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Water Quality Assessment of Eastern shore of Lake Hawassa Using Physico-chemical Parameters and Benthic Macro-invertebrates

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Water Quality Assessment of Eastern shore of Lake Hawassa Using Physico-chemical Parameters and Benthic Macro-invertebrates

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ABSTRACT

At present, the use of benthic macro-invertebrates together with physico-chemical parameters has become a reliable and timeliness method for water quality assessment. The main aim of this study was determining water quality of Hawassa Lake from eastern shore using biological and physico-chemical parameters. The study was carried out in Hawassa Lake, Ethiopia from September, 2010 to March, 2011. During the study, a total of $0.56m^2$ *area sampled from each of six sites along eastern shore of the lake using Ekman grab and D-net. Totals of 1872 benthic macro-invertebrates belonging to 38 taxa were collected. The study showed that most of the physico-chemical results were significantly correlated with benthic metrics. The high occurrence of Chironomidae at S6 showed strong positive correlation with high concentration of* NO_3^- *(*$r= 0.960, P< 0.05$*). The low occurrence of Gastropods in S1 was negatively correlated with electrical conductivity, TDS and* PO_4^{3-} *(*$r= -0.831, P< 0.05$*;* $r= -0.877, P< 0.05$ *and* $r= -0.86, P< 0.05$*), respectively. Hilsenhoff biotic index categorized most of the sites under fairly poor water quality but S1 was categorized under good water quality in contrast to results of physico-chemical parameters. The reference site S4 and S3 contain large number of macro-invertebrates with moderate tolerance and pollution sensitive groups. The result of the study indicates that benthic metrics designed for rivers and stream assessment also work for discriminating impacted sites in lakes.*

Key words/phrases: Benthic macro-invertebrates; Bioassessment; Hilsenhoff biotic index; Lake Hawassa; Physico-chemical parameters; Water quality.

DECLARATION

I, the undersigned, hereby declare that this thesis is my original work, has not been presented for a degree in any other University and all source of materials used for the study have been duly acknowledged.

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1. INTRODUCTION

The earth contains approximately 1.39 billion cubic kilometers (331 million cubic miles) of water, with 96.5 percent stored in the oceans of the world. Approximately 1.7 percent is stored in glaciers, permanent snow, sea ice and polar ice caps, while another 1.7 percent exists as groundwater and in rivers, lakes, wetlands and the soil (Smol, 2002; The water cycle, 2007).

A lake is any inland body of water that is found in topographic depression. They are fed by surface water runoff and direct precipitation and contain about 0.26 percent of the water resource of the earth and covers about 1.8 % of the earth surface, including saline lake (Raven and Johnson, 1988; Pennington and Cech, 2010). Around the world there are 100 million lakes that are greater than one hectare and approximately one million lakes that are greater than one km^2 (Wetzel, 2001; Smol, 2002). But only 0.01 percent of the vast amount of freshwater on this planet is available as surface water contained in lakes and rivers (Smol, 2002).

Freshwater is a finite resource exploited in all possible way (Wetzel, 1983). It can be used for agriculture, industry and even human existence. Without freshwater of adequate quantity and quality sustainable development will not be possible. Water pollution and wasteful use of freshwater threaten development projects and make water treatment essential in order to produce safe drinking water (Bartram and Balance, 1996).

Around the world the demand of freshwater is increasing due to population growth and industrial development. According to the Food and Agriculture Organization (FAO) of the United Nations, agriculture is the largest user of water resources around the world, accounting for 70 percent of all freshwater withdrawals followed by industry 20 percent, and domestic use 10 percent (FAO, 2006). The importance of freshwater in the evolution of fishes is also evidenced by the fact that over 41 % of all fish species are found in fresh water, even though freshwater habitat represents only a small percentage (0.01 % by volume) of the earth„s water resource (Miller and Harley, 2002).

Aquatic ecosystems are threatened on a world-wide scale by a variety of pollutants as well as destructive land-use or water management practices. The extent of human activities that influence the environment has increased dramatically during the past few decades. Among several factors that contribute to the decline of water quality: exponential growth of human population, industry and agriculture are at the heart of many aspects of pollution on aquatic ecosystem especially fresh water. Until recently, environmental degradation and deterioration of water quality by pollution was not a serious problem. But nowadays, the quantities of wastes are beyond dilution and self purification capacity of water body (Baye Setotaw, 2006).

Ethiopia is a country in the horn of Africa with an estimated area of around 1.1 million km^2. It is often referred to as the ‛‛Water Tower of Africa‘‘‘‘(Tenalem Ayenew, 2009). Around 70,000 km^2 of area is covered with natural inland water bodies including rivers, lakes and associated wetlands (Wood and Talling, 1988). The Wetlands cover 1.14 % of the total landmass of the country (Hillman and Abebe, 1993).

Most of fast growing towns adjacent to lakes of Ethiopia like Zway, Hawassa and Chamo are neighbor rift valley lakes, are the victim of untreated and semi-treated textile, horticulture and other industrial and domestic waste chemical release and agricultural run-off. Most of developing countries also have a trend of releasing 90 percent of wastewater directly into rivers, streams and lakes without any waste treatment or after retention period in stabilization ponds (Shu *et al.*, 2005). Moreover, only few developing countries have national water quality monitoring programs.

Lake Hawassa is one of the small central rift valley lakes of Ethiopia, which is being affected by pollution from textile, urban, institutional wastes and agricultural run-off. Textile waste water contains high concentration of inorganic and organic chemicals and is highly colored from the residual dye stuffs. The effluents contain a wide range of contaminants such as salts, enzymes, surfactants, oxidizing, and reducing agents (Badania *et al.*, 2005). Hawassa textile factory contribute these all to Tikur Wuha River, which is the main feeding river from North eastern side. Hawassa referral hospital also releases chemicals, drugs and other wastes to the lake after retention in stabilization ponds.

Water quality requirements can be usefully determined only in terms of suitability for purposes to control defined impacts on water quality. For instance, the sustainability of aquatic fauna and flora needs continuous assessment of water quality, because pollution affects the community composition and structure (Brian, 1999). On the other hand, water used for drinking should be free from any contamination and microorganisms. Agriculture needs water of low sodium content. Preservation of biodiversity and other conservation measures are being increasingly recognized as valid aspects of water use and have their own requirements for water quality management (Bartram and Balance, 1996).

Water quality monitoring is required for pollution control and to assess long-term trends and environmental impacts. To monitor lake or inland water body, it is necessary to assess its actual condition. A study of water quality could measure the suitability of water for a particular use based on its physical, chemical and biological characteristics. A complete assessment of water quality is based on appropriate monitoring of these elements. Physical and chemical parameters that were measured in the present study include pH, temperature, dissolved oxygen, nutrients (nitrate, nitrite, phosphate, ammonia) and metals such as (mercury, cadmium, lead, zinc and cobalt) (Deliz Quinones, 2005).

Although physical and chemical variables are commonly used to determine water quality, these parameters by themselves can only express the condition of water at the moment of sampling. On the other hand, biological monitoring can give information about the water conditions for a longer period. Previously, most of the biological methods for lake monitoring are based on their trophic level through analysis of nutrient concentrations and/or pelagic primary producers or through analyses of consumer‟s community (oligochaetes, diptera chironomidae and fishes) whose characteristics considered as a trophic level result (Seather, 1979; Wiederholm, 1980)

Recently, benthic macro-invertebrates have been found as the most common faunal assemblages for bioassessment and provide more reliable assessment of long term ecological changes in the quality of an aquatic system compared to its rapidly changing physico-chemical characteristics. Well developed water quality monitoring programs involve measurements of physical, chemical and biological parameters and provide valuable information on the impact of water quality. The benthic macro-invertebrates respond differentially to biotic and abiotic factors in their environment. Consequently, the structure of macro-invertebrate has long been used as bio-indicators to assess the water quality of a water body (Reynoldson *et al*., 1989; Duran, 2006).

The main aim of this study was to assess Hawassa Lake water quality across selected sites using physico-chemical analysis and benthic macro-invertebrates to show the level of pollution in each site because some of the sites were suspected to pollution. The diversity of macro-invertebrates was identified, calculated for specific metrics and correlated with physico-chemical parameters.

2. OBJECTIVES

2.1. General objective

- To assess Hawassa lake water quality using physico-chemical analysis and benthic macro-invertebrates

2.2. Specific objectives

- To determine some physical and chemical parameters at different sampling site;
- To examine the composition of benthic macro-invertebrates with respect to each site;
- To correlate physico-chemical parameters with that of biological parameters; and
- To assess whether macro-invertebrate metrics can be used to monitor change in water quality of Hawassa Lake

3. LITERATURE REVIEW

3.1. Physico-chemical Parameters

Understanding a lake‟s physical, chemical and biological properties is essential to determining the lake‟s condition and in making informed lake management decisions. The most commonly used physico-chemical parameters for water quality measurement of lakes were,

- Physical measurements like temperature and
- Chemical measurements such as nutrients (nitrates and phosphate), total dissolved solids (TDS), pH, and conductivity.

