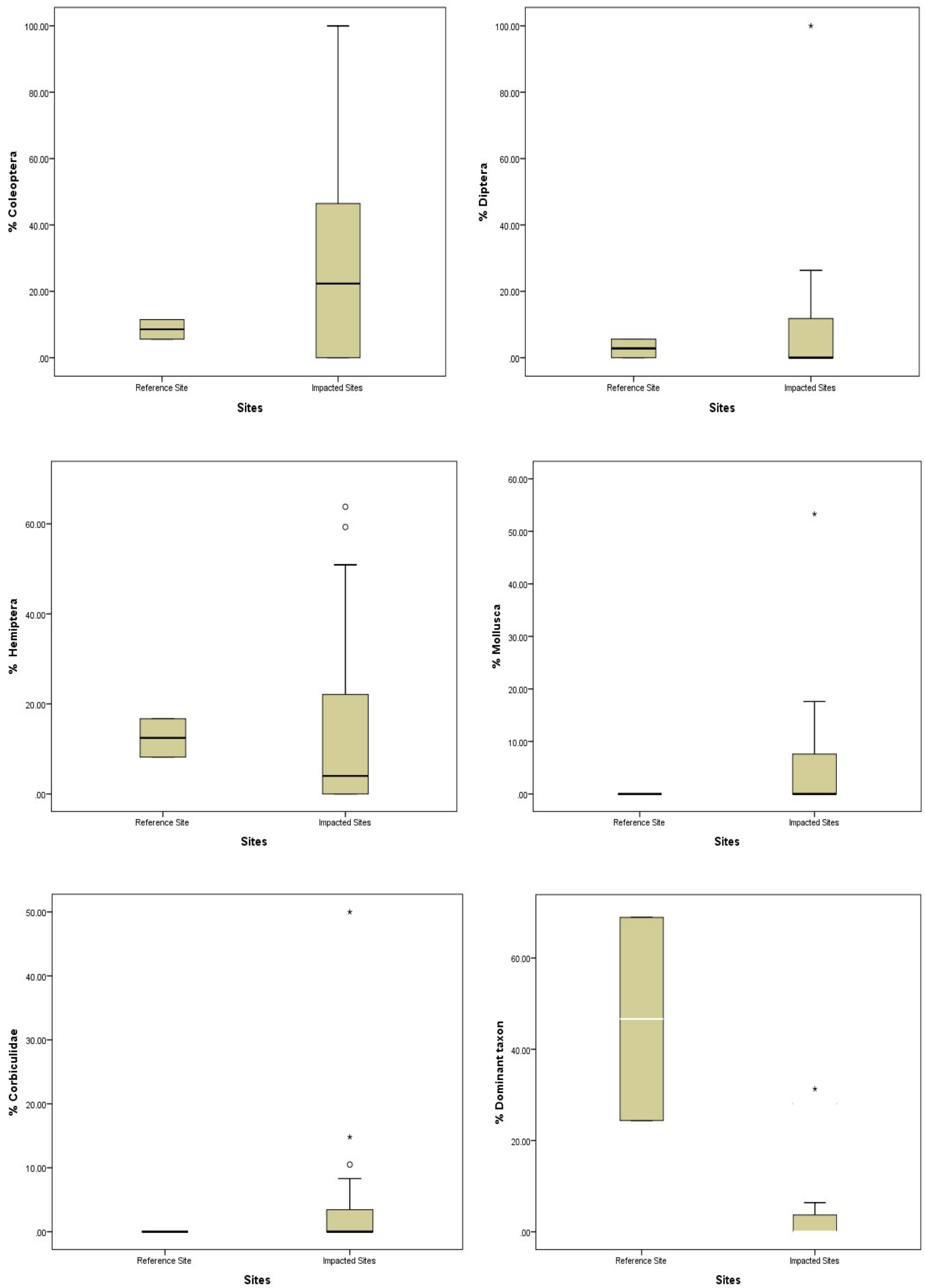


Figure 3.14: Box and whisker plots of the candidate metrics in the reference and impacted sites.

<u>NB</u>. The figures centre horizontal line represents the median value, the outer horizontal lines are the interquartile values, and the range bars show maximum and minimum of non-outliers. Sample sites are 1 and 10 for the reference and impacted sites, respectively.

The observed values of the four metrics for each measurement sites are given in Table 3.21 and 3.22. The observed values for all the metrics initially thought to be applicable to the Lake Tana were already given in Table 3.16 and 3.17. From these values, the percentiles (upper and lower threshold values) of each metric in the reference and impacted sites were calculated (Table 3.23).

Table 3.21: Observed metric values of the four selected metrics for each site of Lake Tana

Metric	Total No. Taxa	No. Odonata	% Odonata	% Dominant taxon
S_0	27	80	7.0	55.7
S_1	16	7	20,0	11.4
S_2	12	23	24.7	21.5
S_3	19	19	20.7	13.0
S_4	7	6	26.1	4.4
S_5	0	0	0	0
S_6	3	0	0	0
S_7	2	0	0	0
S_8	16	12	16.7	1.4
S_9	11	5	5.3	4.2
S_{10}	13	4	7.3	1.8

Table 3.22: Observed metric values of the four selected metrics for each site of Lake Tana in the wet and dry seasons

Metric		Total No. Taxa	No. Odonata	% Odonata	% Dominant Taxon
Wet	**S_0**	13	46	75.4	68.9
Dry	**S_0**	24	34	37.8	24.4
Wet	**S_1**	3	4	25.0	25.0
Dry	**S_1**	12	3	15.8	0.0
Wet	**S_2**	6	20	31.3	31.3
Dry	**S_2**	8	3	10.3	0.0
Wet	**S_3**	7	9	28.1	28.1
Dry	**S_3**	16	10	16.7	5.0
Wet	**S_4**	7	6	26.1	4.3
Dry	**S_4**	0	0	0.0	0.0
Wet	**S_5**	0	0	0.0	0.0
Dry	**S_5**	0	0	0.0	0.0
Wet	**S_6**	2	0	0.0	0.0
Dry	**S_6**	1	0	0.0	0.0
Wet	**S_7**	0	0	0.0	0.0
Dry	**S_7**	2	0	0.0	0.0
Wet	**S_8**	5	5	29.4	0.0
Dry	**S_8**	12	7	12.7	1.8
Wet	**S_9**	6	3	6.4	6.4
Dry	**S_9**	10	2	4.2	2.1
Wet	**S_{10}**	6	0	0.0	0.0
Dry	**S_{10}**	10	4	14.8	3.7

The four metrics were scored on a continuous measurement scale from 0 (poor) to 10 (good) based on the upper and lower threshold value of the proceduraly selected metrics in the reference and impacted sites (Table 3.24) using the formula under section 3.8. LTMI (Lake Tana Metric Index) was developed based on the four metrics. These are total No. of taxa, No. of Odonata, % odonata and % dominant taxon.

Table 3.23: Percentile of the candidate metrics in the reference and impacted sites

Metrics	Measurement site	Percentiles		
		25	50 (Median)	75
No. taxa	reference site	27	27	27
	impacted site	2	11.5	16
No. Odonata	reference site	80	80	80
	impacted site	0	5.5	19
% Odonata	reference site	7.0	7.0	7.0
	impacted site	0	12	24.7
% dominant taxon	reference site	55.7	55.7	55.7
	impacted site	0	3	13

The score for each core metric and the final index score for each site is presented in Table 3.24. The LTMI ranges from 0 at S_5 and S_7, 1 at S_6 to 100 at S_0. A boxplot of LTMI (Figure 3.15) depicted the discriminatory power of the index to distinguish between differentially impacted sites and the reference site. Percent dominant taxa metric tends to decrease with increasing water quality to maintain healthy aquatic ecosystem (Mandaville, 2002). Therefore, lower metric index score at the impacted sites confirms higher ecosystem disturbances (Amanuel, 2011).

Table 3.24: Final index score for each selected metrics in each measurement sites

Metric	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Total No. taxa	10	5.6	4	6.8	2	0	0.4	0	5.6	3.6	4.4
No. Odonata	10	0.9	2.9	2.4	0.8	0	0	0	1.5	0.6	0.5
% Odonata	10	10	10	10	10	0	0	0	10	7.6	10
% Dominant taxon	10	0	2	0	0	0	0	0	0	0	0
Total	40	16.5	18.9	19.2	12.8	0	0.4	0	17.1	11.8	14.9
LTMI Score	100	41.3	47.3	48	32	0	1	0	42.8	29.5	37.3

The final index score for the four selected metrics and in accordance with each selected site was calculated as indicated here:

If 40=100

16.5=?

40=100

18.9=?

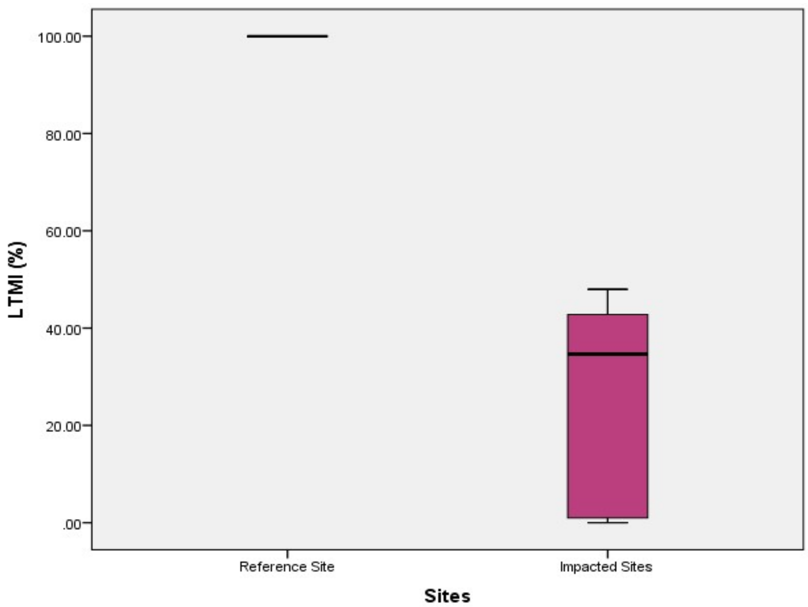


Figure 3.15: Box plot comparing the LTMI score between the reference and impacted sites

Division of the LTMI resulted in four metrics which were 50% of the maximum value observed and was taken to be the mark between good and poor sites. In this study, 100 was the maximum observed value. The range above the 50% mark was subdivided into two with a range between 50% and 75% classified as good and above 75% as very good. The range below 50% was also subdivided into two with a score between 50% and 25% classified as poor and below 25% as very poor. For the LTMI score that ranges from 0 to 100, greater than 75 was very good (S_0=100), 50-74.9 was good (no metric with this division), 25-49.9 was poor (S_1, S_2, S_3, S_4, S_8, S_9 and S_{10} with the score 41.3, 47.3, 48, 32, 42.8, 29.5 and 37.3 respectively) and less than 24.9 was very poor (S_5, S_6 and S_7 with a metric index score of 0, 1 and 0, respectively). So, LTMI developed using the four metrics had successfully classified the differentially impacted sites into different integrity classes and the reference site was very good (100% index).

The four metrics used in the development of LTMI were found to be useful for assessing biological impairment (Table 3.21). They measure different aspects of the macroinvertebrate assemblage. The metric index result in Table 3.24 and the boxplot (Figure 3.15) showed the impairment levels of the study sites, as seven of the sites were in a category of poor (disturbed) and the other three were very poor (highly disturbed). This is justified as noted by Teodora *et al.*, (2013) that high richness, the higher the number of different kinds of animals and the higher the index, the better the aquatic ecosystem condition and the better water quality. That is, number of taxa decreases with decreasing water quality. In Lake Tana, the number of taxa is relatively high in the reference site, S_0. This showed diversity increased where human influence is less but abundance of individuals was higher in polluted sites (Appendix 2). This was also observed in the study of Sanz *et al*. (20014).

Abundance show disturbance of the environment that favour some tolerant, opportunistic and less competent taxa with reduction in sensitive taxa. Hence, the community is dominated by few taxa. When ecosystems are disturbed, the change can adversely affect the biota. As those macroinvertebrates unable to tolerate the altered conditions decline, tolerant organisms increase in numbers due to lack of competition for food and habitat. This is the result of unhealthy biological community dominated by a few tolerant taxa (Patrick *et al.*, 2014). Roy *et al.* (2003) also noted this; absence of intolerant taxa and moderate tolerance taxa is associated with disturbance of the ecosytem.

Several species are very sensitive to degraded environmental conditions in aquatic ecosystems (Teodora *et al.*, 2013). Therefore, runoffs from urban centers, agricultural activities and industries cause habitat degradation that could be possible explanations for the low scores (low biological integrity) in the study sites. The response of the selected metrics and the LTMI scores clearly showed that the structural changes of macroinvertebrates in the Lake Tana are results of upstream and the surrounding area human activities.

Ephemeroptera (Mayflies), Plecoptera (Stoneflies) and Trichoptera (Caddis flies) are the most commonly used sensitive indicator organisms (Patrick *et al.*, 2014). They are often indicators of good water quality because most of them are relatively intolerant of pollution. Percent Ephemeroptera is expected to decrease with the water quality decline (Bouchard, 2004)**.** The reference site of Lake Tana had better richness as compared with other sites; this result indicated that many taxa would disappear in the presence of pollution due to anthropogenic activities in the upstreams and the surrounding area. The sites of Lake Tana showed disturbance that might be a result of anthropogenic factors, such as: domestic waste pollution, agricultural runoff, land cover-land use change, etc (Teodora *et al.,* 2013).

3.4.7. Correlation of Physicochemical Variables and Macroinvertebrates

It was found that physicochemical variables and macroinvertebrate taxa were highly positively correlated with each other ($P < 0.01$). Positive correlation values were ($P< 0.05$), which indicates a moderate or weak correlation (Appendix 7). Physicochemical variables and macroinvertebrate taxa correlations positively significant at 0.01 level were: TDS and Muscidae (0.673199), As and Chironomidae (0.811533), Pb and Gerridae (0.810733), Pb and Corixidae (0.590795), Pb and Notenoctidae (0.779953). And correlations negatively significant at 0.01 level were Temperature and Naucoridae (-0.574035) where as weakly positively correlated (correlation significant at the 0.05 level) were pH and Simuliidae (0.533214), pH and Corbiculidae (0.504922), NO_2^- and Muscidae (0.443946), NH_3 and Belostomatidae (0.462965), PO_4^{3-} and Elimidae (0.426250), Cr and Velidae (0.445348) and *E.coli* and Naucoridae (0.442354) but weakly negatively correlated parameters (Correlation significant at the 0.05 level) were Temperature and Capniidae (-0.449714), Temperature and Calopterygidae (-0.439529), Temperature and Gomphidae (-0.449714), Temperature and Hydrometridae (-0.449714), Temperature and Pleidae (-0.449714), Temperature and Velidae (-0.434465), EC and Hydropsychidae (-0.441485), COD and Hydropsychidae (-0.439083) and pH and Coenogrionidae (-0.444749).

The result of the correlation analysis of the benthic fauna with physicochemical analysis in Lake Tana in presented in Appendix 7. The result indicates that the benthic fauna did correlate significantly with pH, surface water temperature, nitrate, Total dissolved solids, ammonia, posphate, arsenic, lead and chromium. However Temperature negatively correlated significantly with many macroinvertebrate Taxa: Temperature and Capniidae (-0.449714), Temperature and Calopterygidae (-0.439529), Temperature and Gomphidae (-0.449714), Temperature and Hydrometridae (-0.449714), Temperature and Pleidae (-0.449714), Temperature and Velidae (-0.434465), EC and Hydropsychidae (-0.441485), COD and Hydropsychidae (-0.439083) and pH and Coenogrionidae (-0.444749). The data in Appendix 7 depicts the colleration between physicochemical variables and benthic fauna composition in Lake Tana for one yeare study time.

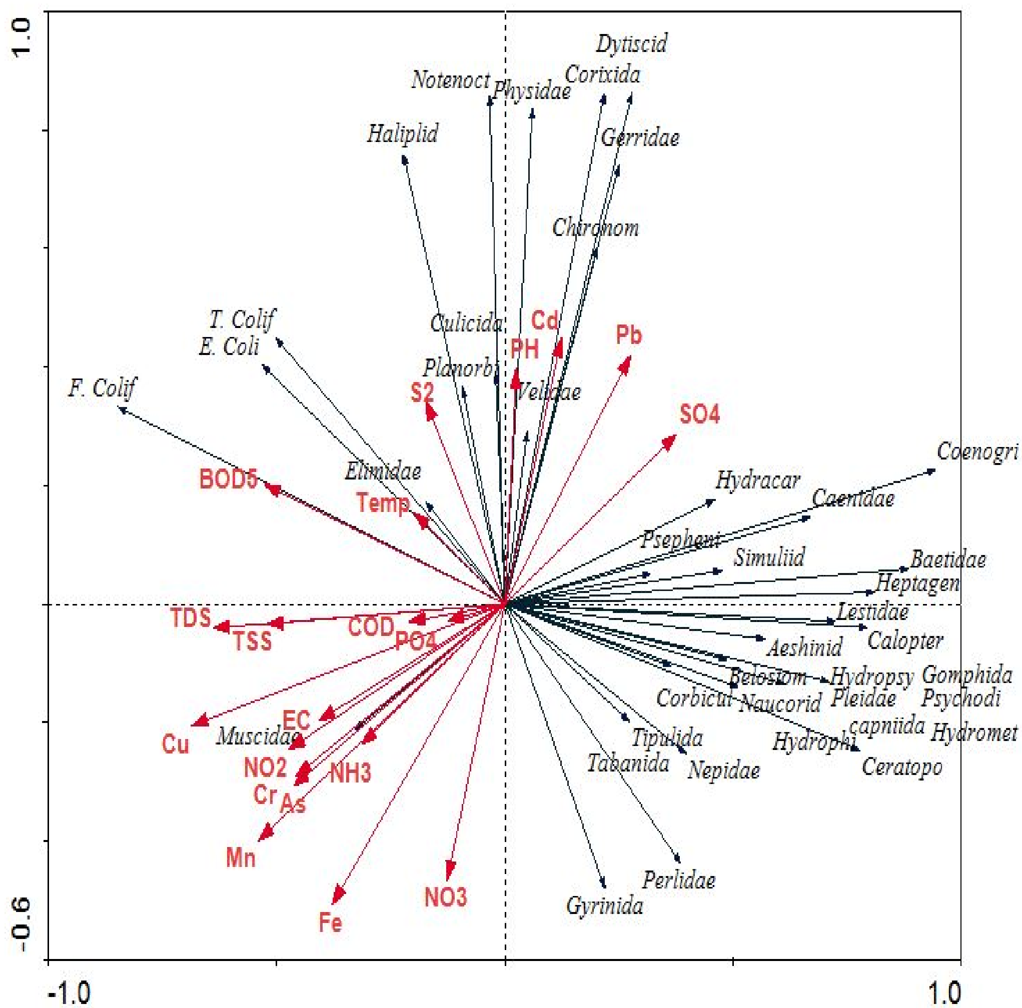


Figure 3.16: Canonical redundancy analysis (RDA) ordination diagram

Canonical redundency analysis (RDA) ordination diagram (because Eigenvalues were horizontal Axis = 0.330 and vertical Axis = 0.224, <3) with 41 macroinvertebrate and bacterial indicators and 20 quantitative environmental variables. The environmental factors are: SO_4^{2-}, Pb, Cd, pH, S^{2-}, water temperaature, BOD_5, TDS, TSS, COD, PO_4^{3}, conductivity (EC), NO_2^-, Cu, NH_3, Mn, Fe and NO_3^-.

The RDA ordination of the species-environmental variable association indicated that pH, Cd, Pb and SO_4^{2-} and and Velidae, Chironomidae, Physidae, Gerridae, Corixidae, Dytiscidae, Caenidae, Coenogrionidae Simuliidae and Psephenidae were negatively correlated while Mussidae positively correlated with these environmental variables (Figure 3.16).

TDS,TSS, Cu, Conductivity (EC), NO_2^-, NH_3, AS, Mn, Fe, NO_3^-, COD and PO_4^{3-} were negatively correlated with macroinvertebrate families Velidae, Chironomidae, Physidae, Gerridae, Corixidae, Dytiscidae, Caenidae, Coenogrionidae Simuliidae and Psephenidae. These environmental variables (TDS, TSS, Cu, Conductivity, NO_2^-, NH_3, AS, Mn, Fe, NO_3^-, COD and PO_4^{3-}) that are segregated in the RDA ordination analysis of the left bottom side of the plot were positively correlated with macroinvertabrate family Mussidae. Relatively high value of BOD_5 was associated with high abundance of Elimidae, Planorbidae, Culicidae, F.colifrom, *E.coli*, T.coliform, Haliplidae and Notenoctidae.These macroinvertebrate families had a positive but very weak correlation with water temperature and S_2 and these enevironmental variables (BOD_5, Water temperature and S^{2-}) had a negative association with the other macroinvertebrate families such as Tipulidae, Tabanidae, Gyrinidae, Pleidae, Nepidae, Hydrophilidae, Aeshinidae, Belostomatidae and many more others.

From the RDA ordination diagrams (Figure 3.16), macroinvertebrate family data were represented by black arrows and environmental variables by red arrows. The ordination diagram display, simultaneously, the patterns of macroinvertebrate community variations that reflect environmental variation and the main pattern of the tolerances of macroinvertebrate families with respect to the environmental variables. In Figure 3.16, macroinvertebrate family arrows correspond to their approximate abundance in the two dimensional ordination axis based on their weighted average, which indicates the macroinvertebrate family distribution along an environmental variable. Differences in weighted averages among macroinvertebrate families indicate differences in their tolerances along the corresponding environmental variable. Environmental variables and macroinvertebrate families are represented by arrows, which point in the direction of maximum change across the ordination diagram (Figure 3.16). The length of the arrows in the ordination diagram is proportional to the rate of change in this direction. Environmental variables and macroinvertebrates with long arrows display a stronger correlation with the ordination axes than those with short arrows where signified by the coordinates of the arrow head. Environmental variables that are strongly correlated with the ordination axes are more closely related to the pattern of macroinvertebrate family variation shown in the ordination diagram (Figure 3.16) as shown by Gary and Pauline (2003). The rule for quantitative interpretation is that each arrow representing an environmental variable determines a direction or axis in the diagram and macroinvertebrate family arrow is projected. That is, macroinvertebrate families with their perpendicular projection end arrows near to or beyond the tip of an arrow will be strongly positively correlated with and influenced by the environmental variable represented by that arrow. Those macroinvertebrate families whose projections lie near the origin will be less strongly affected (Canoco, 2002; Gary and Pauline, 2003). The plots in Figure 3.10 show definite trends relating environmental variables to macroinvertebrate family composition.

Figure 3.16 shows a slightly different ordination of macroinvertebrate families in relation to the environmental variables; these reflect water quality changes in family composition. Macroinvertebrate families at the right of the diagram are organic load sensitive whilst those at the bottom left (Musscidae) are metal and organic load tolerant. This result is in line with the study of Gary and Pauline (2003). Pollution indicator (sensitive and tolerant) families are negatively and positively correlated families respectively with the water quality detoraration indicator environmental variables such as BOD_5, COD and metals as identified from the ordination diagrams (Figure 3.16) which is in line with the study of Gary and Pauline (2003). In the diagram plots, metal and pollution tolerant macroinvertebrates were identified in the lower left section of the plot and with metal and pollution sensitive families in the lower right section. The families most frequently identified as tolerant were Lestidae, Coenogrionidae, Corbiculidae, Physidae, Nepidae, Gerridae, Corixidae, Belostomatidae, Psychodidae, Culicidae, Chironomidae are generally abundant in Lake Tana with elevated concentrations of pollutants but sensitive families identified were Aeshinidae, Perlidae, Cordulegastridae, Notenoctidae and Tipulidae. These results are in agreement with those found in other studies in which families from the orders Ephemeroptera, Tricoptera and Plecoptera were absent from polluted surface waters (Whiting and Clifford, 1983; Casper, 1994; Gower *et al.*, 1994, 1995) as cited by Gary and Pauline (2003).

In identifying the macroinvertebrate families that are tolerant and sensitive to pollution loading, the RDA analyses demonstrate that EPT families are particularly sensitive to elevated pollutant levels; this agrees with the results of Malmqvist and Hoffsten (1999) and Clements *et al*. (2000) as cited by Gary and Pauline (2003).The present research found that the absence of the most sensitive EPT families and the availability of Baetidae (mayflies) and their position in the families-environment ordination diagrams (Figure 3.10) supports the findings of Gower *et al*. (1994, 1995) as cited by Gary and Pauline (2003) that they have moderate pollution tolerance. However, within each family, tolerances vary between species, indicating the importance of species identification.

Water quality, substrate and size of a lake and river significantly affected species diversity. In Lakes and rivers with a low-nutrient level, species richness was higher than in more eutrophic rivers (significant correlation between number of species and total nitrogen, total phosphorus and nitrate) (Roque, 2013; Szoszkiewicz *et al*., 2014). The input of increasing load of pollutants and toxic substance into the surface waters has been reported to cause serious disturbances in the aquatic ecosystems. However, this depends on the nature and quantity of pollutants. Usually various physicochemical methods are used to detect the effect of pollution on the water quality and its effect on macroinvertebrates (Akaahan *et al*., 2014; Sarang and Sharma, 2015). Alterations in water quality are very well reflected in the structure and composition of biotic community as shown by occurrence, diversity and abundance pattern of species (Roque, 2013; Akaahan *et al*., 2014; Sarang and Sharma, 2015). Some authors have established the positive correlation between benthic life and temperature (Roque, 2013) which was evident clearly in this study (TDS, As, Pb,

NO_2^-, PO_4^{3-} and Cr were positively correlated with macroinvertebrate Taxa). pH is another important parameter affecting species diversity and distribution in the lake Tana ecosystem. This is true in the study of Akaahan *et al*. (2014). Alkaline pH is associated with more number of macroinvertebrate species to found (Sarang and Sharma, 2015). Higher pH values are an indicator of pollutant intrusion (Akaahan *et al*., 2014; Sarang and Sharma, 2015) and with samall increasing pH, the number of species has been reported to increase in this study. Many species would probably be able to withstand changes in pH because organisms must continually survive some amount of environmental change. To the reverse highest pH values may affect negatively macroinvertebrate communities. We observed a direct increase in percent composition of mayflies (Ephemeroptera) and caddisflies (Trichoptera) as pH increased (Appendix 7). This is consistent with literature (Gaskill, 2014). Mayflies are widely accepted to be one of the most sensitive orders to acidification that consisting of many important indicator species (Gaskill, 2014). Simpson, Bode, and Colquhoun (1985), Courtney and Clements (1998), and Smith et al. (1989) as cited by Sarang and Sharma (2015) all observed significant declines in Ephemeroptera abundance as pH declined.

Simpson, Bode, and Colquhoun (1985) as cited by Gaskill (2014) examined with a moderate pH (5.8-7.32) and with a lower pH (4.4-5.0). They found that the site with the moderate pH had a higher diversity of macroinvertebrates than the site with the lower pH. In moderate pH, high diversity of macroinvertebrates observed in this study. Akaahan *et al*. (2014) also found that species regimes change with pH. This is in agreement with our study. The study done by Sarang and Sharma (2015) showed that increased acidification is strongly correlated with a decline in the number of benthic macroinvertebrates that are able to survive.

Often, streams are more acidic than lakes since streams continually receive water that contain dissolved soils with little buffering capacity but Lakes are generally composed of more homogeneous water. In streams, discharge and water chemistry is completely dependent on upstream occurrences. This means that benthic macroinvertebrates living in streams have to face a wider range of disturbances that occur at a greater frequency than benthic macroinvertebrates in lakes. It is very possible that benthic macroinvertebrates in lakes are more vulnerable to withstand disturbances than those in streams since disturbances are not as common in lakes as rivers. The fact that many stream studies have found the threshold for declines in macroinvertebrate diversity to be a much lower pH value in streams but the reverse is true to lakes (Gaskill, 2014). This was true in this study finding. It was found that reductions in pH correlated with decreased benthic macroinvertebrate richness. As observed by Smith *et al*. (1998) cited by Sarang and Sharma (2015) in this study there was increased sensitivity of Ephemeroptera to even slight environmental stressors and Trichoptera species, observing declines as disturbances increased (Appendix 7). As the number of taxa decrease, it appears that the percent composition of a few types of taxa increases. This suggests that more tolerant taxa are able to replace sensitive ones, causing a shift in the macroinvertebrate assemblages in the lake. The tolerant taxa not affected by the pH changes increased in number and replaced individual taxa that were negatively affected by low pH. Even if particular taxon is able to survive at a decreased pH, individuals may be less successful to thrive energy and reproduce at the rate experienced in less stressful conditions. This creates an opportunity for taxa that are not affected by the increasing stressors to flourish. So, overall numbers of macroinvertebrates may not change even though the taxonomic diversity changes (Gaskill, 2014).

Phosphorus and nitrogen are the basic nutrients which are important to determine the productivity of lakes. Akaahan *et al*. (2014) stated that inorganic phosphate of more than 0.5 mg/l is an indicator of organic pollution. In eutrophic lake phosphorus and nitrogen levels were comparatively much higher (Roque, 2013; Sarang and Sharma, 2015). In this study, Phosphate and nitrate are positively correlated with macroinvertebrate taxa, as the amount of physicochemical variable increase the no. of macroinvertebrate taxa increased.

The presence of nitrate in a Lake system mostly depends on the characteristics of the catchments area, domestics and agricultural sources. Similar trends of nitrate were reported in surface waters studied by Akaahan *et al*. (2014). The mean nitrate value in this study may be due to the agricultural activities in the catchment of Lake Tana.
Phosphorus is present in the form of phosphate in natural waters and generally occurs in low concentration and it is a nutrient for plant growth and a fundamental element in the metabolic reaction of plants and animals (Roque, 2013). Nevertheless the result of

this study agrees with that of Sarang and Sharma (2015). In this investigation, reasons for the concentration of phosphate determined may be probably attributed to surface water runoff from the catchemnt. Phospahate in water is source of nutrient for the growth of planktons which may serve as source of food for the fish and macroinvertebrates population (Akaahan *et al*., 2014). In the mean while, it was a cause for eutrophication that was obsereved in the Megch study area.

Surface water temperature is an indispensable ecological factor that regulates the physiological behaviour and distribution of aquatic organisms (macroinvertebrates). Lower temperature is reported to reduced metabolism and growth of macroinvertebrates (Tapan *et al.*, 2014). The surface water temperature range in this study may be attributed to the atmospheric temperature that was obtained in the data collection. Although WHO does not set any limit value for surface water temperature, higher values in water above 30.00 ^{o}C may lead to the suppression of all benthic organisms (Akaahan *et al*., 2014).

The total dissolved solids (TDS) in water consist of inorganic salts and dissolved materials that could affect aquatic live forms when it is beyond the natural system (Akaahan *et al*., 2014). This result conforms as TDS has correlation to macroinvertebrates distribution.

Total Suspended Solids (TSS) is an indication of the amount of erosion that took place upstream. The concentration of TSS in this study is due to the level of surface run off to Lake Tana. Bilotta and Brazier (2008) as cited by Steve *et al.* (2015) reported that excess TSS (8.00 mg/l) increased the rate of drift of benthic fauna in surface water. Based on the finding by Bilotta and Brazier (2008) as cited by Steve *et al.*, (2015), the TSS concentration in Lake Tana during the course of this study may contribute to the drift of the benthic fauna (macroinvertebrates). The TSS concentration between 80-100 mg/l would cause injury to the gills of the fish (Fadaeiferd *et al*., 2012) as cited by Akaahan *et al*. (2014)). The TSS concentration of the water samples at some instances may cause injury to the gills of the fish of the Lake Tana (Roque, 2013; Akaahan *et al*., 2014). That might be one reason for the death of fish observed by the FGDs discussants.

Sulphate is a source nutrient that facilitates the growth of planktons that support the fish population but endangered macroinvertebrate with excess concentration (Akaahan *et al*., 2014). But in this study its concentration was not correlated with macroinvertebrates abundance.

Copper is an important element that facilitates the action of some enzymes in the body of humans but not known to affect the reproduction of macroinvertabrates. In the other way; arsenic, lead and cromimum are known with toxicity with their concentaration in the water bodies (Roque, 2013; Akaahan *et al*., 2014). Possible sources of copper, arsenic, lead and cromium in Lake Tana may be due to the municipal waste and lecahtes that are washed into Lake Tana through feeding rivers and streams and affect macroinvertebrates.

The major factor that affects the occurrence and distribution of benthic fauna in lotic and lentic systems include, physicochemistry, the nature of the substrate (bed material), water current, food availability, flood, drought, vegetation and shade (Roque, 2013). At the same time during this study surface water temperature, pH and nitrate correlate significantly with the benthic fauna group in the study period. All the same other studies reported significant correlation between surface water temperature, pH, nitrate and benthic fauna group (Akaahan *et al*., 2014).

It is important that environmental stressors be minimized in order to preserve greater diversity at low trophic levels, as stressor such as low pH value decrease diversity in ecosystems. Tanya *et al*. (2014) found that benthic macroinvertebrate assemblages immediately decreased downstream of dams were much different than assemblages upstream the dams. Gaskill (2014) concluded that disturbances due to the dam construction or other human activity changed benthic macroinvertebrate structure and function and suggested several causes of the changes including high concentrations of trace metals and physicochemical variables change the diversity. It was observed that the increase in physicochemical values from the standard or natural system decreases in Ephemeroptera and increases in Diptera (Chironomid) (Tanya *et al*., 2014). This was true in this study. The Chara Chara dam construction (at the outlet of Blue Nile River) and the whole sampling sites physicochemical variables change might be the reasons for the decrease in Ephemeroptera, Plecopetra and Tricoptera and the increase in Odonata and Diptera (Chironomid) in this study.

CHAPTER 4

ASSESSMENT OF THE IMPACT OF ANTHROPOGENIC ACTIVITIES ON LAKE TANA USING MACROPHYTES AS BIOINDICATORS

4.1 INTRODUCTION

Aquatic plants can be defined as plants that have adapted to living in aquatic environment, both in the fresh waters or in salt waters. Aquatic plants are referred to as hydrophytes or macrophytes which occupy different ecological niche in the aquatic environment) (Uneke and Ekuma, 2015).

Macrophytes are higher plants that grow in ecosystems whose development has been dominated by water and their processes and characteristics are largely controlled by water. The distribution of macrophytes is often related to the mode of water occupation (Mormul *et al*., 2013). The permanency and quality of the water bodies available for their occupation govern the distribution and ecology of these plants. The most variable environmental factors of basic ecological importance for macrophytes are the length of the period during which water is present, the movement (flow) water, the availability of plant nutrients and the quality and quantity of light penetration into the water (Hicks and Frost, 2011).

Macrophytes comprise a diverse group of organisms including angiosperms, ferns, mosses, liverworts and some freshwater macroalgae that occur in seasonally or permanently wet environments (Lacoul and Freedman, 2006). In general, it can be stated that macrophytes are dominant and principal primary producers in shallow freshwater aquatic ecosystems. The main local determinants of the composition of aquatic flora are water level fluctuation, substrate composition and organic matter content, the amount of light and water chemistry (Peter *et al*., 2014). Macrophytes usually show a succession of zones between the dry land and water, each zone with a dominating plant species. Variation in the abundance and diversity depends on the duration of the flooding (water) and may also be affected by ecological disturbance

(Antti, 2012). This chapter was carried out to determine the distribution (abundance and diversity) patterns of macrophytes in Lake Tana due to human activities**.**

4.2 OBJECTIVES

1. Identify the macrophyte communities present in Lake Tana,
2. Investigate the environmental factors that influence macrophyte abundance and distribution
3. Quantify the macrophyte species diversity using indices based on plant species composition of the communities.
4. Analyze the diversity and distribution of aquatic macrophytes and determine the water quality of Lake Tana.

4.3 MATERIALS AND METHODS

4.3.1 Macrophyte Sampling

Sampling Process, Methods and Identification

Macrophyte sampls were collected using Sickele, plastic bags ("baggies") for plant specimens, paper towel(s), labels to mark plastic bags and plant identification keys.

The Lake Tana is blessed with good fresh water harbouring a great variety of aquatic macrophytes. Information of aquatic macrophytes in any water body is of immense importance to understand the wetland ecosystem (Dhore and Lachure, 2014).

Macrophyte surveys were undertaken in wet and dry seasons in the year 2014 to 2015, twice in a year at wet and dry seasons. The aquatic macrophyte inventory was done in 11 sites of Lake Tana (Figure 1.1 and Table 1.1). Sites were chosen based on the impact levels (highly impacted and less impacted urban centers and highly impacted and less impacted agricultural centers) to be representative for the impact levels of Lake Tana as used by Maria *et al*. (2013).

Site selection was also based on the presence of macrophytes monitored along the whole perimeter of the lake selected sites shoreline, with the aim to obtain sufficient relevant data. Monitoring was in selected areas of the shoreline stretches and free water areas of Lake Tana where macrophytes were observed. Each site was monitored twice during the survey period in a year (wet and dry seasons).

Macrophyte field surveys were conducted using the general principles described in the European Standard EN 15460 (CEN, 2007) and European Standard EN 14184 recommended for the assessment of aquatic macrophyte vegetation as indicated in Peter *et al.* (2014) and Selcuk *et al.* (2014) and methods similar to those used by (Manjunath *et al.*, 2016) because of the lack of standardized national methods. It was collected along transects spaced about 100m apart for a total of four transects per site. One m^2 quadrat was sampled at the shoreline. At each sampling point (sampling sites), all macrophytes growing within 1m × 1 m quadrants were collected. Plant species were collected and recorded as used by Anderson and Sidinei (2007), Laura (2011),Peter *et al.* (2014), Hua *et al*. (2014), Selcuk *et al.* (2014) and Manjunath *et al.* (2016). The distribution and abundance of macrophytes in the Lake Tana were assessed on foot along the lake shore and by boat. The macrophytes specimens were collected by rake with hooks and Sickle by hand picking. It was applied at random sampling method with the help of a 1m×1m light wooden quadrat. The macrophytes were counted by hand picking as used by Dhore and Lachure (2014), Selcuk *et al.* (2014) and Dipankar and Jayanta (2015).

The macrophytes of Lake Tana were studied altogether from 72 quadrants in the lake during the year with 36 quadrats in each season. The taxonomic identification followed the specialized literature. After the collection the macrophyte samples were registered and were identified to species level**.** Furthermore, collections were identified by comparison with matieral from Maria *et al*. (2013).

The macrophytes collected were arranged in a paper and covered with a paper to avoid drying up. Macrophytes were recorded at each site and samples were stored in collecting packets. It was quickly transported to ARARI Laboratory for identification. Macrophytes were identified from family to species level with the use of a catalogue (key) and literature used by Minns *et al.* (1993), Gana *et al*. (2011), Laura (2011), Dhore and Lachure (2014), Peter *et al.* (2014), Selcuk *et al.* (2014) and Manjunath *et al.* (2016). In addition, a visual estimate of percentage plant cover along the whole transect was recorded as used by Minns *et al.* (1993) as cited and used by Peter *et al*.

(2014). The identification of aquatic plants was done with the help of standard keys and literatures (Gana *et al*., 2011; Laura, 2011; Peter *et al*., 2014; Selcuk *et al.*, 2014; Manjunath *et al.*, 2016). Macrophyte sample was recorded together with the percentage cover according to the standard methodology used by Gana *et al.* (2011), Laura (2011), Peter et al. (2014), Selcuk *et al.* (2014) and Manjunath *et al.* (2016).

4.3.2 Data Analysis

There was macrophyte inventory within the wet and dry seasons between the reference and impacted sites. Macrophyte diversity, abundance, composition and indices were calculated.

Basic statistical measurement was done and results were expressed as mean. Pearson correlation coefficient (r) was also computed between the macrophytes. Descriptive analyses were used. Graphs were used to evaluate differences among macrophyte families, among sites as well as the wet and dry seasons. All statistical analyses were performed using the SPSS statistical software (Version 23; SPSS Inc, 2016) and Excel spreadsheet, 2007.

4.4 RESULT AND DISCUSSION

4.4.1 Macrophyte Richness

Lake Tana is a shallow lentic water body. Total 43 species were recorded in two seasons (wet and dry), throughout the study year. Maximum plant species diversity were recorded in the wet season compared to the dry season (Table 4.1 and Appendix 8 and 9).

2687 vegetation surveys of aquatic macrophytes were collected along Lake Tana for the period of one year in wet and dry seasons, 1756 number of macropytes in the wet season and 931 number of macropytes in the dry season. A total of 18 families and 43 species of macrophytes collected in the year 2014 to 2015 investigations from 9 sites in Lake Tana (Table 4.1, Appendix 8 and 9). S_5 and S_7 sampling sites were excluded from macrophyte sampling due to absence of macrophytes in these sites by their natural characteristics; these sites are joints of Lake Tana with the tributaries, Gumara and Megech Rivers respectively.

It was almost similar macrophyte taxa recorded in this study as comaperd with macrophyte species (49) from Amazonian lakes as studied by Mormul *et al.*, (2013). The number of aquatic macrophyte Species was higher during the wet season (42) than in the dry season (35) but the number of familes was almost in the same proportion during the wet season (17) and the dry season (16) (Appendix 8). *Echinochloa stagnina* and *Echinochloa ugandensis* species were found dominant during the wet season at S_3 and S_4 sites.

In terms of families' number of plants, Poaceae (1,795 individual organisms with 15 species) showed the largest number in the study; followed by Cyperaceae (295 individual organisms with 15 species) during the sampling year.

It was altogether 18 families and 43 species identified from the 72 quadrants of Lake Tana (Appendix 7). *Echinochloa stagnina* were the most abundant (655 individual organisms) followed by *Sacciolepis africana* (265 individual organisms) and *Echinochloa ugandensis* (222 individual organisms). *Thelypteris confluens* was the least represented (1 individual organism) followed by *Phragmites australis* (2 individual organisms). Based on the field survey it was observed that *Echinochloa stagnina* was more abundant (about 24.4%), more frequent and covered most of the study area. But the abundance and compostion of sampling sites vary by personal judgement in the field survey as indicated in Table 4.4.

It was highlighted the differences in vegetation patterns in response to different seasonal conditions of water bodies, the water became saturated due to heavy precipitation which was conducive for the plant species to grow and propagate and they opined seasonal flourishing of plant biomass ultimately led to enrich the soil and water of lakes during wet season (Roger *et al.*, 2013). As cited by Dipankar and Jayanta (2015) and Das *et al.* (2009) this study found a general relationship between trophic status of a water body and the aquatic plants. Accumulation of silt and detritus from the catchment area and decomposition of macrophytes reduces the water quality of the lake and promotes the macrophytes enrichment (Dipankar and Jayanta, 2015).