These parameters are important to study water quality at the moment of study only because its result fluctuates with the diurnal and seasonal variation of the weather condition and based on level of input of pollutants at a certain time.

A) Temperature

Most aquatic organisms have adapted to survive within a range of water temperature. Organisms like stoneflies and mayflies prefer cooler water, while others like dragonflies need warmer condition. As the temperature of water increases, cool water species will be replaced by warm water organisms. Temperature also affects aquatic life sensitivity to toxic wastes and disease, either due to rising water temperature or the resulting decrease in dissolved oxygen. Water temperature influences aquatic weeds, algal blooms and surrounding air temperature (Gupta *et al.,* 1993). The metabolic and physiological activity and life process such as feeding, reproduction, movements and distribution of aquatic organisms are greatly influenced by water temperature.

B) pH

Lakes and ponds show regional differences in pH due to differences in geology and hydrology of the catchment area, input of acidifying substance, and productivity of the system, but the pH in the majority of lakes on earth is between 6 and 9 (Bronmark and Hansson, 1998). The change in the pH value of water is important to many organisms**.** Aquatic insects are extremely sensitive to pH value below 5. The Gastropods, mayflies, stoneflies and caddis flies are some of macro-invertebrate groups that prefer pH level from 7-9.5. One of the most significant environmental impacts of pH is involvement on synergistic effects. For example, very acidic water can cause heavy metals, such as copper and aluminum to be released into the water. These heavy metals may accumulate on the gills of fish or cause deformities in young fish, reducing their chance of survival. The pH value of a lake mainly depends on the relative quantities of calcium, carbonate and bicarbonate ions in the water (Sivakumar and Karuppasamy, 2008).

C) Conductivity

Conductivity is a measure of the water‟s ability to conduct an electric current. It is also useful for estimating the concentration of total dissolved solids (TDS) in the water. Because the measurement is made using two electrodes placed one centimeter apart, conductivity is generally reported as microsiemen‟s per centimeter (µS/cm). The lakes with high alkalinity often have high conductivity (Bronmark and Hansson, 1998).

D) Phosphate (PO_4^{-3})

Phosphorus comes from several sources like human and animal wastes, industrial wastes, agricultural runoff, and exposed soil erosion. The total phosphorus concentration above 0.03mg/l stimulates the algal growth which result eutrophication, causing a shifting in aquatic life to a fewer number of pollution tolerant species such as midge larvae and worms. Eutrophication threatens to limit organisms‟ diversity and recreational opportunities. Most natural lakes (not affected by man) have phosphorus concentrations of between 1 and 100 µg/l (Bronmark and Hansson, 1998).

E) Nitrates (NO_3^-)

A septic tank system containing household wastewater from toilet, bathtubs and washing machines which are the major sources of nitrate in lakes. The two other important source of nitrate is fertilizers and the runoff from cattle feedlots and dairies. Nitrate concentration is indicates organic pollution in an area. Nitrogen concentrations in lakes vary widely from about 100µg/l to over 6000µg/l. In most lakes the concentration is usually from 4-1500µg/l but in polluted lakes, the level extends to more than 5000µg/l (Bronmark and Hansson, 1998).

3.2. Macro-invertebrates and Water Quality Assessment

The major reason for using benthos in toxicity test is that information of the effects of toxicants on macro-invertebrates is essential in the protection of aquatic ecosystems. Toxicity tests help in evaluating the nature and degree of harmful effects produced on aquatic organisms by toxicants since toxicants alter the distribution, density and behavior of aquatic invertebrates by direct lethal or sub lethal action on a particular species, or indirectly by affecting a species" food, competitors, predators, or habitat (Maciorowski and Clarke, 1977).

According to Maciorowski and Clarke (1977); Metcalfs (1989) and Bode *et al*., (1996) the criteria and/or advantages why benthos should be used in water quality assessment include-

- Sampling procedures are relatively well developed
- Can be operated by someone working alone
- There are identification keys for most groups of macro-invertebrates
- Are reasonably sedentary with comparatively long lives, so that they can be used to assess water quality at a single site over a long period of time
- The size of benthos is almost ideal for water quality testing, since many are macroscopic and can even be recognized with the naked eye.
- The diversity of aquatic invertebrates provides several attributes that can be utilized as responses in laboratory toxicity test.

- Reproduction and life-cycle may be completed with 2 to 4 weeks with genera such as *Daphnia* and *Chironomus* whereas life-cycle studies with rapidly reproducing fish may require 3 months to 2 years.

- The group is heterogeneous and so a single sampling technique may catch a considerable number of species from a range of phyla.

- Since taxa (family, genus or species) differ in their tolerance to pollutants, particular taxa make useful „‟indicators‟‟‟‟of conditions.

- As benthic invertebrates respond sensitively not only to pollution, but also to a number of other human impacts (physical modification, recreational and others) so, they potentially be used for a holistic indication system for Lake Ecosystem health. Their ubiquitous presence and their relative longevity may be seen as strong points recommending them for use in an indication system.

There are some disadvantages of using benthic macro-invertebrates for bioassessment as described according to Metcalfs (1989) and Bode *et al*., (1996):

- Their aggregated (patchy) distribution means that, to obtain a representative sample of a site, many samples must be taken.

- The muddy, depositing substrata of the lowland areas of rivers, or of lakes, are often dominated by chironomids and tubifid worms, which are groups difficult to identify to species level.

- The insect members of the community may be absent for part of the year, so that seasonal variation may prevent comparison of samples and will make interpretation difficult.

3.3. The Role of Benthic Macro-invertebrates for Bioassessment

Several biological communities including microphytobenthos, macrophytes and fishes have been considered in assessments of water quality. However, the use of benthic invertebrate communities as indicators of environmental degradation or restoration has become widespread and reliable for bio-assessment since the benthos broadly reflect environmental conditions (Jackson, 1993; Rosenberg and Resh, 1993).

Freshwater benthic macro-invertebrates, or „‘benthos”, are animals that inhabit the bottom of substrates (for example, sediments, debris, macrophytes and filamentous algae) of their habitats for at least part of their life cycle and are larger than 500µm. They are retained by mesh sizes from 200-500 micrometers. Benthic macro-invertebrates include insect larvae, annelids (leeches), oligochaetes (worms), crustaceans (crayfish and shrimp), mollusks, (clams and mussels), and gastropods (snails). Insect larvae tend to be the most abundant benthic macro-invertebrates in freshwater aquatic ecosystems (Rosenberg and Resh, 1993). Because of their abundance and position as “middlemen” in the aquatic food chain, benthos plays a critical role in natural flow of energy and nutrient (Bode and Novak, 1995; and Barbour *et al*., 1996).

Aquatic invertebrates are morphologically, physiologically and ecologically diverse and therefore exhibit a wide range of responses to toxicants (Maciorowski and Clarke, 1977). As benthic macro-invertebrates tend to remain in their original habitat, they are affected by local changes in water quality. Some are capable of tolerating higher loads of pollution than others. If the pollution is severe, the whole community structure may simply in favor of tolerant species. Although the abundance of certain species may increase, the diversity and species richness decreases. By assessing indicator species, diversity, and functional groups of the benthic macro-invertebrate community, it is possible to determine water quality (Lange, 1994).

3.4. The Status of Using Macro-invertebrates for Bio-assessment

The use of community structure of freshwater organisms for biomonitoring can be traced back to the pioneering work of two German scientists, R. Kolkwitz and M. Marsson, in 1908 on saprobity (degree of pollution) which led to the development of idea for indicator organisms (Tolkamp and Gardeniers, 1988; Rosenberg, 1998). Today, their works are base for the use of biological indicators for water quality assessment activity and to study biological health of aquatic ecosystem.

Developed and developing countries are causing various environmental degradations especially, on aquatic ecosystems. To minimize the problem, Nations designed policy statements regarding the use of biological assessments and criteria in the water quality programs (U.S.EPA 1991). U.S.EPA policy states „‟To help restore and maintain the biological integrity of the nations water, it is the policy of the environmental protection agency that biological surveys shall be fully integrated to toxicity and chemical-specific assessment methods in state water quality programs. The EPA recognizes that biological surveys should be used together with whole-effluent, ambient toxicity testing and chemical-specific analyses to assess attainment/non-attainment of designated aquatic life uses in state water quality standards‟‟‟. In the USA about forty-six states assessed their aquatic ecosystems using both biological and physico-chemical parameters.

Many papers on the community structure of macro-invertebrate in relation to abiotic factors (temperature, dissolved oxygen, pH and ionic concentration) and biotic factor (competitive abilities and predators) are available in the temperate region of the world (Petersony, 1975; Harvey, 1986). However, there have been fewer studies on tropical lakes.