Table 4.1: Total number of families collected and families abundance over the sample period at all sites of Lake Tana

Taxa		Ambobahi		Bahir Dar Study Area (S.A)						Tana Kirkos S.A		Megech S.A		Gorgora S. A						Total Indiv.		
Family	No. of Species	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry			
		S_0	S_0	S_1	S_1	S_2	S_2	S_3	S_3	S_4	S_4	S_6	S_6	S_8	S_8	S_9	S_9	S_{10}	S_{10}	Wet	Dry	T
APIACEAE	1	0	0	0	0	0	0	13	4	0	0	0	0	0	0	0	0	0	0	13	4	17
AMARANTHACEAE	2	0	0	0	0	0	0	0	0	14	5	0	0	0	0	0	0	0	0	14	5	19
ASTERACEAE	4	0	0	0	0	8	3	8	4	14	0	0	0	0	0	0	0	0	0	30	7	37
CERATOPHYLLACEAE	1	8	6	0	0	0	0	8	5	3	4	0	0	0	0	0	0	0	0	19	15	34
CHENOPODIACEAE	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	-	1
COMMELINACEAE	1	0	0	8	3	0	0	6	4	12	0	0	0	6	3	0	0	11	5	43	15	58
CYPERACEAE	5	62	39	0	0	46	48	6	10	38	17	0	0	11	18	0	0	0	0	163	132	295
HYDROCHARITACEAE	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	4	-	4
LYTHRACEAE	2	0	0	4	0	5	0	8	6	4	0	0	0	3	7	0	0	2	4	26	17	43
MELASTOMATACEAE	2	0	0	2	4	15	20	0	0	0	0	0	0	0	0	0	0	0	0	17	24	41
NYMPHECEAE	1	8	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	9	20
POACEAE	15	174	119	93	44	95	61	237	100	358	66	7	0	149	86	40	6	119	41	1272	523	1795
POLYGONACEAE	1	0	0	0	0	10	2	5	3	2	62	0	0	2	0	0	0	4	6	23	73	96
PONTEDERIACEAE	1	0	0	0	0	0	0	0	0	4	0	8	0	0	2	0	0	5	0	17	2	19
POTAMOGETONACEAE	1	0	0	0	0	0	0	3	32	0	0	0	0	0	0	0	0	0	0	3	32	35
THELYPTERIDACEAE	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	-	1	1
TILIACEAE	1	0	0	0	0	0	0	11	8	0	0	0	0	0	0	0	0	0	0	11	8	19
TYPHACEAE	2	18	13	0	0	28	12	13	9	0	0	0	0	15	16	0	0	15	14	89	64	153
Total Macrophytes Abundance		270	183	110	54	207	146	319	186	453	154	15	0	186	132	40	6	156	70	1756	931	2687
Total Number of Species Collected over the sample period																						43
Total number of Families Collected over the sample period																						18

A total of forty three plant species were documented in this investigation (Appendix 8). Table 4.1 reveals that Poaceae (15 species) was the most dominant family, followed by Cyperaceae (5 species). *Echinochloa stagnina (*Poaceae family) was the most commonly occurring taxa among the studied areas. In the study area the most dominant or abundant families Poaceae (1795 individual macrophytes), Cyperaceae (295 individual macrophytes) and Typhaceae (153 individual macrophytes) were collected in all of the sampling sites in the sample period.

The construction of the dams in watercourses causes several changes, mainly in the hydrology and related ecological characteristics. The most significant features, such as a reduction in flow velocity, a rise in water level, water temperature and siltation of the bottom, are manifested in the creation of the suitable ecological conditions for the colonization of macrophytes (Peter *et al.*, 2014). In similar way, Cherechera wiry /Dam/ is also a cause for several hydrological factors change for Lake Tana which was affecting the macrophytes communities.

4.4.2. Macrophyte Abundance

Table 4.2: Mean values of macrophyte families harvested from Lake Tana and S.D = standard deviation of the mean

Family	No. Species	Mean ± S.D
APIACEAE	1	2.04 ± 4.8
AMARANTHACEAE	2	2.28 ± 5.3
ASTERACEAE	4	4.44 ± 9.5
CERATOPHYLLACEAE	1	4.08 ± 8.0
CHENOPODIACEAE	1	0.12 ± 0.3
COMMELINACEAE	1	6.96 ± 14.0
CYPERACEAE	5	35.40 ± 68.3
HYDROCHARITACEAE	1	0.48 ± 1.3
LYTHRACEAE	2	5.16 ± 10.0
MELASTOMATACEAE	2	4.92 ± 10.4
NYMPHECEAE	1	2.40 ± 4.9
POACEAE	15	215.40 ± 421.7
POLYGONACEAE	1	11.52 ± 25.7
PONTEDERIACEAE	1	2.28 ± 5.1
POTAMOGETONACEAE	1	4.20 ± 10.9
THELYPTERIDACEAE	1	0.12 ± 0.3
TILIACEAE	1	2.28 ± 5.0
TYPHACEAE	2	18.36 ± 35.1

The most frequent plant families found in lake Tana were Poaceae with mean 215.40 ± 421.7 followed by Cyperaceae 35.40 ± 68.3 (Table 4.2) which are the most abundant.

Borah and Sarma (2012) indicated a correlation between the global size of higher taxa (family level) and the number of exotic species within these taxa. He found that the largest angiosperm families also supply a large proportion of exotics invaders. Members of Poaceae, Asteraceae, Fabaceae and Brassicaceae represent the world most alien species (Bottino *et al*., 2013). Asteraceae and Fabaceae are the largest known families of flowering plants in the world. In the study analyses of Gautam and Shambhu (2014), Asteraceae and Fabaceae were also contributors to the largest proportion of exotic species. In this study Pontederiaceae (*Eichhornia crassipes*) was the extotic species alarmingly invading and endangering the lake and its ecosystem.

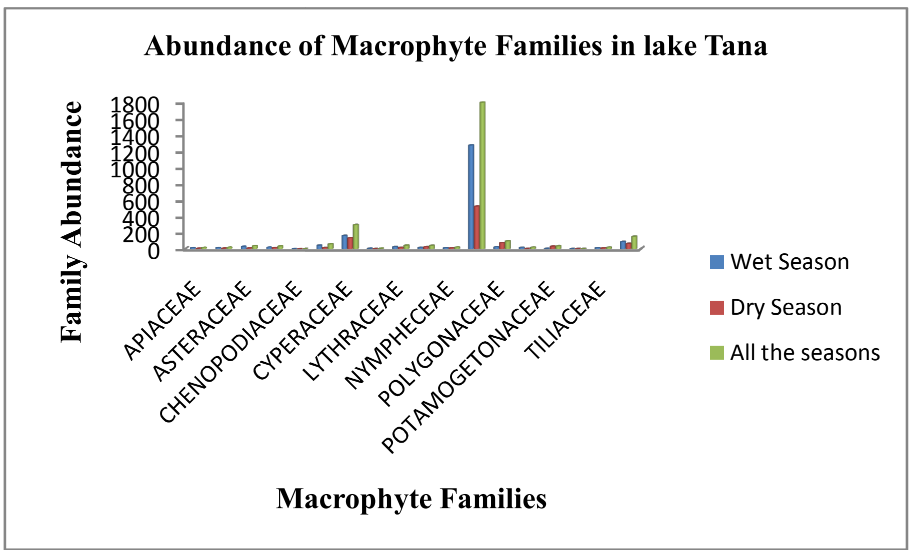


Figure 4.1: Abundance of Lake Tana macrophyte families

Out of the 43 taxa identified in 18 families the number of indicator species in particular site and season fluctuated between 1 and 655 individual spcies and 0 to 12 families; with a mean of family Chenopodiaceae (0.12 ± 0.3) to Poaceae (215.40 ± 421.7) (Table 4.3). The greatest number of indicator species is in the family Poaceae (15 species) having 1795 individual macrophytes (Table 4.1 and Appendix 9). The mean value was recorded from the least 0.12 ± 0.3 to the highest 215.40 ± 421.7 (Table 4.2).

Table 4.3: List of macrophyte species identified in Lake Tana in the study time

Plant species common to the Reference and Impacted Sites (*n* = 16)
Sacciolepis africana, Snowdenia petitiana, Ceratophyllum demersum, Cyperus macrostachyos, Cyperus papyrus, Cyperus pectinatus, Oxycaryam cubensis, Nympheae lotus, Acroceras macrum, Arthraxon prinoides, Cynodon dactylon, Echinochloa pyramidolis, Echinochloa stagnina, Eragrostis tenuifolia, Leersia hexandr and Typha latifolia
Plant species identified only in the Reference site (*n* = 1)
Pennisetum thunbergii
Plant species identified only in Impacted sites (*n* = 26)
Phragmites australis, Hydrocotyle ranunculoides, Achyranthes aspera, Alternative sessilis, Pistia stratiotes, Ageratum conizoides, Galensoga quadriradiata, Veronica abyssinica, Chenopedium ambrosioles, Commelina Africana, Cyperus mundtii, Vallisneria spiralis, Ludwigia abyssinica, Ludwigia laptocarpe, Dissotis canescens, Dissotis princeps, Echinochloa ugandensis, Eragrostis botryodes, Panicum hymeniochilum, Vossia cuspidate, Persicaria senegalensis, Eichhornia crassipes, Potamogeton natan, Thelypteris confluens, Triumfetta annua and Ipomoea cairica

In Lake Tana a total of 43 plant taxa (Species) were recorded, of which 1 was found only in the reference site, 26 only in the impacted sites and 16 in both the reference and the impcted sites (Table 4.3). The list of taxa identified is given in Appendix 9.
Only the *Pennisetum thunbergii* species was found in the reference site. *Sacciolepis africana, Snowdenia petitiana, Ceratophyllum demersum, Cyperus macrostachyos, Cyperus papyrus, Cyperus pectinatus, Oxycaryam cubensis, Nympheae lotus, Acroceras macrum, Arthraxon prinoides, Cynodon dactylon, Echinochloa pyramidolis, Echinochloa stagnina, Eragrostis tenuifolia, Leersia hexandr and Typha latifolia* were found in the reference and the impacted sites.

Hygrophil aschulli, *Alternanthera sessilis*, *Eclipta alba*, *Coldenia procumbens*, *Murdannia nudiflora*, *Cyperus iria* and *Nymphaea nouchali*, are the macrophytes having medicinal value, as recorded by Rao *et al*. (2009) as cited by Doris *et al*.

(2015) in the aquatic flora of Uttar Kannada. *Alternanthera sessilis* was the taxa obsereved in Lake Tana to be an indicator of human influence.

The anthropogenic activities negatively affected the species richness of aquatic macrophytes, since depth and species numbers were positively correlated as studied by Anderson and Sidinei (2007). However, 26 species types occurred in the impacted sites of Lake Tana. The wetlands, a measure of the area occupied by macrophytes, were reduced in dry season (low water periods during habitat contraction) of Lake Tana and it was restored during wet season where the number of families high in the wet season (Figure 4.1). The total number of species varied markedly was through the wet and dry seasons (Figure 4.2, 4.3 and Appendix 8) which are similarly indicated in the study of (Anderson and Sidinei, 2007). In the region wet season and dry season each come once per year. According to Satish and Deepak (2017) quantity of water in the water bodies does not play significant role in maintaining the diversity but it is the quality of water that decides the growth of plants. In the study of Satish and Deepak (2017), Water quantity remains highest in rainy (wet) seasons and a little or less in dry but still maximum plant varieties were recorded in dry. In wet seasons, filling of water body with sewage and canal water also does not favor many plant species to flourish although the water body remains almost completely filled in that season.

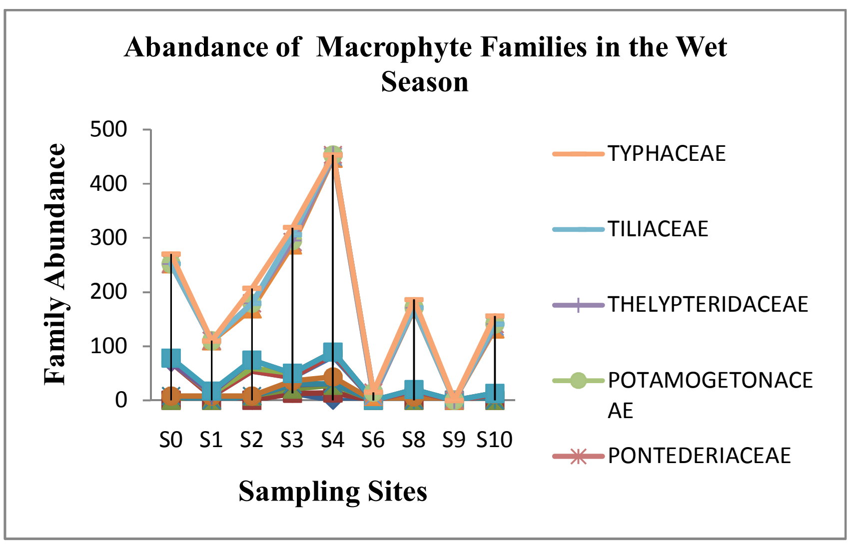


Figure 4.2: Relative abundance of macrophytes family in Lake Tana in the wet season

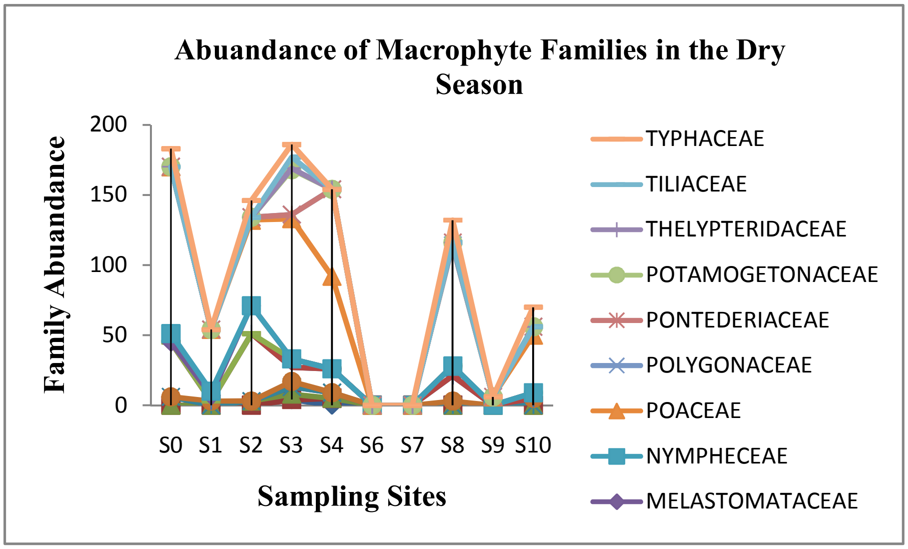


Figure 4.3: Relative abundance of macrophytes family in Lake Tana in the dry season.

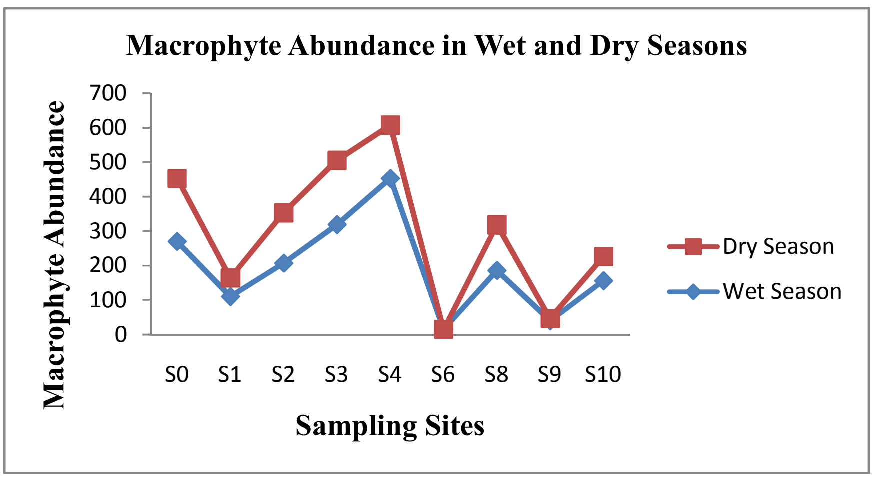


Figure 4.4: Abundance of macrophytes familes (species) in the study area in the study year

The most abundant aquatic macrophyte was *Echinochloa stagnina* species which is belonging to family Poaceae. This is followed by *Sacciolepis Africana and Echinochloa ugandensis* belonging to the family Poaceae. *Cyperus papyrus, Typha latifolia, Oxycaryam cubensis, Echinochloa stagnina and Eragrostis tenuifolia* were some of the species which occured throughout the year. According to the study of Dhore and Lachure (2014) *Eichornia crassipes*, *Vallisneria spiralis*, *Hydrilla verticillata*, *Ipomoea aquatica*, occured throughout the year and *Eichornia crassipes* increase alarmingly (invade the area) with in short period of time.

The macrophytes collected during different seasons exhibited distinct seasonal profile (Figure 4.1, 4.2, 4.3 and 4.4 and Appendix 8), it was true also in the study of Dar *et al*. (2013). Significant changes were seen in all the macrophytes except that of *Ceratophyllum demersum* and *Potamogeton natan* where slight fluctuations were noticed. The period of active growth characterized by high nutrient load and temperature was in the wet season (Dar *et al*., 2013; Peter *et al*., 2014). The analysis of our data revealed some distinct trends in the fresh water macrophytes sampled during different seasons as seen in Figure 4.3 and Appendix 8 and 9. It was also true in the study of Dar *et al*. (2013).

In the field survey the abundance and composition of Lake Tana sampling sites were dominated by *Echinochloa stagnina, Sacciolepis Africana and Cyperus papyrus.* But the sampling site S_6 was differently invaded by the dangerous exotic species *Eichhornia crassipes* (almost 100%). The percentage composition of all the sampling sites was as indicated in Table 4.4 from the survey finding.

Table 4.4: Percentage composition of macrophytes in Lake Tana sampling sites

Study Area	Sampling Site	Macrophyte Species	Percentage (%)
Ambobahir	S_0	*Cyperus papyrus*	76
		Echinochloa stagnina	21
		Typha latifolia	2
		Others	1
Bahir Dar	S_1	*Sacciolepis Africana*	75
		Echinochloa stagnina	19
		Echinochloa ugandensis	2
		Cyperus papyrus	1
		Others	3
	S_2	*Cyperus papyrus*	40
		Sacciolepis Africana	20
		Echinochloa stagnina	10
		Typha latifolia	10
		Others	20
	S_3	*Echinochloa stagnina*	70
		Sacciolepis Africana	20
		Typha latifolia	5
		Others	5
Tana Kirkos	S_4	*Echinochloa stagnina*	40
		Persicaria senegalensis	20
		Sacciolepis Africana	4
		Eragrostis tenuifolia	5
		Cyperus papyrus	1
		Others	30
Megech	S_6	*Eichhornia crassipes*	99.50
		Cynodon dactylon	0.50
Gorgora	S_8	*Sacciolepis Africana*	35
		Cyperus papyrus	35
		Typha latifolia	20
		Echinochloa stagnina	5
		Others	5
	S_9	*Panicum hymeniochilum*	30
		Sacciolepis Africana	30
		Echinochloa ugandensis	20
		Others	20
	S_{10}	*Echinochloa stagnina*	50
		Typha latifolia	40
		Echinochloa ugandensis	20
		Eichhornia crassipes	1
		Others	5

The covering of each aquatic macrophyte species percentage was recorded according to the Domin-Krajina scale (1 ≤ 20%; 2 = 21–40%; 3 = 41–60%; 4 = 61–80%; 5 = 81–100% of covering) as cited by Anderson and Sidinei (2007); Gana *et al*. (2013).

The Lake Tana macrophyte percentage coverage was indicated in Table 4.4 and 4.5 alsmost as the scale indicated.

In all survey units the abundance of each species in the study area was estimated on a five level descriptor scale (1= rare, 2= occasional, 3= frequent, 4= abundant and 5= very abundant) (Gana *et al*., 2013; Maria *et al*., 2013; Selcuk *et al*., 2014). Macrophyte relative abundances were quantified based on percent frequency of occurrence at 9 sampling sites. The study area abundance of macrophytes is as indicated in Table 4.5 and Figure 4.4.

Table 4.5: Abundance of macrophyte species identified in Lake Tana in the study time (Field survey)

Study Area	Sampling Site	Descriptor scale/ Scale in Number/				
		Rare	Occasional	Frequent	Abundent	Very Abundent
		1≤ 20%	2= 21–40%	3=41–60%	4=61–80%	5=81–100%
Ambobahir	S_0	*Typha latifolia*	*Echinochloa stagnina*		*Cyperus papyrus*	
Bahir Dar	S_1	*Echinochloa ugandensis and Cyperus papyrus*	*Echinochloa stagnina*	----	*Sacciolepis Africana*	----
	S_2	*Echinochloa stagnina and Typha latifolia*	*Sacciolepis Africana,*	*Cyperus papyrus*	----	----
	S_3	*Typha latifolia*	*Sacciolepis Africana*	----	*Echinochloa stagnina*	----
Tana Kirkos	S_4	*Sacciolepis Africana , Eragrostis tenuifolia and Cyperus papyrus*	*Persicaria senegalensis*	*Echinochloa stagnina*	----	----
Megech	S_6	*Cynodon dactylon*	----	----	----	*Eichhornia crassipes*
Gorgora	S_8	*Echinochloa stagnina*	*Sacciolepis Africana, Cyperus papyrusand Typha latifolia*	----	----	----
	S_9	----	*Panicum hymeniochilum, Sacciolepis Africana and Echinochloa ugandensis*	----	----	----
	S_{10}	*Eichhornia crassipes*	*Echinochloa ugandensis*	*Echinochloa stagnina and Typha latifolia*	----	----

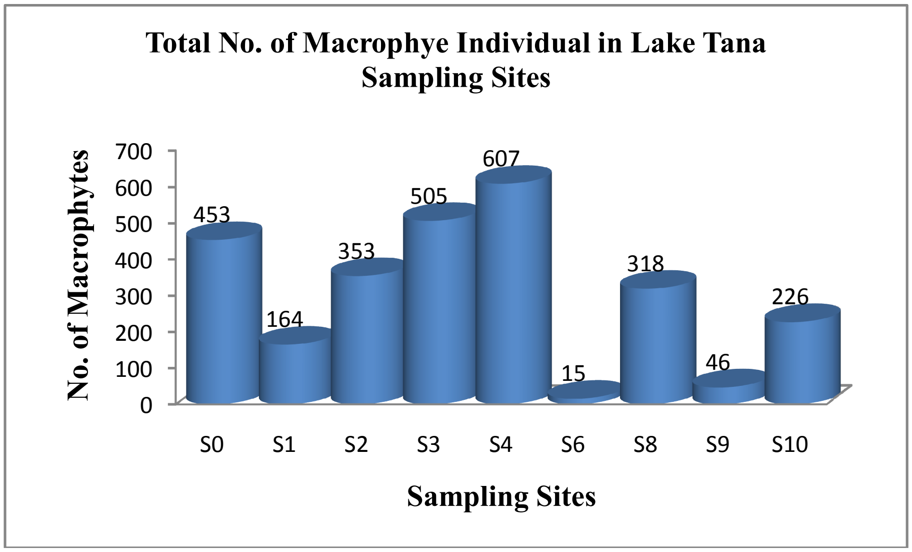


Figure 4.5: Total number of macrophytes species in sampling sites in Lake Tana

Abundance of organisms in the study area is more in the wet season than the dry season as indicated in Figure 4.2, 4.3 and 4.4. The number of organisms and Taxa identified was almost negligible at S_6 and S_9 as indicated by Figures 4.1, 4.2, 4.3, 4.4 and 4.5. This indicated that the impacted sites S_6 and S_9 were much human influenced areas. During the survey in the dry season it was observed that farming activities (recession farming, when the amount of water reduced) at the core area (riparian border) of the lake that highly influenced the macrophyte.

Through out the sampling period in the wet season, sites S_4 (28 Species) and S_3 (21 Species) and S_3 (12 families) followed by S_4 (10 families) while in the dry season Sites S_3 (20 Species) and S_3 (12 families) were characterized by the highest total abundance of taxa in descending order (Figure 4.5 and Appendix 8 and 9).

Tables 4.5 and Appendix 8 and 9 showed that for Lake Tana *Echinochloa stagnina* and *Sacciolepis Africana* were the most representative species in terms of abundance and relative frequency. *Ricciocarpus natans* can also be considered an indicator species inspite of its absence (i.e. it did not occur in the much influenced area). For the impacted areas, the most representative species were *Oxycaryum cubense*, *P. meissnerianum* and *P. ferrugineum* but *Oxycaryum cubense*, *P. meissnerianum* and *P. ferrugineum* were representatives in the study of Anderson and Sidinei (2007).

The substrate parameter (sediment) was the most important environmental factor in determining macrophyte distribution (Richard *et al*., 2010). Sediment accumulation belongs to the factors considerably influencing species distribution, abundance and diversity of macrophytes in aquatic environments (Kuhar *et al*., 2007; Richard *et al*., 2010). Lake Tana is recently highly influenced by sedimentation due to deforestation and human activities in the catchment area. Finer sediment is preferred by typical aquatic species (*Ceratophyllum demersum*, *Myriophyllum spicatum*, *Nuphar lutea* and *Potamogeton crispus*) (Richard *et al*., 2010).

4.4.3. Macrophyte Composition

The taxonomic composition of the lake was dominated by species *Echinochloa stagnina* and family Poaceae. The site areas $S_1$and S_2 (Bahir Dar study area) and S_6 (Megech sudy area) were known with urban pollutant discharges. S_4 (Tana Kirkos sudy area) and S_6 (Megech sudy area) were used for intensive agricultural activities (fertilizers and pesticides applied) most likely had influenced the growth of macrophytes as studied by Dipankar and Jayanta (2015).

Table 4.6: Family level macrophyte composition of Lake Tana

Taxa		Macrophyte Composition					
Family	No. of Species	No. Wet	%	No. Dry	%	No. T	%
APIACEAE	1	13	0.74	4	0.43	17	0.63
AMARANTHACEAE	2	14	0.80	5	0.54	19	0.71
ASTERACEAE	4	30	1.71	7	0.75	37	1.38
CERATOPHYLLACEAE	1	19	1.08	15	1.61	34	1.27
CHENOPODIACEAE	1	1	0.06	-	-	1	0.04
COMMELINACEAE	1	43	2.45	15	1.61	58	2.16
CYPERACEAE	5	163	9.28	132	14.18	295	10.98
HYDROCHARITACEAE	1	4	0.23	-	-	4	0.15
LYTHRACEAE	2	26	1.48	17	1.83	43	1.60
MELASTOMATACEAE	2	17	0.97	24	2.58	41	1.53
NYMPHECEAE	1	11	0.63	9	0.97	20	0.74
POACEAE	15	1272	72.44	523	56.18	1795	66.89
POLYGONACEAE	1	23	1.31	73	7.84	96	3.57
PONTEDERIACEAE	1	17	0.97	2	0.22	19	0.71
POTAMOGETONACEAE	1	3	0.17	32	3.44	35	1.30
THELYPTERIDACEAE	1	-	-	1	0.11	1	0.04
TILIACEAE	1	11	0.63	8	0.86	19	0.71
TYPHACEAE	2	89	5.07	64	6.87	153	5.69
Total Macrophytes Abundance		1756		931		2687	

A shift from rich macrophytes at the impacted sites mainly at S_3 and S_4 to relatively less in the reference site is very clear indication of water quality effect or pollution (Hanganu *et al*., 2008) despite most of the time richeness is an indication of stability or good quality. It is apparent from the study that the quality of the Lake water deteriorated as one moved to the north (Megech study area). This was mainly because of different types of anthropogenic activities in the catchement; mainly agricultural activities in Dembia and Gondar Zuria districs, industrial activities in Gondar city and sewage from Gondar city and the catchment towns. Seasonal changes can modify the value of environmental variable such as temperature, organic matter availability and other factors that can influence life forms including macrophytes as seen from (Figures 4.2, 4.3, 4.4 and 4.5).

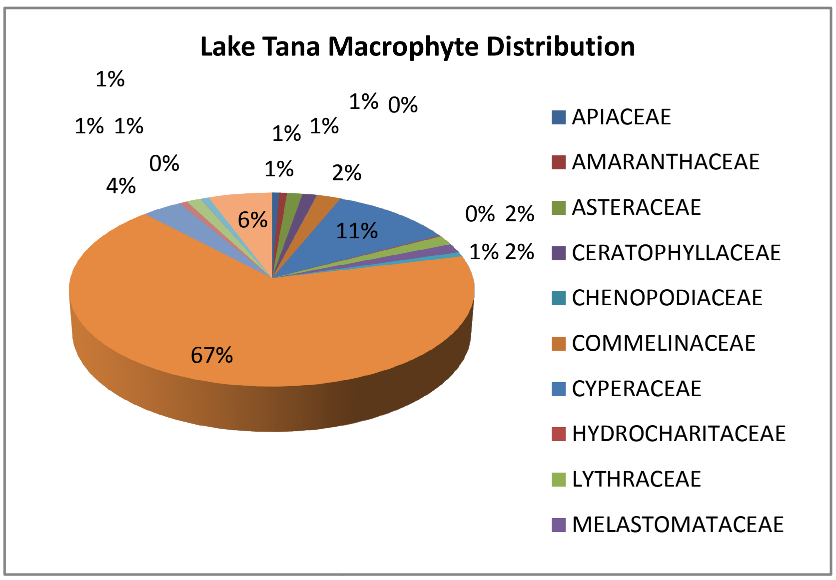


Figure 4.6: Percentage composition of macrophytes distribution in Lake Tana family based distribution

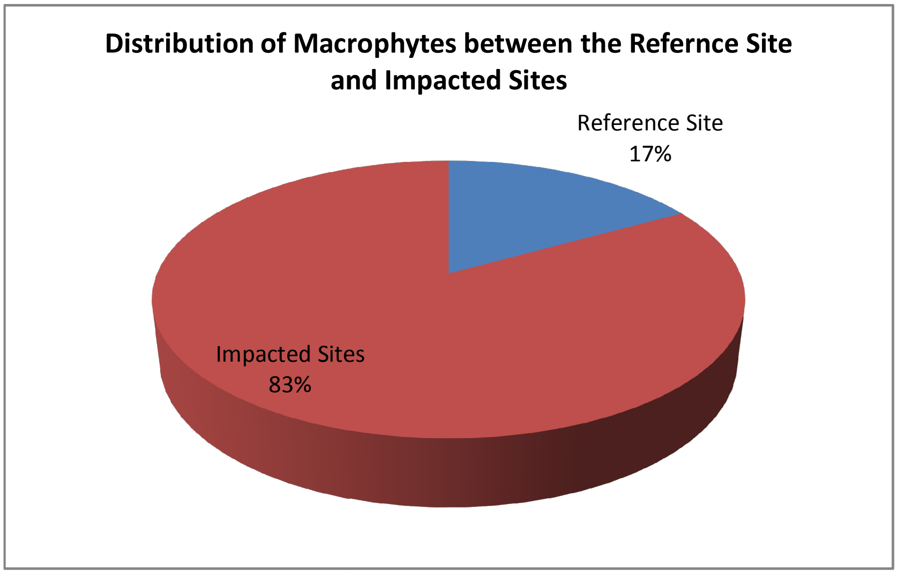


Figure 4.7: Percentage composition of macrophytes distribution in Lake Tana site based distribution

In the wet season the composition of macrophytes was Poaceae 72.44%, Cyperaceae 9.28% and Typhaceae 5.07 %, in the dry season Poaceae 56.18 %, Cyperaceae 14.18 % and Typhaceae 6.87 % and Poaceae 66.89 %, Cyperaceae 10.98 % and Typhaceae 5.69 % (Table 4.6 and Figure 4.6 and 4.7).

Environmental variables are relevant for the distribution and composition of macrophytes in aquatic environments such as sediment accumulation, sediment stability, trophic status, content of nutrients and chemical parameters and hydrological characteristics such as flood, water level fluctuation are very important (Sarma and Deka, 2014; Richard *et al*., 2010).

The effects of water level variation on aquatic plant communities of Lake Tana (considering both an increase in flow and an enlarged flood area) has grown in the last few years in the wet season due to Tana Beles hydroelectric dam while it deacreased in the dry seaseon. One of the reasons is population growth and the country plan to strive the first hydroelectric energy supplier in east Africa that increase in the demand for energy. The same is true in the study of Anderson and Sidinei (2007) and Oyedeyi and Abowei (2012). Usually produced by hydroelectric power stations, fluvial ecosystems started to have their flood regimes regulated by dams, which reduce water flow or flooded the area, altering the connectivity patterns of the surrounding water bodies (Anderson and Sidinei, 2007; Sutela *et al.*, 2012). In this study, the increase in flood plain contributed positively to the increase macrophyte species richness.The probable cause for the reduction in the species richness observed in the low water period (April and March) was alteration (contraction) in habitat. During the period dry season (January, February, March, April and May), evaporation increase and water flow of tributary rivers reduced and the aquatic habitat became exposed (i.e. reduction in surface area of flood plain due to their partial drying out), leading to the mortality of macrophyte species and water receded farming activity. It was also true by the study of Anderson and Sidinei (2007) and Takamura *et al*. (2010). Depth reduction is a factor known to be responsible for aquatic macrophyte mortality (Anderson and Sidinei, 2007).

In this study the most antropogenic activity that affects the macrophye compostion was recession farming activities. Water level fluctuations could also explain differences in species composition that might be due to the Charachara Wiry (dam) to feed Tana Beles hydroelectric project. Even small changes in water level may promote large shifts in plant communities (Cereghino *et al*., 2014). For example, duration of flooding was the best variable in explaining differences in communities' development. Macrophytes initiation of reproduction and seed germination is one of the causes that water level fluctuation might control macrophyte composition (Anderson and Sidinei, 2007; Beck *et al*., 2010).

Increase in light availability follows gradient of macrophyte disturbance intensities. Light has long been recognized as an important plant resource that may interact with other plant resources to affect plant performance. The increase in light availability increases the overall performance of macrophytes particularly the growth rate (Aguiar *et al*., 2011). Yates and Bailey (2011) also reported that light availability in relatively less canopy plant species enhance the growth of macrophytes. But canaopy of trees was not the factor to the macrophyte of this study except larger macrophyte groups such as Cyperus and Typhaceae families influenced the short groups. The dense cover created by vertical stratification of trees may reduce the intensity or duration of light under its canopy and thus decrease the herbaceous macrophytes cover. This could be due to the creation of a photosynthetically inactive light regime at ground level

(Aguiar *et al*., 2011). Below certain thresholds, light limitation alone can prevent herbaceous species survival regardless of nutrient levels (Yates and Bailey, 2011; Gautam and Shambhu, 2014). It is likely that herbs are influenced by the amount of light that reaches the forest floor and this may be probably one of the mechanisms responsible for the decline of herbaceous vegetation. Urbanization and industrialization provide appropriate condition to the invasive species which provides nutrients to increase the amplitude of their invasiveness than the natural condition (Gautam and Shambhu, 2014).

Structure, composition and function of aquatic plant communities are the three important attributes of aquatic ecosystems. The attributes change in response to climate, topography, soil and disturbances. These mentioned factors along with aquatic plant succession are responsible for determination of ecosystem stability (Gautam and Shambhu, 2014). Aquatic plant communities can be also assessed by biological indices.

4.4.4. Biological Indices

4.4.4.1. Beta Diversity Index

Beta diversity index was applied to quantify alterations in species composition (species turnover) along a gradient (Ghosh and Biswas, 2014). Beta diversity index was used to measure species composition changes in sampling sites together in each sampling period. The index (Beta-W) measures the proportion in which the present species richness of of the Lake. It is given by:

Beta-W = $[(R/\alpha) - 1]$

Where R is regional diversity (here, the total number of species recorded in all the sampling sites in each sampling period) and α is the average number of species per sample in each site (Anderson and Sidinei, 2007; Ghosh and Biswas, 2015).

Table 4.7: Beta diversity index in the sampling sites of Lake Tana

Attribute	Abundance	No. of Species	Beta-W
S_0(W)	270	16	2.43
S_0(D)	183	17	3.37
S_0(T)	453	17	2.56
S_1(W)	110	10	1.14
S_1(D)	54	9	1.31
S_1(T)	164	10	1.09
S_2(W)	207	12	1.57
S_2(D)	146	11	1.83
S_2(T)	353	12	1.51
S_3(W)	319	21	3.50
S_3(D)	186	20	4.14
S_3(T)	505	22	3.60
S_4(W)	453	28	5.00
S_4(D)	154	11	1.83
S_4(T)	607	28	4.86
S_6(W)	15	2	-0.57
S_6(D)	0	0	0
S_6(T)	15	2	-0.58
S_8(W)	186	12	1.57
S_8(D)	132	12	2.09
S_8(T)	318	12	1.51
S_9(W)	40	3	-0.36
S_9(D)	6	1	-0.74
S_9(T)	46	3	-0.37
S_{10}(W)	156	9	0.93
S_{10}(D)	70	8	1.06
S_{10}(T)	226	9	0.88
TW	1756	42	7.99
TD	931	35	8.00
T	2687	43	8.00

Higher Beta diversity score indicates better water quality. Hence, the reference site (S_0) score indicates its better water quality except S_3 and S_4 compared with the other eight sampling sites (Table 4.8). Generaly, Lake Tana water quality is good as of the Beta diversity score.

Depth affected the diversity index Beta-W positively, i.e. the species number is lower at low water and maximum during high water periods (Anderson and Sidinei, 2007; Ghosh and Biswas, 2015). Both the depth and length of transects were important in the prediction of species richness (Anderson and Sidinei, 2007).

4.4.4.2. Shannon-Wiener Diversity Index (H')

This is a widely used method of calculating biotic diversity in ecosystems and is expressed as SWI: The basic formula is:

$$H' = -\Sigma \text{ pi ln pi}$$

Where:

H = the Shannon diversity index

pi = the proportion of Importance Value of the ith species (pi = ni / N, ni is the Importance Value of ith species and N is the Importance Value of all the species) or fraction of the entire population made up of species i or the proportion of individuals in the "ith" taxon of the community (ni/N)

S = numbers of species encountered (the total number of taxa in the community)

∑ = sum from species 1 to species S (Upen and Sarada, 2015).

The highest values of the Shannon diversity index during the entire study period were recorded 4.57, 4.36 and 4.16 at sampling site S_2, S_8 and S_4 respectively. Lowest values were recorded 0.69 and 1.03 at sampling sites S_6 and S_9 respectively. S_6 was almost 100% water hyacinth occupied site.

According to Chrisoula *et al*. (2011), Dipankar and Jayanta (2015) and Mariadoss and Ricardo (2015) if the value is between 1 and 2 the water is said to be moderately polluted and if it is less than 1 the water is heavily polluted. Therefore the water in S_9 seems to be moderately polluted while in S_6 it needs immediate steps to prevent further deterioration of the lake water by taking adequate preventive measures (Appendix 10 (A-C)).

Diversity of macrophytes in Lake Tana is given in Appendix 8, 9 and 10 (A-C). The Shannon diversity index of Lake Tana for the wet season was 2.80 and 2.91 for the dry season. The Shannon diversity index normally varies between 0.69 at S_6 and 4.57 at S_2 almost in similar range with the study of Dipankar and Jayanta (2015). At S_2, S_4, S_8, S_9 and S_{10} highest Shannon diversity index score observed in the wet season compared with the dry season while at S_0, S_1 and S_3 the reverse was true. It was observed that H' value (0.50-2.68) higher during dry season and lower during wet (rainy season) in the study of Rimen (2014) and Dipankar and Jayanta (2015). The result of this study was in a broad range compared with the Shannon-Weiner diversity index (HI) value studied by Rimen (2014) 1.67 to 3.28.

This diversity index helps in calculating species relative abundance. A large H value indicates greater diversity, as influenced by a greater number and/or a more equitable distribution of species (Dipankar and Jayanta, 2015). The index values ranges between 0 and 5, where higher index values demonstrates higher diversity, while low index values are considered to indicate pollution. Diversity and anthropogenic disturbances are inversely related to each other. The Shannon index takes account of species richness as well as abundance. It is simply the information entropy of the distribution, treating families as symbols and their relative population sizes as the probability (Ghosh and Biswas, 2015). The advantage of this index is that it takes into account the number of species and the evenness of the species. The index is increased either by having additional unique species, or by having greater species evenness. Diversity is maximum when all species that made up the community are equally abundant (i.e. have a similar population sizes). The diversity is partly a function of the variety of habitats; the more varied habitats tend to be inhabited by a large number of species than less variable ones. Secondly the older habitats usually contain more species than younger ones (Chrisoula *et al*., 2011; Dipankar and Jayanta, 2015).

Some times high diversity can be the result of human influence, as is the case with some managed wetland types (Rimen, 2014). For this reason the absolute species number does not mean much for the quality of an ecosystem and it should be seen in relation to the specific development stage, the intensity of the human influence, the site conditions and other factors. In general, the occurrence of macrophyte vegetation improves the quality of water entering a lentic body (Papastergiadou *et al*., 2008; Satish and Deepak, 2008).

4.4.4.3. Simpson's Dominance Index (D)

The Simpson's index (D) is calculated using the following equation (Dipankar and Jayanta, 2015):

$$\mathrm{D} = \frac{\sum_{i=1}^{S} \mathrm{ni}(\mathrm{ni}-1)}{Ni(\mathrm{Ni}-1)}$$

Where 'ni' is the proportion of individuals of the i^{th} species in the community

Simpson's index gives relatively little weight to the rare species and more weight to the common species (Dipankar and Jayanta, 2015). It weighs towards the abundance of the most common species. It ranges in value from 0 (low abundance) to a maximum abundance 1, where s is the number of species. The value of "D" ranges between 0 and 1. With this, index 0 represents infinite diversity (low abundance) and 1, no diversity (high abundance). The bigger the (D) value the smaller the diversity and the higher the abundance **(**Dipankar and Jayanta, 2015; Upen and Sarada, 2015).

In contrast to evenness index, dominance was generally low and ranged from 0.10 at S_0 and S_2 to 0.47 at S_6 diversity (Appendix 9 (A-C)). The high diversity was pronounced in the study area sites. The result of this study was similar with the study of Barakael *et al*., (2014). Barakael *et al*., (2014) concluded that high diversity is due to food availability.

"The Simpson's index of the Chincoteague Bay was calculated as 0.2122. The minimum and the maximum indices were also calculated given the types of organisms collected. The minimum was 0.0385 (the most diverse), and the maximum was 0.8675 (the least diverse). Given this range, it was concluded that the life in the Chincoteague Bay is quite diverse (Choudhury and Choudhury, 2013). The study result of Lake Tana indicated as the life in the Lake Tana was quite diverse.

In calculation of Simpson's dominant index a value closer to zero means that the ecosystem is more diverse, and a value closer to one means that it is less diverse (Choudhury and Choudhury, 2013; Kalidass, 2014). Hence, Lake Tana macrophyte diversity was high reflecting high human influence. The more dominant species the more water quality is good. Site S_0 is more diversified.

4.4.4.4. Simpson's Diversity Index (1-D) or (D)

Diversity within the macrophyte community was described using the Simpson's diversity index ("D"). The Simpson Diversity Index (D), with values ranging from 0 to 1, is the probability that if two selections are made randomly from a collection of organisms, they will be individuals of the same families. The greater the D value, the greater the sample diversity (Barakael *et al*., 2014; Dipankar and Jayanta, 2015). This index is calculated as follows:

$$D = 1 - [\frac{\sum_{i=1}^{S} \text{ni}(\text{ni}-1)}{Ni(\text{Ni}-1)}]$$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

The value of D ranges between 0 and 1. With this index, 1 represents infinite diversity and 0, no diversity.

This index places relatively little weight on rare families and more weight on common families. Its values range from 0, indicating a low level of diversity, to a maximum of 1 for high level of diversity (Barakael *et al*., 2014).

Simpson's diversity indix (1-D) The seasonal variation in requirements of the diverse growth forms may cause the variation in the family diversity (Dipankar and Jayanta, 2015). Lowest diversity indices were observed during wet season 0.89 as compared to 0.92 in the dry season of the sampling year for all of the macrophyte community in the whole Lake Tana, almost similar score in both seasons. The result was the reciprocal of the study of Barakael *et al*. (2014); Dipankar and Jayanta, (2015) and practically recession farming activity was high in the study area that indicated intense anthropogenic pressure. Hence, this result forwarded extra study by considering different factors.

Appendix 11 (A-C) shows seasonal variations in Simpson index of diversity (1-D) value. It was observed minimum macrophytes Simpson index value 0.53 (wet season) at S_6 to the maximum 0.91 (dry season) at S_0 and 0.90 (average) of Lake Tana. Therfore the macrophyte diversity level of Lake Tana was good. This showed that the more macrophyte diversity, the more human influence unlike may not be generalized as macroinvertebrate communities, due to some environmental factors determine macrophytes to the other direction.

Our high diversity values of Simpson's diversity indices (1-D) indicated that Lake Tana was not free from pollution and had anthropogenic activities that favor different species. The pollution status of Lake Tana sites showed poor to moderate level of pollution load. Similar pollution status was also observed on oxbow lakes of Poland (Barakael *et al*., 2014).

A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance. Simpson's Diversity Index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so diversity increases (Kalidass, 2014; Dipankar and Jayanta, 2015). A perfectly homogeneous population would have a diversity index score of 0. A perfectly heterogeneous population would have a diversity index score of 1 (assuming infinite categories with equal representation in each category). As the number of categories increases, the maximum value of the diversity index score also increases (e.g., 4 categories at 25% = 0.75, 5 categories with 20% = 0.8, etc.) (Gautam and Shambhu, 2014).

Two factors affect diversity scores. These are species richness (or species total) and evenness (or conversely, unequal distributions). An increase in either leads to an increase in diversity. The more species the higher the diversity but if they are not evenly distributed; for example if one species is much more abundant no diversity (Choudhury and Choudhury, 2013; Kalidass, 2014).

4.4.4.5. Margalef's index (M') Measurement of Species Richness

Margalef's index was used as a simple measure of species richness (Margalef, 1958) as cited by Barakael *et al*., (2014). Margalef's index = (S – 1) / In N

S = total number of species

N = total number of individuals in the sample

In = natural logarithm (Satish and Deepak, 2008; Choudhury and Choudhury, 2013; Barakael *et al*., 2014; Kalidass, 2014)

The lowest Margalef's index was observed in the wet season 0.37 and 0.52 at S_6 and S_9 respectively and in the dry season 0 and 1.99 at S_9 and S_4 respectively while in the study year 1.76 and 1.88 at S_1 and S_2 respectively while the highest Margalef's index score observed in the wet season 4.41 and 3.47 at S_4 and S_3 respectively and in the dry season 3.64 at S_3 while in the study year 4.22 and 3.53 at S_4 and S_3 respectively (Appendix 12). The diversity rich sites were less likely human influenced. Lake Tana Margalef's index score were 5.49 in the wet season and 4.97 in the dry season but 5.32 in the study year (Appendix 12). The overall index score showed that Lake Tana macrophyte index was less in the dry season that showed high human influence. The site which has the larger number of species has a greater diversity index than the site with lower number of species (Satish and Deepak, 2008; Dipankar and Jayanta, 2015; Upen and Sarada, 2015). Despite the result of many authors, Satish and Deepak (2008) found such relationship between index of general diversity and index of species richness. As species diversity increased with eutrophication, high species diversity resulted due to eutrophication in the wet season.

The species richness (total number of species) is simply the number of species present in an ecosystem. This index makes no use of relative abundances. In practice, measuring the total species richness in an ecosystem is impossible, except in much managed systems. The observed number of species in the system is a biased estimator of the true species richness in the system and the observed species number increases non-linearly with sampling effort. Thus total number of species, if indicating the observed species richness in an ecosystem, is usually referred to as species density (Gautam and Shambhu, 2014).

4.4.4.6. Evenness Index (E)

This is relative distribution of individuals among taxa groups within a macrophyte community. For calculating the evenness of species, the Pielou's Evenness Index (e) was used (Pielou, 1966) as cited by Kalidass (2014).

$E = H' / \text{In } S$

H = Shannon – Wiener diversity index

S = total number of species in the sample (Choudhury and Choudhury, 2013 and Kalidass, 2014)

It is used for the degree to which the abundances are equal among the groups present in a sample or community (Dipankar and Jayanta, 2015). The species evenness is the relative abundance or proportion of individuals among the species (Gautam and Shambhu, 2014; Upen and Sarada, 2015)

The highest value of evenness index was recorded at sites S_5, S_6 and S_1; the lowest values being recorded at S_4 and S_3. The sites obsedved with high eveness were poor water quality (Dipankar and Jayanta, 2015; Upen and Sarada, 2015).

In terms of annual average family/species evenness index values, in the wet season 1.0 at S_5 and in the dry season 0.93 at S_1 while in the study year 1.7 at S_6. The lowest value was recoreded 0.72 in the wet season at S_4 while to Lake Tana showed highest value (1.0) during the wet season. In Lake Tana with low annual average value of 0.77 and highest annual average value of 0.82 in the dry season (Appendix 13 (A-C)) show more human influence in the dry season and human influence observed in Lake Tana as a whole.

As calculations for index for evenness (e) is dependent on the index of general diversity (H), the evenness index values are species number dependent (Imeri *et al.,* 2008). Thus, the increased value for species richness index was responsible for decreased value of evenness index (Satish and Deepak, 2008; Chrisoula *et al.*, 2011).

4.4.4.7. Schaumburg Trophic Index

For calculation of Schaumburg trophic index in Lake Tana the quantity of species was estimated from the original data and transformed in 5 degree scale (Hanganu *et al*., 2008).

Calculation (1) is the same as Reference Index in Schaumburg *et al*. (2007) as cited by Hanganu *et al*. (2008):

$$\mathrm{TI\ (S)} = \frac{\sum_{i=1}^{nA} \mathrm{QAi} - \sum_{i=1}^{nB} \mathrm{QBi}}{\sum_{i=1}^{nC} \mathrm{QCi}} \mathrm{X\ 100}$$

Where:

TI(S) = trophy-index based on quantity (identical to Reference index in Schaumburg *et al*., 2007), Q*A* = quantity of species *i* in group A (Wet Season), Q*B* = quantity of species *i* in group B (Dry season), Q*C* = quantity of species *i* in all groups (wet and dry season), n*A* = total number of species in group A, n*B* = total number of species in group B, n*C* = total number of species in all groups. Quantity = (semi quantitative score) (Hanganu *et al*., 2008).

TI (S_0) = (16-17)/17 = 0.059, TI (S_1) = (10-9)/10 = 0.1, TI (S_2) = (12-11)/12 = 0.08, TI (S_3) = (21-20)/23 = 0.04, TI (S_4) = (28-11)/28 = 0.61, TI (S_6) = (2-0)/2 = 1, TI (S_8) = (12-12)/13 = 0, TI (S_9) = (3-1)/3 = 0.67, TI (S_{10}) = (9-8)/9 = 0.11 and TI (LT) = (42-35)/43 = 0.16. In the tudy area, the highest TI values were 1 and 0.61 at S6 and S4 respectively. The highest TI values showed good water quality. Hence, the Lake Tana water quality was human influenced in a moderate rate.

Higher TI values are related to relatively small and shallow lakes, with peat bottom, surrounded by extensive reedbeds, hydrologically isolated from the river and dominated by Characeae. Nymphaeids as *Nuphar luteum*, *Nymphaea alba*/*candida* can create large field at the border of large lakes or be dominant in small insulated lakes with peat bottom and surrounded by reed beds (Hanganu *et al*., 2008).

4.4.4.8. Summary of Macrophyte Community Biological Indice Attributes

Table 4.8: Macrophyte community Biological Indice attributes at 11 sampling sites.

Attributes	Sites									Lake Tana
	S_0	S_1	S_2	S_3	S_4	S_6	S_8	S_9	S_{10}	
No. of Spp.	17	10	12	23	28	2	13	3	9	43
Shannon–Weaver Diversity Index (H’)	2.56	4.01	4.57	2.53	4.16	0.69	4.36	1.03	3.54	2.90
Simpson Dominance Index (D)	0.10	0.15	0.10	0.13	0.18	0.47	0.13	0.41	0.22	0.10
Simpson Diversity Index (1-D)	0.90	0.85	0.90	0.88	0.82	0.53	0.87	0.60	0.78	0.90
Margalef’s index (M’)	2.62	1.77	1.88	3.53	4.21	0.37	2.08	0.52	1.48	5.32
Evenness Index (E)	0.90	1.74	1.84	0.81	1.25	1.00	1.70	0.94	1.61	0.77
Schaumburg Trophic Index (TI)	0.06	0.10	0.08	0.04	0.61	1.00	0.00	0.67	0.11	0.16

Species diversity is a useful parameter for the comparison of communities under the influence of human disturbances of any kind or to know the state of succession and stability in the community. Shannon- Weaver diversity Index was found to be maximum in S_2 a highly disturbed area, where waste discharges made favorable condition to vegetation growth as similar result with the study of Upen and Sarada (2015). Simpson’s Index of dominance was highest in S9 during the dry season, as it contains the lowest species diversity as compared to other sampling sites. Evenness Index was also found maximum at S_9 during the dry season. The result was similar with the study of Upen and Sarada (2015). It was found H’ value 2.90, Evenness 0.77 and Species richness (M’) 5.32 analysed from the 43 macrophyte species in Lake Tana which also have quite similarity with the study of Satish and Deepak (2008).

Each diversity index demonstrates a specific aspect of the diversity of a plant community. The examined species richness is the simplest form of diversity index, and shows high diversity in communities with higher species number. High species diversity indicates a high complexity of organization, which is often associated with high stability, although this may not always be the case. In some cases there are species-poor, but ecologically stable ecosystems (Imeri *et al.,* 2008). The indices attributes of Lake Tana indicated that its water quality was at moderate level.

Low species diversity suggests: relatively few successful species in the habitat, the environment is quite stressful with relatively few ecological niches and only a few organisms are really well adapted to that environment and food webs which are relatively simple change in the environment would probably have quite serious effects. To the reverse high species diversity suggests: a greater number of successful species and a more stable ecosystem, more ecological niches are available and the environment is less likely to be hostile and complex food webs environmental change is less likely to be damaging to the ecosystem as a whole (Upen and Sarada, 2015).

Species biodiversity may be used to indicate the 'biological health' of a particular habitat. However, care should be used in interpreting biodiversity measures. Some habitats are stressful and so few organisms are adapted for life there, but, those that do may well be unique or rare. Such habitats are important even if there is little biodiversity. Nevertheless, if a habitat suddenly begins to lose its animal and plant types, ecologists become worried and search for causes (e.g. a pollution incident). Alternatively, an increase in the biodiversity of an area may mean that corrective measures have been effective (Imeri *et al.,* 2008; Upen and Sarada, 2015). The study indicates that normal human interferance in the form of use of wetland for farming and grazing by the people of its surrounding areas exist in the more degraded study area of Megech and Tana kirkos. This was also similar with the study of Upen and Sarada (2015). The natural disturbance in the form of annual flood by the river megech from the catchment washing down the industrial and sewage waste badly affected the macrophytic community of the Megch study area (S_6) in addition to the invasion by water hyacinth and the recession farming affected the Tana Kirkos study area macrophyte community. This result is similar with the study of Upen and Sarada (2015).

Megech study area was about 100% invaded (occupied) by water hyacinth (*Eichhornia crassipes*) due to the aggressive growth of this invasive exotic aquatic weed. Due to recision farming activity significantly heavy siltation from the tributaries of Lake Tana causing shrinkage of the macrophyte population specially the northern and eastern part of Lake Tana where there is high antropogenic activities. It is also clear from the different diversity indices of plant communities that wet season shows the greatest species diversity in comparison to dry season due to the availability of sufficient water during the season which is the prime medium for the growth of the macrophytes. Besides the high organic contents leached from the surrounding areas of human habitations and agricultural fields in the form of remains of detritus and cow and urban wastes (industrial and sewage) by rain water enhances the nutrient contents of the habitat for the growth of macrophytes as reported by Upen and Sarada (2015)

Each diversity index demonstrates a specific aspect of the diversity of a plant community. The examined species richness is the simplest form of diversity index, and shows high diversity in communities with higher species number. High species diversity indicates a high complexity of organization, which is often associated with high stability, although this may not always be the case (Chrisoula *et al*., 2011).

In some cases there are species-poor, but ecologically stable ecosystems such as moors, heathlands, etc. The evenness diversity index provides information about species distribution and indicates whether the high diversity of a plant community is due to the presence of many species with different abundances or to a smaller number of species with a more homogeneous distribution and therefore shows different pattern (Kiran, 2015). However, high diversity can be the result of human influence. For this reason the absolute species number does not mean much for the quality of an ecosystem and it should be seen in relation to the specific development stage, the intensity of the human influence, the site conditions and so on. In general, the occurrence of macrophyte vegetation improves the quality of water entering a lake (Chrisoula *et al*., 2011). *Ceratophyllum demersum* is frequently found in stagnant and slow flowing water of lowlands. It also successfully inhabits man-made water bodies because of its vegetative propagation. *Potamogeton nodosus* is comparatively abundantly spread in slowly flowing and standing waters (Maria *et al*., 2013). It is also a pioneer species in new reservoirs.

The increased diversity of identified aquatic macrophyte species on Lake Tana was season dependent and with the highest species diversity index of 5.49 during the wet period was probably due to the flooding of the shoreline areas leading to the increase in diversity. The Lake has its highest volume of water during the wet season when water from all its tributaries reaches Lake Tana. But this phenomenon was true in dry season by the study of Adesina *et al*. (2011) on Jebba Lake. The main threat to aquatic ecosystems arises from the cultivation of surrounding land in addition to the lack of knowledge regarding the importance of wetland ecosystems among the local population (Chrisoula *et al*., 2011).

The effect of human impacts in terms of non-fishing activities like crop farming and animal husbandry in the riparian communities indirectly enrich the lake through application of inorganic and organic fertilizers. Lake Tana catchment basins service several thousand livestock especially cattle, sheep and goats as grazing and farming activities similar as the study of Adesina *et al*. (2011)

Lake Tana hydrological characteristics encourage the proliferation of floating aquatic macrophytes like water hyacinth (*Eichhornia crassipes*) that may affect Blue Nile River sourced from Lake Tana. This was true in different tributaries of Kainji Lake and is subsequently washed downstream into Jebba Lake during the annual flooding as reported by Adesina *et al*. (2011). *Eichhornia crassipes*, which is listed in 1995 as one of the invasive, problematic aquatic plants (Adesina *et al*., 2011) was found as one of the dominant macrophytes on the Megech study area of Lake Tana.

4.4.5. Eichhornia crassipes /Water Hyacinth/

S_6 was dominated by *Eichhornia crassipes*, specialy in the wet season (Appendix 8 and 9). The field survey revealed that about 100 % of the Megech study area in the wet season was covered (invaded) by *Eichhornia crassipes* but in the dry season the study area was bare land with no macrophyte due to the lake size reduction.

Area coverage of *Eichhornia crassipes* has been increased at alarming rate in Lake Tana. Its coverage at the inception period in 2011 was about 80 to 100 ha (BoEPLAU, 2012) as cited by Tewabe, (2015). Tremendous amount of human labour, time and money has been exerted each year by both the surrounding community and the government but its coverage continues to increase to 50,000 ha in the subsequent years (Anteneh et al., 2015) as cited by Tewabe *et al*. (2017). The status of water hyacinth/ *Eichhornia crassipes/* infestation by the year 2015 on the shore of Lake Tana from northen to eastern corridor estimated 34,500 ha. Drained input fertilizer and other agricultural inputs from farming activities in the catchment area of the lake aggravates water hyacinth to over dominate other floras **(**Tewabe *et al*., 2017). Therefore, shore area floras which would be important fish breeding site and livestock foder source become damaged and eroded **(**Tewabe *et al*., 2017).

Water hyacinth /*Eichhornia crassipes/* provides highly complex habitat structure by restricting the growth of other macrophytes. This modification and habitat change affect fishes and other fauna (Anteneh *et al.*, 2015). Generally, area infested by water hyacinth has reduced fishing efficiency of the study area (from Megech to Tana kirkos) **(**Tewabe *et al*., 2017). Lake Tana surrounding is known by potentially rich dairy cattle breeds, known as Fogera breeds. The shore area of Lake Tana is rich in grass (including hippo grass) which feeds cattle of the surrounding inhabitants. However, due to invasion of *Eichhornia crassipes* and over smarting the native species grasses were absent and bareland in the dry season while overfloked by this species in the wet season.

Eichhornia crassipes also makes rice production frustrating by covering the rice field. Farmers observed that *Eichhornia crassipes* makes the farmland more compacted due to its long root that makes the farm land difficult to plough (Anteneh *et al*., 2015; Tewabe *et al*., 2017). In the last five years, managing the farmlands for recession agriculture has become labor intensive due to infestation of *Eichhornia crassipes* from the northern to southern eastern part of Lake Tana.

Eichhornia crassipes invasions change the balance of ecological communities and the whole ecosystem. It threatens the survival of many plants and animals including migratory birds. Lake Tana is known with many fish, animals and plant endmic species and a home to many flora and fauna that could fulfil Ramsar site criteria but it is affected by the agrassive species, *Eichhornia crassipes*. Its competition with native plants for space, nutrients and sunlight is high that could reduce and eliminate biodiversity (Tewabe *et al*., 2017).

Eichhornia crassipes also leads to deoxygenation of the water and enhances evapotranspiration. Therfore, it affects all aquatic organisms (Asmare *et al*., 2016; Tewabe *et al*., 2017). High Nutrient content favors its productivity and it also creates a high influx of nutrients into the lake which favored high reproduction rate of the weed itself. Water level fluctuation, high level of eutrophication associated with agricultural practice and the urban waste discharges to the lake would affect population dynamics of *Eichhornia crassipes* (Asmare *et al*., 2016). The high nutrient inputs from sewerage, industrial waste and flood created favourable conditions for the proliferation of the weed (Firehun *et al*., 2014)

Reports indicated that outside its native area, *Eichhornia crassipes* can grow quickly to a very high density. Climatic factors are mainly attributed to the weed infestation. Nutrient influx (N, P, K) agricultural input in Ethiopia are also major factors. The other factor to water hyacinth productivity was known to be depth of the water bodies (Firehun *et al*., 2014). When the water hyacinth dies and sinks to the bottom the decomposing biomass depletes oxygen content in the water body (Michalska-Hejduk *et al*., 2009). Depletion of dissolved oxygen endangered fish and other life forms. Low dissolved oxygen could facilitate the release of phosphorus from the sediment which in turn accelerates eutrophication and can lead to a subsequent increase in *Eichhornia crassipes* or algal blooms. Its death and decay also deteriorates water quality (Patel, 2012).

Most of the species were introduced mainly from the tropical areas of Asia and America, which is in accordance with the findings of other studies conducted in different parts of the tropics. Species introduced from tropical origin adapt well in tropical destinations (Gautam and Shambhu, 2014). Water hyacinth is the prominent and very dangerous species invading Lake Tana that is expected to have tropical origin of Latin America.

Disturbance events increase resource availability and reset succession. This increases the chance of colonization and establishment for many invasive species. Disturbance events can be natural (floods, cyclones, landslides) or anthropogenic (eutrophication, land use change, clearing) (Gautam and Shambhu, 2014).

Firehun *et al*. (2014) showed that a positive relationship between human impact and the exotic species abundance in the lake ecosystems. Land use change facilitates the introduction of alien species. For the study area, exotic and native richness are significantly negatively correlated. This indicated that land use change intensity facilitates the introduction of alien species as studied by Patel (2012). Nutrient enrichment was found to support exotic species as reported by Gautam and Shambhu (2014).

Generally excessive growth of invasive aquatic weed like *Eichhornia crassipes* (Water hycine) can be used as bioindicator of water quality of lake Tana gradually degrading the lake due to various anthropogenic activities (Dipankar and Jayanta, 2015).

Northen part of Lake Tana becomes choked by water hyacinth, the number of birds, fish and other animals in the upper strata of the food chain decreases significantly as reported by Dipankar and Jayanta (2015) and the wetland is bare in the dry season as seen in the field survey.

4.4.6. Correlation among Different Macrophytes of Lake Tana Wetalnds

Table 4.9: Correlation coefficient matrix between different macrophytes of Lake Tana

	Apia Ceae	Ama ran tha ceae	Aste race ae	Cera top hylla ceae	Chen opodi aceae	Com melin aceae	Cyper aceae	Hydro charita ceae	Lyth Raceae	Mela stomat aceae	Nym phec eae	Poa Ceae	Poly gona ceae	Pon teder iaceae	Potam ogeto n aceae	Thely Pterid aceae	Tiliac eae	Typha Ceae
Apiaceae	1																	
Amaranthaceae	.669**	1																
Asteraceae	.856**	.910**	1															
Ceratophyllaceae	.866**	.802**	.878**	1														
Chenopodiaceae	.964**	.621**	.814**	.765**	1													
Commelinaceae	.833**	.873**	.940**	.896**	.774**	1												
Cyperaceae	.759**	.824**	.894**	.953**	.659**	.900**	1											
Hydrocharitaceae	.624**	.953**	.893**	.686**	.621**	.828**	.718**	1										
Lythraceae	.871**	.812**	.923**	.935**	.776**	.958**	.934**	.725**	1									
Melastomataceae	.637**	.649**	.771**	.789**	.523**	.759**	.902**	.523**	.830**	1								
Nympheceae	.701**	.710**	.774**	.934**	.610**	.842**	.933**	.610**	.855**	.775**	1							
Poaceae	.856**	.888**	.961**	.949**	.792**	.982**	.953**	.828**	.968**	.802**	.891**	1						
Polygonaceae	.578**	.672**	.621**	.797**	.438*	.674**	.792**	.423*	.755**	.759**	.709**	.717**	1					
Pontederiaceae	.735**	.820*	.878**	.788**	.713**	.915**	.810**	.811**	.846**	.653**	.742**	.900**	.548**	1				
Potamogetonaceae	.568**	.453*	.520**	.708**	.327	.562**	.653**	.293	.691**	.640**	.600**	.586**	.695**	.402*	1			
Thelypteridaceae	.493*	.407*	.458*	.655**	.242	.505*	.609**	.242	.637**	.608**	.559**	.528**	.673**	.346	.996**	1		
Tiliaceae	.964**	.668*	.836**	.905**	.858**	.832**	.803**	.581**	.903**	.704**	.741**	.857**	.676**	.704**	.767**	.707**	1	
Typhaceae	.810**	.768*	.891**	.941**	.716**	.930**	.973**	.669**	.971**	.883**	.905**	.958**	.772**	.834**	.661**	.612**	.846**	1

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

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

Except Chenopodiaceae and Potamogetonaceae, Chenopodiaceae and Thelypteridaceae, Hydrocharitaceae and Potamogetonaceae, Hydrocharitaceae and Thelypteridaceae, Pontederiaceae and Thelypteridaceae, Potamogetonaceae and Chenopodiaceae, Potamogetonaceae and Hydrocharitaceae, Thelypteridaceae and Chenopodiaceae, Thelypteridaceae and Hydrocharitaceae and Thelypteridaceae and Pontederiaceae all the families in Table 4.9 correlated with significant level 0.01 and 0.05.

Hydrilla verticillata, *Vallisneria spiralis*, *Chara sp*., *Nitella sp*. were found to be association with *Vallisneria spiralis*, *Potamogeton*, *Ceratophyllum demersum* (Dhore and Lachure, 2014). *Ottelia allismoides*, *Valisneria spiralis* found to be associated with each other. The study represents the aquatic vegetation of different wetlands in Yavatmal district as reported by Dhore and Lachure (2014).

The positive correlation between taxa suggests that macrophyte assemblages are influenced by common external factors such as nutrients, temperature, depth of the water body, climatic conditions, etc (Anderson and Sidinei, 2007).

Dipankar and Jayanta, (2015) and Chatenet *et al.*, (2006) pointed out aquatic plants like *Lemna sp*, *Eichhornia sp*, *Myriophyllum sp* and *Potamogeton sp* as pollution indicator. *Potamogeton sp, Trapa sp, Marsilea sp* and *Cyperus sp were* also reported as pollution indicator. Vis *et al.*, (2007) studied as populations of *Myriophyllum alterniflorum* L. as bioindicator of pollution in acidic to neutral rivers in the Limousin region, France; macrophytes in and around a water body plays important role in determination of hydrobiological and trophic status of ecosystems. According to a study of Dipankar and Jayanta (2015), eutrophic conditions can be generally characterized by increasing number of aquatic plants in water body. But aquatic macrophytes have advantages like, maintaining O_2-CO_2 balance, provide food to some herbivorous fishes and they also provide protection to tiny fishes from aggressive predators (Das *et al*., 2009; Dhore and Lachure, 2014).

Janne (2011) identified native species richness to be the most important predictor for both the diversity and abundance of alien species. A decrease in the percentage of alien species with the number of native species is expected in any case assuming regularly distributed area and exotic species richness. For the relationship between exotic and native species richness, however, controversial results have been reported inducing a debate as the "invasion paradox" (Janne, 2011; Gautam and Shambhu, 2014).

Janne (2011) found positive relationship between native and non-native species richness for studies conducted over broad spatial scales, while fine scales and in particular experimental settings support a negative relationship. The discussion is mainly based on the large number of studies in temperate systems. In general, disturbed areas are suspected to support exotic species invasions (Gautam and Shambhu, 2014)

4.4.7. Pollution Indicator Macrophyte species

Pollution Indicator Macrophyte species (Hanganu *et al*., 2008) are given in Table 4.10. Some of the indicator species were found in the composition of Lake Tana macrophytes. Some of these were *Ceratophyllum demersum, Nymphaea spp, and Potamogeton natans.*

Table 4.10: List of pollution indicator macrophyte species (Hanganu *et al*., 2008)

A. Sensitive species	**B. Tolerant species**	**C. Indifferent species**
Chara globularis	*Hydrocharis morsus-ranae*	*Ceratophyllum demersum*
Elodea canadensis	*Nuphar luteum*	*Elodea nuttallii*
Nitella flexilis	*Nymphaea alba*	*Lemna gibba*
Nitellopsis obtusa	*Nymphaea candida*	*Lemna minor*
Nitella mucronata	*Nymphoides peltata*	*Lemna trisulca*
Potamogeton gramineus	*Potamogeton lucens*	*Myriophyllum spicatum*
Potamogeton nodosus	*Potamogeton perfoliatus*	*Myriophyllum verticillatum*
Potamogeton mucronatus	*Potamogeton pusillus*	*Najas marina*
Tolypella glomerata	*Potamogeton natans*	*Potamogeton crispus*
	Ranunculus aquatilis	*Potamogeton berchtoldii*
	Trapa natans	*Potamogeton compressus*
	Zannichellia palustris	*Potamogeton trichoides*
		Potamogeton pectinatus
		Salvinia natans
		Spirodella polyrrhiza
		Stratiotes aloides
		Utricularia vulgaris

Although macrophytes are regarded reliable indicators of trophic status in aquatic environment, macrophyte species richness is generally considered a poor indicator of habitat quality. This is why aquatic macrophyte monitoring is mainly based on numerical indices considering presence and abundance of indicative plants (Szoszkiewicz *et al.*, 2010). To confirm our results with respect to species number, the revealed relationship should be tested on a larger set of data representing a longer trophic gradient as indicated by Szoszkiewicz *et al.* (2014). With this gap the sample analysis revealed that the ecological potential of the Lake Tana was assessed as “Moderate”.

CHAPTER 5

THE IMPACT OF ANTHROPOGENIC ACTIVITIES ON LIVELIHOOD OF LAKE TANA VICINITY COMMUNITY

5.1 INTRODUCTION

Humans are an integral part of the ecosystem and hence influence and are influenced by ecosystems. The main direct drivers that lead to changes in Lakes and Lake wetland ecosystems around the world emanate from land use/land cover changes as a result of agricultural activities (Bergström *et al*., 2011). The indirect drivers of aquatic ecosystem changes include population growth rate, institutions and policies and economic factors such as globalization, trade and markets (Tihut, 2009). In general, changes in population, technology and lifestyle indirectly affect lake ecosystems (Margaret, 2013). As many other countries challenged in the world, population rise, urbanization, agricultural development, industrialization and other development activities have resulted in a degradation of aquatic ecosystem of Lake Tana (Dereje, 2014).

Lake Tana has much national significance: great potential for irrigation, hydroelectric power, high value crop and livestock production, ecotourism and others. Tana sub-basin is one of the five growth corridors in Ethiopia due to abundant water resources, productive land and relatively developed infrastructure (Fanny, 2012) and significantly contribute to the livelihoods of millions of people (Fanny, 2012; Gemechu, 2010). Lake Tana and its wetlands are under very high human impact that leads it to be lost. Hence, to the mitigation and remediation action, identifying the impact levels and their sources is unquestionable. It is against this background that this chapter focuses on the understanding of the pattern of livelihoods of people living in Lake Tana vicinity.

5.2 RESEARCH QUESTIONS

1) What are the significance of Lake Tana and its wetlands resources?
2) What are the means of livelihood to surrounding people of Lake Tana?
3) What are the major threats of Lake Tana resources?

5.3 OBJECTIVES

1. Identify the types of Lake Tana and its wetland resources
2. Examine the means of livelihoods of the people of Lake Tana and its vicinity
3. Identify the major threats of Lake Tana and its wetland resources

5.4 MATERIALS AND METHODS

5.4.1 Methods of Data collection

Data was collected in the year 2014/2015 and qualitative research method applied to collect data on Lake Tana resources and livelihood of Lake Tana communities. Qualitative research methodology produces descriptive data as it is people's own written or spoken words and observable behavior (Zachary, 2008; Seyoum, 2011). The data was collected using the guding questions given in Appendix 14 and 15. The analysis of livelihood situation in the Lake Tana was descriptive,

5.4.2 Research design

The researcher hypothesized that (1) Lake Tana resources contribute significantly to the household economy of the local people. The data used for this study were derived from primary and secondary sources. Primary data for this study were drawn from sources: (a) in depth key informant interviews, (b) series of focus group discussion, and (c) direct observations.

The primary data were gathered through key informant interview, focus group discussion (FGD) and observations. Seven key informant interviews and five FGDs were conducted in the five study areas; one FGD in each study area, this was done to get information that are communal and institutional which have impact either positive or negative on livelihoods activities of the people; administered with the guiding questions (Appendix 12 and 13). FGD and KIs were organized from appropriate sectors who are mainly working on Lake Tana. Five FGD participants attended the meeting: local farmers, elder people and the head of a local conservation organization (adapted from Ajala, 2008; Zachary, 2008; Seyoum, 2011).

Key informant interviews (KIIs): were held with members and non-members of the community that are regarded as well versed with issues regarding the utilization of wetland resources in the area. Key informants interviewed included the Amhara Region Agricultural Research Institute (ARARI) officer, ARS (Amhara Regional State) Bureau of Environmental Protection Land Administration and Use (EPLUA) officer, a person who has worked in many researches and have projects on Lake Tana and from birth to work high experience of Lake Tana from BDU (Bahir Dar), The elder person who have experience on the lake Tana resource and its utilization at Gorgora, the agriculture development agent at Tana kirkos, Head of Tana Basin Authority, Lake Tana transport officer, Head of Bahir Dar city clean and greening office. Information collected through this method was crucial in developing a broad understanding of the main uses of the wetland in the area and the type of users utilizing these resources with the livelihood types and levels.

Focused Group discussion (FGD): discussions were made with a group of farmers and expertise composed of different social groups. The elders were important source of information sharing their observations and experiences on the change in the natural resource bases and their values. In light of this, various scholars suggest varying group sizes regarding FGD. For instance, 3-14 participants (Pugsley 1996; Thomas 1999); 6-9 participants (Krueger 1994, 1998); 6-10 participants (Morgan 1997); 6-12 participants (Johnson & Christensen 2004); 8–12 participants (Baumgartner *et al.* 2002) as the optimum size for FGD as cited by Creswell (2012). In this study a total of five focus group discussions were held on several issues pertaining to the utilization of wetland resources; total of 28 (5 female participant, one from each study area) people participated in the group discussions (Bahir Dar 7, Gorgora 6, Tana Kirkos, Megech and Ambobahir each 5 individuals in a group). Each group of 5-7 people is a mixture of both male and female, in the age range of 17 to 70 years. Issues discussed in the groups included ranking the most important wetland resources, rules and regulations that govern the access and extent of wetland resources and wealth ranking of community members.

Guiding questions were prepared to lead the discussions (Appendix 15). The major focuses of the discussions were to generate information at community level that can complement the survey data regarding the value and threats of wetlands. The discussions were also supplemented with personal observation of the facts on the ground. In depth interview was employed with 7 key informants that is selected through purposive sampling method, in relation to their responsibilities linked to environmental conservation. This helped to know the opinion, importance, interest, shortcoming, the interaction, awareness and commitment to cooperate with other stakeholders in the use and management of the lake resource.

Structured guiding questions facilitate the gaining of more in depth responses from the people about their experiences, perceptions, opinions, feelings and knowledge about life and activities around the lake (Zachary, 2008; Seyoum, 2011). Through this means detailed information about their general sources of living and broad view of life and society was illuminated thereby helping to indicate whether it was as a result of the agricultural and urban or from other sources activities the community livelihood dependent. This type of methodology gave the participants the opportunity to freely express their opinions regarding the emerging issues about the problems and their reactions. This was used in identifying resultant impacts on Lake Tana and their effects on the community livelihoods, whether positively or negatively. According to Yin (2003) as cited by Caroline *et al*. (2013), a case study about human affairs is best done by use of guiding questions to conversational interviews for good data collection. This is important because in the process of interview, the interviewer may get to learn more from the respondent in terms of unspoken gestures and feelings (Zachary, 2008; Seyoum, 2011).

During the FGD data collection, discussions were conducted with local people and different stakeholders either as individuals or as groups. By having a small informal group of 5-7 people, there were benefits of group interaction and greater participation to spark ideas that could not have come from the one to one interactions. This helps the researcher to get more respondents within the short period of field work (McCartney, 2010; Seyoum, 2011).

The interviews may yield biased outcomes due to poorly constructed questions; the response may be equally biased; inaccuracies due to poor recall and a situation where an interviewee gives what the interviewer wants to hear. In a situation like the case at the Lake Tana with mixed reactions (FGD, observation and document analysis) regarding the use of the wetland, it was possible to encounter such problems.

In focus groups, it was possible to have peer pressures to remain silent or readily agree to dominant views while the presence of others in the group may inhibit full and frank participation of other members. However, these drawbacks may have been overcome as more than one type of qualitative methods employed in data collection such as KII (Key Informant Interview), observation and document analysis which can complement the drawbacks.

Observations: Another qualitative research method in this study employed in data collection was the researcher's direct observations on the activities and physical environment. In this method relevant behaviors and environmental conditions were available for observation. By this method the daily activities of the people in the Lake Tana community in relation to earnings for their livelihoods provided, supplementary information were gathered. For example, observable physical indicators in connection with livelihoods and their sources: wetland, small scale farms, self-employment or the activities and employment at other forms of jobs. Some digital pictures were taken that help illustrate physical conditions and changes that were actually observable at the time of data collection. Direct observations offer additional information about the study and what takes place in the real world. Therefore, they are valuable and may require use of photographs as evidence to outside observers (Seyoum, 2011; Abha and Khundrakpam, 2012). Direct observation offers reality and covers context of events and it is equally time consuming as FGDs and KIIs.

Secondary data was from review of documents from published and unpublished materials such as books, journals, reports, maps, thesis's and photographic and from relevant offices (districts, local, regional and national offices, NGOs/CBOs) were made from the printed and electronic media and literature reviews.

It is, however, important to note that for high quality data, mixed approach data collection methods are recommended. Hence, this study combined interviews, observations, focus group discussions and secondary data and thereafter triangulates the gathered information to enhance data reliability and convergent validation for use in analysis and interpretation of the results.

5.4.3 Data Analysis

Data analysis was carried out using qualitative descriptions. The data collected through different instruments (key informant interviews (KIIs), focus group discussions (FGDs) and observation) were analyzed using descriptive statistics. Historical trend analyses of major changes in the Lake resource and the livelihood were used. This helps the researcher to draw some inference or to make some generalization from the collected data. Descriptive analysis was used to compare and correlate stakeholder views towards the wetland conversion into different uses and its impacts on the local people's livelihoods. Since wetland ecosystems are very complex and difficult to interpret only by qualitative descriptive, photographs were used to supplement ground truth data collection through field work, this is helpful to interpret changes detected on different land use for the comparison on the actual ground.

5.5 RESULT AND DISCUSSION

5.5.1 Lake Tana and its Wetland Resources

Lake Tana is a home of different flora and fauna including endemic species. The known forms of flora are macrophytes and forest resources which are used mainly for traditional medicine, fuel wood, rope, pole, habitat of birds, animal feed, etc. and the fauna which includes fish, hippos, crocodiles, invertebrates, etc. But also these forms of life make the area a good habitat for indigenous cattle breeds (Fogera breed) and filed crops gene center (Friedrich, 2012). This is true as per the key informants (KIs). The Lake Tana has a number of important habitats favorable to biodiversity. These are wetlands: floodplains, riparian, river mouth, lake shore, natural reservoirs (for wetland plant species like papyrus, typha and medicinal plants, breeding areas of endemic and migratory birds, microinvertebrates and fish), aquatic ecosystems: the lake and river mouths (16 fish species, wildlife like Hippopotamus, Crocodile and Nile monitor), habitat of the Fogera cattle breed: one of the best native Ethiopian milk cow breeds which is at risk of genetic dilution; and remnant church forests, known as islands of biodiversity (indigenous trees species, gene pools of wild coffee and field crop varieties, bird habitats) (Gebrekidan & Teka, 2006). 500,000 ha of Lake Tana is estimated as important bird areas that qualify as Ramsar sites (Friedrich, 2012). Field crop varieties which are found in the Lake Tana area include noug (*Guizotia abyssinica*), tef (*Eragrostis tef*) and mashila (*Sorghum bicolor*) (Ayalew, 2010)**.** Some of the indigenous medicinal plant forms known in lake Tana are *endod* (*Phytolacca dodecandra*), kosso (*Hagyinia abyssinica*), gesho (*Rhamnus prinoides*), *wanza* (*Cordia africana)* and girawa (*Vernonia amygdalina*) (Tihut, 2009; Teshale *et al*., 2011). According to Teklehaymanot and Giday (2007) as cited by Friedrich (2012), only from the natural forest of Zegie Peninsula 67 documented medicinal plants are found but documented woody plant species are 113 in Church forests of Zegie and in Bahir Dar Blue Nile River Millennium Park 140 woody plant species identified (Ayalew, 2010; Friedrich, 2012).

As per the study findings, Lake Tana and its vicinity resources are categorized as:

5.5.1.1 Land

Data on land resource utilization or land use system was collected from participants of the focus group discussion and KIs in all of five study areas. These types of information are useful to understand the value of the land resources in the wetlands. The major source of livelihood of the people in Ethiopia in general and the study area in particular is crop production. Both annual crops and perennial crops are grown in the study area. As per the response of FGD and KI participants, annual crops like maize, sorghum, rice and tef are cultivated in the area. Rice is one of the grains produced by majority of the farmers. During the focus group discussions and KIs the participants indicated that crop production is becoming impossible without fertilizer due to high soil degradation in the catchment that affected Lake Tana ecosystem. On the other hand the perennial crops have dual purposes. Production of fruits that can be consumed by the house hold or sold to generate income and ecological values since they help in maintaining the soil fertility, erosion control, and serve as shade trees. The study result is similar with the study of Gemechu (2010).

The FGDs result showed that in all study areas of Lake Tana the size of land per house hold declined during the last 20 years. The size of land for crop production, fodder production, private woodlots and private holding adjacent to the wetland areas declined over time due to increasing population pressure. Land was distributed by parents to the landless young farmers, resulting in small and fragmented farmland which was similar with the study of Erick *et al.* (2013).

Ethiopian wetlands support diverse crops that people growing in or around the wetlands for food or cash. A number of cereals, pulses, vegetables, oil crops and bulbs that grow on the Ethiopian up lands of the wetlands such as Lake Tana North western highlands. Wetlands also provide pasture for riparian keeping livestock with in and around Lake Tana and its surrounding supported the known Ethiopian Fogera cattle breed (Seleshi *et al.*, 2012).

5.5.1.2 Vegetation Resources

During field observation Pilla, Papyrus and other forms of macrophytes were common in Lake Tana. Molla (2010) as cited by Shimelis Aynalem (2011) identified 62 species of herb and grass species in Lake Tana (Ayalew, 2010). The wetlands around Lake Tana are dominated by Papyrus and Typha stands based on field observation and it was justified by the study of Shimelis Aynalem (2011) as cited by Teshale *et al.* (2011).

Forest Resources

The study area is covered by some natural forests particularly around the Zegie Penzula, Dek, Daga Estifanos, Kibran Gebrel, Tana Kirkos, Gorgora, Debre Mariam and many other church areas, largely dominated by wood land that are increasingly becoming more degraded. According to the key informants, 10 years ago, Zegie Penzula and Dek were densely covered by canopy of indigenous trees. These plants provide diverse benefits: support people's livelihoods, conserve the environment and used as shelter to wildlife.

The data collected using field observation and KIs showed as the area is known with upland montane forests species: dominated by Wanza, Besana, Abalo, Kuwara, Bamba, Warka, Zegeta, Wonahi and Dedeho. All these species are common in the church forests.

The high number of churches and monasteries with their culture to protect the surrounding environment and forest vegetation contributed to a high biodiversity in Lake Tana.

Zegie Peninsula, Daga Estifanos and Kibran Gegrel Monasteries and some others may be the only habitat forests remaining in the study area known by dry evergreen afromontane forests. They host several endemic and endangered species which were destroyed completely in other places over the last decades. The church forests are serving as insitu conservation sites (Teshale *et al.*, 2011).140 species of woody plants were identified in Lake Tana of which 13 are endemic that require special attention for conservation and rehabilitation (Marye, 2009) as cited by McCartney *et al.* (2010). Molla (2010) identified additional 28 species of woody plants as cited by McCartney *et al.* (2010) in addition to (Michael and Fanny 2013). Natural areas in the study area also provide wild fruits and other forest products for different purposes, like edible wild fruits such as Mimusops kummel, Cordia Africana, Syzygium guineense and Diospros mespiliformis. Mimusops kummel also has a medicinal value against stomach parasites and healing amoebic dysentery (Marye, 2010) as cited by Fanny (2012).

Indigenous agroforestry practice of keeping naturally regenerated trees on cropland is a common tradition. These multipurpose tree species are consciously planted and taken care of by the farmers because of their multiple benefits, including *Croton macrostachyus*, *Cordia africana*, *Faidherbia albida*, *Ficus thunninghii*, *Ficus sycomorus* and *Acacia seyal*. Eucalyptus (exotic species) woodlots in high density are standing and with short rotation periods are increasing in the Lake Tana area, especially in the south, south-east and North. Eucalyptus species are dominant in these privately owned plantation forests (*Eucalyptus globulus* and *Eucalyptus camaldulensis*) (Friedrich, 2012). But deforestation due to population growth and the associated expansion of farming, increasing demand for fuel, construction wood and charcoal are critical factors deteriorating forest resource in the lake and its wetlands. Charcoal production is becoming a serious cause for concern in the Lake Tana surrounding communities (Stave *et al*., 2017).

5.5.1.3 Wildlife Resources

During the field survey, there were a number of wild life resources observed in the study area. For example, there were a great varity of indigenous and migratory bird species that resides in the area; Pelicans were among the birds in the lake. In addition to the avifauna, large mammals have been in the area. There are many mammal species in Lake Tana. Some of the mammals found in Lake Tana as mentioned by FGD participants were monkey, great kudu, hippopotamus, bushbuck, crocodile, python, leopard, hyena, foxes. But, these mammals are now rare in abundance and species composition. These have been reduced or eliminated and its species composition affected by human disturbance (Friedrich, 2012). Hippopotamus *(Hippopotamus amphibius)* are the most prominent large mammal that are found in the inlet and outlet of Lake Tana. Higher mammals in Lake Tana are endangered by habitat fragmentation, overgrazing, farmland expansion, settlements, hunting and deforestation. Among the reptiles, python is critically endangered by habitat loss and hunting (Fanny, 2012). There are also small mammals like Rats, Mouse, and Rabbits found in the area. But due to the habitat degradation wildlife resources are threatened, endangered and extinct as argued by KIs and FGDs.

Lake Tana has been proposed as a Ramsar site of international importance as it fullfils its criteria. In some years significant fish tilapia cached in among which *Labeobarbus spp* was the dominant (Dereje, 2014). However, today fishing is not as it was in the Lake 10 years before. The surrounding lake side wetlands were appropriate site for arthropods required as food for fish and birds. Such nature of the lake makes Lake Tana and its wetlands an ideal site for bird area (Shimelis *et al*., 2011).

Twenty of the twenty seven fish species of Lake Tana are endemic to the Lake Tana catchment (Gebremedhin *et al*., 2013). Fishing is done by almost all communities in Lake Tana. Typical fish species caught are: *Oreochromis niloticus* (Karasso), *Clarias gariepinus* (Ambaza or African Catfish) and *Labeobarbus spp*. Overfishing has become a severe problem due to improved fishing skills, the use of modern equipment and technologies, the increasing number of fishermen and the destruction of aquatic vegetation and the associated factors (Friedrich, 2012).