In Ethiopia as well as in the whole of Africa, the use of macro-invertebrate characteristics for assessment and monitoring of lake conditions is less common (Baye Setotaw, 2006). However, a South Africa scoring system for rapid bioassessment of water quality in rivers is being used in a national biomonitoring program in South Africa (Dallas, 1997). In Ethiopia, benthos of streams and rivers has been studied for various reasons. For instance, Baye Setotaw (2006) studied some benthic macro-invertebrate structures in relation to environmental degradation in some rivers; Birenesh Abay (2007) assessed pollution of downstream effluent along Tikur Wuha River using macro-invertebrate indicators; Harrison and Hynes (1988) were pioneers to study benthos in Ethiopia, especially the benthic fauna of highland streams and Tesfaye Berhe (1988) studied degradation of Kebena river using macro-invertebrate structures and composition.

Regarding lakes, Tilahun Kibret and Harrison (1989) studied the benthic and weed-bed fauna of Lake Awassa; Hayal Desta and Seyoum Mengistou (2009) studied water quality parameters and macro- invertebrate index of biotic integrity of the Jimma wetlands and Tujuba Ayele (2010)**,** studied macro-invertebrates abundance and community structure of Lake Kuriftu. Ethiopia has not been using biological assessment activity as national water quality assessment program, but individuals, institutions and organizations are doing limited studies in bio-assessment.

3.5. Benthic Macro-invertebrate Data processing

Many different biotic and diversity indices have been used to evaluate the benthic macro-invertebrate communities in order to summarize information collected from the field and assess pollution effects on aquatic organisms. The use of a biotic and diversity index to describe the biological impact of water quality reduces the amount of information extracted from the data. However, easy and understandable calculation of indices should be used to correlate with the measured physico-chemical parameters of water quality to be better understood (Rosenberg and Resh, 1993; Mason, 1996). The following are some indices mostly employed to assess the health of rivers (and lakes).

3.5.1. Biotic Indices

A biotic index takes account of the sensitivity or tolerance of individual species or group to pollution and assigns them a value, the sum of which gives an index of pollution for a site. The data may be qualitative (presence-absence) or quantitative (relative abundance or absolute density). Biotic indices have been developed largely to measure response to organic pollution and may be unsuitable for detecting other forms of pollution.

3.5.1.1. Hilsenhoff Family-level Biotic Index (H-FBI)

This biotic index is calculated by multiplying the number of individuals of each family by an assigned tolerance value, summing these products, and dividing by the total number of individuals (Hilsenhoff, 1988). Each family is given a score between 0-10 depending on its tolerance to low dissolved oxygen level and has only been evaluated for organic pollutants (Bode *et al*., 1996). Those taxa least tolerant to pollution, such as Mayflies and Stoneflies, are given the lowest scores of H-FBI (Mason, 1996). High H-FBI values are indicative of organic pollution, while low value indicative of clear-water conditions.

$$\text{H-FBI}=\Sigma\,(x_i \times t_i)/n$$

Where, x_i = number of individuals within the taxon

t_i = tolerance value of a taxon

n= total number of organisms in the sample.

3.5.2. Diversity Indices

Unlike biotic indices which measure response of organisms to pollution, diversity indices are used to measure stress in the environment. It is considered that unpolluted environments are characterized by a large number of species, with no single species making up the majority of the community. Most species diversity indices take account of both the number of species in a sample and their relative abundance but the sensitivity of individual species to particular pollutants is not allowed (Mason, 1996). Diversity indices used in this study are:

- Total number of taxa (Family level Richness)
- %Dominant taxa
- %Chironomidae

3.5.2.1. Total number of taxa (Family level Richness) (TR)

Taxa richness is used as an indicator of habitat quality. This metric is the measure of communities diversity, number of different families found in samples of each site (Mason, 1996). Reductions in community diversity have been positively associated with various forms of environmental pollution, including nutrient loading, toxic substances and sedimentation. Generally, taxa-richness increases with increasing water quality, habitat diversity, and habitat suitability (Barbour *et al*., 1996; Fore *et al*., 1996).

3.5.2.2. Percentage Dominant taxa (% DT)

It is the measure of community balance by calculating the percentage contribution of numerically dominant taxon in relation to total number of organisms in the sample (Mandaville, 2002). High dominant value indicate unbalanced community highly dominated by few families (Bode *et al*., 1996) whereas a community dominated by relatively few families would have a high % DT value, thus indicating the community is under the influence of environmental stress (Plafkin *et al*., 1989).

3.5.2.3. Percentage Chironomidae (% CHIR)

It is a diversity measure for which the percentage of chironomids from the sample is calculated. Research results show that the percentage of chironomidae tends to increase with a decrease in water quality (Plafkin *et al*., 1989; Bode *et al*., 1996) because chironomids tend to be very tolerant of nutrient enrichment or pollution condition. At highly contaminated sites, this taxon is often the abundant invertebrates.

4. MATERIALS AND METHODS

4.1. Study Area

Lake Hawassa (Figure 1) is situated on the floor of the rift valley between longitude 38^{0} $22^{'}$ E and 38^{0} $27^{'}$ E, and latitudes 6^{0} $58^{''}$ N and 7^{0} $8^{''}$ N, at an altitude of 1680m a.s.l. and 275 km to the south of Addis Ababa in the Southern Nations Nationality and Peoples Regional State (SNNPRS). The lake is oval in shape and approximately 16 Km long and 5.5 to 7.0 Km wide. It has normal maximum depths of 21 to 22m according to season. The surface area is about $88km^{2}$; it is one of the smaller lakes in Ethiopian rift excepting the many crater lakes (Tilahun Kibret and Harrison, 1989; Zinabu *et al*., 1999).

4.1.1. Climate

The climatic condition of the study area can be classified under „‘Kola‘‘‘‘ climate zone. The area receives the highest rainfall mainly from May to September, wet season (Figure 2). The maximum temperature was recorded from January to April and from October to December during dry season. The area recorded minimum temperature during wet season (Figure 3). The level of the lake water highly changes with rainfall; during wet season the water level increases round a meter.

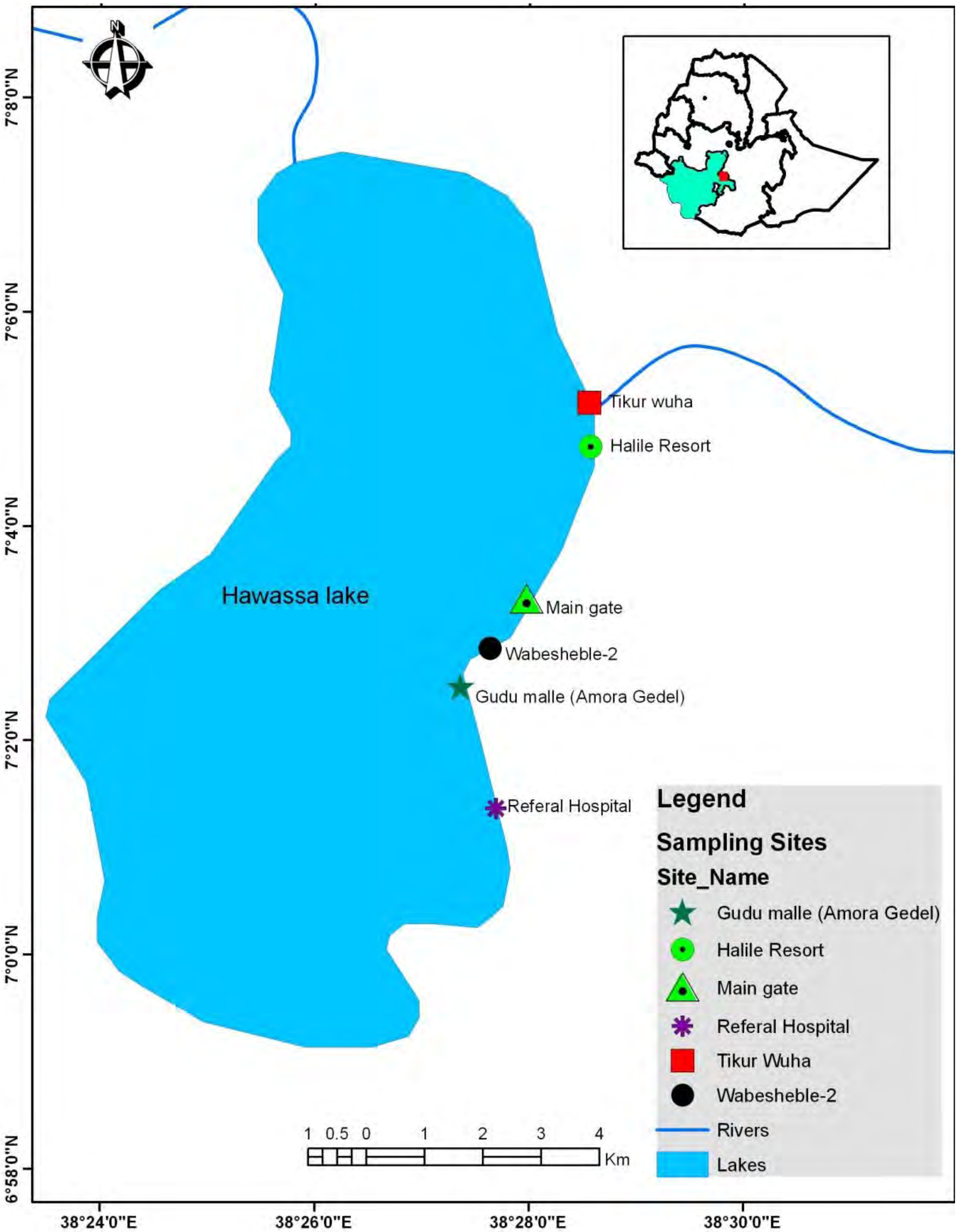

Figure 1. The map of study area with marked sampling sites

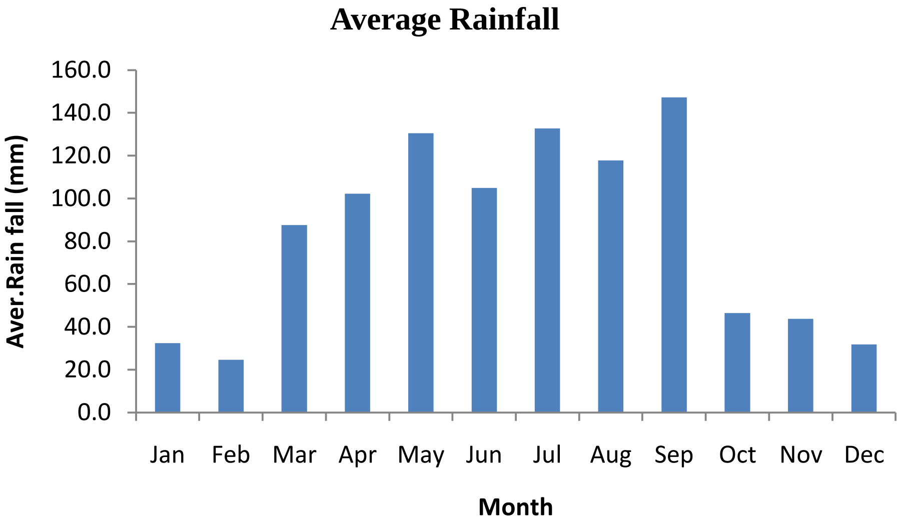

Figure 2. Average annual rainfall of the study area from year 2005-2010 (Source: National Meteorological Agency, Hawassa Branch).

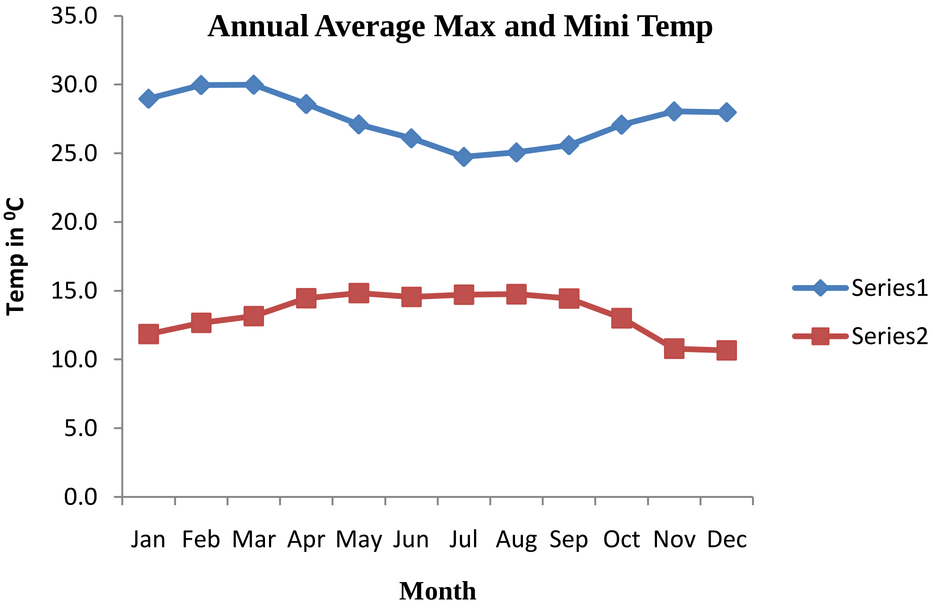

Figure 3. Average annual maximum and minimum temperature of the study area from year 2005-2010 (Source: National Meteorological Agency, Hawassa Branch).

4.1.2. Study sites description

Six sites (S_1-S_6) were selected purposely for sampling, starting from northeastern site 1 and 2 (Tikur wuha river entry and Haile resort respectively). The S_3 and S_4 are located (to the front of Piassa- Gebreal Street and Wabeshebele-2 hotel respectively). The S_5 and S_6 are from Gudumalle recreational area and the back of Hawassa University Referral Hospital respectively).

Site 1 (S1) is located at the entry of Tikur Wuha River. The area is covered by distinctive vegetations, grasses and aquatic weeds not found in other sites. It was highly influenced by the river (Plate 1&2).

Site 2 (S2) is round Haile resort, it was covered mainly by grass of few species. The area was disturbed by peoples who are washing clothes, swimming and watering cattle but the hotel managers are giving protection for the area (Plate 3).

Site 3 (S3) is situated to the front of Piassa-Gebrel church Street road (Main gate). Since the area is used as a main gate to the lake, there is a lot of population pressure. Consequently, the shore was highly polluted by non degradable use-throw plastic wastes. The shore was covered by *Cyperus exltatus*, *Scirpus brachycera,* and isolated patches of *Typha angustifolia* to the center. The Water-lily *Nymphaea caerulea* and *Potamogeton schweinfurthii* are also floating and submerged grasses (Plate 5, a-f). This site has buffer zones (Plate 6, a-c). Although it was not mainly built as a buffer for the lake, it is very important to minimize direct effect of wastes discharged from the town. Except plastic wastes, the site was well protected from any direct waste discharge.

Site 4 (S4) is situated in front of the Wabeshebelle-2 hotel. It was selected as reference site; to be used as basis for comparing changes with the rest of five sites. The site selection was based on observation of minimally impacted physical habitat, low human population pressure; no known discharge and good vegetation cover (Plate 7).

Site 5 (S5) is round Gudumalle (Amora Gedel) recreational area. It is fish collecting and processing site for market. The site was covered by grasses and limited patches of *Cyperus exltatus* (ketema). The area rounded by mountain Tabor from east and has a lot of old trees along the shore (Plate 8, a-d).

Site 6 (S6) is the area at the back of Hawassa University Referal Hospital. This site, mainly round shore was used for agriculture, the channel for discharge not covered by vegetation; various solid wastes including plastics polluted the site. Lack of vegetation along channel and agriculture near the shore exposed the area for sedimentation (Plate 9, a-f). The site is also highly affected by wastes released from Hospital Septic tank (Plate 10, a&b).

4.1.3. Vegetations of study area

The shore is covered by emergent vegetations 20-40 meters to the center in the eastern and northeastern part of the lake. The lake includes vegetations like *Cyperus exltatus*, *Scirpus brachycera,* and isolated patches of *Typha angustifolia*. The Water-lily *Nymphaea caerulea* and *Potamogeton schweinfurthii* were floating and submerged vegetations of the lake (Plate 11, a-e). The grass *Paspalidium geminatum* was the dominant macrophyte of the lake covering about 50-100 meters to the center (Tilahun Kibret and Harrison, 1989; Zerihun Desta, 2004).

Table 1. Summary of sampling points and site description along Hawassa Lake

Sites	Altitude	GPS location	Description
S1	1690m	N 07°05‘‘485‘‘‘‘ E 038°28‘‘912‘‘‘‘	Good vegetation cover, Tikur Wuha River entry area.
S2	1687m	N 07°04‘‘841‘‘‘‘ E 038°28‘‘726‘‘‘‘	Less vegetation cover mainly grass, highly disturbed due to human and animal interference.
S3	1682m	N 07°03‘‘260‘‘‘‘ E 038°28‘‘020‘‘‘‘	Most part of the site is covered by Variety of vegetations. Adjacent to the site, there are about three buffer areas which were highly eutrophicated and polluted by direct discharges from Hawassa town. Few meters gap from buffers.
S4(Reference)	1685m	N 07°02‘‘981‘‘‘‘ E 038°27‘‘621‘‘‘‘	Mainly covered by grass. Wabeshebelle Hotel managers protect the area so very minimal human interference than other sites and no direct discharge.
S5	1686m	N 07°02‘‘575‘‘‘‘ E 038°27‘‘412‘‘‘‘	It is Gudumalle recreational area. There is vegetation and its good bird viewing area. It is also fish collection and processing site.
S6	1686m	N 07°01‘‘485‘‘‘‘ E 038°27‘‘886‘‘‘‘	The surrounding areas and channels were not covered by vegetation so exposed for sedimentation. Referral Hospital wastes retain in the septic tanks before released to this site.