The Lake Tana is also inhabited by globally threatened and migratory bird species and large numbers of waterfowls including Palaearctic and intra-African migrants (Fanny, 2012). Acording to Marye (2010) as cited by Friedrich (2012), more than 160 bird species were observed in the Blue Nile park of Lake Tana, including wetland birds, water fowls, riverine and woodland birds. Some of the common Lake Tana region bird species are Crane (*Grus grus*), Northern Shoveller (*Anas clypeata*), Northern Pintail (*Anas acuta*), Black-tailed Godwit (*Limosa limosa*) and Ruff (*Philomachus pugnax*). It provides habitats for several endangered and endemic Bird species, such as Wattled Crane (*Grus carunculatus*), Wattled Ibis (*Bostrychia carunculata*), White-collared Pigeon (*Columba albitorques*), Black-winged Lovebird (*Agapornis taranta*) and White-cheeked Turaco (*Tauraco leucotis*), Pallid Harrier (*Circus macrourus*) and Black-crowned Crane (*Balearica pavonina*) (Shimelis *et al*., 2011; Friedrich, 2012).

FGD discussants have explained that it has become common for them to see many dead fish and birds along the north side shores of the lake (Megech area). The reason might be pollution.

5.5.1.4 Cultural Landscapes

KIs argue that Lake Tana is the cultural landscape due to its churches and monasteries that was not exploited effectively as tourist site. Lake Tana has 37 islands and 16 peninsulas with 21 churches and monasteries constructed before 14th century. They are important cultural and religious heritages at the same time tourist destinations. Out of nine world heritages in Ethiopia, three are located in the Amhara Region: Lalibela churches, Gondar castles and Simien Mountains National Park (Friedrich, 2012). Recently, due to its unique cultural and natural reserves, Lake Tana has become a world heritage site (Fanny, 2012).

5.5.2 Functions of Lake Tana and its Wetlands

Lake Tana and its wetlands provisioning services are grazing field, subsistence farming, water collection, fishing, medicinal plants, hunting, harvesting (grass, poles, and papyrus), fuel wood and ropes collection, moulding bricks, grazing (pasture) and water transport and others as per the KIs and FGD discussants in February 2015.

As per the KIs (Bhair Dar University professor), wetlands of Lake Tana provide environmental services (Regulation services), such as carbon sink, absorb pollutants, control flood flow, absorb sediments, etc. and socioeconomic services for production of crops, fish and fodder. It was justified by the report of Gemechu (2010).

Lake Tana ecosystems have a high local and global significance as environmental and economic resource. Its ecosystems support a diverse flora and fauna. In 2004, the National Consultative Workshop on the Ramsar Convention and the World Habitat Society identified Lake Tana and the Fogera wetlands as potential sites for a biosphere reserve and wetland conservation (Friedrich, 2012).

Most study participants in the KIs and FGDs said they could derive more than the above mentioned wetland uses as a way of enhancing livelihood sources. They further said most of the uses were for household subsistence use with few options open for sale in the local markets, particularly fish, papyrus products, medicinal plants and materials for construction. However, water, fuel wood and grass are the most important resource utilized by the local community. FGD participants prioritize water to be the first benefit exploited from the Lake for both the domestic needs and for their animals, while grazing field as the second most important activity done in the wetlands. Other Lake Tana and its wetland uses in the third most important activity include papyrus collection and subsistence farming. From these results the use of the wetlands had greatly reduced thereby jeopardizing Lake Tana community livelihoods. It was true also in the study of Zachary, (2008). Changes in ground water levels, evaporation rates, droughts, floods and storm frequency have strong implications for wetland ecosystems (Emmanue *et al.*, 2011).

Lake Tana wetlands have a greater livelihood value. Some of the values are source of potable water, livestock grazing, subsistence harvests (farming), irrigation water, fuel wood, and fishing and for other socio-cultural uses. Wetland stakeholders can be divided as subsistence farmers, intensive farmers, ecotourism practitioners, fishery and managers of formal conservation areas (Turpie, 2010). All forms of stake holders are stakeholders of Lake Tana.

In the responses of key informants and focus group discussions similar views were reflected, more than 50 percent of benefits from Lake Tana and its wetlands were on a multiple use basis before 10 years ago. Now they are claiming as they have no much access of the resources due to degradation and hence their livelihood level has drastically decreased. A similar study by Zachary (2008) justified the KIs and FGD participants view. The Lake Tana and its wetlands provide several benefits that can be categorized into provisioning, regulation, supporting and cultural (amenity) functions indicated in Table 5.1.

Table 5.1: Ecosystem goods and services provided by Lake Tana and its wetlands (Adapted from Friedrich (2012) based on classification of Turpie *et al.* (2010); Stearner (2013)).

Ecosystem goods and Services	**Benefits to human wellbeing**
Provisioning (socioeconomic benefits)	
Food	Used as grazing sites/forage, crop production for rice, pulses, fruit, vegetables, Fish / seedling nursery site
Water	Water for livestock and domestic consumption and water transport
Energy	Fuel wood and hydroelectric power supply
Health	Better health through water purification / medicinal plants
Construction and material	Thatching grass for houses / Papyrus for construction and handicraft, clay for pottery, poles, fuel wood
Genetic resources	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species
Regulating services (ecological benefits)	
Hydrological Regulation	Groundwater recharge including maintenance of springs and moderation of stream flow and floods / water storage
Water purification	Pollutant filtration and sediment trapping
Waste treatment	Breaking down of waste, detoxifying pollution, dilution and transport of pollutants
Erosion regulation	Sediment and nutrient retention / protection of dams from siltation
Natural hazard protection	Flood control
Climate regulation	Creation of unique microclimates /wetlands are part of the carbon cycle or carbon sequestration (carbon sinks), but the opposite may be true
Regulation of pests and Pathogens	Change in ecosystem health affects the abundance or prevalence of malaria, bilharzia, liver fluke, black fly, invasive plants, etc.
Biodiversity	Habitats for biodiversity (Flora and fauna), such as birds (roosting and feeding and breeding areas (IBA)), habitat for pollinators, critical breeding, feeding or watering habitat for fauna populations

Supporting services	
	Nutrient cycle, crop pollination, photosynthesis, etc
Cultural and Scenic services	
	Education e.g. research, spiritual and religious e.g. Baptism, recreational use and enjoyment (Aesthetic and heritage) e.g. Habitat for biodiversity

(Adapted from Friedrich, 2012 based on classification of Turpie *et al., 2*010; Stearner, 2013).

5.5.2.1 Vegetation and Forest Functions

As per KIs and FGDs discussants, macrophytes have been used for ropes, house construction, breeding site for fish and other many benefits. Lake Tana wetland contains a diversity of flora (Stearner, 2013).

5.5.2.1.1 Forests Social Functions

"Forests are like houses" said FGD participant, a young man from Ambobahir. FGD participants said, local people cannot detach themselves with their forests and have a sense of responsibility, because they are merely dependent on them. For the people coming to and living in Bahir Dar, the forest is a place of relaxation, satisfaction and happiness. The natural aesthetics is highly valued by the elder FGD participant. But From a religious perspective the forest is seen as spiritual home and a place of praying for the monks and priests as per the FGD in Tana Kirkos. It is a living space for saints in the form of ghosts. People believe that the saints can only live in the forests. If the forest is cut, the saints will disappear. It was also justified by the report of Friedrich (2012).

5.5.2.1.2 Ecological Functions of Forests

FGD participants are aware of the ecological functions of forests. FGDs in Ambobahir, Gorgora, Bahir Dar and KIs said, the forests provide shade, moist and fresh air and precipitation. The litter will decompose and used as natural fertilizer. The forests prevent soil erosion and regulate the water cycle. Thus, on the shoreline of Zegie peninsula in Lake Tana a special tree species of *Syzygium guineense* are conserved and planted. This species is particularly important for the stabilization of the shoreline and for water storage (Misganaw and Getu, 2016).

The local people are aware of endangered species *Cordia africana*, *Ficus vasta*, *Juniperus procera*, *Olea africana*, and *Podocarpus falcatus*. Indigenous species are preferred for new plantations, particularly *Cordia africana*, *Olea Africana* and *Croton macrostachyus* due to their benefit preference by the FGDs. Cordia africana is planted to preserve the species and to sell it as a high quality timber on local markets. As indicated by FGDs people have knowledge about endangered species, their preservation as well as the ecosystem services and habitat for wild life.

The local community perceived the consequences of deforestation to loss of wild animals and climatic changes with rising temperatures and seasonal fluctuations of rainfall and drought as responded by the FGDs and KIs. It is assumed that in the future, poverty and food insecurity will occur due to poor harvests, health problems, such as malaria because of rising temperatures, will emerge and death and migration of people and animals of the forest will increase as a result of climate change (Stave *et al*., 2017).

5.5.2.1.3 Economic Functions of Forests

The field survey justified that in Zegie peninsula the forest is the main source of income from the sale of fuel wood and Timber for the community. Coffee (*Coffea arabica*), gesho (*Rhamnus prinoides*) for production of local beer "Tela" and various fruits (*Carica papaya*, *Citrus aurantium L., Citrus aurantifolia, Magnifera indica, Persea americana*) are grown and beekeeping practiced as sources of income to Lake Tana community as per the KIs and FGDs in all study areas. In addition, grass is harvested on area closure sites as fodder and to roof cover.

The marketing of natural products (coffee, honey, cosmetics, and medicinal plants) are promising alternative income generation sources to the Lake Tana communities, particularly for young landless people. But Illegal logging is common practice in Lake Tana area. Therefore, better financial source alternatives to the local people would moderate illegal logging (Albinus *et al*., 2008).

In Daga Estifanos and Kibran Gebrel, the use of the forest resources is forbidden for the local communities. The people benefit only indirectly from the forest with produced fresh air and precipitate. The church forest is used by the monks and priests for the production of handicrafts, beekeeping and harvesting of fruits and it is justified by the report of Friedrich (2012).

From field observation it was understood that in many parts of Lake Tana the use of the forest as source of timber forbidden, therefore the benefit of the community in terms of income generation is less. Thus, they have low sense of ownership for the forest. Nevertheless, there are people who appreciate the forest for its own sake (existence value). For instance an old man in Ambobahir from FGD participants said as he would preserve the forest to leave to his grandchildren and future generations.

5.5.2.2 Fisheries

In the field observation it was seen that traditional fishing was done with papyrus boats and subsistence based to fish tilapia. It was also investigated by the KIs as fishing and associated businesses are a source of life to communities living around Lake Tana. FGDs also confirmed that fishing supplemented to the daily diet and source of income to Lake Tana communities. This result coincides with the report of Dereje (2014). According to the BoFED (2011) as cited by Fanny (2012), 150,000 qt./year of fish is estimated to be produced from the lake Tana but the potential for fish production of 13,000 t/a, including *Tilapia* breed (Historically, fishing was not an important income activity, because fish was mainly eaten during the religious fasting periods (Gordon *et al.*, 2007). However, with the growing urban population, tourism and changing diets due to different reasons, the demand for fish is increasing. Through the introduction of motorized fishery in 1986, fishery became commercial and fish catch of Lake Tana has increased. Traditional fishing of catfish by spear in the night, traps, hooks and lines are common in Lake Tana communities for income generation and subsistence (Dereje, 2014).

5.5.2.3 Energy

It was observed in the field observation as well as in KIs and FGDs indicated that biomass is the main source of energy (fuel wood, cow dung and crop residues) in the study area which leads to an alarming depletion of forest resources. As a counter strategy and to meet the future energy demand the government of Ethiopia is promoting the construction of hydroelectric power supply for the growing population of Ethiopians and the neighboring countries such as Sudan, Djibouti, Kenya and South Sudan. In the Lake Tana, the Tana-Beles hydroelectric power station has been constructed, which annually diverts approximately 2,985 million m^3 of the lake water into the Beles River through 11 km tunnel to generate 460 megawatt (Friedrich, 2012).

5.5.2.4 Water Transport

In Lake Tana water transport takes place from Bahir Dar to Zegie, Esy Debir, Delgy, Gorgora and Tana kirkos via Tana transport boats. KIs and FGDs also confirmed as some households use motorized small boats for transportation in all corners of Lake Tana (on average, a boat can carry 20 people per trip) and traditionally made papyrus boats. The average income per household engaged in motorized boat water transport is 500 Birr per day, the information collected during field survey.

5.5.2.5 Agriculture

The information collected through field observation, FGDs and KIs indicate that the local population depends on the wetlands of Lake Tana for rice production and cattle grazing. Apart from, rice and livestock communities also produce maize, peas and sorghum. Wetland people are practicing similar agricultural activities as indicated in the study of (Stearner, 2013). Thomson (2006) as cited by Stearner (2013) reported that the sustainability of agricultural production depends on the availability of water in the wetlands. He indicated that during dry seasons the practice is low.

The removal of natural forests for expansion of settlements and farmland exert a high pressure on Lake Tana and its wetlands. Overgrazing and extensive use of vegetation (Papyrus and Typha) prevail Lake Tana degradation from diverse point of view. In the course of the urban expansion, there is an increased competition between farming and building construction (Friedrich, 2012).

5.5.3 Ecosystem goods and services provided by Lake Tana wetland

Lake Tana wetlands ecosystem goods and services were assessed based on four services upon the collected data during field surveys. The goods and services that are provided by Lake Tana wetlanda are summarized in Table 5.1 and Figure 5.1.

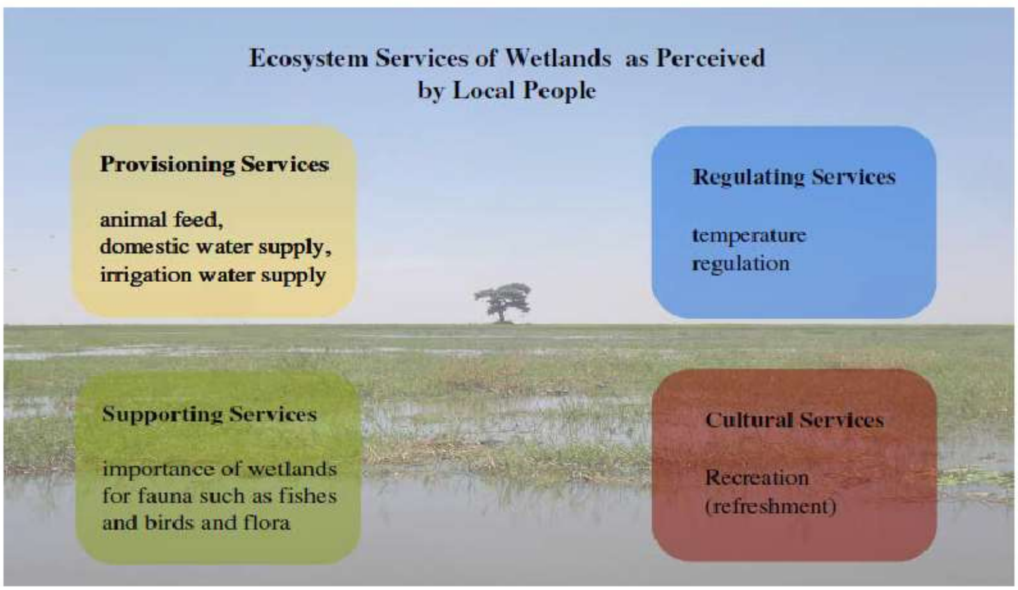


Figure 5.1: Ecosystem services of wetlands (Springsguth, 2011) as cited by Friedrich (2012); Stearner (2013).

5.5.3.1 Provisioning services

The provisioning services are one of the most important services of Lake Tana and its wetlands performing. The communities of the surrounding villages depend on various goods and services from it. There is a variety of goods (listed in Table 5.1) that are obtained from the Lake Tana and the surrounding wetlands.

It was investigated in the Field observation, KIs and FGDs agreed that Fish and crop production are the main goods which contribute to the livelihoods of the Lake Tana communities. The main crop types which are grown are rice and maize for both home consumption and income. The area is also important for bee keeping and livestock raring. This study result is similar to the report of Stearner (2013).

Fish forms, the main sources of income for Lake Tana communities and the dominant fish species found in Lake Tana include *Oreochromis shiranus*, *Tillapia rendalli*, *Clarias gariepinus* and *Barbus paludinosus*. The marshes of the Lake Tana wetlands provide the breeding habitat for fish (Stearner, 2013).
FGDs showed that the communities also obtain building materials such as grass, ropes and poles for their housing. Raw materials like ropes, poles and fuel wood are harvested in smaller quantities because of deforestation. And it is true Lake Tana provides water for both domestic use and irrigation agriculture as well as for livestock. The community of Lake Tana depends on shallow wells and directly from the lake for the water supply. The lake is also used for water transport by Tana transport organization and rural communities using boat. It is a similar result with the result of Stearner (2013).

5.5.3.2 Regulating Services

The only benefit that was easily identified in the wetland under this service is the water regulation service (water table recharge and discharge) which is the source of water supply from wells and boreholes for the surrounding communities. The wetlands also provide water for dry season farming (Yuerlita, 2013).

Lake Tana wetlands regulate the flood drained by inflow streams to Lake Tana. It was identified as per the KIs wetlands of Lake Tana are reducing the risk of floods in the surrounding villages and crop fields. However, there are more benefits from this are waste treatment, climate and rainfall regulation, reduction in the spread of diseases, etc..

Wetlands of Lake Tana are important for the ecosystem stabilization. Hence, alteration of these wetlands can affect the whole dynamics of the Lake’s ecosystem. But also the wetlands are important for the filtering of sediments and purification of waste waters (pollutants) which come into the lake from the catchment. Hence conservation of wetlands is unquestionable to cope up with the increasing discharge of pollution and sediments from the catchments. Lake Tana wetlands are also critical for groundwater recharge and this is important in terms of drinking water supplies and maintaining the water table of the surrounding areas (Berhanu *et al*., 2001).

5.5.3.3 Supporting Services

Among the benefits that are accrued from the Lake Tana and its wetlands are supporting flora and fauna. Some to mention are the nutrient cycling, soil formation, crop pollination (important for crop production), fish, livestock production, etc. Photosynthesis is another indirect service that the wetland provides as primary benefit to biodiversity in the wetland ecosystems according to the information gathered from KIs. This result is similar to the result of Stearner (2013).

5.5.3.4 Cultural services

Lake Tana churches and monasteries have great cultural significance. These non-material benefits are contributing to human wellbeing via the direct economic benefits of their exploitation, tourism (Scenic) and their psychosocial value, spiritual (religion) that the Christians use the wetland for baptism. The benefits that are also provided by Lake Tana is the educational value for scientific research. Currently fisheries research is common in Lake Tana. The wetland also supports a wide range of biodiversity which is potential for eco-tourism. All these services were mentioned by KIs. The studies of Fanny (2012) also dictated the same result.

5.5.4 Threats and Challenges of Lake Tana

Lake Tana is exposed to a set of interrelated environmental problems induced by human influence such as deforestation, erosion, sedimentation, water level reduction, erratic rainfall, flood, and competition for water resources, pollution and introduction of alien species affecting local species´ gene pools (Ayalew, 2010). One of the major underlying forces that endanger the ecosystems and biodiversity of Lake Tana is population growth that exerts resource use pressure. Overgrazing, farmland expansion, cultivation of marginal lands (shorelines), encroachment of communal land and vegetation removal to meet demand for food and fuel wood are the very much observed danger to the Lake Tana survival. Other underlying causes that threatening biodiversity and forests in particular are limited governmental, institutional and legal capacity (Gemechu, 2010).

Shortage of agricultural land derived from increased human and livestock populations, the low awareness of communities regarding the ecological benefits of wetlands and the lack of technical and financial support for wetland conservation are underlying factors exerting pressure on the wetlands (Lamsal *et al.,* 2015). The lack of conservation and sustainable use of wetlands are (a) political shortcomings (giving high priority to short term economic benefits rather than to sustainability issues) (b) the absence of policy and a strong legal framework for the conservation and sustainable use of wetlands, e.g. change in grazing system towards year-round grazing due to land ownership as communal grazing land, (c) institutional shortcomings by the absence of legally structured institution or within existing institutions responsible to Lakes and wetlands and (d) socio-economic and environmental shortcomings such as poverty, lack of awareness, population pressure and climate change (Friedrich, 2012).

Farmland expansion on wetlands is linked to the intensification of cultivation and the introduction of rice. One reason for the conversion of wetlands is the area despite their benefits; wetlands are seen as wastelands and mosquitoes as well as other diseases breeding sites and flood plains. So that government policies usually encourages wetland draining (Friedrich, 2012; Stave *et al*., 2017).

Wetlands produce an ecological equilibrium in the environment by maintaining the integrity of life support systems for sustainable socio-economic development. There is little or no awareness of the current status, threats or values of the lake and its wetlands, even the need for their conservation and sustainable utilization in the study area. Therefore, there are different threats to Lake Tana and its wetlands. These could be broadly divided into natural, population pressure, and overexploitation resources and lack of institutional coordination (Gemechu, 2010).

5.5.4.1 Climatic Change

The annual variation in rain fall and water inputs is also significant and exerts pronounced impacts of climate change on Lake Tana and its wetlands. Freshwater and run-off discharged to Lake Tana is increasing, at the same time due to invasive species and high temperature the evaporation rate of Lake Tana increased by promoting chemical concentration of the water as raised by the KIs.

During the focus group discussions, they were asked how they perceived the annual crop yield trends in the area; they responded that it is decreasing since the area is vulnerable to rainfall pattern fluctuation. Sharing this view, some of the FGD participant elder men of the local community mentioned that in the dry season the amount of water flowing is drastically reduced and most of the time the channel remain bare up to the rain is coming. The flow of Megech, Gumara, Gilgel Abay, Rib and Dirma the main feeder rivers of Lake Tana erupted and that helps to the shrink of lake Tana as compared to fifteen to twenty years ago. Regarding the lake water and the moisture of the wetlands, FGDs raised that the Lake water size fluctuate in size according to the precipitation trends in the adjacent highlands. Cherechara wiry (Dam) and Tana Beles hydroelectric project are factors to Lake Tana water fluctuation and disruption.

Besides global climate stressors, the main driving forces in declining of precipitation pattern are mainly the changes in vegetation cover. The regional climate shows an increasing trend in rainfall variability that causes droughts and floods around Lake Tana (Stave *et al*., 2017).

As wetlands can be sinks and sources of greenhouse gases, there is a reciprocal relationship between wetlands and climate change. Wetland degradation exacerbates climate change which in turn can cause wetland degradation through increased extreme weather events leading to floods and drought. Properly managed wetlands can contribute to climate mitigation or carbon sink (Lamsal *et al*., 2015). The impacts of climate change on wetlands are expected to be tremendous due to their highly vulnerable hydrological regimes. Because, wetlands Flora and fauna is sensitive to small changes in the water level and temperature and stressed by pollution. On the other hand wetlands play an important role in creating ecological benefits for climate protection for the following reasons: carbon sink, buffer for extreme weather events like floods and droughts, regulating stream flows by storing and slowing down flood flows, retain polluted floodwaters and improve their quality, reduce peak water flow by delaying and storing flood water and recharge groundwater during rainy season and availability during droughts (Ayalew, 2010).

Some flora and fauna species are particularly at risk by climatic stress, like *Cordia africana, Olea europea* (olive)*, Juniperus procera* (East African juniper) and *Hagenia abyssinica* (African redwood) and fish like *Labeobarbus* in Lake Tana (Friedrich, 2012). The livestock productivity is also threatened by climate impacts on the quantity and quality of forage as well as by the spread of disease (Stave *et al*., 2017).

5.5.4.2 Population Pressure

The population of Ethiopia is growing at a rate of 2.5-2.9% per year (Gemechu, 2010); this is also true in the Lake Tana region. This demands the expansion of agricultural land to feed the rapidly growing population.

The focus group discussants were asked whether there was increased in population growth or not in the area. They responded that if they compared the population number of the area before 20 to 30 years ago with that of today, high population number was observed today. As a result, the people are forced to find an extra farming land to feed their family. Due to this increasing population Lake Tana and its resources were over exploited. This was supported by key informants. Thus, the growth of population resulted in enforcing the people to encroach the wetlands in the area and practicing recession farming, apparently over exploiting other resources. Therefore, Lake Tana is under continual threat of deforestation and wetland degradation due to population growth. This is also true in the report of Stearner (2013).

5.5.4.3 Poverty

Even if agriculture is the main sources of livelihood that could satisfy almost all people of the Lake area, there are some who are food insecure; especially in the urban centers as per KIs and FGDs. Shortage of animal feed as seen in Figure 5.2 and high rate of livestock diseases are other factors which aggravated poverty in the area. The study area also suffers from rainfall pattern change that significantly affects agricultural production and productivity. Hence, intensive cutting of trees as an alternative means of livelihood, source of income and energy for the local poor accompanied by unsatisfactory farming and livestock herding, aggravate the overall utilization of the wetland resources of the lake. This was also true in the report of Michael and Fanny (2013).

Figure 5.2: Photo showing over grazed land in Megech area, by the researcher (2015)

5.5.4.4 Endangered Fish Resources and Bird Species

Twenty of the twenty seven fish species of Lake Tana are endemic to the Lake Tana catchment (Friedrich, 2012). Despite the unique fish biodiversity and its high economic value for Lake Tana, fish resources are under pressure from several threats. According to the KIs, the major threats are illegal fishing and habitat destruction (wetlands, rivers and the lake itself) due to the human intervention.

The fish breeding sites are destroyed by the removal of vegetated shores and river mouths along the lake. Dangerous fishing techniques (gillnet) threaten *Labeobarbus* having caused a 75% stock decline in the 1990s (Friedrich, 2012; Stave *et al*., 2017). The Lake regulation by dam constructions leads to environmental degradation and further decline of the fish resources (Stave *et al*., 2017).

Regarding ecological significance, the study area is known for its Important Bird Areas (IBAs) and its support of globally threatened bird species (Stave *et al*., 2017). Government officials interviewed, as well as regional offices indicated that the fish resources are threatened due to ecological degradation caused by drainage and channeling, invasion by alien species and farmland expansion in the area.

5.5.4.5 Land Use Change

In light of the recent severe environmental degradation in developing countries, monitoring and analysis of land use/cover changes has become very critical as land use/cover changes have significant impact on basic processes such as biogeochemical cycling, soil erosion and biodiversity (Michael and Fanny, 2013). In Africa, it is estimated that five million square kilometers of land is moderately to severely degrade due to rapid land use/cover change which have been caused by population pressure, agricultural expansion, deforestation, mining, poor land management and recurrent droughts (Gemechu, 2010). Traditional agricultural practice is the major cause to the study area land use/cover change (Michael and Fanny, 2013).

Agriculture is the most and important economic sector which is key for food security. The agricultural production is mainly based on smallholder farming and livestock raring. Securing food supply is an overall objective of agricultural activities. Wetlands play an important role for food security, because they provide a wide set of ecological and socio-economic benefits for local livelihoods, particularly in dry seasons and drought periods, including: water, sedge, fish, fodder, craft materials, medicinal plants and crop and livestock production. The conversion of wetlands creates benefits for small segments of the community while destroying the resource base of poor households and women (Stave *et al*., 2017).

Wetlands resource utilization issues are becoming increasingly challenging. Ethiopian people wetlands dependency has long history but limited information. Therefore, wetland information is part of wetland conservation plan. This study data and information would be useful as a land use planning tool.

Land issue discussed during key informants and focus group discussions in terms of ownership, access, control and use. In all the sessions, all the respondents narrated the history of the Lake Tana dating back 20 years and above. The level of degradation is severe expected to be more than 85%. For a long time, the local people accessed it and used in their various daily activities on free access basis to their livelihood. As a result the community lost wetlands, one of the most important capital assets for their livelihoods. This is clearly reflected in their responses during both key informant and focus group discussions where more than half of the respondents accused of local politicians and the local authorities for wrongly concluding their relation with the investors in depriving their source of livelihood by perceiving them as the net beneficiaries of the development project at their expense. This is one of the reasons local community claimed the government to increasing poverty in the area. However the local authorities disagreed with this view as per KIs and FGDs.

According to the findings of the study, Lake Tana has undergone tremendous changes over time ranging from communal and government owned extensive uses for natural resource extraction to conversion into agricultural use up to the present status where a private investment companies took the Lake Tana shorelines caused a major impact that has elicited the present controversy over ownership and use of the Lake Resources. While some FGD respondents from the community felt have benefited from the new privatized venture through increased employment opportunities, improved infrastructure, increased food production, etc. On the other hand respondents who depend on fisheries of the lake fear that the lake is in danger of ‘pollution’ and hence loss of the biodiversity including the fish, their main source of livelihood.

There was evidence of over-exploitation of Lake Resources adjacent to urban centers. The fishers in the FGD said that because some members of community no longer do subsistence farming at the lake wetlands any more as land is limited; they have resorted to fishing with local authorities grouping as job opportunity. It was observed in the field study, at the Northern and eastern part of the lake, more land use changes have been with new activities being initiated that included rice farming and horticulture ever before the grazing land.

Lake Tana degradation caused by: deforestation, overgrazing, unsustainable agricultural practices and wetland degradation. The lakes resilient capacity to stress has lost from sediment loads and farming conversion, pollution and recession farming. Lake Tana was known with high diversity of fauna and flora but several of the species are endangered and extinct due to Lake Tana degradation. In particular the degradation of forests and wetlands has caused severe habitat destruction for both flora and fauna. As a result, various species are very few in numbers and are at the risk of local extinction (Seleshi *et al*., 2012).
Compare to 20 years back and today the major land use change observed by the farmers due to conversion of communal grazing lands and wetlands to cultivated land as a result of an increasing population pressure. Formerly, the Fogera floodplains had mainly been used for livestock grazing before they were changed into arable land of rice (*Oryza spp.*) cultivation and to some extent replaced other crops such as tef (*Eragrostis tef*) and maize (*Zea mays*). It is also justified by literature (Friedrich, 2012).

The farm land has become scarce and pasture land for an increasing number of livestock overgrazed. Sedimentation processes have accelerated favoring the cultivation of lakeshore areas and river banks rather than making use of them as pastures (Caroline *et al.*, 2013). Flood occurred more frequently and recession farming aggravated Lake Sedimentation that reduced water level of Lake Tana. Typical wetland plant species like Papyrus (*Cyperus papyrus*) have radically been declined in their distribution or even became locally extinct (Springsguth, 2011) as cited by Friedrich (2012). As a consequence, the deltas of the main tributaries are affected by sediment. Between 1986 and 2010 for example the Gilgel Abay Delta increased by 586.1 ha (49.8%) and the Gumara River Delta by 101.6 ha (218.4%) respectively (Friedrich, 2012). It is also shown in Figure 5.3. The soils are highly susceptible to erosion with a high rate of surface erosion. The usually fertile topsoil is transported into the river systems and consequently causing sedimentation of the lake. 91 % of sediment accumulates in the lake are originated from human induced soil erosion on arable, grazing and forest lands in the catchment (Fanny, 2012). As a result of soil loss, the overall biomass productivity including crops and fodder is being reduced. The overall ecosystem integrity as well as crop diversity declined. This in turn affects food production and income for farmers by exacerbating poverty (Erick *et al*., 2013).

"a" "b"

Figure 5.3: Lake Tana River Delta growing from sedimentation ("a" Gilgel Abay Delta and "b" Gumara Delta) (Friedrich, 2012).

Lack of legal grounds on land use planning and system are some of the gaps that help to the Lake Tana degradation. Some of the observed gaps were:

5.5.4.5.1 Land-use Systems in Wetlands

Land ownership determines the management of wetlands and can be divided into the following types (a) Individual holdings of cultivated wetlands, (b) communal grazing wetlands with free access as a common resource and (c) state holding: large swamps and lakes. Cultivated wetlands are small pockets for thatching and fodder grass managed by individual, groups and public institutions (schools, churches). On communal land there are some management committees of the local community that protect the papyrus stocks and surrounding forests from illegal clearing (Ayalew, 2010). But all the mentioned ownerships are not governed by legal ground or community bylaw.

5.5.4.5.2 The Land Tenure System

Land as a resource belongs to one of the most sensitive topics triggered by farmer's concern. Land tenure insecurity and unclear land tenure and land use rights are causes of unsustainable resource utilization (Stave *et al*., 2017). This is true in Lake Tana.

5.5.4.5.3 Registering Recession Farmland

Farmers have followed the receding Lake Tana for many years to recession farming as seen in Figure 5.4. The land tenure status of recession farmland varies from *kebele* to *kebele* and sometimes even from village to village. Does recession farmland belong to the lake and is therefore held by the state? Is recession farmland private land cultivated by a farmer for his whole life? Even officials are confused by the holding rights of recession farmland. In some villages recession farmland is not registered and in some other villages it is. In some villages it is registered as communal land and in some other villages as private land. Before 2004 recession farmland was held communally in Libo Kemkem until the administration of a *kebele* decided to allocate this land to people. Thus, during the land registration process in 2004, it was registered as private land as reported by Friedrich (2012).

Figure 5.4: Recession farming at Tana Kirkos area, by the researcher (2015)

5.5.4.5.4 Registering and Delineating Wetlands

The same is true for wetlands as the recession farming. The land tenure status and even the definition of wetlands are unclear to the expertise. Farmers considered wetlands to be communal holdings. But some experts argued that wetlands could not be defined as communal lands according to the revised Amhara National Regional State Rural Land Administration and Use Proclamation No. 133/2006. Therefore, wetlands are not expected to be plotted for registration. Practically, wetlands are registered in some Kebeles as communal land but in some others they are freely accessible to all people. Besides, a delineation of wetlands by Environmental Experts in the *woreda* (district) level remains to be confusion. For this reason, there has to be a clear, consistent definition of wetlands taking into account the various wetland types and their registration (Friedrich, 2012).

5.5.4.6 Deforestation

The causes of deforestation mentioned by the local communities in the FGDs are poverty and low income. The rainfall declined in the last 20 years and shifted seasonally. In addition, there is no irrigation system for agricultural activities on Zegie. As an additional income generation, fuel wood and timber are taken and sold in local markets illegally. And illegal fuel wood markets were seen in the field study.

In the Lake Tana, dry Afromontane forests have experienced such vast exploitation that only few remnants of Church forests left only 0.39 %. Plantation forests are dominated by Eucalyptus. Corresponding with a profound population increase and demand for food, most of these forests have been converted into farmland and grazing land (Stave *et al*., 2017). Farmland cultivation can be found in the important areas of cultivation with fairly productive soils (Vertisols and alluvial soils) are the plains in the east and south east of Lake Tana, e.g. Libo kemkem, Fogera and Deara Plains (South Gondar Zone) (Michael and Fanny, 2013). One fifth of Lake Tana Watershed (>3000km^2) is covered by the water of Lake Tana which creates a smooth transition to various types of seasonal and permanent wetlands that surround the lake and form large areas along the eastern shores of Lake Tana wetlands (Friedrich, 2012)..

Few remnant natural forests are located in the Lake Tana that are disturbed due to pressure exerted by the local people with the exception of those surrounding monasteries and churches. Long term clearing and loss of forests will continue to significantly increase greenhouse gases and aggravate climate change at regional and global level (Fanny, 2012).

The local people in the FGDs mentioned loss of shade, soil erosion, climatic changes with temperature rise and reduced rainfall, drought and migration as possible consequences of deforestation and visions of the future.

5.5.4.7 Urbanization

Urban settlements and pollution from industrialization are putting pressure on the wetlands by adding sewage and effluent threatening the Lake Tana ecosystems and converted to settlement and construction which already caused the loss of wetland ecosystems around the lake as seen in Figure 5.5. This Lake Tana problem was also discussed by Stave *et al*. (2017).

“a” “b”

Figure 5.5: Urban constructions in the Lake Tana wetland, Bahir Dar study area (“a” Blue Nile Resort Hotel and “b” Tayitu recreational center (© The researcher, 2015).

5.5.4.8 Environmental pollution

Lake Tana is a sink for dumping municipal, industrial and domestic wastes of a growing urban population of Bahir Dar, Gondar, Gorgora and others in the catchment via the rivers flowing to the lake. Solid wastes and sewage from homes and hotels, effluents from factories reach the lake untreated, enhanced by urban run-off due to wetlands degradation. This increases the risk of life forms toxification and biodivestity loss as noted by KIs. And this is underlined in the report of Friedrich (2012).

During key informant interviews and focus group discussions most respondents referred to ‘pollution’ as the major recent problem of the Lake water as compared to their earlier experiences. Industrial activities, agricultural activities and sewage from urban centers in the catchment are responsible for pollution of Lake Tana. Most of the KIs including members of focus group discussion agreed that the use of fertilizers and pesticides in the agricultural activities affect biodiversity of the lake including birds. Studies done in the basin have also highlighted the potential for nutrient loading and consequent eutrophication as seen in Figure 5.6 and water pollution of adjacent water bodies including Lake Tana due to fertilizer application on adjacent agricultural fields (Zachary, 2008; Lamsal *et al*., 2015).

Sediments, organic and inorganic fertilizers and sewage from the agricultural fields and urban centers that enter the lake by runoff may result in eutrophication of the lake. Because, in the dry season eutrophication was observed in the northern patches shoreline of Lake Tana as observed in the field study**.** It is also true in the report of Stave *et al*. (2017).

Figure 5.6: Eutrophication in Lake Tana (Megech study area) (The Researcher, 2015)

A floriculture site of 700 ha for export is under construction envisaged as a replication of floriculture investment around Addis Ababa in the surrounding areas of Lake Tana. This form of investment is known with the use of intensive fertilizers, pesticides, herbicides and growth regulators that may harm the Lake Tana and its resources.

5.5.4.9 Weak Institutional Coordination

KIs argue that resource use and conservation is weakly coordinated among the different institutions authorized with natural resources management. The differences between the management practices, local officials and their partners (legal provisions) and the practice of local people in the area have clear ill-coordination. The same is true for Lake Tana and wetlands management in the study area. For instance, the management of Lake Tana wetlands presents problems because of the many interests competing for the resource. The major interests in Lake Tana include the expansion of human settlement, farm land, grazing for livestock and harvesting construction materials (reeds and sedges for thatching and roofing) and others. During the focus group discussion and key informants, it was evident to the institutions that may have role to address Lake Tana ecosystem management are not doing well. For instance, the office of Agricultural and Natural Resource development, Environment and Wild life protection and Culture and tourism are the local institutions responsible for the Lake Tana conservation. However, the government main focus is the improvement of livelihood through providing fertilizers, improved seeds and increase agricultural diversification and productivity and paid less attention for natural resource conservation. Even though, these institutions are responsible, they were not coordinated to safeguard Lake Tana from invasion by water hycine and different forms of degradation. This was also an argument of KIs.

FGDs and KIs reflected that the resource exploitations such as wetland farming, papyrus and grass collection set by the government bodies as a mechanism of creating job opportunity to organized youths and a means of enhancing income diversification for the local youth and other local communities. This is partly responsible for forest degradation and other biodiversity loss in the area and affects the tourism environment as a whole which may lose the objectives of resource management, the conservation of wild animals and biodiversity of the area. This clearly indicates that, there is weak coordination among stakeholders, in the area where all local institutions work independently. This is a similar to the result obtained by Gemechu (2010).

To bring the national economic development, the regional and national government of Ethiopia to promote investment activities in the study area and its surrounding. The establishment of floriculture industries, loges and irrigation farm activities in the lake catchments and along the shore line of the Lake without looking the adverse consequences on the environment were the major challenges as observed in the field study.

Thus, due to the above all mentioned problems, institutions blame one another for what is happening in the area. However, Lake Tana issues must be cross cutting and an integrated wetland resource management strategy calls for the coordination of several institutions nationally and internationally

5.5.5 Livelihoods

5.5.5.1 Livelihood Components

The key components of livelihoods constitute peoples' basic needs including food and environmental security. For example, there is need for arable land for food production (including wetlands), shelter, money for school fees, good health, etc. which also form peoples' basic needs (Zachary, 2008).

5.5.5.2 Lake Resources Extraction for Livelihood

The Lake and its wetland resources that are commonly used by the local communities include fuel wood, fodder, fish, etc. Fuel wood, as a source of cooking energy and income, was found to be the first and the most extracted wetland resources. In addition, fish is the second collected for food and sale. The third resource where Lake Tana communities depend on is fodder for their livestock. This information was obtained mainly from KIs and FGDs in Megech area and this finding is supported by the findings of Lamsal *et al.* (2015).

5.5.5.3 Socio- economic Characteristics of Lake Tana

Lake Tana communities have limited employment opportunities and they are forced to heavily depend on the natural resources: land, water, fish and wild life (Michael & Fanny, 2013). The study area consists of poor and low income households which have no formal income at all. More importantly, about 90% of the rural population earns their living through farming, fishing, carpentry, bricklaying, water transportation and small business (Stearner, 2013).

However, most of the livelihood systems of Lake Tana are very traditional. As a result, majority of the people are living in poverty. Most of the youths have no any sources of income in the area and thereby over utilize the natural resources as alternative sources of income through fishing and fuel wood extraction, papyrus reed harvesting and farmland encroachment towards wetlands. All these information were obtained from FGDs. Besides crop cultivation and livestock the main off farm activities are: cottage industries, like blacksmithing, carpentry, tailoring and weaving and sale of goods such as papyrus, petty and souvenirs. Alternative livelihoods which are still marginal are fishery communities and cottage industry practitioners as per the KIs. And it was true in the report of Friedrich (2012).

Potable water is one of the challenges faced by the Lake Tana communities that causes for the prevalence of different water-borne diseases (cholera, typhoid), giardia and amoeba. The households depend on boreholes, shallow wells and in the dry season they draw water directly from the lake for their multiple uses. Other diseases become prevalent in the Lake Tana area were hepatitis, schistosomasis, liver fluke, cancer and malaria that highly affected the poor. This was view of KIs and FGDs.

5.5.5.4 Livelihood System

In the study area, the households generate their livelihoods from different activities such as crop, livestock production and fishing are the major sources. Accordingly, livestock husbandry was the major type of livelihood activity practiced by the local community of the study area before 15/20 years. However, due to the increase of the population number, the possibility of making their livelihood had decreased considerably specially after the 1980s (Fesseha, 2013). Thus, population increment in the area led to a declining in livestock herding and farm land.

The farmers in the FGDs were asked if there was a change in the income situations between ten years ago and now; the result shows that the income from activities increased for some of households while it decreased for most of them. It is true as per the FGDs that income from livestock production declined for some significant number of households and many of the participants felt that the income from selling of fuel wood and charcoal declined due to resource degradation. Fishery was also means of livelihood for many of the people but today the means of livelihood is affected by the declining of fish stock in the lake.

The main socioeconomic activities done in the study area for subsistence, FGDs results indicated that, the most are water, subsistence farming, papyrus harvesting, and fishing and medicinal herbs collection. However, these activities have been changing in response to demographic trends. As the responses of the FGDs respondents, the youths didn't have a consistent economic activity for their livelihood because they are landless. Generally according to the response of FGDs respondents, Lake Tana and its wetlands degradation has adverse impact on livelihoods and food security of the local community. But local authorities believe that private companies have created employment opportunities and it is possible that in the long term basis more opportunities to enhance substance farming may be possible in form of technology transfer to the local farmers and provisioning credit facilities. Amhara credit and saving is the source of credit in the rural area while in the urban areas banks, Amhara credit and saving and village cooperatives that help to find out alternative income sources to small businesses and asset development. The situation makes the study area people more vulnerable to shocks and seasonality that may not effectively influence and access available livelihood assets in achieving desired livelihood outcomes with an exception of those having employment opportunities either in government offices or private companies. This shows high poverty levels in the area. Studies conducted on Lake Victoria by Albinus *et al*. (2008) had similar observations (Zachary, 2008). Households depended on Lake Tana either for their own consumption or for the sale of such resources to obtain money for food. Tihut (2009) found that > 80% of the population living near the wetlands in Uganda depend on lake resources for maintaining household food security and livelihoods. Halima and Munishi (2009) found that 94% of the local people residing around Nyumba Ya Mungu wetland in northern

Tanzania depend on its resources to supplement their income and food. Overall, we found that each local household extracted wetland resources with an annual economic value (Lamsal *et al*., 2015).

5.5.5.5 Changes in Livelihoods

According to the study results in KIs and FGDs peoples' livelihoods had changed either positively (Yes) or negatively (No) since 20 years. There is evidence that people are now seeking alternative sources for their livelihood as others put more pressure on fishing, land, forest and other resources at the lake and seek employment opportunities. Other livelihood changes now involve engagement in self-employment and small scale businesses of new markets and trade opportunities opening up from the population increment due to urban expansion and migration to the urban centers.

The majority of the respondents from the FGDs and Key informant interview reported that their livelihoods had changed negatively as the result of resource degradation and positive impacts with the coming of the private companies into the area. The positive impact is reflected in those who had employment and good salary, good business, improved standard of living, good infrastructure and schools, increased production of crops due to agricultural extension and reduced cases of malaria due to establishment of health centers. Despite, those saying many youths have experienced negative livelihoods listed as less access to farm land, loss of grazing field, loss of livestock, less papyrus and construction materials, low fish catches and increased incidences of conflict.

It is apparent from the points raised in KIs and FGDs that Lake Tana and the wetlands around it are experiencing changing environmental conditions and the persistence of unsustainable resource utilization (development activities). Climate change is also a factor affecting environmental conditions of the lake resources**.** The increased sedimentation of the lake and the reduction of fish catch reported by local fishermen indicated that the Lake is experiencing environmental changes which could have adverse effect for the sustainability of community economy and livelihood. Climate change, population growth and socioeconomic activities are major factors to the lake ecosystem degradation**.** Pollution of the lake from the human activities was also the other risk to its ecosystem degradation emanated from socioeconomic activities. It is important to note that the water quality of Lake Tana has declined. The other increasing problem in Lake Tana is massive growth (invasion) of water hyacinth that covers a good part of its area as seen in Figure 5.7 and eutrophication that has devastating effect on the lake resources as a whole. Lake Tana is whispering alarm being it is in between death and life. However, at present little or nothing has been done to save Lake Tana**.**

"a" "b"

Figure 5.7: Water Hyacinth invasion of Lake Tana ("a" invaded area in the wet season while "b" in the dry season) (The researcher, 2015).

5.5.5.6 Environmental Implications of Livelihood Diversification

Findings from this study show variations in the use of the natural resources. There was generally an increase in the use of natural resources associated with increasing population and the subsequent increase in the demand for the resources. A decrease in use happens where natural resources depleted or degraded (Lamsal *et al*., 2015).

The impacts of intensive use of some of the resources include limited availability forest products, limited availability of fish, diminished land for grazing and farm land. New types of demand and new technologies led to the intensification of the use of natural resources. For example, the mining of sand, stones (quarry) and clay have all intensified because of the increasing interest of society (Stave *et al*., 2017).

According to FGDs, the status of vegetation cover and agrodiversity in the study areas revealed that both have deteriorated considerably in the last ten years. This is a clear indication that the resources users themselves understand the local trends of vegetation cover and biodiversity loss. when FGDs participants asked about their perception of the effect of the increasing resource use on the environment in their respective areas, the respondents were also concerned about increasing water scarcity, water pollution, deforestation, wetland depletion, soil erosion, reduced crop yields, erratic rainfall, reduced vegetation cover, reduced fish stocks in the lake, increased crop diseases and pests, decreased pasture availability, land fragmentation and resource use conflicts.

While the decrease in vegetation cover was reported to be associated with expansion of farmlands, overgrazing and settlements, the decrease in agro-diversity was attributed to the need to produce crops that have markets and those that can somewhat withstand the decreasing soil fertility (Gordon *et al*., 2007).

FGDs response of this study showed that the poorest have a narrower range of livelihood activities, while the least poor had a broader range, because they have access to various types of resources. The nature of livelihood activity that a household adopts is also partly influenced by household socio-economic characteristics, including its poverty and affluence levels. This was true in Lamsal *et al*. (2015).

5.5.6 Farmers´ Views on Wetlands

FGDs perceived that as the population increased, so did the dependency on lake resources. The lack of alternative livelihood options means overexploitation of the wetland resources.

KIs and FGDs almost have the same argument that wetlands valued by farmers for their economic functions, i.e. their provisioning services such as source of animal feed, irrigation and domestic water supply, home for wild life (e.g. fish breeding) and plants (supporting service), rainfall and temperature regulation (regulating service) and recreation and religious (cultural service). The values of wetlands depend upon the needs and motivations of the community. Some prefer the conversion of the wetlands to farm land due to their fertile soil; others need to preserve the wetlands as a source of fodder.

The views of all FGDs coincide with the fact that external factors affecting their livelihoods apart from their limited capacities; these are land tenure, urbanization, diseases and inaccessibility to health care centers. Water borne diseases and others (diarrhoea, malaria, typhoid fever, cholera, tuberculosis, skin lesion, etc.) are major health risks in the study area where they don't have enough money to buy drugs and go long distance to have health center access. As a result deaths in the community are common especially infant mortality. According to (Ajala, 2008) the rate of urbanization which necessitates physical expansion is a major reason for high demand for land. Thus, the local people are at disadvantage due to land for urban development and farming and people on marginal land are the worse for it. It is true of the study area.

Apart from effect of urbanization on land matters, the FGD groups claimed that urbanization has disrupted their social fabric. Some of these are our young people: move to the city because there is not enough land to cultivate engaged in maid servant and the females in prostitution (come back with deadly diseases (HIV/AIDS), males engaged in theft of Livestock, fishing nets and crop harvest.

5.5.7 Lake Resource Sustainability Trends

The FGDs were asked to express their perceptions of general trends in the uses and condition of Lake Tana resources over the last 20 years period. They perceived that the conditions of the wetland resources, including fuel wood, fodder availability and fish, decreased sharply during the last 20 years. Direct human impacts such as farming, overgrazing, deforestation and overfishing were found to have increased, resulting in the degradation of land, vegetation and fish stock, confirmed the information obtained during FGDs. These results are consistent with the findings of Ayalew (2010), who reported intense socioeconomic activities and poor management practices as the main causes of wetland ecosystem degradation in the Lake Tana and its surrounding. Iftekar and Takama

(2008) as cited by Lamsal *et al*. (2015) provide a similar observation regarding the Nijhum Dwip Island of Bangladesh, where > 80% of the population perceived that the degraded condition of the mangrove wetland ecosystem was due to overexploitation.

FGDs confirmed that total agricultural land area was positively and significantly related to wetland income. Farmers with larger holdings received more benefits from the lake than those with smaller holdings. This is because households with more land also have more livestock and greater exploitation of natural resources such as fuel wood and fodder. Households which are aware of conservation and involved with in conservation activities extracted fewer resources because they were environmentally more aware than those who were not involved.

5.5.8 Lake Tana Governance and its Natural Resources Management

The issue of Lake Tana governance featured throughout the study period with FGD respondents in all stakeholder groups giving varying ownership positions. The wetlands have been used on a free open access by the community for exploitation of its goods and services. However, the part under contestation has been leased by private companies. Most FGD respondents agreed that they never gained much from the private companies except for some people employment opportunities while some could be allowed to carry out subsistence cultivation on their farm rice cultivation and related crops. There was evidence of silent opposition and conflict, FGD respondents said, they have developed change of attitude on opposing the activities of the private companies following emerging benefits from the companies to local communities employment and infrastructure opportunities. Most of the FGD respondents put a lot of blame to the local authorities and local political leaders for the current problems in Lake Tana.

During FGD, a majority of the participants raised concerns about the degradation of the lake ecosystem from excessive resource extraction. Habitat destruction, as a result of cutting trees and shrubs from the lake that causes the loss of habitat for flora and fauna. From large mammals to the local and migratory bird species are also in a declining state. According to Lamsal *et al*. (2015) the current population pressure and increased settlements and expansion of agricultural land are the major factors contributing to habitat degradation.

From the field observations, Lake Tana rural community is in need of development initiatives to address the prevailing poverty and food insecurity and poor infrastructure in order to raise the standard of living of the people. There was evidence of poor coordination, integration and involvement of key stakeholders regarding the management of the Lake Tana. It remains a challenge to decision-makers whether the proposals will be implemented including strict enforcement of monitoring and evaluation of project activities by competent authorities and lead agencies.

A lot of politics seems to be surrounding the investment companies splitting the local people into two opposing camps. Some community members view the local authorities and government as collaborators with the investors in a play to snatch their source of livelihoods. At the same time, a number of community and local leaders see some locals as being selfish and anti-development agents by refusing to support the investment companies.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

This chapter is outlined to conclude based on the major findings and to recommende appropriate solutions. It is known that Lake Tana is home to large number of migratory and several endemic bird, fish, algae species (in general flora and fauna) but threatened by farming activities, intensive livestock grazing, urbanization, settlements and industrialization and recently the expansion of the highly invasive water Hyacinths (*Eichhornia crassipes*) at the fore front of danger to lake Tana. The increasing levels of pollutants in Lake Tana and its wetlands were as a result of agricultural, industrial, urban and domestic waste discharges that make an issue of concern on water quality, human health and quality of aquatic environment. On the basis of this assessment of Lake Tana using physicochemical, heavy metal, bacteria, macroinvertebrate, macrophyte and livelihood of vicinity community has been done and reached on conclusion.

Lake Tana and its wetlands perform important hydrological and ecological functions and play an important role in local livelihoods and regional as well as national economic conditions. It can mitigate the impacts of floods, reduce erosion, recharge ground water, maintain and improve water quality, store carbon dioxide and stabilize micro-climate condition. From an ecological point of view, it is important for maintaining biological diversity where aquatic and terrestrial species find appropriate conditions for their reproduction and growth. Furthermore, Lake Tana improves local livelihoods through agriculture and fisheries. It also provides food, medicine, shelter, tourism and recreation. But all these services are endangered.

The current study has revealed that there was an undesirable impact on the physicochemical and microbial characteristics of Lake Tana. The major were discharge of untreated waste entering into the watershed from municipalities, industries and agricultural activities. This poses a health risk to several rural communities that rely on the water body for domestic and recreational purposes. The physicochemical, heavy metal and bacterial analysis of Lake Tana water indicated that it is polluted.The analysis showed that seasonal variations in water quality were experienced. The lake was found to be polluted and suffered from eutrophication. The WQI values of Lake Tana also indicated that the water was very poor for drinking and the water require proper water treatment before use. NH_3 and PO_4^{3-} were the major paramaters high above the permissible limits which makes the lake water quality very poor.

Macroinvertebrate analysis was the other assessment mechanism. In this study the highest taxa diversity was recorded in the reference site in the western part of Lake Tana. Based on macroinvertebrate metrics such as: number of taxa, EPT taxa, percent odonata, total abundance, etc (macroinvertebrates Richness, Composition and Tolerance) and Lake Tana Biotic Indices the ecological potential of Lake Tana was in the range of “Good” to “Bad or very poor”. Most of the sites were assessed as having “Moderate” ecological potential.

The examination of aquatic macrophyte distributions of Lake Tana was also done to complement the analysis of physicochemical and macroinvertebrates. The growth of the macrophytes reveals the lower productive nature of the lake and slow trend of succession towards shorelines. Biological indices also show Lake Tana macrophyte distribution was affected. In this study lower average diversity values of Shannon Wiener index (2.90), Simpson Diversity Index (1-D) (0.90), Simpson Dominance Index (D) (0.10), Margalef’s index (M’) richness index (5.32) and Evenness Index (E) (0.77) throughout the study year render moderate water quality status while presence of certain bio-indicators species like *Eichhornia*, *Potamogeton* and *Cyperus* in the lake also confirm pollution. The result of this study also indicated a dangerous trend in the rate at which invasive aquatic plant Water Hyacinth (*Eichhornia crassipes*) colonized Lake Tana from the Northern to the Southeastern parts.

Moreover, the correlations observed among elevated physicochemical parameters reflecting the presence of anthropogenic sources of pollution. In this regard, the physicochemical parameters were noticed to be correlating significantly with the macroinvertebrates which is indication that the physicochemistry of the lake is impacting the macroinvertebrate fauna community. But also the study indicated that macroinvertebrate in the lake is affected by physicochemical and macrophyte diversity. It appears that as sensitive taxa (namely Ephemeroptera, Plecoptera and Trichoptera) declined, more tolerant taxa increased in number. This has a potential to cause disruptions on food web as some species of fish and others might not be able to acquire sufficient food. But also the study revealed that the physicochemical parameters were significantly correlated with macrophyte species. Nutrient concentration plays an important role in controlling growth of plant species. That was why the exotic invasive species *Eichhornia crassipes* was the dominant macrophyte species in the Megech study area that endangered the life of Lake Tana. It was identified as there was a positive relationship between human impact and exotic species richness. It was observed as the high concentration of phosphate connected to higher number of exotic species (*Eichhornia crassipes)*.

It was true that aquatic macrophytes and physicochemical and macroinvertebrates relationships are significant and strong. Habitat degradation negatively impacts macroinvertebrate communities, which in turn results in decreased nutrient cycling. RDA analysis has been shown to be capable of discriminating macroinvertebrate families and macrophyte relationships with physicochemical, metal and indicator bacteria. As anticipated, there is damage on macrophytes that directly and indirectly influence the macroinvertebtares as pollution increased. All these dangers and problems of Lake Tana influence the livelihood of the vicinity community. The lake and its vicinity environment have united the inhabitants in to the society, which has a definite culture and livelihood pattern. Due to the availability of wide variety of harvestable products, the people of Lake Tana vicinity have subsistence-oriented economy and livelihood. The major sources of livelihoods are particularly cultivating crops, livestock, extracting different resources like sand, papyrus, fish and others. But all these are endangered as a result of the Lake Tana resources deterioration. Generally, all water quality (Physicochemical, heavy metal and bacterial), macroinvertebrates and macrophyte studies revealed that Lake Tana was deteriorated and the livelihood of the vicinity community affected.

The information generated in this study can assist local authorities to gain further insight on the state of the lake and livelihood of the vicinity community. Furthermore, the information can be utilized to revise the management systems thereby assisting water resource managers in restoring this impacted water resource.

6.2 RECOMMENDATIONS

On the basis of the finding the following are recommended:-

1. To use the water of Lake Tana for drinking purposes it needs special water treatment.
2. Water quality monitoring and evaluation is needed to prevent the deterioration of the ecosystem. Indigenous technologies should be adopted to make the water fit for societal use.
3. A research to find out the levels of physicochemical and metals in sediments at different depths is essential because parameters have different time span in the lake strata that can pose a danger at different level in differet starat of the lake.
4. Research on other metals not covered in this study to find out their concentration levels in sediments, water, macroinvertebrates, macrophytes and different fish species of the lake is needed.
5. Research on human health effects due to metal bioaccumulation (Pollution) whose concentration levels in the fish and other organisms species is essential to be studied.
6. In depth research on flora and fauna of Lake Tana is needed.
7. Exotic species control strategies should be taken into account including the potential effects on the flora and fauna found in the lake. Outlining Lake Tana management plan is very essential.
8. There is a need for implementation of Lake Tana management plan and land use planning in the Lake Tana catchment and along the feeding rivers so as to reduce silt and nutrient loads using a directive policy framework.
9. Buffer zone delination and implementation is crucial to minimize human activity in the core zone and to determine the human activity types in buffer zone based on Lake Tana Bio-reserve study and criteria.
10. Finally it is recommended that a social study has to be carried out to find out the level of communities awareness on the dangers of aquatic pollution to the users of natural

resources in Lake Tana shore side. This research work is original and all sources that I have used or quoted have been indicated and acknowledged as references.

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APPENDICES

APPENDIX 1: Physicochemicals, Metals and Bacterial parameters of 11 sites in wet and dry season of Lake Tana

	Ambobahir		Bahir Dar Study area (S.A)						Tana Kirkos S.A				Megech S.A				Gorgora S. A					
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Parameter	S_0	S_0	S_1	S_1	S_2	S_2	S_3	S_3	S_4	S_4	S_5	S_5	S_6	S_6	S_7	S_7	S_8	S_8	S_9	S_9	S_{10}	S_{10}
Temp (Oc)	20	23	23.5	24.6	23.7	24.9	22	24.5	21.3	23.4	22.4	24.3	22.1	23.7	23.2	24.9	20	23.2	20.8	23.8	22.2	24.5
PH	6.99	7.35	7.09	7.35	6.93	7.76	7.23	8.4	6.93	7.13	7.2	7.31	7.74	7.84	7.71	7.9	7.7	7.89	7.31	7.84	7.58	7.94
EC (µS/cm)	78	89	180	252	196	234	146.2	219	131.4	155.6	133	149.8	214	282	242	393	123.9	137.9	143.2	151	139.4	172.3
BOD5 (mg/l)	4	13	50	92	33.3	48	12	26	20	37	36	26	8	61	29	114	25	16	8	76	20	67
COD (mg/l)	44	41	520	562	270	502	325	480	102	156	72	138	310	490	456	680	645	39	281	274	344	231
TSS (mg/l)	0.105	0.025	1.143	0.167	0.195	0.202	0.159	0.161	0.13	0.12	0.54	0.44	1.225	0.514	0.115	0.113	0.265	0.116	0.235	0.122	0.945	0.434
TDS (mg/l)	74	39	68.4	73.6	69	72.2	66.7	66	73	72.6	73.3	69.5	116.9	252	119	234	67.4	70.7	69.7	120.2	67.1	113.5
NO_3 (mg/l)	0.443	0.217	0.381	0.363	1.23	0.43	0.151	0.501	0.306	0.673	0.226	0.563	1.218	0.097	1.112	0.7	0.332	0.452	0.275	0.084	0.66	0.416
NO_2 (mg/l)	0.013	0.003	0.046	0.033	0.007	0.02	0.03	0.013	0.016	0.016	0.026	0.007	0.063	0.24	0.072	0.41	0.033	0.006	0.026	0.026	0.066	0.013
NH_3 (mg/l)	0.17	0.17	0.2	0.21	0.12	0.08	0.3	0.08	0.14	0.18	0.12	0.33	0.66	0.21	1.1	0.99	0.11	1.2	0.22	0.19	0.31	0.06
PO_4 (mg/l)	7.5	7.5	6.9	1.9	12.6	3.2	9.6	4.9	8.5	4.4	7.9	3.2	380	10.3	400	10.9	2.6	28.5	2.8	6	3.9	9.4
SO_4 (mg/l)	10	3	18	5	14	8	21	4	27	4	35	2	8	4	10	0	23	2	15	3	20	5
S^{-2} (mg/l)	14	1	26	7	29	6	25	0	30	5	19	3	21	1	35	2	16	2	18	4.5	20	6
Cr (mg/l)	0.08	0	0.05	0.001	0.09	0.003	0.13	0.002	0.04	0.001	0.071	0.002	0.13	0.014	0.09	0.019	0.07	0	0.06	0	0.02	0.001
Mn (mg/l)	0.001	0.003	0.002	0.003	0.004	0.002	0.001	0.002	0.006	0.005	0.044	0.006	0.002	0.012	0.003	0.017	0.001	0.002	0.003	0.003	0.001	0.001
As (mg/l)	0.001	0	0.003	0	0.035	0	0.002	0	0.003	0	0.002	0.001	0.002	0	0.003	0.001	0.007	0	0.002	0	0.001	0
Cd (mg/l)	0.001	0	0.004	0.001	0.008	0.003	0.005	0.001	0.002	0	0.001	0.001	0.004	0	0.0125	0.001	0.002	0	0.004	0.001	0.001	0.001
Cu (mg/l)	0	0	0	0.06	0	0	0.2	0	0	0.22	0.06	0.76	0.01	0.22	0.22	0.34	0	0.12	0.04	0.24	0.08	0.13
Pb (mg/l)	0.01	0.01	0.09	0.04	0.12	0.02	0.11	0.08	0.03	0.001	0.06	0	0.02	0.001	0.04	0	0.01	0.01	0.31	0.03	0.04	0.08

Fe (mg/l)	0	0	0.3	0.04	0.25	0.03	0.3	0.09	0.6	0.35	0.1	0.2	2.45	0.25	1.95	0.01	0.3	0.03	0.55	0.02	0.3	0.04
E. Coli (Cell/ml)	0	2	6	2	13	5	4	6	0	6	0	8	4	5	40	7	48	12	26	14	6	5
F. Coliform (Cell/ml)	0	NT C	124	12	28	10	188	NT C	80	22	6	20	12	26	232	32	64	43	140	103	34	26
T. Coliform (Cell/ml)	2	15	165	17	104	13	200	48	152	18	8	26	18	51	240	65	108	88	187	136	59	48

APPENDIX 2: Macroinvertebrate parameters of 11 sites in wet and dry season of Lake Tana water

Taxa	Ambobahir		Bahir Dar Study area (S.A)						Tana Kirkos S.A				Megech S.A				Gorgora S. A					
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Families	S_0	S_0	S_1	S_1	S_2	S_2	S_3	S_3	S_4	S_4	S_5	S_5	S_6	S_6	S_7	S_7	S_8	S_8	S_9	S_9	S_{10}	S_{10}
Ephemeroptera/Mayflies																						
Baetidae	1	16	0	1	0	17	0	2	2	0	0	0	0	0	0	0	0	2	0	0	2	0
Caenidae	1	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Heptageniidae	0	2	0	0	2	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecopetra/Stoneflies																						
Perlidae	0	1	0	2	0	0	0	3	3	0	0	0	0	0	0	0	0	3	0	0	0	0
Capniidae	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera/Caddisflies																						
Hydropsychidae	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arachinida/Water mites																						
Hydracarina	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata/Damselflies																						
Aeshinidae	0	3	0	2	0	2	0	5	5	0	0	0	0	0	0	0	5	0	0	0	0	0
Calopterygidae	8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenogrionidae	42	22	4	0	20	0	9	3	1	0	0	0	0	0	0	0	0	1	3	1	0	1
Gomphidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lestidae	3	1	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	2
Coleoptera/Beetles																						
Dytiscidae	1	1	0	2	13	0	10	2	0	0	0	0	0	0	0	2	6	0	12	23	9	0
Elimidae	0	1	0	2	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	3	0	0
Gyrinidae	2	1	11	0	0	0	2	1	7	0	0	0	0	0	0	3	0	11	0	0	1	0
Haliplidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Hydrophilidae	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Psephenidae	4	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	2
Diptera/Two winged or"True flies"																						
Ceratopogonidae	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Chironomidae	0	0	0	3	12	1	0	1	0	0	0	0	0	0	0	0	0	0	0	6	0	0
Culicidae	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0
Muscidae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Psychodidae	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simuliidae	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tabanidae	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tipulidae	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera/Water or true bugs																						
Belostomatidae	0	8	0	0	8	0	0	0	4	0	0	0	0	0	0	0	0	27	0	0	0	0
Corixidae	0	3	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2	8	10
Gerridae	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	2
Hydrometridae	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoridae	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Nepidae	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notenoctidae	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	16	2	6	0
Pleidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Velidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Mollusca/Snails																						
Physidae	0	0	1	0	2	0	2	0	0	0	0	0	0	0	0	0	3	0	2	4	0	3
Planorbidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Corbiculidae	0	0	0	1	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Taxa	13	24	3	12	6	8	7	16	7	0	0	0	2	1	0	2	5	12	6	10	6	10
Total Abundance	61	90	16	19	64	29	32	60	23	0	0	0	6	2	0	5	17	55	47	48	28	27
Total Individual Organisms																						629

APPENDIX 3 (A-C): FBI (Family Biotic Index) of 11 sites in Lake Tana water

3A. FBI of Lake Tana in the Wet Season

Family	Value	S_0(W)	S_1(W)	S_2(W)	S_3(W)	S_4(W)	S_5(W)	S_6(W)	S_7(W)	S_8(W)	S_9(W)	S_{10}(W)	TWet	IW
Baetidae	4	0.065574	0	0	0	0.347826	0	0	0	0	0	0.285714	0.068027	0.06867
Caenidae	7	0.114754	0	0	0	0	0	0	0	0	0	0	0.02381	0
Heptageniidae	4	0	0	0.125	0.625	0	0	0	0	0	0	0	0.095238	0.120172
Perlidae	1	0	0	0	0	0.130435	0	0	0	0	0	0	0.010204	0.012876
Capniidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropsychidae	4	0.065574	0	0	0	0	0	0	0	0	0	0	0.013605	0
Hydracarina	-----													
Aeshinidae	3	0	0	0	0	0.652174	0	0	0	0.882353	0	0	0.102041	0.128755
Calopterygidae	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenogrionidae	9	6.196721	2.25	2.8125	2.53125	0.391304	0	0	0	0	0.574468	0	2.418367	1.429185
Gomphidae	1	0.016393	0	0	0	0	0	0	0	0	0	0	0.003401	0
Lestidae	9	0.442623	0	0	0	0	0	0	0	0	0	0	0.091837	0
Dytiscidae	5	0.081967	0	1.015625	1.5625	0	0	0	0	1.764706	1.276596	1.607143	0.867347	1.072961
Elimidae	5	0	0	0	0	0	0	3.333333	0	0	0	0	0.068027	0.085837
Gyrinidae	4	0.131148	2.75	0	0.25	1.217391	0	0	0	0	0	0.142857	0.312925	0.360515
Haliplidae	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrophilidae	5	0	0	0	0.625	0	0	0	0	0	0	0	0.068027	0.085837
Psephenidae	4	0.262295	0	0	0	0	0	1.333333	0	0	0	0.285714	0.108844	0.06867
Ceratopogonidae	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	8	0	0	1.5	0	0	0	0	0	0	0	0	0.326531	0.412017
Culicidae	8	0	0	0	0	0.347826	0	0	0	0	0	0	0.027211	0.034335
Muscidae	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Psychodidae	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Simuliidae	6	0	0	0	0	0	0	0	0	0	0	0	0	0

Tabanidae	6	0	0.375	0	0	0	0	0	0	0	0	0	0.020408	0.025751
Tipulidae	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Belostomatidae	10	0	0	1.25	0	1.73913	0	0	0	0	0	0	0.408163	0.515021
Corixidae	9	0	0	1.265625	0	0	0	0	0	0	1.723404	2.571429	0.795918	1.004292
Gerridae	8	0.131148	0	0	0.25	0	0	0	0	0	0.851064	0	0.190476	0.206009
Hydrometridae	5	0.163934	0	0	0	0	0	0	0	0	0	0	0.034014	0
Naucoridae	5	0.081967	0	0	0	0	0	0	0	0.588235	0	0	0.05102	0.042918
Nepidae	8	0	0	0	0	0	0	0	0	0	0	0	0	0
Notenoctidae	2	0	0	0	0	0	0	0	0	0	0.680851	0.428571	0.14966	0.188841
Pleidae	-													
Velidae	6	0	0	0	0.1875	0	0	0	0	0.352941	0	0	0.040816	0.051502
Physidae	8	0	0	0	0	0	0	0	0	1.411765	0.340426	0	0.136054	0.171674
Planorbidae	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Corbiculidae	8	0	0	0	0	0	0	0	0	0	0	0	0	0
FBI		7.754098	5.375	7.96875	6.03125	4.826087	0	4.666667	0	5	5.446809	5.321429	6.431973	6.085837

3B. FBI of Lake Tana in the Dry Season

Family	Value	S_0(D)	S_1(D)	S_2(D)	S_3(D)	S_4(D)	S_5(D)	S_6(D)	S_7(D)	S_8(D)	S_9(D)	S_{10}(D)	TDry	ID
Baetidae	4	0.711111	0.210526	2.344828	0.133333	0	0	0	0	0.145455	0	0	0.453731	0.359184
Caenidae	7	0.077778	0	0.965517	0	0	0	0	0	0.127273	0	0	0.125373	0.142857
Heptageniidae	4	0.088889	0	0	0.066667	0	0	0	0	0	0	0	0.035821	0.016327
Perlidae	1	0.011111	0.105263	0	0.05	0	0	0	0	0.054545	0	0	0.026866	0.032653
Capniidae	1	0.1	0	0	0	0	0	0	0	0	0	0	0.026866	0
Hydropsychidae	4	0.044444	0	0	0	0	0	0	0	0	0	0	0.01194	0
Hydracarina	-----													
Aeshinidae	3	0.1	0.315789	0.206897	0.25	0	0	0	0	0.272727	0.0625	0.111111	0.170149	0.195918
Calopterygidae	5	0.444444	0	0.172414	0	0	0	0	0	0	0	0	0.134328	0.020408
Coenogrionidae	9	2.2	0	0	0.45	0	0	0	0	0.163636	0.1875	0.333333	0.752239	0.220408
Gomphidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Lestidae	9	0.1	0.473684	0	0.3	0	0	0	0	0.163636	0	0.666667	0.18806	0.220408
Dytiscidae	5	0.055556	0.526316	0	0.166667	0	0	0	2	0	2.395833	0	0.447761	0.591837
Elimidae	5	0.055556	0.526316	0	0	0	0	0	0	0.090909	0.3125	0	0.104478	0.122449
Gyrinidae	4	0.044444	0	0	0.066667	0	0	0	2.4	0.8	0	0	0.191045	0.244898
Haliplidae	5	0	0	0	0	0	0	0	0	0	0.520833	0	0.074627	0.102041
Hydrophilidae	5	0.055556	0	0	0	0	0	0	0	0.090909	0	0	0.029851	0.020408
Psephenidae	4	0.044444	0	0	0	0	0	0	0	0	0	0.296296	0.035821	0.032653
Ceratopogonidae	6	0.133333	0.315789	0	0.1	0	0	0	0	0	0	0	0.071642	0.04898
Chironomidae	8	0	1.263158	0.275862	0.133333	0	0	0	0	0	1	0	0.262687	0.359184
Culicidae	8	0	0	0.275862	0	0	0	0	0	0.145455	0.166667	0	0.071642	0.097959
Muscidae	6	0	0	0	0	0	0	6	0	0	0	0	0.035821	0.04898
Psychodidae	10	0.333333	0	0	0	0	0	0	0	0	0	0	0.089552	0
Simuliidae	6	0	0	0.206897	0.4	0	0	0	0	0	0	0	0.089552	0.122449
Tabanidae	6	0	0	0	0.1	0	0	0	0	0	0	0	0.01791	0.02449

Tipulidae	3	0	0.157895	0	0.05	0	0	0	0	0	0	0	0.01791	0.02449
Belostomatidae	10	0.888889	0	0	0	0	0	0	0	4.909091	0	0	1.044776	1.102041
Corixidae	9	0.3	0	0	0	0	0	0	0	0	0.375	3.333333	0.402985	0.440816
Gerridae	8	0.088889	0	0	0	0	0	0	0	0	0	0.592593	0.071642	0.065306
Hydrometridae	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoridae	5	0.055556	0	0	0	0	0	0	0	0	0	0	0.014925	0
Nepidae	8	0.088889	0.842105	0	0	0	0	0	0	0	0	0	0.071642	0.065306
Notenoctidae	2	0.022222	0	0	0.033333	0	0	0	0	0.036364	0.083333	0	0.029851	0.032653
Pleidae	-													
Velidae	6	0	0	0	0	0	0	0	0	0	0	0.888889	0.071642	0.097959
Physidae	8	0	0.421053	0.551724	0.266667	0	0	0	0	0	0.666667	0.888889	0.286567	0.391837
Planorbidae	6	0	0	0	0	0	0	0	0	0	0	0.222222	0.01791	0.02449
Corbiculidae	8	0	0.421053	0	4	0	0	0	0	0	0	0	0.740299	1.012245
FBI		6.044444	5.578947	5	6.566667	0	0	6	4.4	7	5.770833	7.333333	6.21791	6.281633

3C. FBI of Lake Tana in the Study Year

Family	Value	S_0(T)	S_1(T)	S_2(T)	S_3(T)	S_4(T)	S_5(T)	S_6(T)	S_7(T)	S_8(T)	S_9(T)	S_{10}(T)	TLT	IT
Baetidae	4	0.450331	0.114286	0.731183	0.086957	0.347826	0	0	0	0.111111	0	0.145455	0.27345	0.217573
Caenidae	7	0.092715	0	0.301075	0	0	0	0	0	0.097222	0	0	0.077901	0.073222
Heptageniidae	4	0.05298	0	0.086022	0.26087	0	0	0	0	0	0	0	0.063593	0.066946
Perlidae	1	0.006623	0.057143	0	0.032609	0.130435	0	0	0	0.041667	0	0	0.019078	0.023013
Capniidae	1	0.059603	0	0	0	0	0	0	0	0	0	0	0.014308	0
Hydropsychidae	4	0.05298	0	0	0	0	0	0	0	0	0	0	0.012719	0
Hydracarina	-----													
Aeshinidae	3	0.059603	0.171429	0.064516	0.163043	0.652174	0	0	0	0.416667	0.031579	0.054545	0.138315	0.16318
Calopterygidae	5	0.264901	0	0.053763	0	0	0	0	0	0	0	0	0.071542	0.01046
Coenogrionidae	9	3.81457	1.028571	1.935484	1.173913	0.391304	0	0	0	0.125	0.378947	0.163636	1.531002	0.809623
Gomphidae	1	0.006623	0	0	0	0	0	0	0	0	0	0	0.00159	0
Lestidae	9	0.238411	0.257143	0	0.195652	0	0	0	0	0.125	0	0.327273	0.143084	0.112971
Dytiscidae	5	0.066225	0.285714	0.698925	0.652174	0	0	0	2	0.416667	1.842105	0.818182	0.643879	0.82636
Elimidae	5	0.033113	0.285714	0	0	0	0	2.5	0	0.069444	0.157895	0	0.08744	0.104603
Gyrinidae	4	0.07947	1.257143	0	0.130435	1.217391	0	0	2.4	0.611111	0	0.072727	0.248013	0.301255
Haliplidae	5	0	0	0	0	0	0	0	0	0	0.263158	0	0.039746	0.052301
Hydrophilidae	5	0.033113	0	0	0.217391	0	0	0	0	0.069444	0	0	0.047695	0.052301
Psephenidae	4	0.13245	0	0	0	0	0	1	0	0	0	0.290909	0.069952	0.050209
Ceratopogonidae	6	0.07947	0.171429	0	0.065217	0	0	0	0	0	0	0	0.038156	0.025105
Chironomidae	8	0	0.685714	1.11828	0.086957	0	0	0	0	0	0.505263	0	0.292528	0.384937
Culicidae	8	0	0	0.086022	0	0.347826	0	0	0	0.111111	0.084211	0	0.050874	0.066946
Muscidae	6	0	0	0	0	0	0	1.5	0	0	0	0	0.019078	0.025105
Psychodidae	10	0.198675	0	0	0	0	0	0	0	0	0	0	0.047695	0
Simuliidae	6	0	0	0.064516	0.26087	0	0	0	0	0	0	0	0.047695	0.062762
Tabanidae	6	0	0.171429	0	0.065217	0	0	0	0	0	0	0	0.019078	0.025105

Tipulidae	3	0	0.085714	0	0.032609	0	0	0	0	0	0	0	0.009539	0.012552
Belostomatidae	10	0.529801	0	0.860215	0	1.73913	0	0	0	3.75	0	0	0.747218	0.8159
Corixidae	9	0.178808	0	0.870968	0	0	0	0	0	0	1.042105	2.945455	0.586645	0.715481
Gerridae	8	0.10596	0	0	0.086957	0	0	0	0	0	0.421053	0.290909	0.127186	0.133891
Hydrometridae	5	0.066225	0	0	0	0	0	0	0	0	0	0	0.015898	0
Naucoridae	5	0.066225	0	0	0	0	0	0	0	0.138889	0	0	0.031797	0.020921
Nepidae	8	0.05298	0.457143	0	0	0	0	0	0	0	0	0	0.038156	0.033473
Notenoctidae	2	0.013245	0	0	0.021739	0	0	0	0	0.027778	0.378947	0.218182	0.085851	0.108787
Pleidae	-													
Velidae	6	0	0	0	0.065217	0	0	0	0	0.083333	0	0.436364	0.057234	0.075314
Physidae	8	0	0.228571	0.172043	0.173913	0	0	0	0	0.333333	0.505263	0.436364	0.216216	0.284519
Planorbidae	6	0	0	0	0	0	0	0	0	0	0	0.109091	0.009539	0.012552
Corbiculidae	8	0	0.228571	0	2.608696	0	0	0	0	0	0	0	0.394277	0.518828
FBI		6.735099	5.485714	7.043011	6.380435	4.826087	0	5	4.4	6.527778	5.610526	6.309091	6.317965	6.186192

APPENDIX 4 (A-C): Shannon-Wiener Index (H′) of 11 sites in Lake Tana water

4A. Shannon-Wiener Index (H′) of Lake Tana in the Wet Season

Family	S_0	H(W)	S_1	H(W)	S_2	H(W)	S_3	H(W)	S_4	H(W)	S_5	H(W)	S_6	H(W)	S_7	H(W)	S_8	H(W)	S_9	H(W)	S_{10}	H(W)	Twet	HW	IW	HI
Baetidae																										
Caenidae	1	0.07	0		0		0		2	0.21	0		0		0		0		0		2	0.19	5	0.07	4	0.07
Heptageniidae	1	0.07	0		0		0		0		0		0		0		0		0		0		1	0.02	0	
Perlidae	0		0		2	0.11	5	0.29	0		0		0		0		0		0		0		7	0.09	7	0.11
Capniidae	0		0		0		0		3	0.27	0		0		0		0		0		0		3	0.05	3	0.06
Hydropsychidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Hydracarina	1	0.07	0		0		0		0		0		0		0		0		0		0		1	0.02	0	
Aeshinidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Calopterygidae	0		0		0		0		5	0.33	0		0		0		5	0.36	0		0		10	0.11	10	0.14
Coenogrionidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Gomphidae	42	0.26	4	0.35	20	0.36	9	0.36	1	0.14	0		0		0		0		3	0.18	0		79	0.35	37	0.29
Lestidae	1	0.07	0		0		0		0		0		0		0		0		0		0		1	0.02	0	
Dytiscidae	3	0.15	0		0		0		0		0		0		0		0		0		0		3	0.05	0	
Elimidae	1	0.07	0		13	0.32	10	0.36	0		0		0		0		6	0.37	12	0.35	9	0.36	51	0.3	50	0.33
Gyrinidae	0		0		0		0		0		0		4	0.27	0		0		0		0		4	0.06	4	0.07
Haliplidae	2	0.11	11	0.26	0		2	0.17	7	0.36	0		0		0		0		0		1	0.12	23	0.2	21	0.22
Hydrophilidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Psephenidae	0		0		0		4	0.26	0		0		0		0		0		0		0		4	0.06	4	0.07
Ceratopogonidae	4	0.18	0		0		0		0		0		2	0.37	0		0		0		2	0.19	8	0.1	4	0.07
Chironomidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Culicidae	0		0		12	0.31	0		0		0		0		0		0		0		0		12	0.13	12	0.15
Muscidae	0		0		0		0		1	0.14	0		0		0		0		0		0		1	0.02	1	0.02
Psychodidae	0		0		0		0		0		0		0		0		0		0		0		0		0	

Simuliidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Tabanidae	0		0		0		0		0		0				0		0		0		0		0		0	
Tipulidae	0		1	0.17	0		0		0		0		0		0		0		0		0		1	0.02	1	0.02
Belostomatidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Corixidae	0		0		8	0.26	0		4	0.3	0		0		0		0		0		0		12	0.13	12	0.15
Gerridae	0		0		9	0.28	0		0		0		0		0		0		9	0.32	8	0.36	26	0.21	26	0.24
Hydrometridae	1	0.07	0		0		1	0.11	0		0		0		0		0		5	0.24	0		7	0.09	6	0.09
Naucoridae	2	0.11	0		0		0		0		0		0		0		0		0		0		2	0.03	0	
Nepidae	1	0.07	0		0		0		0		0		0		0		2	0.25	0		0		3	0.05	2	0.04
Notenoctidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Pleidae	0		0		0		0		0		0		0		0		0		16	0.37	6	0.33	22	0.19	22	0.22
Velidae	1	0.07	0		0		0		0		0		0		0		0		0		0		1	0.02	0	
Physidae	0		0		0		1	0.11	0		0		0		0		1	0.17	0		0		2	0.03	2	0.04
Planorbidae	0		0		0		0		0		0		0		0		3	0.31	2	0.13	0		5	0.07	5	0.08
Corbiculidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
HI	0		0		0		0		0				0		0		0				0		0		0	
Abundance		1.35		0.78		1.65		1.66		1.75		0		0.64		0		1.45		1.58		1.55		2.5		2.49

4B. Shannon-Wiener Index (H′) of Lake Tana in the Dry Season

Family	S_0(D)	H(D)	S_1(D)	H(D)	S_2(D)	H(D)	S_3(D)	H(D)	S_4(D)	H(D)	S_5(D)	H(D)	S_6(D)	H(D)	S_7(D)	H(D)	S_8(D)	H(D)	S_9(D)	H(D)	S_{10}(D)	H(D)	Tdry	H(D)	ID	H(D)
Baetidae	16	0.307062	1	0.15497	17	0.313083	2	0.113373	0		0		0		0		2	0.120516	0		0		38	0.246892	22	0.216428
Caenidae	1	0.049998	0		4	0.273242	0		0		0		0		0		1	0.072861	0		0		6	0.072042	5	0.079425
Heptageniidae	2	0.084592	0		0		1	0.068239	0		0		0		0		0		0		0		3	0.042229	1	0.022454
Perlidae	1	0.049998	2	0.236978	0		3	0.149787	0		0		0		0		3	0.158658	0		0		9	0.097171	8	0.111733
capniidae	9	0.230259	0		0		0		0		0		0		0		0		0		0		9	0.097171	0	
Hydropsychidae	1	0.049998	0		0		0		0		0		0		0		0		0		0		1	0.017356	0	
Hydracarina	1	0.049998	0		0		0		0		0		0		0		0		0		1	0.122068	2	0.030573	1	0.022454
Aeshinidae	3	0.113373	2	0.236978	2	0.184424	5	0.207076	0		0		0		0		5	0.21799	1	0.08065	1	0.122068	19	0.162759	16	0.178199
Calopterygidae	8	0.215144	0		1	0.116114	0		0		0		0		0		0		0		0		9	0.097171	1	0.022454
Coenogrionidae	22	0.344365	0		0		3	0.149787	0		0		0		0		1	0.072861	1	0.08065	1	0.122068	28	0.207445	6	0.090845
Gomphidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Lestidae	1	0.049998	1	0.15497	0		2	0.113373	0		0		0		0		1	0.072861	0		2	0.192792	7	0.080828	6	0.090845
Dytiscidae	1	0.049998	2	0.236978	0		2	0.113373	0		0		0		2	0.366516	0		23	0.352526	0		30	0.216084	29	0.252591
Elimidae	1	0.049998	2	0.236978	0		0		0		0		0		0		1	0.072861	3	0.173287	0		7	0.080828	6	0.090845
Gyrinidae	1	0.049998	0		0		1	0.068239	0		0		0		3	0.306495	11	0.321888	0		0		16	0.145268	15	0.171013
Haliplidae	0		0		0		0		0		0		0		0		0		5	0.2356	0		5	0.062757	5	0.079425
Hydrophilidae	1	0.049998	0		0		0		0		0		0		0		1	0.072861	0		0		2	0.030573	1	0.022454
Psephenidae	1	0.049998	0		0		0		0		0		0		0		0		0		2	0.192792	3	0.042229	2	0.03925
Ceratopogonidae	2	0.084592	1	0.15497	0		1	0.068239	0		0		0		0		0		0		0		4	0.05287	2	0.03925
Chironomidae	0		3	0.291446	1	0.116114	1	0.068239	0		0		0		0		0		6	0.25993	0		11	0.112175	11	0.139335
Culicidae	0		0		1	0.116114	0		0		0		0		0		1	0.072861	1	0.08065	0		3	0.042229	3	0.05391