4.2. Sampling Method

4.2.1. Preliminary observation

General features of the lake was observed along with selecting six important sites representing the lake for sample collection before data collection started. One of the sampling sites was considered as reference because of very less human interference, no known discharge and good vegetation cover around the site. All the sampling sites were from eastern shore of the lake because some of the sites were suspected to pollution due to discharges, agricultural activity and human disturbance.

4.2.2. Physico-chemical Sampling

Temperature, pH, conductivity and TDS were measured in the field using instruments (HANNA pH 211 Micro processer and JENWAY 42OO Conductivity meter). Analyses of water samples were performed three times in two months interval from the end of September, 2010 to March, 2011. Ascorbic acid and Cadmium Reduction methods used to analyze phosphate (PO_4^{-3}) and nitrate (NO_3^-) parameters respectively and measured using JENNWAY 6305 Spectrophotometer. The analysis was done within four days after sampling at the Ethiopian Water and Energy Ministry laboratory. The water samples were taken from places where benthic macro-invertebrates were collected.

4.2.3. Benthic Macro-invertebrate sampling

Benthic macro-invertebrate communities across the lake were sampled three times along with physico-chemical measurement. The samples were collected by using D- net and Ekman grab (for deeper sites). The total area of $0.56m^2$ for each site was sampled by nine trials for both Ekman grab and D- net sweep in the bottom. The macro-invertebrates were washed and separated from sediment using 200-500 µm sieves. All the animals collected were immediately fixed in 10% formaldehyde in the field and then transferred to 70% ethanol alcohol. The macro-invertebrates were sorted, identified to the family level using keys given by Bouchard (2004) and counted under stereo microscope in Addis Ababa University Limnology laboratory.

4.3. Statistical analyses

The Pearson Correlation Coefficients was used to determine the level of significance of the relationship among benthic macro-invertebrate metrics and physico-chemical parameters and linear regression was used to evaluate the relationship. The statistical software SPSS version 17.0 was used for statistical analysis.

5. RESULTS AND DISCUSSION

5.1. Water Chemistry

5.1.1. pH and Temperature

Water quality profile for each of the six sites is presented in Appendix 1. The pH values were approximately the same at all sites except that S1 showed slightly acidic pH (6.48±.05). These conditions may be due to relatively higher temperature in the S1 or due to same ions dissociated from wastes of textile, domestic and agricultural runoff. Most organisms have adapted to live in water of a specific pH and may die if it changes even slightly. In this study, the groups EPT (Ephemeroptera, Plecoptera and Trichoptera) were totally absent from S1, because they are very sensitive aquatic insects towards low pH (acidity). Gastropods also prefer pH level greater than seven, hence low occurrence represented at S1 (Appendix 5). Reduction in pH negatively affects the reproduction of many organisms, including crayfish, Daphnia, mollusks, insects, and many fish species, leading to a reduction in abundance of these organisms (Bronmark and Hansson, 1998).

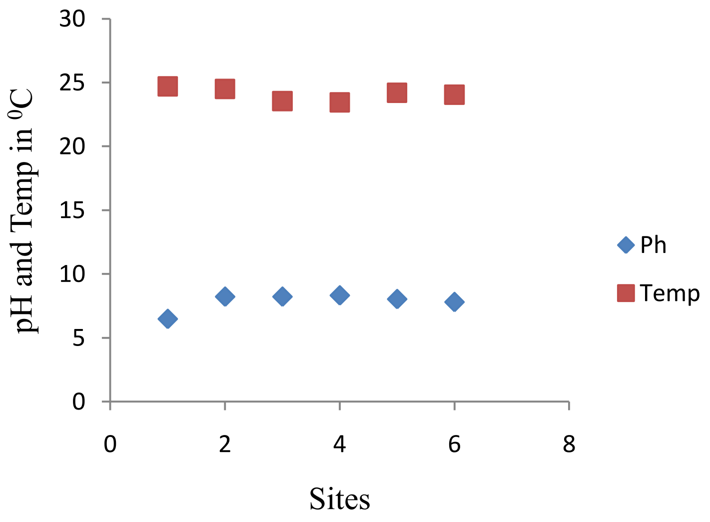

Figure 4. Average water temperature and pH among sampling sites

In this study, comparatively maximum temperature was recorded from S1 as well as the pH value deviating toward acidic medium. In other sites both values goes parallel (Figure. 4). The result in Appendix 1 shows that the lake is alkaline with pH value near 8.2. According to Tilahun Kibret and Harrison (1989) the lake"s pH was 8.8, by suggesting high concentration of HCO_3^- in the water from Wendo Genet Mountain via Tikur Wuha River as the reason for the alkalinity of the lake. The lake"s pH values typically remain within the range from (6.5-9.0) according to state standard.

5.1.2. Conductivity

Electrical conductivity varies among sites ranging from (644.5±67.2 to 818±21.1µS/cm) where highest value recorded was from S1 (Appendix 1). The remaining sites S2, S3, S4, and S5 were comparatively show similar reading except, little deviation in S6 (Figure 5). The high conductivity in S1 was may be due to geology of the area along Tikur Wuha River, agricultural land erosion and by discharges of domestic and industrial effluents. The Wendo Genet Mountains, from which Tikur Wuha River has caused higher concentrations of dissolved salts through the system by releasing, recorded conductivity of 860µS/cm (Tilahun Kibret and Harrison, 1989). The variation in the level of conductivity is associated to the total dissolved solids (TDS) in water (Bauder *et al.*, 2003). This fact is best seen in this study.

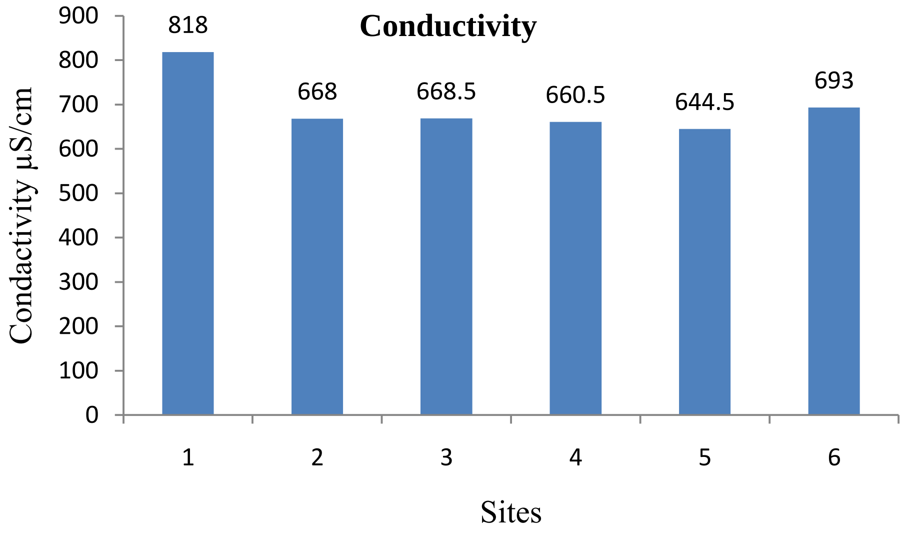

Figure 5. Conductivity among sampling sites

5.1.3. Total Dissolved Solids (TDS)

In this study, all sites have shown high amount of total dissolved solids, beyond WHO‟s maximum allowable concentration (80mg/l). But according to FAO recommendation, the acceptable range for live stock drinking is (100-1,500mg/l). In this study, the highest TDS values were 489.5±10.6 mg/l from S1 and 412±23.3 mg/l from S6. The three sites (S2, S3, S4) were comparatively similar (401±7.1, 401±11.3, and 405±17) but the least TDS recorded from S5 (385.5±40.3 mg/l). Like conductivity, the increase in TDS might be due to increased amount of discharges, erosion and organic detritus load. Hawassa Textile factory also releases 3818.5±20 mg/l of TDS via the Tikur Wuha River (Birenesh Abay, 2007).