Muscidae	0		0		0		0		0		0		2		0		0		0		0		2	0.030573	2	0.03925
Psychodidae	3	0.113373	0		0		0		0		0		0		0		0		0		0		3	0.042229	0	
Simuliidae	0		0		1	0.116114	4	0.180537	0		0		0		0		0		0		0		5	0.062757	5	0.079425
Tabanidae	0		0		0		1	0.068239	0		0		0		0		0		0		0		1	0.017356	1	0.022454
Tipulidae	0		1	0.15497	0		1	0.068239	0		0		0		0		0		0		0		2	0.030573	2	0.03925
Belostomatidae	8	0.215144	0		0		0		0		0		0		0		27	0.34928	0		0		35	0.235992	27	0.243046
Corixidae	3	0.113373	0		0		0		0		0		0		0		0		2	0.132419	10	0.367871	15	0.139078	12	0.14774
Gerridae	1	0.049998	0		0		0		0		0		0		0		0		0		2	0.192792	3	0.042229	2	0.03925
Hydrometridae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Naucoridae	1	0.049998	0		0		0		0		0		0		0		0		0		0		1	0.017356	0	
Nepidae	1	0.049998	2	0.236978	0		0		0		0		0		0		0		0		0		3	0.042229	2	0.03925
Notenoctidae	1	0.049998	0		0		1	0.068239	0		0		0		0		1	0.072861	2	0.132419	0		5	0.062757	4	0.067183
Pleidae	0		0		0		0		0		0		0		0		0		0		0		0		0	
Velidae	0		0		0		0		0		0		0		0		0		0		4	0.282895	4	0.05287	4	0.067183
Physidae	0		1	0.15497	2	0.184424	2	0.113373	0		0		0		0		0		4	0.207076	3	0.244136	12	0.119256	12	0.14774
Planorbidae	0		0		0		0		0		0		0		0		0		0		1	0.122068	1	0.017356	1	0.022454
Corbiculidae	0		1	0.15497	0		30	0.346574	0		0		0		0		0		0		0		31	0.220252	31	0.261573
HI		2.521248		2.40616		1.419627		1.964926		0		0		0		0.673012		1.678356		1.735207		1.96155		3.069505		2.938706
Abundance	90		19		29		60		0		0		2		5		55		48		27		335		245	

4C. Shannon-Wiener Index (H′) of Lake Tana in the Study year

Family	S_0(T)	H(T)	S_1(T)	H(T)	S_2(T)	H(T)	S_3(T)	H(T)	S_4(T)	H(T)	S_5(T)	H(T)	S_6(T)	H(T)	S_7(T)	H(T)	S_8(T)	H(T)	S_9(T)	H(T)	S_{10}(T)	H(T)	Total	H(T)	IT	H(T)
Baetidae	17	0.245888	1	0.101581	17	0.31064	2	0.083231	2	0.212378	0		0		0		2	0.099542	0		2	0.120516	43	0.183412	26	0.158367
Caenidae	2	0.057273	0		4	0.135325	0		0		0		0		0		1	0.059398	0		0		7	0.05006	5	0.047701
Heptageniidae	2	0.057273	0		2	0.082569	6	0.178045	0		0		0		0		0		0		0		10	0.065843	8	0.068455
Perlidae	1	0.033227	2	0.163554	0		3	0.111625	3	0.26568	0		0		0		3	0.132419	0		0		12	0.075534	11	0.086797
capniidae	9	0.168083	0		0		0		0		0		0		0		0		0		0		9	0.060767	0	
Hydropsychidae	2	0.057273	0		0		0		0		0		0		0		0		0		0		2	0.018286	0	
Hydracarina	1	0.033227	0		0		0		0		0		0		0		0		0		1	0.072861	2	0.018286	1	0.012907
Aeshinidae	3	0.077854	2	0.163554	2	0.082569	5	0.15828	5	0.331751	0		0		0		10	0.274178	1	0.047936	1	0.072861	29	0.141857	26	0.158367
Calopterygidae	8	0.155647	0		1	0.048738	0		0		0		0		0		0		0		0		9	0.060767	1	0.012907
Coenogrionidae	64	0.363824	4	0.247892	20	0.330509	12	0.26568	1	0.136326	0		0		0		1	0.059398	4	0.133372	1	0.072861	107	0.301319	43	0.216656
Gomphidae	1	0.033227	0		0		0		0		0		0		0		0		0		0		1	0.010245	0	
Lestidae	4	0.096185	1	0.101581	0		2	0.083231	0		0		0		0		1	0.059398	0		2	0.120516	10	0.065843	6	0.054952
Dytiscidae	2	0.057273	2	0.163554	13	0.275048	12	0.26568	0		0		0		2	0.366516	6	0.207076	35	0.367879	9	0.2962	81	0.26395	79	0.297516
Elimidae	1	0.033227	2	0.163554	0		0		0		0		4	0.346574	0		1	0.059398	3	0.109114	0		11	0.070761	10	0.0809
Gyrinidae	3	0.077854	11	0.363771	0		3	0.111625	7	0.362047	0		0		3	0.306495	11	0.287034	0		1	0.072861	39	0.172404	36	0.194768
Haliplidae	0		0		0		0		0		0		0		0		0		5	0.15497	0		5	0.038432	5	0.047701
Hydrophilidae	1	0.033227	0		0		4	0.136326	0		0		0		0		1	0.059398	0		0		6	0.044379	5	0.047701
Psephenidae	5	0.112842	0		0		0		0		0		2	0.346574	0		0		0		4	0.190621	11	0.070761	6	0.054952
Ceratopogonidae	2	0.057273	1	0.101581	0		1	0.04915	0		0		0		0		0		0		0		4	0.032164	2	0.022914
Chironomidae	0		3	0.210577	13	0.275048	1	0.04915	0		0		0		0		0		6	0.17445	0		23	0.120984	23	0.145993
Culicidae	0		0		1	0.048738	0		1	0.136326	0		0		0		1	0.059398	1	0.047936	0		4	0.032164	4	0.040028

Muscidae	0		0		0		0		0		0		2	0.346574	0		0		0		0		2	0.018286	2	0.022914
Psychodidae	3	0.077854	0		0		0		0		0		0		0		0		0		0		3	0.025495	0	
Simuliidae	0		0		1	0.048738	4	0.136326	0		0		0		0		0		0		0		5	0.038432	5	0.047701
Tabanidae	0		1	0.101581	0		1	0.04915	0		0		0		0		0		0		0		2	0.018286	2	0.022914
Tipulidae	0		1	0.101581	0		1	0.04915	0		0		0		0		0		0		0		2	0.018286	2	0.022914
Belostomatidae	8	0.155647	0		8	0.211024	0		4	0.304209	0		0		0		27	0.367811	0		0		47	0.193827	39	0.204468
Corixidae	3	0.077854	0		9	0.226004	0		0		0		0		0		0		11	0.24964	18	0.365551	41	0.177986	38	0.201291
Gerridae	2	0.057273	0		0		1	0.04915	0		0		0		0		0		5	0.15497	2	0.120516	10	0.065843	8	0.068455
Hydrometridae	2	0.057273	0		0		0		0		0		0		0		0		0		0		2	0.018286	0	
Naucoridae	2	0.057273	0		0		0		0		0		0		0		2	0.099542	0		0		4	0.032164	2	0.022914
Nepidae	1	0.033227	2	0.163554	0		0		0		0		0		0		0		0		0		3	0.025495	2	0.022914
Notenoctidae	1	0.033227	0		0		1	0.04915	0		0		0		0		1	0.059398	18	0.31519	6	0.241699	27	0.135141	26	0.158367
Pleidae	1	0.033227	0		0		0		0		0		0		0		0		0		0		1	0.010245	0	
Velidae	0		0		0		1	0.04915	0		0		0		0		1	0.059398	0		4	0.190621	6	0.044379	6	0.054952
Physidae	0		1	0.101581	2	0.082569	2	0.083231	0		0		0		0		3	0.132419	6	0.17445	3	0.158658	17	0.097592	17	0.118658
Planorbidae	0		0		0		0		0		0		0		0		0		0		1	0.072861	1	0.010245	1	0.012907
Corbiculidae	0		1	0.101581	0		30	0.36541	0		0		0		0		0		0		0		31	0.148354	31	0.177415
HI		2.333536		2.351081		2.157518		2.322741		1.748717		0		1.039721		0.673012		2.075206		1.929906		2.1692		2.976559		2.908366
Abundance	151		35		93		92		23		0		8		5		72		95		55		629		478	

APPENDIX 5(A-C): Simpson's Diversity Index (D) of 11 sites in Lake Tana water

5A. Simpson's Diversity Index (D) of Lake Tana in the Wet Season

Family	S0	n-1	n(n-1)	S1	n-1	n(n-1)	S2	n-1	n(n-1)	S3	n-1	n(n-1)	S4	n-1	n(n-1)	S5	n-1	n(n-1)	S6	n-1	n(n-1)	S7	n-1	n(n-1)	S8	n-1	n(n-1)	S9	n-1	n(n-1)	S10	n-1	n(n-1)	Twet	n-1	n(n-1)	IW	n-1	n(n-1)
Baetidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	5	4	20	4	3	12
Caenidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Heptageniidae	0	-1	0	0	-1	0	2	1	2	5	4	20	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	7	6	42	7	6	42
Perlidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	3	2	6
Capniidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Hydropsychidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Hydracarina	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Aeshinidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	0	-1	0	0	-1	0	0	-1	0	5	4	20	0	-1	0	0	-1	0	10	9	90	10	9	90
Calopterygidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Coenogrionidae	42	41	1722	4	3	12	20	19	380	9	8	72	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	0	-1	0	79	78	6162	37	36	1332
Gomphidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Lestidae	3	2	6	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	0	-1	0
Dytiscidae	1	0	0	0	-1	0	13	12	156	10	9	90	0	-1	0	0	-1	0	0	-1	0	0	-1	0	6	5	30	12	11	132	9	8	72	51	50	2550	50	49	2450
Elimidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	4	3	12	4	3	12
Gyrinidae	2	1	2	11	10	110	0	-1	0	2	1	2	7	6	42	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	23	22	506	21	20	420
Haliplidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Hydrophilidae	0	-1	0	0	-1	0	0	-1	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	4	3	12	4	3	12
Psephenidae	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	2	1	2	8	7	56	4	3	12
Ceratopogonidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0

Chironomidae	0	-1	0	0	-1	0	12	11	132	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	12	11	132	12	11	132
Culicidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0
Muscidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Psychodidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Simuliidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0		-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Tabanidae	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0
Tipulidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Belostomatidae	0	-1	0	0	-1	0	8	7	56	0	-1	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	12	11	132	12	11	132
Corixidae	0	-1	0	0	-1	0	9	8	72	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	9	8	72	8	7	56	26	25	650	26	25	650
Gerridae	1	0	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	0	-1	0	7	6	42	6	5	30
Hydrometridae	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0
Naucoridae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	3	2	6	2	1	2
Nepidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Notenoctidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	16	15	240	6	5	30	22	21	462	22	21	462
Pleidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Velidae	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	2	1	2	2	1	2
Physidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	2	1	2	0	-1	0	5	4	20	5	4	20
Planorbidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Corbiculidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0		-1	0	0	-1	0	0	-1	0	0	-1	0		-1	0	0	-1	0	0	-1	0	0	-1	0
	61						1744			16						122			64						798			32						196			23		
N-1	60			15			63			31			22			0			5						16			46			27			293			232		
N(N-1)	3660			240			4032			992			506						30						272			2162			756			86142			54056		
D	0.476503			0.508333			0.197917			0.197581			0.162055						0.466667						0.213235			0.218316			0.214286			0.126651			0.107629		

5B. Simpson's Diversity Index (D) of Lake Tana in the Dry Season

Family	S0	n-1	n(n-1)	S1	n-1	n(n-1)	S2	n-1	n(n-1)	S3	n-1	n(n-1)	S4	n-1	n(n-1)	S5	n-1	n(n-1)	S6	n-1	n(n-1)	S7	n-1	n(n-1)	S8	n-1	n(n-1)	S9	n-1	n(n-1)	S10	n-1	n(n-1)	Tdry	n-1	n(n-1)	ID	n-1	n(n-1)
Baetidae	16	15	240	1	0	0	17	16	272	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	38	37	1406	22	21	462
Caenidae	1	0	0	0	-1	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	6	5	30	5	4	20
Heptageniidae	2	1	2	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	1	0	0
Perlidae	1	0	0	2	1	2	0	-1	0	3	2	6	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	0	-1	0	0	-1	0	9	8	72	8	7	56
Capniidae	9	8	72	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	9	8	72	0	-1	0
Hydropsychidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Hydracarina	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	2	1	2	1	0	0
Aeshinidae	3	2	6	2	1	2	2	1	2	5	4	20	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	1	0	0	1	0	0	19	18	342	16	15	240
Calopterygidae	8	7	56	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	9	8	72	1	0	0
Coenogrionidae	22	21	462	0	-1	0	0	-1	0	3	2	6	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0	1	0	0	28	27	756	6	5	30
Gomphidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Lestidae	1	0	0	1	0	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	2	1	2	7	6	42	6	5	30
Dytiscidae	1	0	0	2	1	2	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	23	22	506	0	-1	0	30	29	870	29	28	812
Elimidae	1	0	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	3	2	6	0	-1	0	7	6	42	6	5	30
Gyrinidae	1	0	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	11	10	110	0	-1	0	0	-1	0	16	15	240	15	14	210
Haliplidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	0	-1	0	5	4	20	5	4	20
Hydrophilidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	2	1	2	1	0	0
Psepheniidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	3	2	6	2	1	2

Ceratopogonidae	2	1	2	1	0	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	4	3	12	2	1	2
Chironomidae	0	-1	0	3	2	6	1	0	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	6	5	30	0	-1	0	11	10	110	11	10	110
Culicidae	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0	0	-1	0	3	2	6	3	2	6
Muscidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	2	1	2
Psychodidae	3	2	6	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	0	-1	0
Simuliidae	0	-1	0	0	-1	0	1	0	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	5	4	20
Tabanidae	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0
Tipulidae	0	-1	0	1	0	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	2	1	2
Belostomatidae	8	7	56	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	27	26	702	0	-1	0	0	-1	0	35	34	1190	27	26	702
Corixidae	3	2	6	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	10	9	90	15	14	210	12	11	132
Gerridae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	3	2	6	2	1	2
Hydrometridae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Naucoridae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Nepidae	1	0	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	2	1	2
Notenoctidae	1	0	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	2	1	2	0	-1	0	5	4	20	4	3	12
Pleidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0
Velidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	4	3	12	4	3	12	4	3	12
Physidae	0	-1	0	1	0	0	2	1	2	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	4	3	12	3	2	6	12	11	132	12	11	132
Planorbidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0	1	0	0
Corbiculidae	0	-1	0	1	0	0	0	-1	0	30	29	870	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	31	30	930	31	30	930
	90		908	19		16	29		288	60		922	0		0	0		0	2		2	5		8	55		840	48		578	27		114	335		6644	245		3978

N-1	89	18	28	59			1	4	54	47	26	334	244
N(N-1)	8010	342	812	3540			2	20	2970	2256	702	111890	59780
D	0.113358	0.046784	0.35468	0.260452			1	0.4	0.282828	0.256206	0.162393	0.05938	0.066544
DI	0.886642	0.953216	0.64532	0.739548			0	0.6	0.717172	0.743794	0.837607	0.94062	0.933456

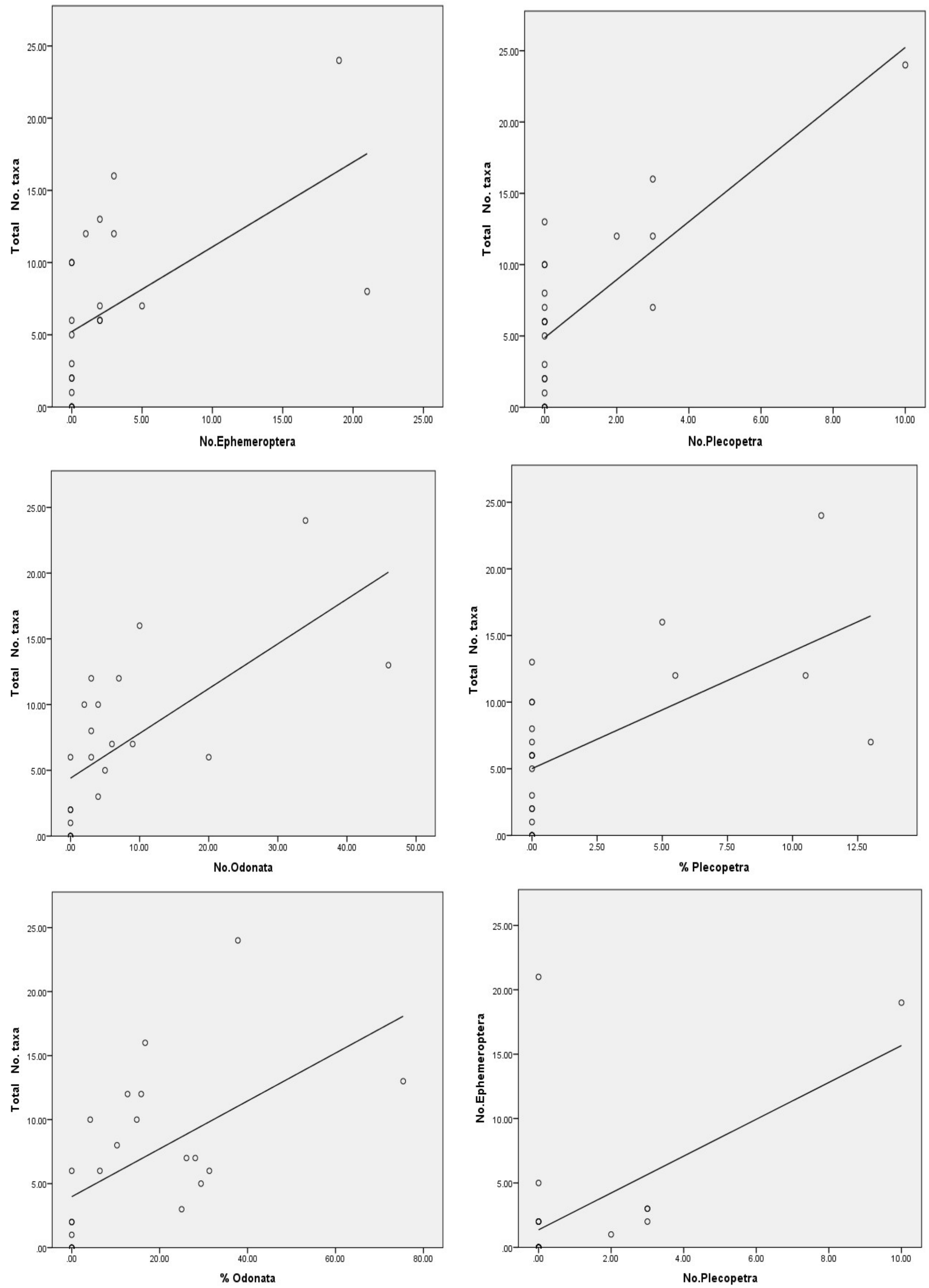
5C. Simpson's Diversity Index (D) of Lake Tana in the Study Year

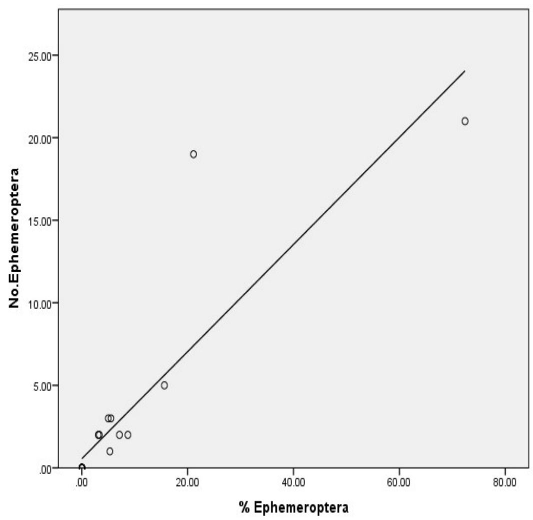
Family	S0	n-1	n(n-1)	S1	n-1	n(n-1)	S2	n-1	n(n-1)	S3	n-1	n(n-1)	S4	n-1	n(n-1)	S5	n-1	n(n-1)	S6	n-1	n(n-1)	S7	n-1	n(n-1)	S8	n-1	n(n-1)	S9	n-1	n(n-1)	S10	n-1	n(n-1)	LTT	n-1	n(n-1)	IT	n-1	n(n-1)
Baetidae	17	16	272	1	0	0	17	16	272	2	1	2	2	1	2	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	2	1	2	43	42	1806	26	25	650
Caenidae	2	1	2	0	-1	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	7	6	42	5	4	20
Heptageniidae	2	1	2	0	-1	0	2	1	2	6	5	30	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	10	9	90	8	7	56
Perlidae	1	0	0	2	1	2	0	-1	0	3	2	6	3	2	6	0	-1	0	0	-1	0	0	-1	0	3	2	6	0	-1	0	0	-1	0	12	11	132	11	10	110
Capniidae	9	8	72	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	9	8	72	0	-1	0
Hydropsychidae	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0
Hydracarina	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	2	1	2	1	0	0
Aeshinidae	3	2	6	2	1	2	2	1	2	5	4	20	5	4	20	0	-1	0	0	-1	0	0	-1	0	10	9	90	1	0	0	1	0	0	29	28	812	26	25	650
Calopterygidae	8	7	56	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	9	8	72	1	0	0
Coenogrionidae	64	63	4032	4	3	12	20	19	380	12	11	132	1	0	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	4	3	12	1	0	0	107	106	11342	43	42	1806
Gomphidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Lestidae	4	3	12	1	0	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	2	1	2	10	9	90	6	5	30
Dytiscidae	2	1	2	2	1	2	13	12	156	12	11	132	0	-1	0	0	-1	0	0	-1	0	2	1	2	6	5	30	35	34	1190	9	8	72	81	80	6480	79	78	6162
Elimidae	1	0	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	4	3	12	0	-1	0	1	0	0	3	2	6	0	-1	0	11	10	110	10	9	90
Gyrinidae	3	2	6	11	10	110	0	-1	0	3	2	6	7	6	42	0	-1	0	0	-1	0	3	2	6	11	10	110	0	-1	0	1	0	0	39	38	1482	36	35	1260
Haliplidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	0	-1	0	5	4	20	5	4	20
Hydrophilidae	1	0	0	0	-1	0	0	-1	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	6	5	30	5	4	20
Psephenidae	5	4	20	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	4	3	12	11	10	110	6	5	30
Ceratop	2	1	2	1	0	0	0	-	0	1	0	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	4	3	12	2	1	2

ogonidae								1						1			1			1			1			1			1			1							
Chironomidae	0	-1	0	3	2	6	13	12	156	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	6	5	30	0	-1	0	23	22	506	23	22	506
Culicidae	0	-1	0	0	-1	0	1	0	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0	0	-1	0	4	3	12	4	3	12
Muscidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	2	1	2
Psychodidae	3	2	6	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	0	-1	0
Simuliidae	0	-1	0	0	-1	0	1	0	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	5	4	20
Tabanidae	0	-1	0	1	0	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	2	1	2
Tipulidae	0	-1	0	1	0	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	2	1	2
Belostomatidae	8	7	56	0	-1	0	8	7	56	0	-1	0	4	3	12	0	-1	0	0	-1	0	0	-1	0	27	26	702	0	-1	0	0	-1	0	47	46	2162	39	38	1482
Corixidae	3	2	6	0	-1	0	9	8	72	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	11	10	110	18	17	306	41	40	1640	38	37	1406
Gerridae	2	1	2	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	5	4	20	2	1	2	10	9	90	8	7	56
Hydrometridae	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0
Naucoridae	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	2	1	2	0	-1	0	0	-1	0	4	3	12	2	1	2
Nepidae	1	0	0	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	2	1	2
Notenoctidae	1	0	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	18	17	306	6	5	30	27	26	702	26	25	650
Pleidae	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0
Velidae	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	0	-1	0	4	3	12	6	5	30	6	5	30
Physidae	0	-1	0	1	0	0	2	1	2	2	1	2	0	-1	0	0	-1	0	0	-1	0	0	-1	0	3	2	6	6	5	30	3	2	6	17	16	272	17	16	272
Planorbidae	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	1	0	0	1	0	0	1	0	0
Corbiculidae	0	-1	0	1	0	0	0	-1	0	30	29	870	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	0	-1	0	31	30	930	31	30	930
	151		4560	35		138	93		1110	92		1226	23		82	0		0	8		16	5		8	72		948	95		1724	55		444	629		29102	478		16280

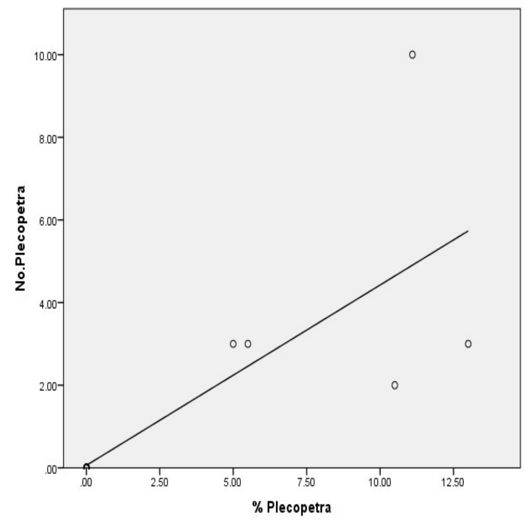
N-1	150	34	92	91	22		7	4	71	94	54	628	477
N(N-1)	22650	1190	8556	8372	506		56	20	5112	8930	2970	395012	228006
D	0.798675	0.884034	0.870266	0.853559	0.162055		0.285714	0.4	0.185446	0.193057	0.149495	0.926326	0.071402
DI	0.201325	0.115966	0.129734	0.146441	0.837945		0.714286	0.6	0.814554	0.806943	0.850505	0.073674	0.928598

APPENDIX 6: Bivariate scatterplot developed for Lake Tana

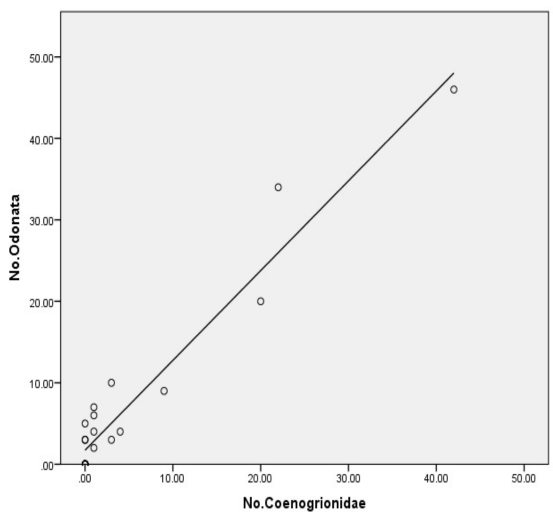




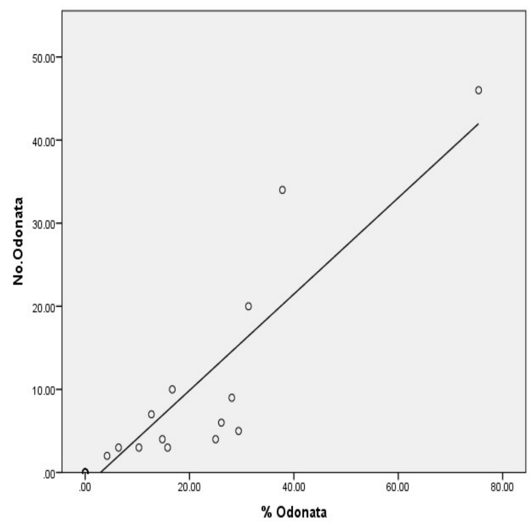
No.Ephemeroptera
% Ephemeroptera



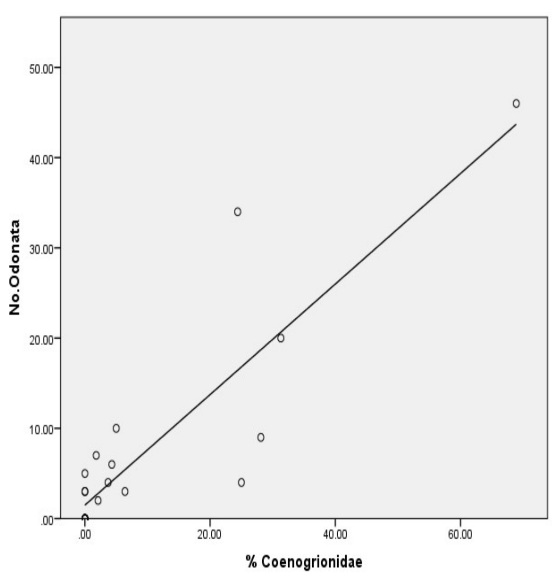
No.Plecopetra
% Plecopetra



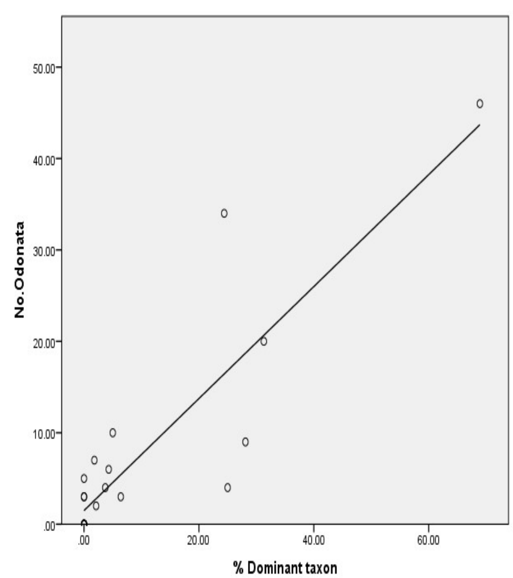
No.Odonata
No.Coenogrionidae



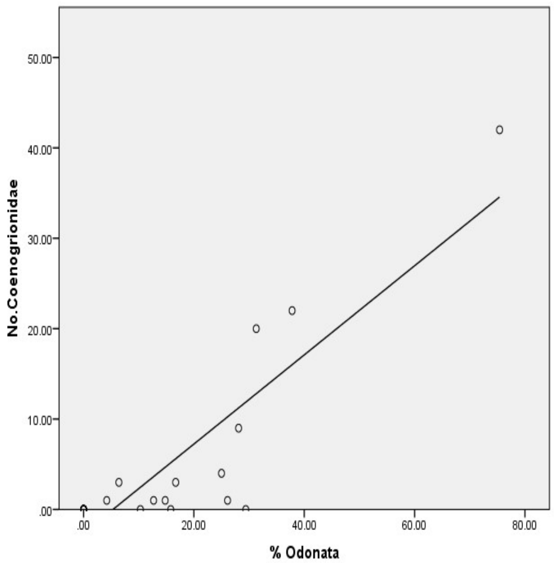
No.Odonata
% Odonata

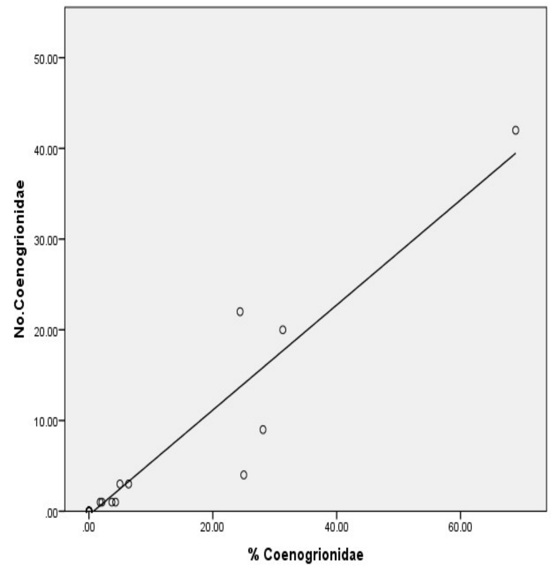


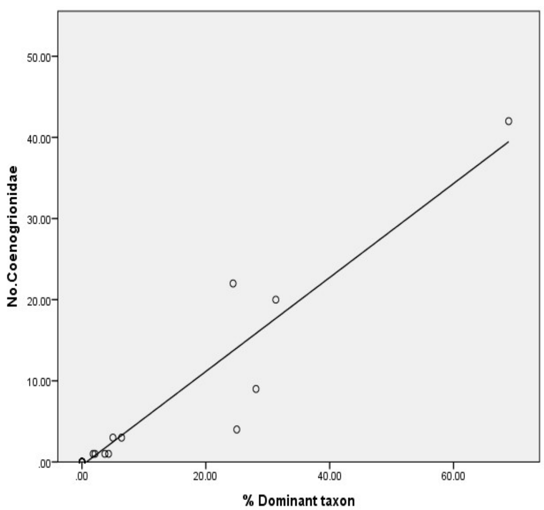
No.Odonata
% Coenogrionidae

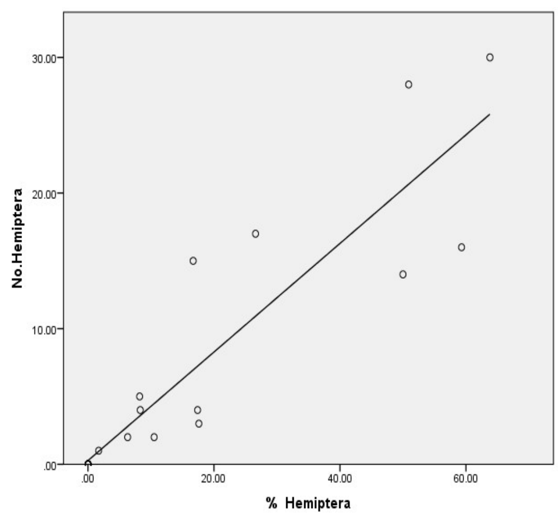


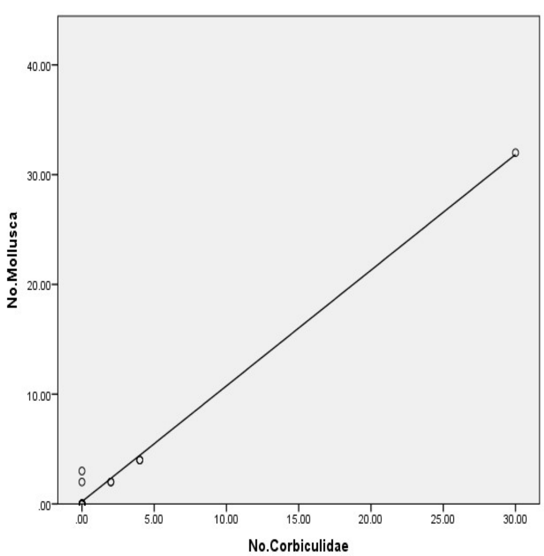
No.Odonata
% Dominant taxon

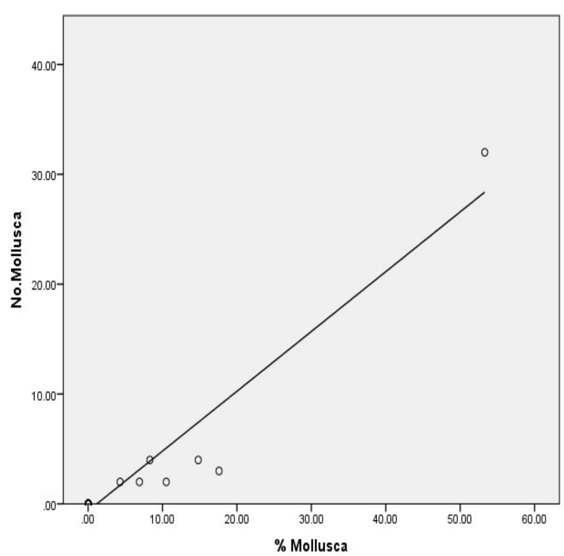

No.Coenogrionidae
50.00
40.00
30.00
20.00
10.00
.00
.00
20.00
40.00
60.00
80.00
% Odonata

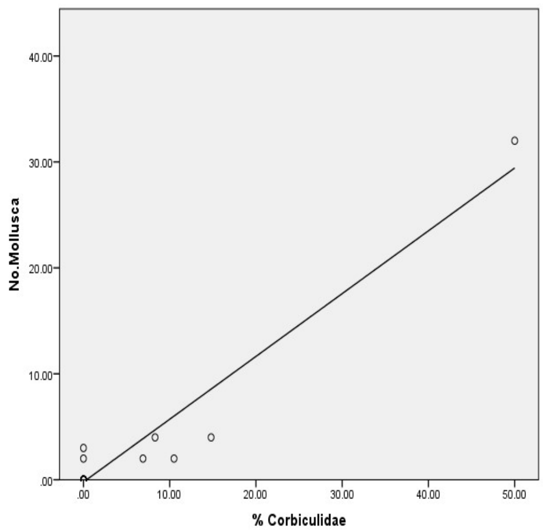

No.Coenogrionidae
50.00
40.00
30.00
20.00
10.00
.00
.00
20.00
40.00
60.00
% Coenogrionidae


No.Coenogrionidae
50.00
40.00
30.00
20.00
10.00
.00
.00
20.00
40.00
60.00
% Dominant taxon

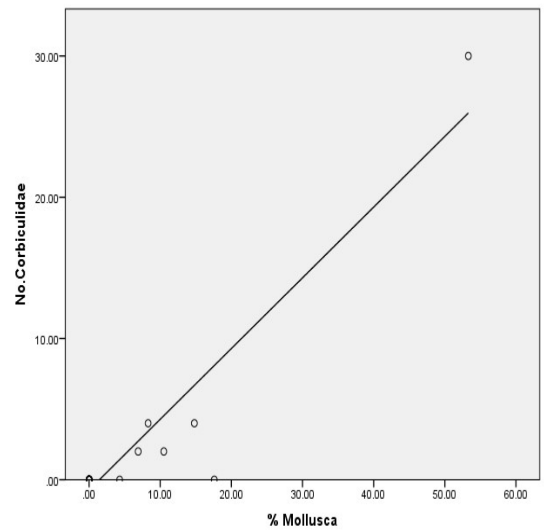

No.Hemiptera
30.00
20.00
10.00
.00
.00
20.00
40.00
60.00
% Hemiptera


No.Mollusca
40.00
30.00
20.00
10.00
.00
.00
5.00
10.00
15.00
20.00
25.00
30.00
No.Corbiculidae

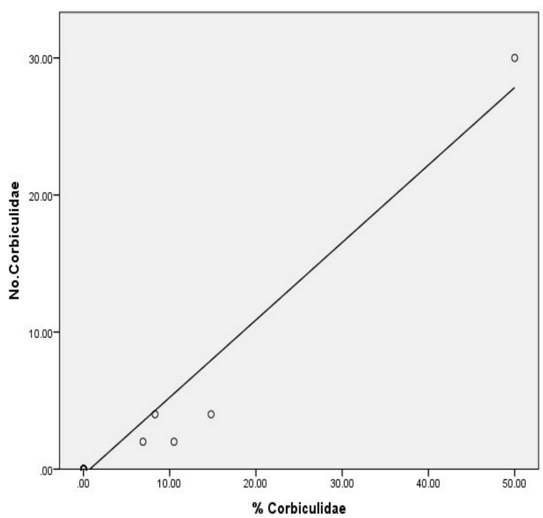

No.Mollusca
40.00
30.00
20.00
10.00
.00
.00
10.00
20.00
30.00
40.00
50.00
60.00
% Mollusca



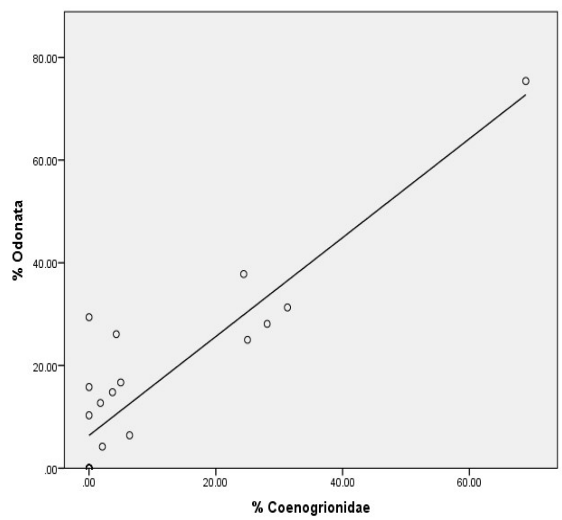
No.Mollusca
% Corbiculidae



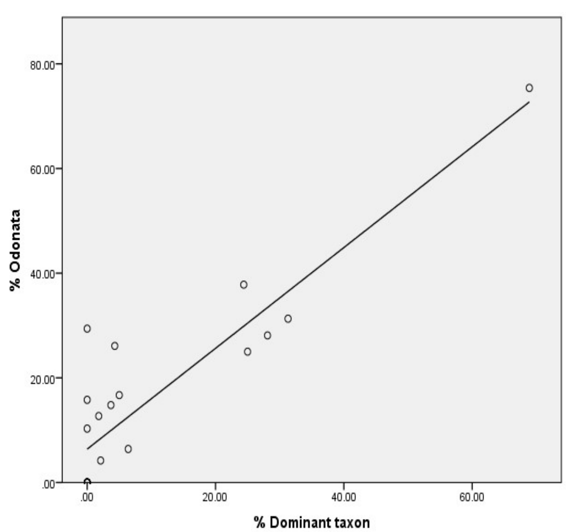
No.Corbiculidae
% Mollusca



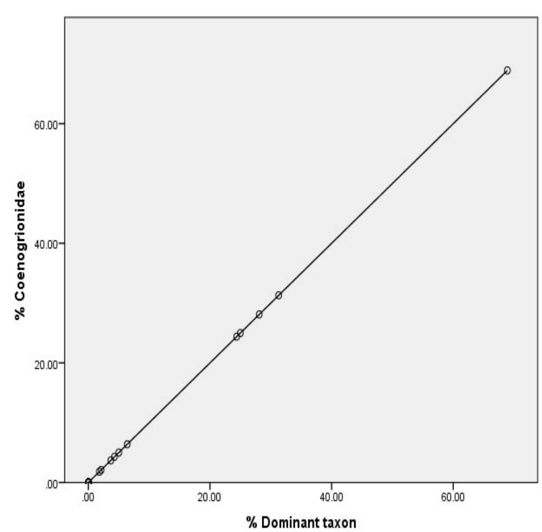
No.Corbiculidae
% Corbiculidae



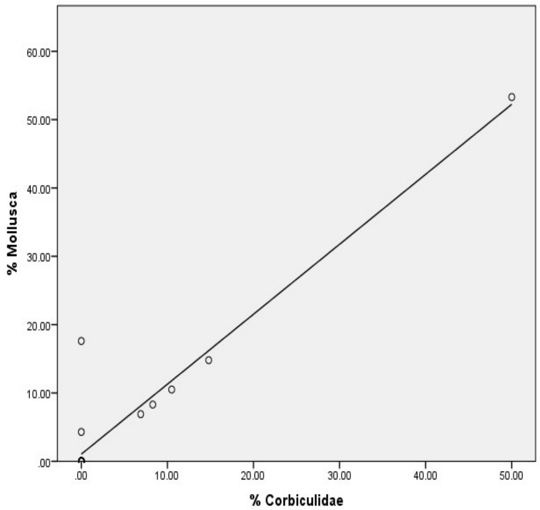
% Odonata
% Coenogrionidae



% Odonata
% Dominant taxon



% Coenogrionidae
% Dominant taxon


60.00
50.00
40.00
30.00
20.00
10.00
.00
% Mollusca
.00
10.00
20.00
30.00
40.00
50.00
% Corbiculidae

Appendix 7: Pearson Correlation of Physico-chemical variables and Macroinvertebrates of Lake Tana