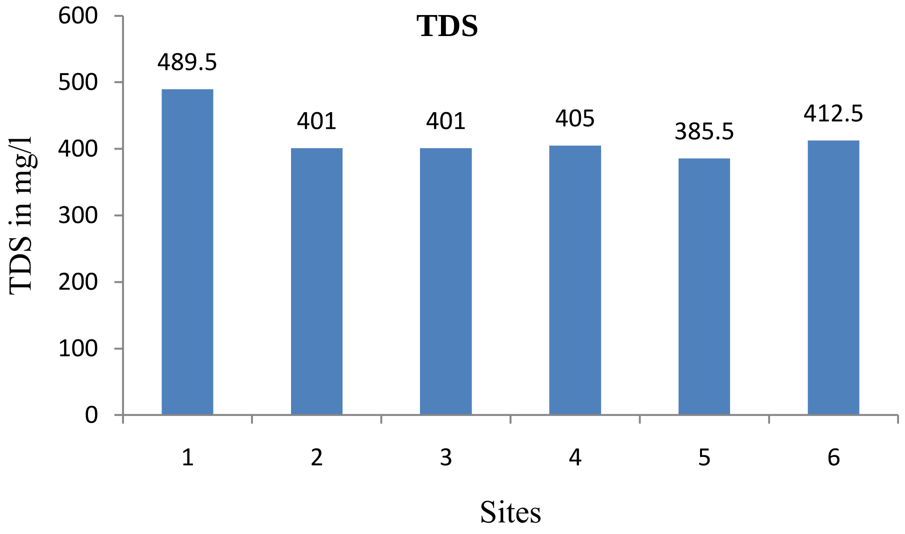

Figure 6. Total dissolved solids among sampling sites

5.1.4. Nitrate (NO_3^-)

According to Ayers and Westcott (1976) the required maximum concentration of NO_3^- for live stock and irrigation were 100 and 30mg/l respectively and the concentration below 5mg/l will not affect flora and the soil. The level of NO_3^- among sites showed very high variation. The three sites S4, S3 and S2 contain very little concentration of < 1 mg/l and followed by S5 1.59±0.55 mg/l. The highest records were from S1 (8.08±9.1 mg/l) and S6 (10.74±13.5 mg/l). The high concentration in S6 might be due to cumulative effect of poor vegetation round catchment, agricultural activity along the shore (Plate 9) and Hawassa Referral Hospital effluent discharged from Septic tanks. During this study, a sample was taken from hospital waste septic tank to measure (NO_3^-). It showed the highest result (58.9 mg/l) above WHO‟s maximum allowable concentration (45 mg/l). In S1 the load was best correlated to the discharge of 17.8±0.2 mg/l of nitrate from

Hawassa textile factory (Birenesh Abay, 2007) and agricultural and domestic wastes via Tikur Wuha River.

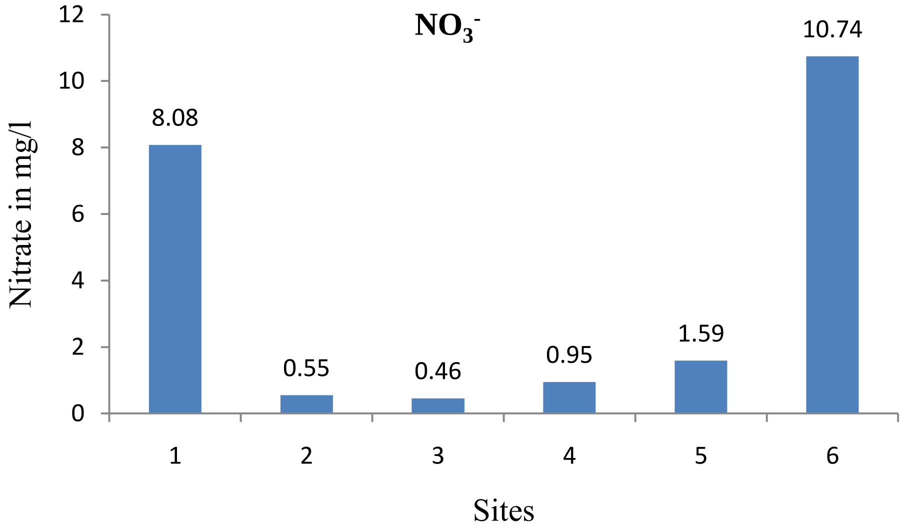

Figure 7. Nitrates concentration among sampling sites

5.1.5. Phosphate (PO_4^{-3})

According to Ayers and Westcot (1985), the maximum allowable concentration of phosphate for irrigation water is 2mg/l. In this study**,** except S1 that contains 3.2±3.4 mg/l, the remaining five sites containing concentrations of < 0.7 mg/l (Appendix 1). High level in S1 was possibly due to effluent discharge of 9.04±2.5 mg/l from Hawassa textile factory (Birenesh Abay, 2007) and fertilizer runoff from MIDROC farm via Tikur Wuha River. S6 also showed very slight increase due to leaching of rock particles from the channel and domestic wastes from the surrounding. According to Illinois water quality standard for total phosphorus in lakes is 0.05mg/l but concentrations above 0.03mg/l are enough to stimulate algae growth.

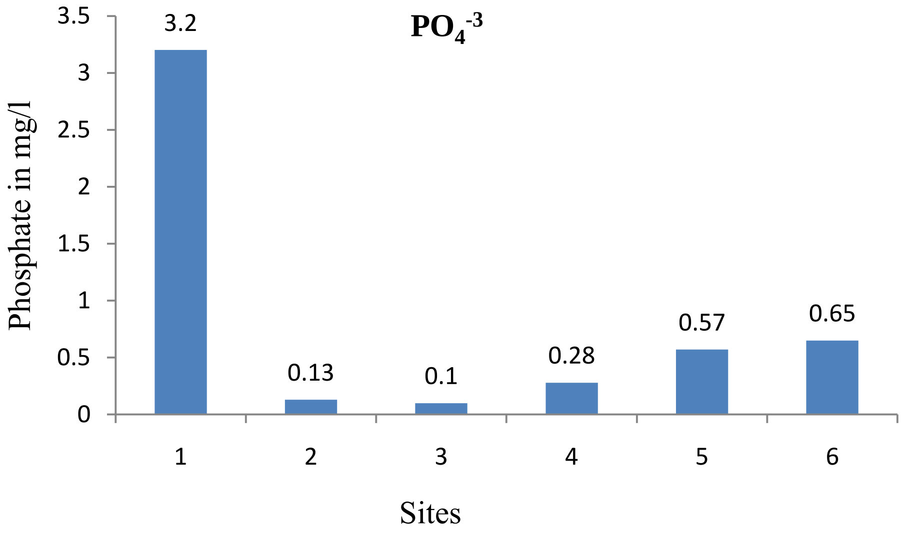

Figure 8. Phosphate Concentration among sampling sites

5.2 Benthic Macro-invertebrates

A total of 38 taxa comprising of 1872 benthic macro-invertebrate specimens were collected from the 6 sites. The Gastropod Families (Pleuroceridae, Physidae) were dominant taxa that contribute largest number (n=837, 44.7% of the total sample) (Table 4 & Figure 12). The second dominant group was Hemiptera containing most common Families like (Naucoridae, Notonectidae) with n=523, (28% of a sample). Percentage EPT and Diptera compose 6% each even though their distribution varies. The abundance and taxa richness of the whole benthos data are shown in Appendix 5 and percentage composition of benthos within each site is shown in Figure 11 and Table 3.

5.2.1. Benthic Metrics and their Correlation with Physico-chemical Parameters

A) Family Level Taxa richness (TR)

Richness among the sites was comparatively similar except slight change in S2, containing 22 taxa. The remaining five sites contain 17-18 taxa. This change was not meaningful difference among sites but the composition of each taxon with their tolerance value among sites tells a lot about the impacts (Appendix 5). The presence or absence of certain taxa is also related to water quality rather than other ecological factors (Mason, 1996). In this study, the presence of pollution sensitive group EPT (Ephemeroptera, Plecoptera and Trichoptera) of very less tolerance value in S4 and S3 comparatively in larger number from other sites and it was totally absent in S1. The %EPT is mainly used for rivers and streams systems but Hemiptera and Odonata of moderate tolerance value were indicators of water quality in lakes. For instance, the Family Naucoridae represents 275 individuals out of the total Hemiptera of 523 specimens. From 275 individuals 135 (25.8% of all Hemiptera) were collected from S4 and 65 from S3. These data more probably indicates that S3 and S4 were under good water quality. According to Hilsenhoff (1988), the presence of pollution sensitive groups rather than pollution tolerant groups can indicate water quality because pollution tolerant groups can inhabit both habitats according to their niche preference.

B) % Chironomidae

In this study, S6 and S1 show comparatively high percentage of chironomidae (Figure 9) indicating that the sites were highly impacted representing 37.7% and 17.9 % of the total chironomidae found in S1 and S6 respectively (Appendix 5). The high percentage of Chironomidae in S6 was significantly correlated with NO_3^- concentration ($r= 0.960$, $P< 0.05$). The site was also highly affected by sedimentation due to lack of vegetation along the channel and open agricultural activities near the shore (Plate-9, a-f). S1 was also highly affected by agricultural, domestic and wastes of textile factory releasing 17.8 mg/l of NO_3^- through Tikur Wuha River; it was shown by high nitrate concentration from the site (Figure 7).

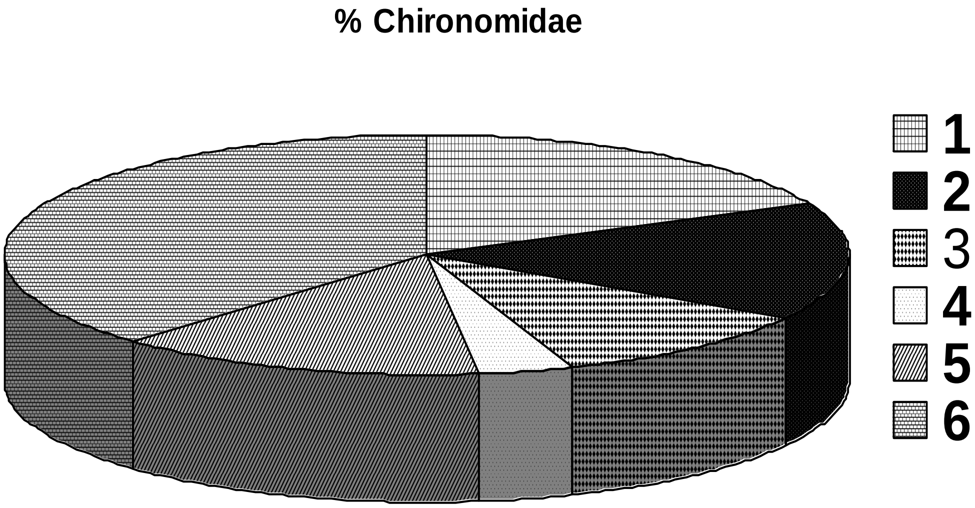

Figure 9. Show % Chironomidae contribution among sites

C) Hilsenhoff Family-level Biotic Index (H-FBI)

The Modified Family Biotic Index (FBI) was developed to detect organic pollution. In this study, five sites show higher FBI values; suggesting comparatively low water quality and lower FBI was calculated from S1; suggesting comparatively higher water quality, while physico-chemical parameters and major benthos metrics indicating higher pollution in the site S1 (Table 3 & Appendix 1). According to Hilsenhoff 1988, this condition happens because FBI usually indicate greater pollution of clear lakes by overestimating biotic index values and also usually indicating less pollution in polluted lakes then frequently it will lead to error conclusion about water quality. Because both pollution sensitive and tolerant forms are present in “clean” waters, it is the absence of the former groups with the presence of the latter which may indicate damage (Zimmerman, 1993). The site were categorized in (Table 2) according to calculated value of modified family biotic index.

In this study, large number of Gastropods obtained from S3, S2, S4, S5 and S6 but only 2.4% out of the total 837 individuals were occurred in S1(Appendix 5). Less percentage in S1 was possible due to significant negative effect of Conductivity, TDS and Phosphate ($r= -0.831$, $P< 0.05$; $r= -0.877$, $P< 0.05$ & $r= -0.860$, $P< 0.05$ respectively). The average phosphate concentration in S1 (3.2mg/l) was above recommended level. This might be due to 9.04 mg/l of phosphate load from textile factory wastes of detergents where, Gastropods could not resist the effect of detergents.

Table 2. Evaluation of water quality using H-FBI Score Interpretation (Hilsenhoff, 1988)

FBI	Water Quality	Degree of Organic pollution	Site category based on organic pollution
0.00-3.50	Excellent	No apparent organic pollution	
3.51-4.50	Very good	Possible slight organic pollution	
4.51-5.50	Good	Some organic pollution	S1
5.51-6.50	Fair	Fairly significant organic pollution	S4
6.51-7.50	Fairly Poor	Significant organic pollution	S2, S3, S5,S6
7.51-8.50	Poor	Very significant organic pollution	
8.51-10.00	Very Poor	Severe organic pollution	

D) % Dominant taxa (DT)

In this study, the dominant group gastropoda mainly (Pleuroceridae and Physidae) show major change in composition among sites (2.4%, 28.5%, 35.5%, 14.6%, 11.3% and 7.65%) respectively from site 1 to site 6 (Appendix 5 & Figure 10).

The less percentage in S1 and S6 might be due to higher load of nitrate in this sites ($r= -0.753$, $P< 0.05$) (Appendix 2 & 3) and instability of the area by the inflow of Tikur Wuha River, runoff and waste disposal from referral hospital area through the channel. Some unstressed habitats are dominated by only a few taxa due to habitat, flow, and seasonal effects (Bode *et al.,* 1996). The better stability in S3 and S4 promoted the higher abundance moreover; S4, reference site incorporated Family Pleuroceridae having moderate tolerance value in large number indicating water quality of the site. The habitat preference might indicate that the biology of Gastropods needs to stay attached to vegetations in settled areas. However, dominant taxa (Gastropods) have high tolerance value to the change in water quality. Highest percentage of Gastropods was mainly collected from submerged vegetations of all sites (Figure 11 and Appendix 5). This may indicates that the lake is under long term environmental stresses.

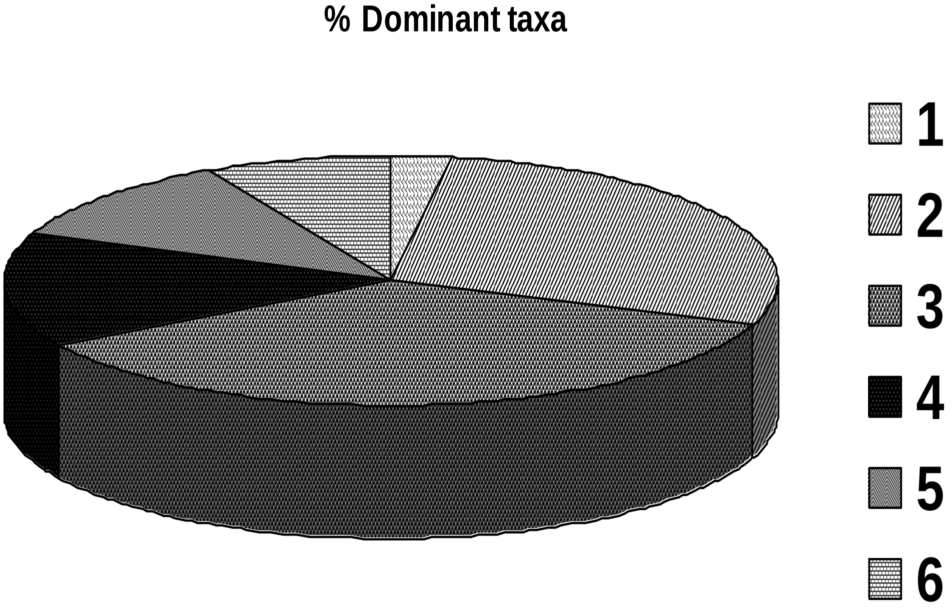

Figure 10. Show % contribution of dominant taxa (Gastropods) among each site

Table 3. Percentage contribution of major benthic macro-invertebrates within site comparisons

Metrics	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
% EPT	0	2.6	7.8	12	2.7	7.3
% Odonata	11.5	22.3	3.2	7	19.9	21.2
% Hemiptera	61	17.5	17.2	41.2	27.1	24.2
%Blood red chironomidae	10.4	3.6	2.5	1.2	6.8	17.3
% Dominant taxa(Gastropods)	10.9	53	68	37.6	43.4	28.1