	Tem (oC)	PH	EC	BOD5	COD	TSS	TDS	NO_3^-	NO_2^-	NH_3	PO_4^{3-}	SO_4^{2-}	S^{2-}	Cr	Mn	As	Cd	Cu	Pb	Fe	*E. Coli*	F. Coliform	T. Coliform
Baetidae	.196	.069	-.107	-.110	-.088	-.226	-.274	-.173	-.179	-.178	-.137	-.175	-.291	-.331	-.143	-.154	-.145	-.273	-.190	-.213	-.208	-.287	-.319
Caenidae	.172	.099	-.015	-.067	-.022	-.205	-.181	-.099	-.156	-.065	-.114	-.167	-.247	-.226	-.144	-.138	-.071	-.224	-.190	-.200	-.152	-.248	-.303
Heptageniidae	-.057	-.199	-.160	-.270	-.087	-.234	-.240	-.094	-.153	-.129	-.118	.142	.192	.399	-.151	.280	.237	-.052	.226	-.095	-.140	.281	.272
Perlidae	.093	.181	-.063	-.097	-.130	-.314	-.247	-.155	-.218	.121	-.143	-.089	-.185	-.344	-.132	-.149	-.262	-.244	-.099	-.141	-.206	-.176	-.031
capniidae	**-.450***	-.292	-.322	-.256	-.301	-.152	-.081	-.033	-.097	-.102	-.069	-.023	.016	.205	-.110	-.056	-.107	-.156	-.132	-.127	-.178	-.190	-.246
Hydropsychidae	-.326	-.276	**-.441***	-.321	**-.439***	-.259	-.225	-.159	-.159	-.148	-.100	-.152	-.166	.002	-.125	-.104	-.208	-.226	-.191	-.185	-.232	-.275	-.327
Hydracarina	.000	-.088	-.287	-.187	-.305	-.204	-.229	-.186	-.121	-.102	-.069	-.188	-.245	-.203	-.063	-.087	-.181	-.156	-.132	-.127	-.142	-.190	-.205
Aeshinidae	-.15	.152	-.13	-.13	.219	-.29	-.30	-.22	-.21	-.33	-.19	.176	-.07	-.18	-.16	-.04	-.17	-.38	-.13	-.11	.148	-.17	-.045

	8		0	2		4	0	8	2	9	0		4	2	7	6	8	2	8	5		7	
Calopterygidae	**-.440***	-.321	-.321	-.244	-.273	-.087	-.094	-.043	-.100	-.112	-.078	-.002	.048	.211	-.121	-.056	-.092	-.175	-.116	-.130	-.186	-.159	-.212
Coenogrionidae	-.372	**-.445***	-.416	-.362	-.404	-.261	-.258	.025	-.215	-.210	-.148	-.025	.084	.263	-.182	.296	.033	-.280	.020	-.196	-.211	-.173	-.163
Gomphidae	**-.450***	-.292	-.322	-.256	-.301	-.152	-.081	-.033	-.097	-.102	-.069	-.023	.016	.205	-.110	-.056	-.107	-.156	-.132	-.127	-.178	-.190	-.246
Lestidae	-.045	.167	-.240	-.104	-.266	-.256	-.175	-.122	-.240	-.144	-.165	-.302	-.340	-.190	-.233	-.193	-.302	-.248	-.077	-.287	-.273	-.379	-.378
Dytiscidae	-.143	-.029	-.166	.050	.050	-.152	-.075	-.128	-.112	-.194	-.202	.085	.131	.125	-.189	.342	.146	-.019	.418	-.170	.258	.322	.404
Elimidae	.064	.204	.036	.093	-.046	.252	.050	.144	-.087	.182	**.426***	-.295	-.120	.084	-.156	-.138	-.083	-.086	-.180	.417	-.116	-.119	-.162
Gyrinidae	-.055	-.141	-.106	-.076	-.101	.143	-.115	-.137	-.003	.338	-.140	.105	.136	-.071	-.109	-.091	-.093	-.157	-.060	-.121	-.165	.168	.282
Haliplidae	.120	.190	-.092	.298	-.047	-.141	.115	-.276	-.066	-.089	-.072	-.188	-.175	-.203	-.063	-.087	-.107	.149	-.067	-.120	.072	.168	.174
Hydrophilidae	-	-	-	-	-	-	-	-	-	.09	-	.133	.11	.34	-	-	.09	.05	.12	-	-	.39	.319

	.138	.120	.205	.273	.139	.198	.186	.274	.112	9	.086		5	7	.143	.067	7	6	3	.079	.128	1	
Psephenidae	-.375	-.083	-.336	-.297	-.333	.251	-.080	.158	-.122	-.088	.143	-.055	.023	.190	-.225	-.131	-.161	-.233	-.148	.075	-.279	-.320	-.386
Ceratopogonidae	-.415	-.415	-.320	-.260	-.157	.042	-.161	-.158	-.115	-.129	-.116	.152	.224	.393	-.178	-.057	.040	-.157	.025	-.126	-.227	.138	.063
Chironomidae	.243	-.181	.077	.202	.023	-.190	-.075	.304	-.156	-.204	-.116	-.070	.149	.067	-.091	**.812****	.299	-.115	.167	-.131	.038	-.067	.078
Culicidae	.097	.122	-.113	.044	-.176	-.277	-.083	-.254	-.190	.110	-.132	-.049	-.112	-.319	-.123	-.138	-.150	-.090	-.197	-.144	-.085	.033	.114
Muscidae	.105	.190	.321	.182	.192	.113	**.673****	-.267	**.444***	-.076	-.064	-.164	-.245	-.131	.151	-.087	-.181	.123	-.161	-.038	-.089	-.099	-.092
Psychodidae	.000	-.088	-.287	-.187	-.305	-.204	-.229	-.186	-.121	-.102	-.069	-.188	-.245	-.203	-.063	-.087	-.181	-.156	-.132	-.127	-.142	-.190	-.205
Simuliidae	.290	**.533***	.162	-.065	.228	-.136	-.134	-.005	-.115	-.198	-.092	-.178	-.296	-.235	-.106	-.106	-.094	-.191	.070	-.122	-.091	-.224	-.151
Tabanidae	.217	.197	.089	.007	.294	.294	-.159	-.050	-.084	-.177	-.105	.002	-.006	-.101	-.125	-.060	.007	-.226	.163	-.084	-.102	.037	.119

Tipulidae	.337	.304	.253	.242	.328	-.165	-.143	-.059	-.107	-.172	-.112	-.221	-.283	-.282	-.108	-.126	-.154	-.170	.045	-.151	-.154	-.245	-.218
Belostomatidae	.022	.045	-.215	-.236	-.416	-.241	-.195	.044	-.187	-.463*	-.072	-.180	-.146	-.177	-.109	.168	-.111	-.113	-.108	-.145	-.015	-.105	.018
Corixidae	-.030	-.061	-.176	-.064	-.152	.085	-.138	.147	-.171	-.250	-.172	.052	.138	-.033	-.194	.409	.127	-.172	.591**	-.151	.081	.002	.112
Gerridae	-.335	-.112	-.251	-.244	-.183	-.129	-.139	-.240	-.150	-.171	-.135	.042	.037	.109	-.152	-.088	.051	-.134	.811**	-.029	.155	.255	.260
Hydrometridae	-.450*	-.292	-.322	-.256	-.301	-.152	-.081	-.033	-.097	-.102	-.069	-.023	.016	.205	-.110	-.056	-.107	-.156	-.132	-.127	-.178	-.190	-.246
Naucoridae	-.574**	-.068	-.410	-.270	.051	-.193	-.224	-.185	-.135	-.207	-.126	.152	-.050	.133	-.167	.046	-.150	-.265	-.225	-.126	.442*	-.134	-.118
Nepidae	.219	-.121	.076	.298	.109	-.195	-.180	-.164	-.101	-.116	-.105	-.214	-.226	-.272	-.086	-.119	-.180	-.144	-.092	-.161	-.194	-.221	-.275
Notenoctidae	-.330	-.030	-.187	-.255	-.058	.031	-.147	-.145	-.081	-.062	-.122	.112	.076	.003	-.121	-.071	.033	-.121	.780**	-.015	.248	.253	.300
Pleidae	-.45	-.29	-.32	-.25	-.30	-.15	-.08	-.03	-.09	-.10	-.06	-.023	.016	.205	-.11	-.05	-.10	-.15	-.13	-.12	-.17	-.19	-.246

	0*	2	2	6	1	2	1	3	7	2	9				0	6	7	6	2	7	8	0	
Velidae	**-.434***	-.033	-.206	-.210	.270	-.120	-.160	-.245	-.077	-.114	-.104	.378	.212	**.445***	-.160	.072	.115	-.042	.045	-.030	.415	.359	.335
Physidae	-.146	.068	-.222	.132	.114	-.095	-.057	-.237	-.201	-.307	-.201	.110	.100	.126	-.239	.271	.121	-.055	.383	-.148	.413	.343	.417
Planorbidae	.225	.246	-.025	.228	-.095	.061	.086	-.051	-.097	-.174	-.065	-.141	-.145	-.197	-.110	-.087	-.107	.009	.096	-.113	-.089	-.099	-.101
Corbiculidae	.233	**.505***	.130	-.073	.190	-.120	-.118	.003	-.099	-.164	-.077	-.169	-.270	-.199	-.089	-.090	-.110	-.158	.095	-.099	-.075	-.195	-.108

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

APPENDIX 8 Shows seasonal variations in macrophytes density and coverage of Lake Tana

Species Name	Study Area																				
	Ambobahir		Bahir Dar								Tana kirkos		Megech		Gorgora						L. Tana		
	S_0 (w)	S_0 (D)	S_1 (w)	S_1 (D)	S_2 (w)	S_2 (D)	S_3 (w)	S_3 (D)	S_4 (W)	S_4 (D)	S_6 (w)	S_6 (D)	S_8 (w)	S_8 (D)	S_9 (w)	S_9 (D)	S_{10} (w)	S_{10} (D)	T (w)	T (D)	T
Hydrocotyle ranunculoides	0	0	0	0	0	0	13	4	0	0	0	0	0	0	0	0	0	0	13	4	17
Achyranthes aspera	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	6	0	6
Alternative sessilis	0	0	0	0	0	0	0	0	8	5	0	0	0	0	0	0	0	0	8	5	13
Pistia stratiotes	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3	0	3
Ageratum conizoides	0	0	0	0	0	0	3	2	3	0	0	0	0	0	0	0	0	0	6	2	8
Galensoga quadriradiata	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	8	0	8
Veronica abyssinica	0	0	0	0	8	3	5	2	0	0	0	0	0	0	0	0	0	0	13	5	18
Ceratophyllum demersum	8	6	0	0	0	0	8	5	3	4	0	0	0	0	0	0	0	0	19	15	34
Chenopedium ambrosioles	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Commelina Africana	0	0	8	3	0	0	6	4	12	0	0	0	6	3	0	0	11	5	43	15	58
Cyperus macrostachyos	4	2	0	0	0	0	0	0	5	3	0	0	0	0	0	0	0	0	9	5	14
Cyperus mundtii	0	0	0	0	13	18	0	0	0	0	0	0	0	0	0	0	0	0	13	18	31
Cyperus papyrus	35	31	0	0	33	30	6	10	22	12	0	0	11	18	0	0	0	0	107	101	208
Cyperus pectinatus	3	2	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	7	4	11
Oxycaryam cubensis	20	4	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	27	4	31
Vallisneria	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	4	0	4

spiralis																					
Ludwigia abyssinica	0	0	4	0	5	0	6	6	0	0	0	0	3	7	0	0	2	4	20	17	37
Ludwigia laptocarpe	0	0	0	0	0	0	2	0	4	0	0	0	0	0	0	0	0	0	6	0	6
Dissotis canescens	0	0	0	0	15	20	0	0	0	0	0	0	0	0	0	0	0	0	15	20	35
Dissotis princeps	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6
Nympheae lotus	8	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	9	20
Acroceras macrum	20	20	4	2	12	7	19	9	10	8	0	0	21	15	0	0	16	3	102	64	166
Arthraxon prinoides	10	4	0	0	0	0	0	0	5	0	0	0	8	3	0	0	0	0	23	7	30
Cynodon dactylon	0	16	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	7	16	23
Echinochloa pyramidolis	7	5	0	0	18	15	9	4	8	6	0	0	0	0	0	0	0	0	42	30	72
Echinochloa stagnina	67	26	32	9	30	13	107	42	195	41	0	0	0	0	0	0	65	28	496	159	655
Echinochloa ugandensis	0	0	21	7	20	18	38	7	37	0	0	0	32	12	8	0	16	6	172	50	222
Eragrostis botryodes	0	0	0	0	0	0	0	0	15	0	0	0	28	6	0	0	0	0	43	6	49
Eragrostis tenuifolia	19	9	0	0	0	0	17	6	22	0	0	0	0	0	0	0	0	0	58	15	73
Leersia hexandr	19	16	8	6	0	0	0	0	14	0	0	0	10	7	0	0	0	0	51	29	80
Panicum hymeniochilum	0	0	8	6	0	0	15	9	23	0	0	0	8	5	12	0	22	4	88	24	112
Pennisetum thunbergii	12	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	8	20
Phragmites australis	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Sacciolepis	12	12	20	14	15	8	32	23	15	8	0	0	42	38	20	6	0	0	156	109	265

Africana																					
Snowdenia petitiana	8	3	0	0	0	0	0	0	5	3	0	0	0	0	0	0	0	0	13	6	19
Vossia cuspidate	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	7	0	7
Persicaria senegalensis	0	0	0	0	10	2	5	3	2	62	0	0	2	0	0	0	4	6	23	73	96
Eichhornia crassipes	0	0	0	0	0	0	0	0	4	0	8	0	0	2	0	0	5	0	17	2	19
Potamogeton natan	0	0	0	0	0	0	3	32	0	0	0	0	0	0	0	0	0	0	3	32	35
Thelypteris confluens	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
Triumfetta annua	0	0	0	0	0	0	11	8	0	0	0	0	0	0	0	0	0	0	11	8	19
Ipomoea cairica	0	0	0	0	0	0	8	5	0	0	0	0	0	0	0	0	0	0	8	5	13
Typha Latifolia	18	13	0	0	28	12	5	4	0	0	0	0	15	16	0	0	15	14	81	59	140
Total no. of Macrophytes Collected	270	183	110	54	207	146	319	186	453	154	15	0	186	132	40	6	156	70	1756	931	2687

APPENDIX 9: Distribution of Macrophytes in 11 sites of Lake Tana wetlands (In wet and dry seasons)

Taxa		Study Area																								
		Ambobahir		Bahir Dar						Tana kirkos				Megech				Gorgora						L. Tana		
Family Name	**Species Name**	S_0 (w)	S_0 (D)	S_1 (w)	S_1 (D)	S_2 (w)	S_2 (D)	S_3 (w)	S_3 (D)	S_4 (W)	S_4 (D)	S_5 (w)	S_5 (D)	S_6 (w)	S_6 (D)	S_7 (w)	S_7 (D)	S_8 (w)	S_8 (D)	S_9 (w)	S_9 (D)	S_{10} (w)	S_{10} (D)	T (w)	T (D)	T
APIACEAE	Hydrocotyle ranunculoides	0	0	0	0	0	0	13	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	4	17
AMARANTHACEAE	Achyranthes aspera	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6
	Alternative sessilis	0	0	0	0	0	0	0	0	8	5	0	0	0	0	0	0	0	0	0	0	0	0	8	5	13
ASTERACCEAE	Pistia stratiotes	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3
	Ageratum conizoides	0	0	0	0	0	0	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	8
	Galensoga quadriradiata	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8
	Veronica abyssinica	0	0	0	0	8	3	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	5	18
CERATOPHYLLACEAE	Ceratophyllum demersum	8	6	0	0	0	0	8	5	3	4	0	0	0	0	0	0	0	0	0	0	0	0	19	15	34
CHENOPODIACEAE	Chenopedium ambrosioles	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
COMMELINACEAE	Commelina Africana	0	0	8	3	0	0	6	4	12	0	0	0	0	0	0	0	6	3	0	0	11	5	43	15	58
CYPERACEAE	Cyperus macrostachyos	4	2	0	0	0	0	0	0	5	3	0	0	0	0	0	0	0	0	0	0	0	0	9	5	14
	Cyperus mundtii	0	0	0	0	13	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	18	31
	Cyperus papyrus	35	31	0	0	33	30	6	10	22	12	0	0	0	0	0	0	11	18	0	0	0	0	107	101	208
	Cyperus pectinatus	3	2	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	7	4	11
	Oxycaryam cubensis	20	4	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	27	4	31
HYDROCHARITACEAE	Vallisneria	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4

	spiralis																									
LYTHRACEAE	Ludwigia abyssinica	0	0	4	0	5	0	6	6	0	0	0	0	0	0	0	0	3	7	0	0	2	4	20	17	37
	Ludwigia laptocarpe	0	0	0	0	0	0	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6
MELASTOMATACEAE	Dissotis canescens	0	0	0	0	15	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	20	35
	Dissotis princeps	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6
NYMPHECEAE	Nympheae lotus	8	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	9	20
POACEAE	Acroceras macrum	20	20	4	2	12	7	19	9	10	8	0	0	0	0	0	0	21	15	0	0	16	3	102	64	166
	Arthraxon prinoides	10	4	0	0	0	0	0	0	5	0	0	0	0	0	0	0	8	3	0	0	0	0	23	7	30
	Cynodon dactylon	0	16	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	7	16	23
	Echinochloa pyramidolis	7	5	0	0	18	15	9	4	8	6	0	0	0	0	0	0	0	0	0	0	0	0	42	30	72
	Echinochloa stagnina	67	26	32	9	30	13	107	42	195	41	0	0	0	0	0	0	0	0	0	0	65	28	496	159	655
	Echinochloa ugandensis	0	0	21	7	20	18	38	7	37	0	0	0	0	0	0	0	32	12	8	0	16	6	172	50	222
	Eragrostis botryodes	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	28	6	0	0	0	0	43	6	49
	Eragrostis tenuifolia	19	9	0	0	0	0	17	6	22	0	0	0	0	0	0	0	0	0	0	0	0	0	58	15	73
	Leersia hexandr	19	16	8	6	0	0	0	0	14	0	0	0	0	0	0	0	10	7	0	0	0	0	51	29	80
	Panicum hymeniochilum	0	0	8	6	0	0	15	9	23	0	0	0	0	0	0	0	8	5	12	0	22	4	88	24	112
	Pennisetum thunbergii	12	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	8	20
	Phragmites australis	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
	Sacciolepis	12	12	20	14	15	8	32	23	15	8	0	0	0	0	0	0	42	38	20	6	0	0	156	109	265

	Africana																									
	Snowdenia petitiana	8	3	0	0	0	0	0	0	5	3	0	0	0	0	0	0	0	0	0	0	0	0	13	6	19
	Vossia cuspidate	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	7
POLYGONACEAE	Persicaria senegalensis	0	0	0	0	10	2	5	3	2	62	0	0	0	0	0	0	2	0	0	0	4	6	23	73	96
PONTEDERIACEAE	Eichhornia crassipes	0	0	0	0	0	0	0	0	4	0	0	0	8	0	0	0	0	2	0	0	5	0	17	2	19
POTAMOGETONACEAE	Potamogeton natan	0	0	0	0	0	0	3	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	32	35
THELYPTERIDACEAE	Thelypteris confluens	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
TILIACEAE	Triumfetta annua	0	0	0	0	0	0	11	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	8	19
TYPHACEAE	Ipomoea cairica	0	0	0	0	0	0	8	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	5	13
	Typha latifolia	18	13	0	0	28	12	5	4	0	0	0	0	0	0	0	0	15	16	0	0	15	14	81	59	140
Total no. of Macrophytes Collected		270	183	110	54	207	146	319	186	453	154	0	0	15	0	0	0	186	132	40	6	156	70	1756	931	2687
No. of Species Collected over the sample period		16	17	10	9	12	11	21	20	28	11	0	0	2	0	0	0	12	12	3	1	9	8	42	35	43
No. of Families Collected over the sample period		5	5	5	4	7	6	12	12	10	5	0	0	2	0	0	0	6	6	1	1	5	5	17	16	18

APPENDIX 10 (A-C): Shannon-Wiener Index (H′) of 11 sites in Lake Tana wetlands

10A. Shannon-Wiener Index (H′) of Lake Tana in the Wet Season

Species Name	S_0(W)	H(W)	S_1(W)	H(W)	S_2(W)	H(W)	S_3(W)	H(W)	S_4(W)	H(W)	S_6(W)	H(W)	S_8(W)	H(W)	S_9(W)	H(W)	S_{10}(W)	H(W)	TW	H(W)
Acroceras macrum	20	0.19	4	0.12	12	0.17	19	0.17	10	0.08	0		21	0.25	0		16	0.23	102	0.17
Achyranthes aspera	0		0		0		0		6	0.06	0		0		0		0		6	0.02
Ageratum conizoides	0		0		0		3	0.04	3	0.03	0		0		0		0		6	0.02
Alternative sessilis	0		0		0		0		8	0.07	0		0		0		0		8	0.02
Arthraxon prinoides	10	0.12	0		0		0		5	0.05	0		8	0.14	0		0		23	0.06
Ceratophyllum demersum	8	0.1	0		0		8	0.09	3	0.03	0		0		0		0		19	0.05
Chenopedium ambrosioles	0		0		0		1	0.02	0		0		0		0		0		1	0
Commelina Africana	0		8	0.19	0		6	0.07	12	0.1	0		6	0.11	0		11	0.19	43	0.09
Cynodon dactylon	0		0		0		0		0		7	0.36	0		0		0		7	0.02
Cyperus macrostachyos	4	0.06	0		0		0		5	0.05	0		0		0		0		9	0.03
Cyperus mundtii	0		0		13	0.17	0		0		0		0		0		0		13	0.04
Cyperus papyrus	35	0.26	0		33	0.29	6	0.07	22	0.15	0		11	0.17	0		0		107	0.17
Cyperus pectinatus	3	0.05	0		0		0		4	0.04	0		0		0		0		7	0.02
Dissotis canescens	0		0		15	0.19	0		0		0		0		0		0		15	0.04
Dissotis princeps	0		2	0.07	0		0		0		0		0		0		0		2	0.01
Echinochloa pyramidolis	7	0.09	0		18	0.21	9	0.1	8	0.07	0		0		0		0		42	0.09
Echinochloa stagnina	67	0.35	32	0.36	30	0.28	107	0.37	195	0.36	0		0		0		65	0.36	496	0.36
Echinochloa ugandensis			21	0.32	20	0.23	38	0.25	37	0.2	0		32	0.3	8	0.32	16	0.23	172	0.23
Eichhornia crassipes	0		0		0		0		4	0.04	8	0.34	0		0		5	0.11	17	0.04
Eragrostis botryodes	0		0		0		0		15	0.11	0		28	0.29	0		0		43	0.09
Eragrostis tenuifolia	19	0.19	0		0		17	0.16	22	0.15	0		0		0		0		58	0.11
Galensoga quadriradiata	0		0		0		0		8	0.07	0		0		0		0		8	0.02
Ipomoea cairica	0		0		0		8	0.09	0		0		0		0		0		8	0.02
Leersia hexandr	19	0.19	8	0.19	0		0		14	0.11	0		10	0.16	0		0		51	0.1
Ludwigia abyssinica	0		4	0.12	5	0.09	6	0.07	0		0		3	0.07	0		2	0.06	20	0.05
Ludwigia laptocarpe	0		0		0		2	0.03	4	0.04	0		0		0		0		6	0.02
Nympheae lotus	8	0.1	3	0.1	0		0		0		0		0		0		0		11	0.03
Oxycaryam cubensis	20	0.19	0		0		0		7	0.06	0		0		0		0		27	0.06
Panicum hymeniochilum	0		8	0.19	0		15	0.14	23	0.15	0		8	0.14	12	0.36	22	0.28	88	0.15
Pennisetum thunbergii	12	0.14	0		0		0		0		0		0		0		0		12	0.03
Persicaria senegalensis	0		0		10	0.15	5	0.07	2	0.02	0		2	0.05	0		4	0.09	23	0.06
Phragmites australis	0		0		0		0		2	0.02	0		0		0		0		2	0.01
Pistia stratiotes	0		0		0		0		3	0.03	0		0		0		0		3	0.01
Potamogeton natan	0		0		0		3	0.04	0		0		0		0		0		3	0.01
Sacciolepis Africana	12	0.14	20	0.31	15	0.19	32	0.23	15	0.11	0		42	0.34	20	0.35	0		156	0.22
Snowdenia petitiana	8	0.1	0		0		0		5	0.05	0		0		0		0		13	0.04
Thelypteris confluens	0		0		0		0		0		0		0		0		0		0	
Triumfetta annua	0		0		0		11	0.12	0		0		0		0		0		11	0.03
Typha latifolia	18	0.18	0		28	0.27	5	0.07	0		0		15	0.2	0		15	0.23	81	0.14

Vallisneria spiralis	0		0		0		0		4	0.04	0		0		0		0		4	0.01
Veronica abyssinica	0		0		8	0.13	5	0.07	0		0		0		0		0		13	0.04
Vossia cuspidate	0		0		0		0		7	0.06	0		0		0		0		7	0.02
Water pennywort /Hydrocotyle spp/	0		0		0		13	0.13	0		0		0		0		0		13	0.04
	270	2.47	110	1.97	207	2.36	319	2.41	453	2.39	15	0.69	186	2.19	40	1.03	156	1.78	1756	2.8

10B. Shannon-Wiener Index (H′) of Lake Tana in the Dry Season

Species Name	S_0(D)	H(D)	S_1(D)	H(D)	S_2(D)	H(D)	S_3(D)	H(D)	S_4(D)	H(D)	S_6(D)	H(D)	S_8(D)	H(D)	S_9(D)	H(D)	S_{10}(D)	H(D)	TD	H(D)
Acroceras macrum	20	0.242	2	0.122	7	0.15	9	0.15	8	0.15	0		15	0.25	0		3	0.13	64	0.18
Achyranthes aspera	0		0		0		0		0		0		0		0		0		0	
Ageratum conizoides	0		0		0		2	0.05	0		0		0		0		0		2	0.01
Alternative sessilis	0		0		0		0		5	0.11	0		0		0		0		5	0.03
Arthraxon prinoides	4	0.084	0		0		0		0		0		3	0.09	0		0		7	0.04
Ceratophyllum demersum	6	0.112	0		0		5	0.1	4	0.09	0		0		0		0		15	0.07
Chenopedium ambrosioles	0		0		0		0		0		0		0		0		0		0	
Commelina Africana	0		3	0.161	0		4	0.08	0		0		3	0.09	0		5	0.19	15	0.07
Cynodon dactylon	16	0.213	0		0		0		0		0		0		0		0		16	0.07
Cyperus macrostachyos	2	0.049	0		0		0		3	0.08	0		0		0		0		5	0.03
Cyperus mundtii	0		0		18	0.26	0		0		0		0		0		0		18	0.08
Cyperus papyrus	31	0.301	0		30	0.33	10	0.16	12	0.2	0		18	0.27	0		0		101	0.24
Cyperus pectinatus	2	0.049	0		0		0		2	0.06	0		0		0		0		4	0.02
Dissotis canescens	0		0		20	0.27	0		0		0		0		0		0		20	0.08
Dissotis princeps	0		4	0.193	0		0		0		0		0		0		0		4	0.02
Echinochloa pyramidolis	5	0.098	0		15	0.23	4	0.08	6	0.13	0		0		0		0		30	0.11
Echinochloa stagnina	26	0.277	9	0.299	13	0.22	42	0.34	41	0.35	0		0		0		28	0.37	159	0.3
Echinochloa ugandensis			7	0.265	18	0.26	7	0.12	0		0		12	0.22	0		6	0.21	50	0.16
Eichhornia crassipes	0		0		0		0		0		0		2	0.06	0		0		2	0.01
Eragrostis botryodes	0		0		0		0		0		0		6	0.14	0		0		6	0.03
Eragrostis	9	0.148	0		0		6	0.11	0		0		0		0		0		15	0.07

tenuifolia																				
Galensoga quadriradiata	0		0		0		0		0		0		0		0		0		0	
Ipomoea cairica	0		0		0		5	0.1	0		0		0		0		0		5	0.03
Leersia hexandr	16	0.213	6	0.244	0		0		0		0		7	0.16	0		0		29	0.11
Ludwigia abyssinica	0		0		0		6	0.11	0		0		7	0.16	0		4	0.16	17	0.07
Ludwigia laptocarpe	0		0		0		0		0		0		0		0		0		0	
Nympheae lotus	6	0.112	3	0.161	0		0		0		0		0		0		0		9	0.04
Oxycaryam cubensis	4	0.084	0		0		0		0		0		0		0		0		4	0.02
Panicum hymeniochilum	0		6	0.244	0		9	0.15	0		0		5	0.12	0		4	0.16	24	0.09
Pennisetum thunbergii	8	0.137	0		0		0		0		0		0		0		0		8	0.04
Persicaria senegalensis	0		0		2	0.06	3	0.07	62	0.37	0		0		0		6	0.21	73	0.2
Phragmites australis	0		0		0		0		0		0		0		0		0		0	
Pistia stratiotes	0		0		0		0		0		0		0		0		0		0	
Potamogeton natan	0		0		0		32	0.3	0		0		0		0		0		32	0.12
Sacciolepis Africana	12	0.179	14	0.35	8	0.16	23	0.26	8	0.15	0		38	0.36	6	0	0		109	0.25
Snowdenia petitiana	3	0.067	0		0		0		3	0.08	0		0		0		0		6	0.03
Thelypteris confluens	0		0		0		1	0.03	0		0		0		0		0		1	0.01
Triumfetta annua	0		0		0		8	0.14	0		0		0		0		0		8	0.04
Typha latifolia	13	0.188	0		12	0.21	4	0.08	0		0		16	0.26	0		14	0.32	59	0.17
Vallisneria spiralis	0		0		0		0		0		0		0		0				0	
Veronica abyssinica	0		0		3	0.08	2	0.05	0		0		0		0		0		5	0.03
Vossia cuspidate	0		0		0		0		0		0		0		0		0		0	
Water pennywort /Hydrocotyle	0		0		0		4	0.08	0		0		0		0		0		4	0.02

spp/																				
	183	2.553	54	2.038	146	2.21	186	2.54	154	1.77	0	0.7	132	2.16	6	0	70	1.76	931	2.91

10C. Shannon-Wiener Index (H′) of Lake Tana in the Study year

Species Name	S_0(T)	H(T)	S_1(T)	H(T)	S_2(T)	H(T)	S_3(T)	H(T)	S_4(T)	H(T)	S_6(T)	H(T)	S_8(T)	H(T)	S_9(T)	H(T)	S_{10}(T)	H(T)	T	H(T)
Acroceras macrum	40	0.21	6	0.12	19	0.16	28	0.16	18	0.1	0		36	0.25	0		19	0.21	166	0.17
Achyranthes aspera	0		0		0		0		6	0.05	0		0		0		0		6	0.01
Ageratum conizoides	0		0		0		5	0.05	3	0.03	0		0		0		0		8	0.02
Alternative sessilis	0		0		0		0		13	0.08	0		0		0		0		13	0.03
Arthraxon prinoides	14	0.11	0		0		0		5	0.04	0		11	0.12	0		0		30	0.05
Ceratophyllum demersum	14	0.11	0		0		13	0.09	7	0.05	0		0		0		0		34	0.06
Chenopedium ambrosioles	0		0		0		1	0.01	0		0		0		0		0		1	0
Commelina africana	0		11	0.18	0		10	0.08	12	0.08	0		9	0.1	0		16	0.19	58	0.08
Cynodon dactylon	16	0.12	0		0		0		0		7	0.36	0		0		0		23	0.04
Cyperus macrostachyos	6	0.06	0		0		0		8	0.06	0		0		0		0		14	0.03
Cyperus mundtii	0		0		31	0.21	0		0		0		0		0		0		31	0.05
Cyperus papyrus	66	0.28	0		63	0.31	16	0.11	34	0.16	0		29	0.22	0		0		208	0.2
Cyperus pectinatus	5	0.05	0		0		0		6	0.05	0		0		0		0		11	0.02
Dissotis canescens	0		0		35	0.23	0		0		0		0		0		0		35	0.06
Dissotis princeps	0		6	0.12	0		0		0		0		0		0		0		6	0.01
Echinochloa pyramidolis	12	0.1	0		33	0.22	13	0.09	14	0.09	0		0		0		0		72	0.1
Echinochloa stagnina	93	0.33	41	0.35	43	0.26	149	0.36	236	0.37	0		0		0		93	0.37	655	0.34
Echinochloa ugandensis	0		28	0.3	38	0.24	45	0.22	37	0.17	0		44	0.27	8	0.3	22	0.23	222	0.21
Eichhornia crassipes	0		0		0		0		4	0.03	8	0.34	2	0.03	0		5	0.08	19	0.04
Eragrostis botryodes	0		0		0		0		15	0.09	0		34	0.24	0		0		49	0.07

Eragrostis tenuifolia	28	0.17	0		0		23	0.14	22	0.12	0		0		0		0		73	0.1
Galensoga quadriradiata	0		0		0		0		8	0.06	0		0		0		0		8	0.02
Ipomoea cairica	0		0		0		13	0.09	0		0		0		0		0		13	0.03
Leersia hexandr	35	0.2	14	0.21	0		0		14	0.09	0		17	0.16	0		0		80	0.1
Ludwigia abyssinica	0		4	0.09	5	0.06	12	0.09	0		0		10	0.11	0		6	0.1	37	0.06
Ludwigia laptocarpe	0		0		0		2	0.02	4	0.03	0		0		0		0		6	0.01
Nympheae lotus	14	0.11	6	0.12	0		0		0		0		0		0		0		20	0.04
Oxycaryam cubensis	24	0.16	0		0		0		7	0.05	0		0		0		0		31	0.05
Panicum hymeniochilum	0		14	0.21	0		24	0.14	23	0.12	0		13	0.13	12	0.4	26	0.25	112	0.13
Pennisetum thunbergii	20	0.14	0		0		0		0		0		0		0		0		20	0.04
Persicaria senegalensis	0		0		12	0.11	8	0.07	64	0.24	0		2	0.03	0		10	0.14	96	0.12
Phragmites australis	0		0		0		0		2	0.02	0		0		0		0		2	0.01
Pistia stratiotes	0		0		0		0		3	0.03	0		0		0		0		3	0.01
Potamogeton natan	0		0		0		35	0.18	0		0		0		0		0		35	0.06
Sacciolepis Africana	24	0.16	34	0.33	23	0.18	55	0.24	23	0.12	0		80	0.35	26	0.3	0		265	0.23
Snowdenia petitiana	11	0.09	0		0		0		8	0.06	0		0		0		0		19	0.04
Thelypteris confluens	0		0		0		1	0.01	0		0		0		0		0		1	0
Triumfetta annua	0		0		0		19	0.12	0		0		0		0		0		19	0.04
Typha latifolia	31	0.18	0		40	0.25	9	0.07	0		0		31	0.23	0		29	0.26	140	0.15
Vallisneria spiralis	0		0		0		0		4	0.03	0		0		0		0		4	0.01
Veronica abyssinica	0		0		11	0.11	7	0.06	0		0		0		0		0		18	0.03
Vossia cuspidate	0		0		0		0		7	0.05	0		0		0		0		7	0.02
Water pennywort /Hydrocotyle spp/	0		0		0		17	0.11	0		0		0		0		0		17	0.03
	453	2.56	164	4.01	353	4.57	505	2.53	607	4.16	15	0.69	318	4.36	46	1	226	3.54	2687	2.9

APPENDIX 11(A-C): Simpson's Diversity Index (D) of 11 sites in Lake Tana wetlands

11A. Simpson's Diversity Index (D) of Lake Tana in the Wet Season

Species Name	**S_0(W)**	**D(W)**	**S_1(W)**	**D(W)**	**S_2(W)**	**D(W)**	**S_3(W)**	**D(W)**	**S_4(W)**	**D(W)**	**S_6(W)**	**D(W)**	**S_8(W)**	**D(W)**	**S_9(W)**	**D(W)**	**S_{10}(W)**	**D(W)**	**TW**	**D(W)**
Acroceras macrum	20	0.01	4	0	12	0	19	0.0034	10	0.0004395	0	0	21	0.01227	0	0	16	0.01	102	0.003343
Achyranthes aspera	0	0	0	0	0	0	0	0	6	0.0001465	0	0	0	0	0	0	0	0	6	9.73E-06
Ageratum conizoides	0	0	0	0	0	0	3	6E-05	3	2.93E-05	0	0	0	0	0	0	0	0	6	9.73E-06
Alternative sessilis	0	0	0	0	0	0	0	0	8	0.0002735	0	0	0	0	0	0	0	0	8	1.82E-05
Arthraxon prinoides	10	0	0	0	0	0	0	0	5	9.768E-05	0	0	8	0.00164	0	0	0	0	23	0.000164
Ceratophyllum demersum	8	0	0	0	0	0	8	0.0006	3	2.93E-05	0	0	0	0	0	0	0	0	19	0.000111
Chenopedium ambrosioles	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Commelina Africana	0	0	8	0	0	0	6	0.0003	12	0.0006447	0	0	6	0.00088	0	0	11	0	43	0.000586
Cynodon dactylon	0	0	0	0	0	0	0	0	0	0	7	0.2	0	0	0	0	0	0	7	1.36E-05
Cyperus macrostachyos	4	0	0	0	0	0	0	0	5	9.768E-05	0	0	0	0	0	0	0	0	9	2.34E-05
Cyperus mundtii	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	13	5.06E-05
Cyperus papyrus	35	0.02	0	0	33	0.02	6	0.0003	22	0.0022563	0	0	11	0.00321	0	0	0	0	107	0.00368
Cyperus pectinatus	3	0	0	0	0	0	0	0	4	5.861E-05	0	0	0	0	0	0	0	0	7	1.36E-05
Dissotis canescens	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	15	6.81E-05
Dissotis princeps	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6.49E-07
Echinochloa pyramidolis	7	0	0	0	18	0.01	9	0.0007	8	0.0002735	0	0	0	0	0	0	0	0	42	0.000559
Echinochloa stagnina	67	0.06	32	0.08	30	0.02	107	0.1118	195	0.1847565	0	0	0	0	0	0	65	0.17	496	0.079668
Echinochloa ugandensis		0	21	0.04	20	0.01	38	0.0139	37	0.0065053	0	0	32	0.02899	8	0.04	16	0.01	172	0.009544
Eichhornia crassipes	0	0	0	0	0	0	0	0	4	5.861E-05	8	0.27	0	0	0	0	5	0	17	8.83E-05
Eragrostis botryodes	0	0	0	0	0	0	0	0	15	0.0010256	0	0	28	0.02209	0	0	0	0	43	0.000586
Eragrostis	19	0	0	0	0	0	17	0.0027	22	0.0022563	0	0	0	0	0	0	0	0	58	0.001073

tenuifolia																				
Galensoga quadriradiata	0	0	0	0	0	0	0	0	8	0.0002735	0	0	0	0	0	0	0	0	8	1.82E-05
Ipomoea cairica	0	0	0	0	0	0	8	0.0006	0	0	0	0	0	0	0	0	0	0	8	1.82E-05
Leersia hexandr	19	0	8	0	0	0	0	0	14	0.0008889	0	0	10	0.00263	0	0	0	0	51	0.000827
Ludwigia abyssinica	0	0	4	0	5	0	6	0.0003	0	0	0	0	3	0.00018	0	0	2	0	20	0.000123
Ludwigia laptocarpe	0	0	0	0	0	0	2	2E-05	4	5.861E-05	0	0	0	0	0	0	0	0	6	9.73E-06
Nympheae lotus	8	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	3.57E-05
Oxycaryam cubensis	20	0.01	0	0	0	0	0	0	7	0.0002051	0	0	0	0	0	0	0	0	27	0.000228
Panicum hymeniochilum	0	0	8	0	0	0	15	0.0021	23	0.0024712	0	0	8	0.00164	12	0.08	22	0.02	88	0.002484
Pennisetum thunbergii	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	4.28E-05
Persicaria senegalensis	0	0	0	0	10	0	5	0.0002	2	9.768E-06	0	0	2	5.8E-05	0	0	4	0	23	0.000164
Phragmites australis	0	0	0	0	0	0	0	0	2	9.768E-06	0	0	0	0	0	0	0	0	2	6.49E-07
Pistia stratiotes	0	0	0	0	0	0	0	0	3	2.93E-05	0	0	0	0	0	0	0	0	3	1.95E-06
Potamogeton natan	0	0	0	0	0	0	3	6E-05	0	0	0	0	0	0	0	0	0	0	3	1.95E-06
Sacciolepis Africana	12	0	20	0.03	15	0	32	0.0098	15	0.0010256	0	0	42	0.05032	20	0.24	0	0	156	0.007846
Snowdenia petitiana	8	0	0	0	0	0	0	0	5	9.768E-05	0	0	0	0	0	0	0	0	13	5.06E-05
Thelypteris confluens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triumfetta annua	0	0	0	0	0	0	11	0.0011	0	0	0	0	0	0	0	0	0	0	11	3.57E-05
Typha latifolia	18	0	0	0	28	0.02	5	0.0002	0	0	0	0	15	0.00614	0	0	15	0.01	81	0.002103
Vallisneria spiralis	0	0	0	0	0	0	0	0	4	5.861E-05	0	0	0	0	0	0	0	0	4	3.89E-06
Veronica abyssinica	0	0	0	0	8	0	5	0.0002	0	0	0	0	0	0	0	0	0	0	13	5.06E-05
Vossia cuspidate	0	0	0	0	0	0	0	0	7	0.0002051	0	0	0	0	0	0	0	0	7	1.36E-05
Water pennywort /Hydrocotyle spp/	0	0	0	0	0	0	13	0.0015	0	0	0	0	0	0	0	0	0	0	13	5.06E-05
Abundance	270		110		207		319		453		15		186		40		156		1756	
D’		0.11		0.17		0.1		0.1496		0.2042822		0.47		0.13003		0.36		0.23		0.11372
1-D		0.89		0.83		0.9		0.8504		0.7957178		0.53		0.86997		0.64		0.77		0.88628

11B. Simpson's Diversity Index (D) of Lake Tana in the Dry Season

Species Name	**S_0(D)**	**D(D)**	**S_1(D)**	**D(D)**	**S_2(D)**	**D(D)**	**S_3(D)**	**D(D)**	**S_4(D)**	**D(D)**	**S_6(D)**	**D(D)**	**S_8(D)**	**D(D)**	**S_9(D)**	**D(D)**	**S_{10}(D)**	**D(D)**	**TD**	**D(D)**
Acroceras macrum	20	0.01	2	0.0007	7	0.002	9	0.00209	8	0.0024	0	0	15	0.0121	0	0	3	0.001	64	0.004657
Achyranthes aspera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ageratum conizoides	0	0	0	0	0	0	2	5.8E-05	0	0	0	0	0	0	0	0	0	0	2	2.31E-06
Alternative sessilis	0	0	0	0	0	0	0	0	5	0.0008	0	0	0	0	0	0	0	0	5	2.31E-05
Arthraxon prinoides	4	0	0	0	0	0	0	0	0	0	0	0	3	0.0003	0	0	0	0	7	4.85E-05
Ceratophyllum demersum	6	0	0	0	0	0	5	0.00058	4	0.0005	0	0	0	0	0	0	0	0	15	0.000243
Chenopedium ambrosioles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Commelina Africana	0	0	3	0.0021	0	0	4	0.00035	0	0	0	0	3	0.0003	0	0	5	0.004	15	0.000243
Cynodon dactylon	16	0.01	0	0	0	0	0	0	0	0	0	-0.2	0	0	0	0	0	0	16	0.000277
Cyperus macrostachyos	2	0	0	0	0	0	0	0	3	0.0003	0	0	0	0	0	0	0	0	5	2.31E-05
Cyperus mundtii	0	0	0	0	18	0.0145	0	0	0	0	0	0	0	0	0	0	0	0	18	0.000353
Cyperus papyrus	31	0.03	0	0	30	0.0411	10	0.00262	12	0.0056	0	0	18	0.0177	0	0	0	0	101	0.011665
Cyperus pectinatus	2	0	0	0	0	0	0	0	2	8E-05	0	0	0	0	0	0	0	0	4	1.39E-05
Dissotis canescens	0	0	0	0	20	0.0179	0	0	0	0	0	0	0	0	0	0	0	0	20	0.000439
Dissotis princeps	0	0	4	0.0042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1.39E-05
Echinochloa pyramidolis	5	0	0	0	15	0.0099	4	0.00035	6	0.0013	0	0	0	0	0	0	0	0	30	0.001005
Echinochloa stagnina	26	0.02	9	0.0252	13	0.0074	42	0.05004	41	0.0696	0	0	0	0	0	0	28	0.157	159	0.029015
Echinochloa ugandensis		0	7	0.0147	18	0.0145	7	0.00122	0	0	0	0	12	0.0076	0	0	6	0.006	50	0.00283
Eichhornia crassipes	0	0	0	0	0	0	0	0	0	0	0	-0.3	2	0.0001	0	0	0	0	2	2.31E-06
Eragrostis botryodes	0	0	0	0	0	0	0	0	0	0	0	0	6	0.0017	0	0	0	0	6	3.46E-05
Eragrostis tenuifolia	9	0	0	0	0	0	6	0.00087	0	0	0	0	0	0	0	0	0	0	15	0.000243
Galensoga quadriradiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ipomoea cairica	0	0	0	0	0	0	5	0.00058	0	0	0	0	0	0	0	0	0	0	5	2.31E-05
Leersia hexandr	16	0.01	6	0.0105	0	0	0	0	0	0	0	0	7	0.0024	0	0	0	0	29	0.000938
Ludwigia abyssinica	0	0	0	0	0	0	6	0.00087	0	0	0	0	7	0.0024	0	0	4	0.002	17	0.000314
Ludwigia laptocarpe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nympheae lotus	6	0	3	0.0021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	8.32E-05

Oxycaryam cubensis	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1.39E-05
Panicum hymeniochilum	0	0	6	0.0105	0	0	9	0.00209	0	0	0	0	5	0.0012	0	0	4	0.002	24	0.000638
Pennisetum thunbergii	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	6.47E-05
Persicaria senegalensis	0	0	0	0	2	9E-05	3	0.00017	62	0.1605	0	0	0	0	0	0	6	0.006	73	0.00607
Phragmites australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pistia stratiotes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potamogeton natan	0	0	0	0	0	0	32	0.02883	0	0	0	0	0	0	0	0	0	0	32	0.001146
Sacciolepis Africana	12	0	14	0.0636	8	0.0026	23	0.01471	8	0.0024	0	0	38	0.0813	6	1	0	0	109	0.013596
Snowdenia petitiana	3	0	0	0	0	0	0	0	3	0.0003	0	0	0	0	0	0	0	0	6	3.46E-05
Thelypteris confluens	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Triumfetta annua	0	0	0	0	0	0	8	0.00163	0	0	0	0	0	0	0	0	0	0	8	6.47E-05
Typha latifolia	13	0	0	0	12	0.0062	4	0.00035	0	0	0	0	16	0.0139	0	0	14	0.038	59	0.003952
Vallisneria spiralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Veronica abyssinica	0	0	0	0	3	0.0003	2	5.8E-05	0	0	0	0	0	0	0	0	0	0	5	2.31E-05
Vossia cuspidate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water pennywort /Hydrocotyle spp/	0	0	0	0	0	0	4	0.00035	0	0	0	0	0	0	0	0	0	0	4	1.39E-05
Abundance	183		54		146		186		154		0		132		6		70		931	
D’		0.09		0.1335		0.1165		0.10782		0.2437		-0.5		0.1412		1		0.217		0.078105
1-D		0.91		0.8665		0.8835		0.89218		0.7563		1.47		0.8588		0		0.783		0.921895

11C. Simpson's Diversity Index (D) of Lake Tana in the Study Year

Species Name	S_0(T)	D(T)	S_1(T)	D(T)	S_2(T)	D(T)	S_3(T)	D(T)	S_4(T)	D(T)	S_6(T)	D(T)	S_8(T)	D(T)	S_9(T)	D(T)	S_{10}(T)	D(T)	T	D(T)
Acroceras macrum	40	0.00762	6	0	19	0.002752	28	0.00297	18	0.000832	0	0	36	0.012499	0	0	19	0.006726	166	0.003795
Achyranthes aspera	0	0	0	0	0	0	0	0	6	8.16E-05	0	0	0	0	0	0	0	0	6	4.16E-06
Ageratum conizoides	0	0	0	0	0	0	5	7.9E-05	3	1.63E-05	0	0	0	0	0	0	0	0	8	7.76E-06
Alternative sessilis	0	0	0	0	0	0	0	0	13	0.000424	0	0	0	0	0	0	0	0	13	2.16E-05
Arthraxon prinoides	14	0.00089	0	0	0	0	0	0	5	5.44E-05	0	0	11	0.001091	0	0	0	0	30	0.000121
Ceratophyllum demersum	14	0.00089	0	0	0	0	13	0.00061	7	0.000114	0	0	0	0	0	0	0	0	34	0.000155
Chenopedium ambrosioles	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Commelina africana	0	0	11	0	0	0	10	0.00035	12	0.000359	0	0	9	0.000714	0	0	16	0.00472	58	0.000458
Cynodon dactylon	16	0.00117	0	0	0	0	0	0	0	0	7	0.2	0	0	0	0	0	0	23	7.01E-05
Cyperus macrostachyos	6	0.00015	0	0	0	0	0	0	8	0.000152	0	0	0	0	0	0	0	0	14	2.52E-05
Cyperus mundtii	0	0	0	0	31	0.007485	0	0	0	0	0	0	0	0	0	0	0	0	31	0.000129
Cyperus papyrus	66	0.02095	0	0	63	0.031435	16	0.00094	34	0.00305	0	0	29	0.008055	0	0	0	0	208	0.005966
Cyperus pectinatus	5	9.8E-05	0	0	0	0	0	0	6	8.16E-05	0	0	0	0	0	0	0	0	11	1.52E-05
Dissotis canescens	0	0	0	0	35	0.009577	0	0	0	0	0	0	0	0	0	0	0	0	35	0.000165
Dissotis princeps	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	4.16E-06
Echinochloa pyramidolis	12	0.00064	0	0	33	0.008499	13	0.00061	14	0.000495	0	0	0	0	0	0	0	0	72	0.000708
Echinochloa stagnina	93	0.04179	41	0.06	43	0.014535	149	0.08664	236	0.150771	0	0	0	0	0	0	93	0.16826	655	0.059353
Echinochloa ugandensis	0	0	28	0.03	38	0.011315	45	0.00778	37	0.003621	0	0	44	0.018769	8	0.02705	22	0.009086	222	0.006798
Eichhornia crassipes	0	0	0	0	0	0	0	0	4	3.26E-05	8	0.267	2	1.98E-05	0	0	5	0.000393	19	4.74E-05
Eragrostis botryodes	0	0	0	0	0	0	0	0	15	0.000571	0	0	34	0.01113	0	0	0	0	49	0.000326

Eragrostis tenuifolia	28	0.00369	0	0	0	0	23	0.00199	22	0.001256	0	0	0	0	0	0	0	0	73	0.000728
Galensoga quadriradiata	0	0	0	0	0	0	0	0	8	0.000152	0	0	0	0	0	0	0	0	8	7.76E-06
Ipomoea cairica	0	0	0	0	0	0	13	0.00061	0	0	0	0	0	0	0	0	0	0	13	2.16E-05
Leersia hexandr	35	0.00581	14	0.01	0	0	0	0	14	0.000495	0	0	17	0.002698	0	0	0	0	80	0.000876
Ludwigia abyssinica	0	0	4	0	5	0.000161	12	0.00052	0	0	0	0	10	0.000893	0	0	6	0.00059	37	0.000185
Ludwigia laptocarpe	0	0	0	0	0	0	2	7.9E-06	4	3.26E-05	0	0	0	0	0	0	0	0	6	4.16E-06
Nympheae lotus	14	0.00089	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	5.27E-05
Oxycaryam cubensis	24	0.0027	0	0	0	0	0	0	7	0.000114	0	0	0	0	0	0	0	0	31	0.000129
Panicum hymeniochilum	0	0	14	0.01	0	0	24	0.00217	23	0.001376	0	0	13	0.001548	12	0.06377	26	0.012783	112	0.001723
Pennisetum thunbergii	20	0.00186	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	5.27E-05
Persicaria senegalensis	0	0	0	0	12	0.001062	8	0.00022	64	0.010961	0	0	2	1.98E-05	0	0	10	0.00177	96	0.001264
Phragmites australis	0	0	0	0	0	0	0	0	2	5.44E-06	0	0	0	0	0	0	0	0	2	2.77E-07
Pistia stratiotes	0	0	0	0	0	0	0	0	3	1.63E-05	0	0	0	0	0	0	0	0	3	8.31E-07
Potamogeton natan	0	0	0	0	0	0	35	0.00468	0	0	0	0	0	0	0	0	0	0	35	0.000165
Sacciolepis Africana	24	0.0027	34	0.04	23	0.004072	55	0.01167	23	0.001376	0	0	80	0.062695	26	0.31401	0	0	265	0.009693
Snowdenia petitiana	11	0.00054	0	0	0	0	0	0	8	0.000152	0	0	0	0	0	0	0	0	19	4.74E-05
Thelypteris confluens	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Triumfetta annua	0	0	0	0	0	0	19	0.00134	0	0	0	0	0	0	0	0	0	0	19	4.74E-05
Typha latifolia	31	0.00454	0	0	40	0.012555	9	0.00028	0	0	0	0	31	0.009226	0	0	29	0.015969	140	0.002696
Vallisneria spiralis	0	0	0	0	0	0	0	0	4	3.26E-05	0	0	0	0	0	0	0	0	4	1.66E-06
Veronica abyssinica	0	0	0	0	11	0.000885	7	0.00017	0	0	0	0	0	0	0	0	0	0	18	4.24E-05
Vossia cuspidata	0	0	0	0	0	0	0	0	7	0.000114	0	0	0	0	0	0	0	0	7	5.82E-06
Water pennywort	0	0	0	0	0	0	17	0.00107	0	0	0	0	0	0	0	0	0	0	17	3.77E-05

/Hydrocotyle spp/																				
Abundance	453		164		353		505		607		15		318		46		226		2687	
D’		0.09692		0.15		0.104333		0.12471		0.176739		0.467		0.129357		0.40483		0.220295		0.09595
1-D		0.90308		0.85		0.895667		0.87529		0.823261		0.533		0.870643		0.59517		0.779705		0.90405

APPENDIX 12: Margalef's index (M') Measurement of species richness, 11 sites in Lake Tana wetlands

Species Name	S0(W)	S0(D)	S0(T)	S1(W)	S1(D)	S1(T)	S2(W)	S2(D)	S2(T)	S3(W)	S3(D)	S3(T)	S4(W)	S4(D)	S4(T)	S6(W)	S6(D)	S6(T)	S8(W)	S8(D)	S8(T)	S9(W)	S9(D)	S9(T)	S10(W)	S10(D)	S10(T)	TW	TD	T	S0(W)	S0(D)	S0(T)	S1(W)	S1(D)
Acroceras macrum	20	20	40	4	2	6	12	7	19	19	9	28	10	8	18	0	0	0	21	15	36	0	0	0	16	3	19	102	64	166	20	20	40	4	2
Achyranthes aspera	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6	0	0	0	0	0
Ageratum conizoides	0	0	0	0	0	0	0	0	0	3	2	5	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	6	2	8	0	0	0	0	0
Alternative sessilis	0	0	0	0	0	0	0	0	0	0	0	0	8	5	13	0	0	0	0	0	0	0	0	0	0	0	0	8	5	13	0	0	0	0	0
Arthraxon prinoides	10	4	14	0	0	0	0	0	0	0	0	0	5	0	5	0	0	0	8	3	11	0	0	0	0	0	0	23	7	30	10	4	14	0	0
Ceratophyllum demersum	8	6	14	0	0	0	0	0	0	8	5	13	3	4	7	0	0	0	0	0	0	0	0	0	0	0	0	19	15	34	8	6	14	0	0
Chenopedium ambrosioles	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Commelina Africana	0	0	0	8	3	11	0	0	0	6	4	10	12	0	12	0	0	0	6	3	9	0	0	0	11	5	16	43	15	58	0	0	0	8	3
Cynodon dactylon	0	16	16	0	0	0	0	0	0	0	0	0	0	0	0	7	0	7	0	0	0	0	0	0	0	0	0	7	16	23	0	16	16	0	0
Cyperus macrostachyos	4	2	6	0	0	0	0	0	0	0	0	0	5	3	8	0	0	0	0	0	0	0	0	0	0	0	0	9	5	14	4	2	6	0	0
Cyperus mundtii	0	0	0	0	0	0	13	18	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	18	31	0	0	0	0	0
Cyperus papyrus	35	31	66	0	0	0	33	30	63	6	10	16	22	12	34	0	0	0	11	18	29	0	0	0	0	0	0	107	101	208	35	31	66	0	0
Cyperus pectinatus	3	2	5	0	0	0	0	0	0	0	0	0	4	2	6	0	0	0	0	0	0	0	0	0	0	0	0	7	4	11	3	2	5	0	0
Dissotis canescens	0	0	0	0	0	0	15	20	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	20	35	0	0	0	0	0
Dissotis princeps	0	0	0	2	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6	0	0	0	2	4
Echinochloa pyramidolis	7	5	12	0	0	0	18	15	33	9	4	13	8	6	14	0	0	0	0	0	0	0	0	0	0	0	0	42	30	72	7	5	12	0	0
Echinochloa stagnina	67	26	93	32	9	41	30	13	43	107	42	149	195	41	236	0	0	0	0	0	0	0	0	0	65	28	93	496	159	655	67	26	93	32	9
Echinochloa ugandensis			0	21	7	28	20	18	38	38	7	45	37	0	37	0	0	0	32	12	44	8	0	8	16	6	22	17	50	22			0	21	7

																											2		2					
Eichhornia crassipes	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	8	0	8	0	2	2	0	0	0	5	0	5	17	2	19	0	0	0	0	0
Eragrostis botryodes	0	0	0	0	0	0	0	0	0	0	0	0	15	0	15	0	0	0	28	6	34	0	0	0	0	0	0	43	6	49	0	0	0	0	0
Eragrostis tenuifolia	19	9	28	0	0	0	0	0	0	17	6	23	22	0	22	0	0	0	0	0	0	0	0	0	0	0	0	58	15	73	19	9	28	0	0
Galensoga quadriradiata	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	0	0	0	0	0
Ipomoea cairica	0	0	0	0	0	0	0	0	0	8	5	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	5	13	0	0	0	0	0
Leersia hexandr	19	16	35	8	6	14	0	0	0	0	0	0	14	0	14	0	0	0	10	7	17	0	0	0	0	0	0	51	29	80	19	16	35	8	6
Ludwigia abyssinica	0	0	0	4	0	4	5	0	5	6	6	12	0	0	0	0	0	0	3	7	10	0	0	0	2	4	6	20	17	37	0	0	0	4	0
Ludwigia laptocarpe	0	0	0	0	0	0	0	0	0	2	0	2	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6	0	0	0	0	0
Nympheae lotus	8	6	14	3	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	9	20	8	6	14	3	3
Oxycaryam cubensis	20	4	24	0	0	0	0	0	0	0	0	0	7	0	7	0	0	0	0	0	0	0	0	0	0	0	0	27	4	31	20	4	24	0	0
Panicum hymeniochilum	0	0	0	8	6	14	0	0	0	15	9	24	23	0	23	0	0	0	8	5	13	12	0	12	22	4	26	88	24	112	0	0	0	8	6
Pennisetum thunbergii	12	8	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	8	20	12	8	20	0	0
Persicaria senegalensis	0	0	0	0	0	0	10	2	12	5	3	8	2	62	64	0	0	0	2	0	2	0	0	0	4	6	10	23	73	96	0	0	0	0	0
Phragmites australis	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0
Pistia stratiotes	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0
Potamogeton natan	0	0	0	0	0	0	0	0	0	3	32	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	32	35	0	0	0	0	0
Sacciolepis Africana	12	12	24	20	14	34	15	8	23	32	23	55	15	8	23	0	0	0	42	38	80	20	6	26	0	0	0	156	109	265	12	12	24	20	14
Snowdenia petitiana	8	3	11	0	0	0	0	0	0	0	0	0	5	3	8	0	0	0	0	0	0	0	0	0	0	0	0	13	6	19	8	3	11	0	0
Thelypteris confluens	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Triumfetta annua	0	0	0	0	0	0	0	0	0	11	8	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	8	19	0	0	0	0	0
Typha latifolia	18	13	31	0	0	0	28	12	40	5	4	9	0	0	0	0	0	0	15	16	31	0	0	0	15	14	29	81	59	140	18	13	31	0	0

Vallisneria spiralis	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	0	0	0	0	0	0	0	0	0		0	4	0	4	0	0	0	0	0
Veronica abyssinica	0	0	0	0	0	0	8	3	11	5	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	5	18	0	0	0	0	0
Vossia cuspidate	0	0	0	0	0	0	0	0	0	0	0	0	7	0	7	0	0	0	0	0	0	0	0	0	0	0	0	7	0	7	0	0	0	0	0
Water pennywort /Hydrocotyle spp/	0	0	0	0	0	0	0	0	0	13	4	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	4	17	0	0	0	0	0
Abundance	270	183	453	110	54	164	207	146	353	319	186	505	453	154	607	15	0	15	186	132	318	40	6	46	156	70	226	1756	931	2687	270	183	453	110	54
No. SPP	16	17	17	10	9	10	12	11	12	21	20	23	28	11	28	2	0	2	12	12	13	3	1	3	9	8	9	42	35	43	16	17	17	10	9
M'	2.679326	3.07132	2.616135	1.914698	2.005523	1.764752	2.062738	2.006579	1.875063	3.469096	3.635844	3.534387	4.414728	1.985327	4.213135	0.369269	#NUM!	0.369269	2.104962	2.252805	2.082592	0.54217	0	0.522379	1.584204	1.647642	1.475869	5.488038	4.97348	5.319027	2.679326	3.07132	2.616135	1.914698	2.005523

APPENDIX 13 (A-C): Eveness (E′) of 11 sites in Lake Tana wetlands

13A. Eveness (E′) of Lake Tana in the Wet Season

Species Name	S_0(W)	H(W)	S_1(W)	H(W)	S_2(W)	H(W)	S_3(W)	H(W)	S_4(W)	H(W)	S_6(W)	H(W)	S_8(W)	H(W)	S_9(W)	H(W)	S_{10}(W)	H(W)	TW	H(W)
Acroceras macrum	20	0.19	4	0.12	12	0.17	19	0.17	10	0.08	0		21	0.25	0		16	0.23	102	0.17
Achyranthes aspera	0		0		0		0		6	0.06	0		0		0		0		6	0.02
Ageratum conizoides	0		0		0		3	0.04	3	0.03	0		0		0		0		6	0.02
Alternative sessilis	0		0		0		0		8	0.07	0		0		0		0		8	0.02
Arthraxon prinoides	10	0.12	0		0		0		5	0.05	0		8	0.14	0		0		23	0.06
Ceratophyllum demersum	8	0.1	0		0		8	0.09	3	0.03	0		0		0		0		19	0.05
Chenopedium ambrosioles	0		0		0		1	0.02	0		0		0		0		0		1	0
Commelina Africana	0		8	0.19	0		6	0.07	12	0.1	0		6	0.11	0		11	0.19	43	0.09
Cynodon dactylon	0		0		0		0		0		7	0.36	0		0		0		7	0.02
Cyperus macrostachyos	4	0.06	0		0		0		5	0.05	0		0		0		0		9	0.03
Cyperus mundtii	0		0		13	0.17	0		0		0		0		0		0		13	0.04
Cyperus papyrus	35	0.26	0		33	0.29	6	0.07	22	0.15	0		11	0.17	0		0		107	0.17
Cyperus pectinatus	3	0.05	0		0		0		4	0.04	0		0		0		0		7	0.02
Dissotis canescens	0		0		15	0.19	0		0		0		0		0		0		15	0.04
Dissotis princeps	0		2	0.07	0		0		0		0		0		0		0		2	0.01
Echinochloa pyramidolis	7	0.09	0		18	0.21	9	0.1	8	0.07	0		0		0		0		42	0.09
Echinochloa stagnina	67	0.35	32	0.36	30	0.28	107	0.37	195	0.36	0		0		0		65	0.36	496	0.36
Echinochloa ugandensis			21	0.32	20	0.23	38	0.25	37	0.2	0		32	0.3	8	0.32	16	0.23	172	0.23
Eichhornia crassipes	0		0		0		0		4	0.04	8	0.34	0		0		5	0.11	17	0.04
Eragrostis botryodes	0		0		0		0		15	0.11	0		28	0.29	0		0		43	0.09
Eragrostis tenuifolia	19	0.19	0		0		17	0.16	22	0.15	0		0		0		0		58	0.11
Galensoga quadriradiata	0		0		0		0		8	0.07	0		0		0		0		8	0.02
Ipomoea cairica	0		0		0		8	0.09	0		0		0		0		0		8	0.02
Leersia hexandr	19	0.19	8	0.19	0		0		14	0.11	0		10	0.16	0		0		51	0.1
Ludwigia abyssinica	0		4	0.12	5	0.09	6	0.07	0		0		3	0.07	0		2	0.06	20	0.05
Ludwigia laptocarpe	0		0		0		2	0.03	4	0.04	0		0		0		0		6	0.02
Nympheae lotus	8	0.1	3	0.1	0		0		0		0		0		0		0		11	0.03
Oxycaryam cubensis	20	0.19	0		0		0		7	0.06	0		0		0		0		27	0.06
Panicum hymeniochilum	0		8	0.19	0		15	0.14	23	0.15	0		8	0.14	12	0.36	22	0.28	88	0.15
Pennisetum thunbergii	12	0.14	0		0		0		0		0		0		0		0		12	0.03
Persicaria senegalensis	0		0		10	0.15	5	0.07	2	0.02	0		2	0.05	0		4	0.09	23	0.06

Phragmites australis	0		0		0		0		2	0.02	0		0		0		0		2	0.01
Pistia stratiotes	0		0		0		0		3	0.03	0		0		0		0		3	0.01
Potamogeton natan	0		0		0		3	0.04	0		0		0		0		0		3	0.01
Sacciolepis Africana	12	0.14	20	0.31	15	0.19	32	0.23	15	0.11	0		42	0.34	20	0.35	0		156	0.22
Snowdenia petitiana	8	0.1	0		0		0		5	0.05	0		0		0		0		13	0.04
Thelypteris confluens	0		0		0		0		0		0		0		0		0		0	
Triumfetta annua	0		0		0		11	0.12	0		0		0		0		0		11	0.03
Typha latifolia	18	0.18	0		28	0.27	5	0.07	0		0		15	0.2	0		15	0.23	81	0.14
Vallisneria spiralis	0		0		0		0		4	0.04	0		0		0		0		4	0.01
Veronica abyssinica	0		0		8	0.13	5	0.07	0		0		0		0		0		13	0.04
Vossia cuspidate	0		0		0		0		7	0.06	0		0		0		0		7	0.02
Water pennywort /Hydrocotyle spp/	0		0		0		13	0.13	0		0		0		0		0		13	0.04
Abundance and H’	270	2.47	110	1.97	207	2.36	319	2.41	453	2.39	15	0.69	186	2.19	40	1.03	156	1.78	1756	2.8
No. SPP	16		10		12		21		28		2		12		3		9		42	
E’		0.89		0.86		0.95		0.79		0.72		0.997		0.88		0.94		0.81		0.75

13B. Eveness (E′) of Lake Tana in the Dry Season

Species Name	**S_0(D)**	**H(D)**	**S_1(D)**	**H(D)**	**S_2(D)**	**H(D)**	**S_3(D)**	**H(D)**	**S_4(D)**	**H(D)**	**S_6(D)**	**H(D)**	**S_8(D)**	**H(D)**	**S_9(D)**	**H(D)**	**S_{10}(D)**	**H(D)**	**TD**	**H(D)**
Acroceras macrum	20	0.242	2	0.122	7	0.15	9	0.15	8	0.15	0		15	0.25	0		3	0.13	64	0.18
Achyranthes aspera	0		0		0		0		0		0		0		0		0		0	
Ageratum conizoides	0		0		0		2	0.05	0		0		0		0		0		2	0.01
Alternative sessilis	0		0		0		0		5	0.11	0		0		0		0		5	0.03
Arthraxon prinoides	4	0.084	0		0		0		0		0		3	0.09	0		0		7	0.04
Ceratophyllum demersum	6	0.112	0		0		5	0.1	4	0.09	0		0		0		0		15	0.07
Chenopedium ambrosioles	0		0		0		0		0		0		0		0		0		0	
Commelina Africana	0		3	0.161	0		4	0.08	0		0		3	0.09	0		5	0.19	15	0.07
Cynodon dactylon	16	0.213	0		0		0		0		0		0		0		0		16	0.07
Cyperus macrostachyos	2	0.049	0		0		0		3	0.08	0		0		0		0		5	0.03
Cyperus mundtii	0		0		18	0.26	0		0		0		0		0		0		18	0.08
Cyperus papyrus	31	0.301	0		30	0.33	10	0.16	12	0.2	0		18	0.27	0		0		101	0.24
Cyperus pectinatus	2	0.049	0		0		0		2	0.06	0		0		0		0		4	0.02
Dissotis canescens	0		0		20	0.27	0		0		0		0		0		0		20	0.08
Dissotis princeps	0		4	0.193	0		0		0		0		0		0		0		4	0.02
Echinochloa pyramidolis	5	0.098	0		15	0.23	4	0.08	6	0.13	0		0		0		0		30	0.11
Echinochloa stagnina	26	0.277	9	0.299	13	0.22	42	0.34	41	0.35	0		0		0		28	0.37	159	0.3
Echinochloa ugandensis			7	0.265	18	0.26	7	0.12	0		0		12	0.22	0		6	0.21	50	0.16
Eichhornia crassipes	0		0		0		0		0		0		2	0.06	0		0		2	0.01
Eragrostis botryodes	0		0		0		0		0		0		6	0.14	0		0		6	0.03
Eragrostis tenuifolia	9	0.148	0		0		6	0.11	0		0		0		0		0		15	0.07
Galensoga quadriradiata	0		0		0		0		0		0		0		0		0		0	
Ipomoea cairica	0		0		0		5	0.1	0		0		0		0		0		5	0.03
Leersia hexandr	16	0.213	6	0.244	0		0		0		0		7	0.16	0		0		29	0.11
Ludwigia abyssinica	0		0		0		6	0.11	0		0		7	0.16	0		4	0.16	17	0.07
Ludwigia laptocarpe	0		0		0		0		0		0		0		0		0		0	
Nympheae lotus	6	0.112	3	0.161	0		0		0		0		0		0		0		9	0.04
Oxycaryam cubensis	4	0.084	0		0		0		0		0		0		0		0		4	0.02
Panicum hymeniochilum	0		6	0.244	0		9	0.15	0		0		5	0.12	0		4	0.16	24	0.09
Pennisetum thunbergii	8	0.137	0		0		0		0		0		0		0		0		8	0.04
Persicaria senegalensis	0		0		2	0.06	3	0.07	62	0.37	0		0		0		6	0.21	73	0.2
Phragmites australis	0		0		0		0		0		0		0		0		0		0	

Pistia stratiotes	0		0		0		0		0		0		0		0		0		0	
Potamogeton natan	0		0		0		32	0.3	0		0		0		0		0		32	0.12
Sacciolepis Africana	12	0.179	14	0.35	8	0.16	23	0.26	8	0.15	0		38	0.36	6	0	0		109	0.25
Snowdenia petitiana	3	0.067	0		0		0		3	0.08	0		0		0		0		6	0.03
Thelypteris confluens	0		0		0		1	0.03	0		0		0		0		0		1	0.01
Triumfetta annua	0		0		0		8	0.14	0		0		0		0		0		8	0.04
Typha latifolia	13	0.188	0		12	0.21	4	0.08	0		0		16	0.26	0		14	0.32	59	0.17
Vallisneria spiralis	0		0		0		0		0		0		0		0				0	
Veronica abyssinica	0		0		3	0.08	2	0.05	0		0		0		0		0		5	0.03
Vossia cuspidate	0		0		0		0		0		0		0		0		0		0	
Water pennywort /Hydrocotyle spp/	0		0		0		4	0.08	0		0		0		0		0		4	0.02
Abundance and H’	183	2.553	54	2.038	146	2.21	186	2.54	154	1.77	0	0.7	132	2.16	6	0	70	1.76	931	2.91
No. SPP	17		9		11		20		11		0		12		1		8		35	
E’		0.9		0.93		0.92		0.85		0.74		-		0.87		-		0.85		0.82

13C. Eveness (E′) of Lake Tana in the Study year

Species Name	S_0(T)	H(T)	S_1(T)	H(T)	S_2(T)	H(T)	S_3(T)	H(T)	S_4(T)	H(T)	S_6(T)	H(T)	S_8(T)	H(T)	S_9(T)	H(T)	S_{10}(T)	H(T)	T	H(T)
Acroceras macrum	40	0.21	6	0.12	19	0.16	28	0.16	18	0.1	0		36	0.25	0		19	0.21	166	0.17
Achyranthes aspera	0		0		0		0		6	0.05	0		0		0		0		6	0.01
Ageratum conizoides	0		0		0		5	0.05	3	0.03	0		0		0		0		8	0.02
Alternative sessilis	0		0		0		0		13	0.08	0		0		0		0		13	0.03
Arthraxon prinoides	14	0.11	0		0		0		5	0.04	0		11	0.12	0		0		30	0.05
Ceratophyllum demersum	14	0.11	0		0		13	0.09	7	0.05	0		0		0		0		34	0.06
Chenopedium ambrosioles	0		0		0		1	0.01	0		0		0		0		0		1	0
Commelina Africana	0		11	0.18	0		10	0.08	12	0.08	0		9	0.1	0		16	0.19	58	0.08
Cynodon dactylon	16	0.12	0		0		0		0		7	0.36	0		0		0		23	0.04
Cyperus macrostachyos	6	0.06	0		0		0		8	0.06	0		0		0		0		14	0.03
Cyperus mundtii	0		0		31	0.21	0		0		0		0		0		0		31	0.05
Cyperus papyrus	66	0.28	0		63	0.31	16	0.11	34	0.16	0		29	0.22	0		0		208	0.2
Cyperus pectinatus	5	0.05	0		0		0		6	0.05	0		0		0		0		11	0.02
Dissotis canescens	0		0		35	0.23	0		0		0		0		0		0		35	0.06
Dissotis princeps	0		6	0.12	0		0		0		0		0		0		0		6	0.01
Echinochloa pyramidolis	12	0.1	0		33	0.22	13	0.09	14	0.09	0		0		0		0		72	0.1
Echinochloa stagnina	93	0.33	41	0.35	43	0.26	149	0.36	236	0.37	0		0		0		93	0.37	655	0.34
Echinochloa ugandensis	0		28	0.3	38	0.24	45	0.22	37	0.17	0		44	0.27	8	0.3	22	0.23	222	0.21
Eichhornia crassipes	0		0		0		0		4	0.03	8	0.34	2	0.03	0		5	0.08	19	0.04
Eragrostis botryodes	0		0		0		0		15	0.09	0		34	0.24	0		0		49	0.07
Eragrostis tenuifolia	28	0.17	0		0		23	0.14	22	0.12	0		0		0		0		73	0.1
Galensoga quadriradiata	0		0		0		0		8	0.06	0		0		0		0		8	0.02
Ipomoea cairica	0		0		0		13	0.09	0		0		0		0		0		13	0.03
Leersia hexandr	35	0.2	14	0.21	0		0		14	0.09	0		17	0.16	0		0		80	0.1
Ludwigia abyssinica	0		4	0.09	5	0.06	12	0.09	0		0		10	0.11	0		6	0.1	37	0.06

Ludwigia laptocarpe	0		0		0		2	0.02	4	0.03	0		0		0		0		6	0.01
Nympheae lotus	14	0.11	6	0.12	0		0		0		0		0		0		0		20	0.04
Oxycaryam cubensis	24	0.16	0		0		0		7	0.05	0		0		0		0		31	0.05
Panicum hymeniochilum	0		14	0.21	0		24	0.14	23	0.12	0		13	0.13	12	0.4	26	0.25	112	0.13
Pennisetum thunbergii	20	0.14	0		0		0		0		0		0		0		0		20	0.04
Persicaria senegalensis	0		0		12	0.11	8	0.07	64	0.24	0		2	0.03	0		10	0.14	96	0.12
Phragmites australis	0		0		0		0		2	0.02	0		0		0		0		2	0.01
Pistia stratiotes	0		0		0		0		3	0.03	0		0		0		0		3	0.01
Potamogeton natan	0		0		0		35	0.18	0		0		0		0		0		35	0.06
Sacciolepis Africana	24	0.16	34	0.33	23	0.18	55	0.24	23	0.12	0		80	0.35	26	0.3	0		265	0.23
Snowdenia petitiana	11	0.09	0		0		0		8	0.06	0		0		0		0		19	0.04
Thelypteris confluens	0		0		0		1	0.01	0		0		0		0		0		1	0
Triumfetta annua	0		0		0		19	0.12	0		0		0		0		0		19	0.04
Typha latifolia	31	0.18	0		40	0.25	9	0.07	0		0		31	0.23	0		29	0.26	140	0.15
Vallisneria spiralis	0		0		0		0		4	0.03	0		0		0		0		4	0.01
Veronica abyssinica	0		0		11	0.11	7	0.06	0		0		0		0		0		18	0.03
Vossia cuspidate	0		0		0		0		7	0.05	0		0		0		0		7	0.02
Water pennywort /Hydrocotyle spp/	0		0		0		17	0.11	0		0		0		0		0		17	0.03
Abundance and H’	453	2.56	164	4.01	353	4.57	505	2.53	607	4.16	15	0.69	318	4.36	46	1	226	3.54	2687	2.9
No. SPP	17		10		12		23		28		2		13		3		9		43	
E’		0.9		1.74		1.84		0.81		1.25		1		1.7		0.94		1.61		0.77

APPENDIX 14: Key Informant Interview Guiding Questions

NB: The information provided will be treated with confidentiality and only for research purposes.

Title: **Assessment of the Impact of Anthropogenic Activities on Water quality, Biodiversity and Livelihood of Lake Tana surrounding community, Northwestern Ethiopia**

Questionnaire: Background information-Key informant (eg. City/Town/Kebele heads, etc)

Region:..
Zone:...
Woreda/district: ....
City/Town/Village: ....

Date: ....
Interviewer: ....

1.Age: ....

2. Organization: ....

3.Position: ....

4. How long have you been serving in this City/Town/village/organization?

....

1. Land use land cover

1.1. Have you observed a gradual land use-land cover change in this area?

☐ Yes ☐ No

1.2.If yes to Q.1.1, what are the changes that you have observed in the City/Town/Kebele?

____

____

1.3. If yes for 1.1., what do you think are the major causes to the land use-land cover change in City/Town/Kebele?

____

____

1.4.What do you think are the effects of land use- land cover change?

1.5. What is the land degradation status in the area?

1.6. What are the causes of land degradation?

1.7. What is the status of soil fertility in the area?

1.8. List the forms of environmental degradation observed in the area?

1.9. What are the causes of environmental degradation in the area?

1.10. What are the effects of this environmental degradation?

1.11. Do you observe social instability (conflict over scarce resources, theft, water shortage, food shortage, migration, etc) as a result of these problems?

Yes ☐ No ☐

1.12. What is the level of understanding in the society of environmental degradation?

☐ Very high ☐ Medium ☐ Low ☐ Very low

1.13. How can you describe the status of the forest resource in/ near the / City/Town/Kebele recently in comparison to 10 years ago?

1.14. What are the types of ownership and user rights over forestland?

1.15. How has ownership and use of forestland affected the environment?

1.16. Is there a protected forest? What is the status? Explain.

1.17. Are there organizations that own forest resources?

1.18. What are the activities that the organizations conduct on the resource?

1.19. What other activities are taking place in the forest?

1.20. What is the status of the wetlands in the area as compared to the past 10 years?

1.21. What are the types of ownership and user rights over the wetland?

1.22. How has the ownership and use of the wetland affected the area?

1.23. Is the wetland in the area protected? Explain

1.24. Are there organizations that own wetlands in the area?

1.25. How has land use distribution affected the environment?

1.26. What are the common land conservation measures used in the area?

1.27. How can you describe the current status of land productivity in comparison to the situation 20 years ago?

1.28. What is the reason for the current status of productivity?

1.29. Issues related to the forest, wetland and biodiversity in/ near/ City/Town/Kebele

Issues	Yes/No	Year	Notes
Most villagers are not aware of the forest's status			
Forest boundary is not clear			
Forest boundary has been established without the agreement of the community			
Community land is inside the forest area			

Logging by outsiders			
Logging by villagers			
Animal/bird migration			
Disturbance of traditional activities inside the forest (Traditional medicine, bee hiving, honey collection, etc)			
Flooding and landslides			
Famine			
Lake depth decrease			
Lake pollution			
Lake biodiversity reduction (Loss of spp)			
Land conflicts between villages			
Land conflicts within village			
Grazing land conflict			
Livestock theft			
Cattle plague			
Pests: locusts, mice, etc			
Outbreak of human diseases			
Wetland degradation			
Fish stock reduction			
Lake Biodiversity degradation			
Siltation			
Drought, water shortage			
Conflict on range land			
Conflict on irrigation water			
Other..........			

2. Policy and institutional arrangements

2.1. Are there policy directions and institutional arrangements for managing land-use and land cover change?

____

____

2.2. Does it improve the land or reduce the degradation? Why?

____

____

2.3. What is your personal opinion regarding the land policy of Ethiopia with respect to land use and land cover change?

____

____

2.4. What is the organization responsible for environmental conservation in the area?

2.5. Is it effective in its organizational goals? Why?

3. Access to social services

3.1. **Energy**

3.1.1. What are the major sources of energy?

3.1.2. What is the preferred source of energy and why?

3.1.3. How does it affect land use and land cover?

3.1.4. Please describe energy use in the area

Source of energy and water	Yes	Since when?	No
Fuel wood			
Kerosene			
Charcoal (Plant residue, etc.)			
State company electricity Source of water			

3.2. **Water and Sanitation**

3.2.1. What is the source of water for household purposes?

3.2.2. How can you explain the water sanitation?

3.2.3. In your expert judgment, what are the causes of degradation of the water used for different purposes?

3.2.4. Please describe water and sanitation in the area

Source of energy and water	Yes	Since when?	No
Open well			
Closed well (drilled, etc.)			
River			
Streams			
Lake			
Marshes			
Latrine			

3.3.**Health**

3.3.1.List the most common human and animal disease types prevalent in the area.

____

____

3.3.2. Describe the relationship between these disease types and environmental degradation?

____

____

3.3.3. What are coping mechanisms for the prevalent human and animal diseases?

____

____

3.3.4. Do people in this City/Town/Kebele use traditional medicines (medicinal plants, etc.)? Yes ☐ No ☐

3.3.5. Where do they collect such plants from?

Plant origin	Yes	No
Home garden		
Wetland		
Farming land		
Dry field		
Forest		
Surrounding village		
Others...........		

3.3.6. Are the traditional medicine plants threatened by the environmental degradation? How can you explain their status?

4. Livelihood

4.1.**Agricultural activities**

4.1.1.What are the most common agricultural activities in the area?

4.1.2. Describe their contribution to the livelihoods of the community and their positive and negative effects to the environment?

4.1.3. List the common crop types produced in the area.

4.1.4.What are the agricultural inputs used in the area (e.g. fertilizers, manure, pesticides, herbicides, etc)?

4.1.5.Describe the trends in agricultural production and access of agricultural production to the community.

4.1.6.How can you describe the food security of the area?

4.1.7.What is the trend of fertilizer/pesticide/herbicide/fungicide use?

4.1.8. Do you think that fertilizer/pesticide/herbicide/fungicide use is affecting the environment? Explain the observed phenomenon.

4.1.9. List the common agro-forestry types in the area.

4.1.10. How can you describe the current agro-forestry status of the area compared to that for 20 years ago?

____

____

4.1.11. Is there an active cooperative/Union organization in this village?

☐ Yes ☐ No

4.1.12. What are the cooperative's/Union's activities?

Activity / Response	Savings and loans	Agriculture input loan	Marketing	Other.....
Yes/No*				

4.1.13. Do people have access to credit? From what sources?

Source of credit	Yes	No
Bank		
Amhara Credit and Saving Institute		
Village cooperative		
Others		

4.1.14. Describe the effect of the cooperatives/Unions on the livelihoods of the community in the area.

____

____

4.1.15. What are the contributions of cooperatives to environmental conservation?

____

____

4.1.16. Do farmers use irrigation for farming?

☐ Yes ☐ No

Infrastructure	Since when
Simple irrigation	
Semi-technical irrigation	
Technical irrigation	

4.2.**Livestock and fisheries**

4.2.1.What livestock are reared in the City/Town/Kebele?

____

____

4.2.2. Explain the condition of cattle feeding (Cut and carry or free grazing).

____

____

4.2.3. How does it affect the land use and land cover?

4.2.4. What are the methods of fishing?

4.2.5. What is its effect on biodiversity?

4.2.6.What other factors influence livestock and fishery?

4.3.**Other Economic activities**

4.3.1.List the most common economic activities

No.	Activities
1	
2	
3	
4	

4.4.**Wealth status of the community**

4.4.1. List the common assets of the community in the area.

4.4.2.Describe the assets held by City/Town/Kebele households.

4.4.3.How can you describe the area income distribution?

4.4.4.Describe the economic status of the society and its effect on land use and land cover change.

4.4.5.What is the relationship between land use and land cover and the livelihood of the community?

4.4.6. Do you observe livelihood changes in your community from what has been 10 years ago? ☐ Yes ☐ No

4.4.7. What are the manifestations of changes in the environment and livelihood patterns?

____

____

4.4.8. What are coping mechanisms for the environmental problems (eg. Water scarcity, soil fertility reduction, etc?

____

____

5. Development programmes

5.1. What development assistance has been received from the government and NGOs in the area in the past 5 years?

____

____

5.2. What are the technologies used in the area?

____

____

5.3. Do you think that the development program affects the environment positively or negatively?

____

____

General comments:

....

....

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....

Thank you for your cooperation!

APPENDIX 15: Focus Group Discussion Guiding Questions

NB: The information provided will be treated with confidentiality and only for research purposes.

Title: **Assessment of the Impact of Anthropogenic Activities on Water quality, Biodiversity and Livelihood of Lake Tana surrounding community, Northwestern Ethiopia**

Questionnaire 2. Focus group discussion (eg. indigenous people and professionals)

Region : ....
Zone : ....
Woreda/District : ....
Group : ....
Participants : ....

Date : ....
Interviewer : ....

1. Please discuss the problem of land degradation, wetland degradation, soil erosion, deforestation, biodiversity loss, water quality reduction and siltation.
2. What do you know about 'rights to land' or 'rights to forest resources'?
   a. Do you know of any rules that affect forest resources? Please list and explain them. What do you understand these rules to mean?
   b. Do you know of any rules that affect land resource use? Please list and explain them. What do you understand these rules to mean?
3. How do you use the land and forest resources?
   a. What are the main products from the forest that the study area community depends on? Sort them by order of importance. (List three types of products for subsistence and three types of products for sale)
   b. What are the forest resource socio-economic and livelihood importance?
4. Why is the land and forest resource in the study area degraded?
5. Why is there a problem of forest management in the study area?

6. How are the benefits of forest management associated with employment, income, etc.?
7. Do you believe that land and forest degradation are due to gaps in benefit sharing?
8. How can you describe the land use and land cover change in the study area?
9. What are the causes of land use and land cover change?
10. What is its relation with livelihoods of the community in the study area?
11. What can you say about the standard of living in the city/town/kebele? Increasing/decreasing? How? What are the indicators?
12. How can you rate the status of the study area society livelihood?
13. Who is responsible for the degradation of the forest, Lake Tana water, the biodiversity and the land?
14. Who is responsible for solving this problem?
15. How it can be done/ achieved?
16. How can the above problems be linked to the livelihoods of the community in the study area.
17. How are the above problems hampering agricultural production and causing a decline in agricultural income. How is losing forests impacting negatively on the livelihoods of the community.
18. Kindly tell me the causes and effects of land degradation, wetland degradation, soil erosion, deforestation, biodiversity loss, water quality reduction and siltation on the livelihoods of the community.

Thank you for your cooperation!