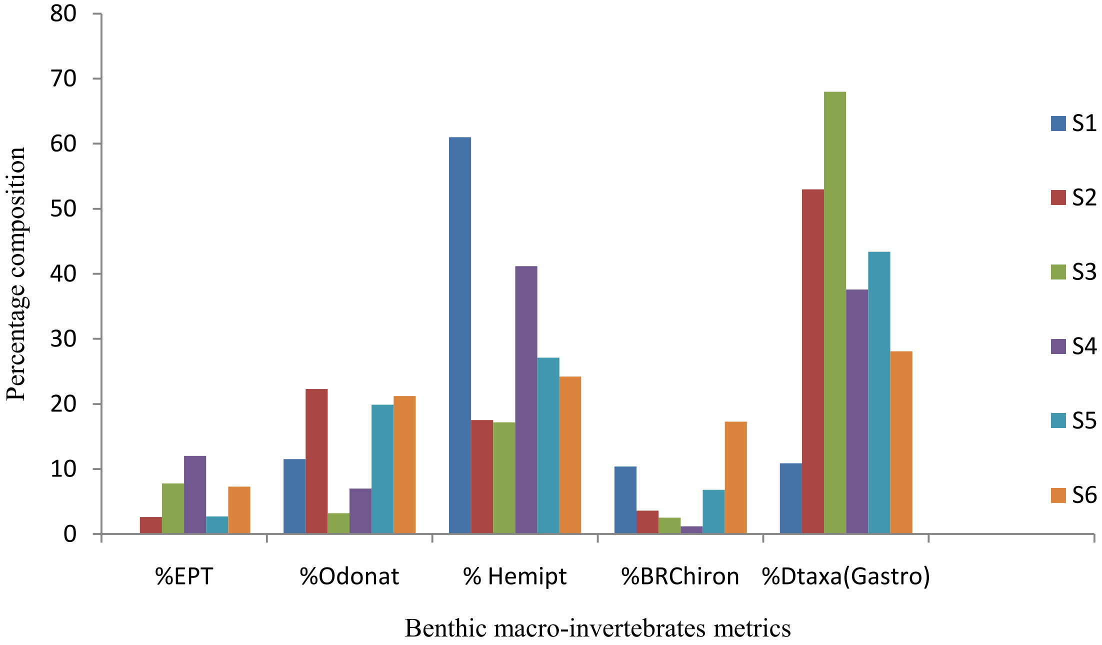

Figure 11. Percentage composition of benthic macro-invertebrates within site comparison

Tabel 4. The Percentage composition of overall benthic macro-invertebrate communities along eastern shore of Hawassa Lake

%Ephmero	%Tricho	%Pleco	% Hemipt	%Odonat	%Dipter	% Colepte	% Gastro	% Leeches
5.6	0	0.16	28	13.6	6	1.07	44.7	0.75

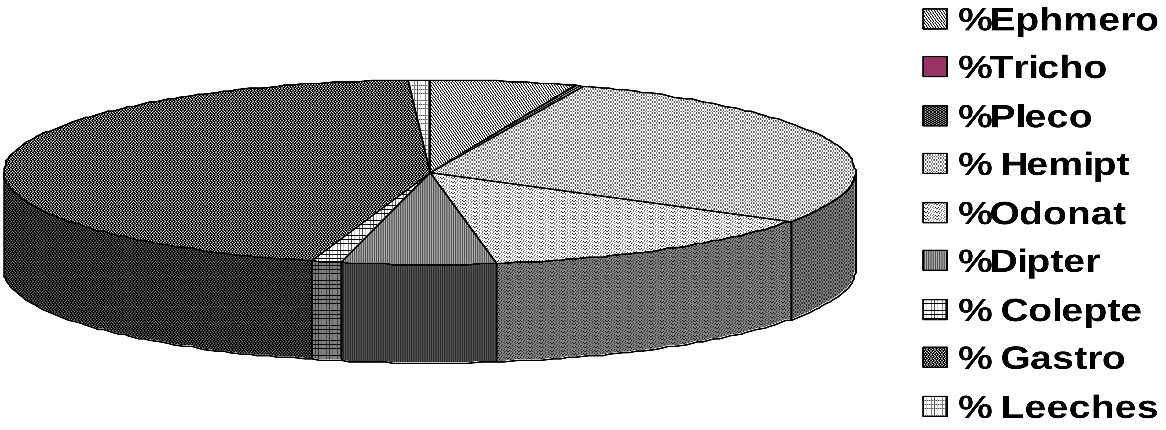

Figure 12. Chart show Percentage composition of overall benthic macro-invertebrate community along eastern shore of Hawassa Lake

6. CONCLUSION

Hawassa Lake is one of tourist attraction sites in the country for large number of national and international visitors. However, sufficient attention has not been given for the protection of water quality and Biodiversity in and round the lake.

According to H-FBI result, S1 (Tikur Wuha Site) was categorized under good water quality due to some organic pollution. However, physico-chemical parameters showed value representing high pollution in the site. The remaining four sites were categorized under fairly poor water quality due to significant organic pollution. The reference site (S4) was categorized under fair due to fairly significant organic pollution.

Most of physico-chemical parameters indicated high pollution in S1 and S6; the remaining four sites were comparatively same to one another. The benthos metrics also showed significant correlation. The result of the study indicates that some benthic metrics designed for rivers and downstream assessment also work for discriminating impacted sites in lakes.

The overall percentage composition of benthic macro-invertebrates of the lake was highly dominated by pollution tolerant families of Gastropoda, Odonata and Chironomids but less percentage from pollution sensitive families of EPT (Ephemeroptera, Plecoptera and Trichoptera) (Table 4 & Figure 12) indicating that the lake was under long term environmental stress. Because macro-invertebrates provide more reliable assessment for long-term ecological changes in the quality of aquatic system as compared to rapidly changing physico-chemical characteristics, benthic metrics should be used to monitor the impact and to assess the ecological integrity of lakes.

Rapid population growth, faster urbanization and industrialization, change in land use around the lake and the release of chemical wastes from factory, institutions and agricultural land were the main threats of the lake which will have negative impact on the overall biological integrity and sustainability of Lake Fauna and Flora.

7. RECOMMENDATIONS

The lake provides a lot of benefits in the agriculture, recreation, industries and also it is habitat for large number of wildlife. Therefore, protection of lakes needs urgent intervention.

It needs regular monitoring of lakes by using essential biological and physico-chemical parameters. The scientific information obtained from studies should be placed in systematic and accessible database in an appropriate institution to follow the trend.

The use of a few parameters may lead to wrong conclusion about the lake, as for instance, H-FBI results in this study. Therefore, one needs employ physical, chemical, and biological approaches and also habitat and catchment assessments to predict the overall impact on the lake.

Benthic macro-invertebrate metrics were mainly designed for river and stream water quality assessment; however; this study showed that they also work to discriminate impacted sites of lakes. Hence farther studies should be done to adopt the macro-invertebrate bio-assessment method for lake ecosystems.

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9. APPENDICES

Appendix-1. Average physico-chemical data collected in conjunction with benthic macro-invertebrates assessment at each site

Parameters	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**WHO mac**
pH	6.48±.05	8.22±.48	8.22±.58	8.32±.53	8.03±.33	7.9±.16	6.5-8.5
Temperature in (^{0}c)	24.7±.42	24.5±.42	23.55±1.0	23.45±1.2	24.20±0.0	24.05±0.8	40^{0}C
Conductivity in (µS/cm)	818.0±21.1	668.0±12.7	668.5±19.5	660.5±50.2	644.5±67.2	693.0±43.8	1000µS/cm
Total dissolved solids mg/l	489.5±10.6	401.0±7.1	401.0±11.3	405.0±17	385.5±40.3	412.5±23.3	80mg/l
Nitrate (mg/l No_3)	8.08±9.1	0.55±.01	0.46±.01	0.95±.40	1.59±.55	10.74±13.5	45mg/l
Phosphate (mg/l Po_4)	3.20±3.4	0.13±.03	0.10±.11	0.28±.20	0.57±.36	0.65±.31	-

WHO mac = (World Health Organization maximum allowable concentration)

Appendix-2. Linear regressions of 9 benthic macro-invertebrate metrics and physico-chemical parameters (-1< r <1) where, Negative sign indicates opposite correlation.

Parameters	%EPT	%Ephemero	%Trichop	%Plecop	%Odonat	%Dipter	%BRChirono	%NonInsec	%DTaxa
pH	.639	.621	.265	.265	-.003	-.560	-.560	.803	.042
Temp	-.936	-.893	-.514	-.514	.620	.458	.458	-.507	-.111
Cond	-.533	-.523	-.182	-.182	-.122	.473	.473	-.752	.021
TDS	-.473	-.460	-.194	-.194	-.182	.408	.408	-.758	.076
Nitrate	-.219	-.177	-.356	-.356	.304	.960	.960	-.772	-.753
Phosphate	-.606	-.583	-.298	-.298	-.059	.465	.465	-.817	.056

Appendix-3. P-value for Pearson Correlation Coefficient among 9 benthic macro-invertebrate metrics and physico- chemical parameters (P< 0.05, show Significance)

Parameters	%EPT	%Ephemero	%Trichop	%Plecop	%Odonat	%Dipter	%BRChirono	%NonInsec	%DTaxa
pH	**.086**	**.094**	.306	.306	.498	.124	.124	**.027**	.468
Temp	**.003**	**.008**	.149	.149	**.094**	.180	.180	.152	.417
Cond	.138	.144	.365	.365	.409	.171	.171	**.042**	.485
TDS	.172	.179	.356	.356	.365	.211	.211	**.040**	.443
Nitrate	.339	.368	.244	.244	.279	**.001**	**.001**	**.036**	**.042**
Phosphate	.101	.112	.283	.283	.456	.176	.176	**.024**	.458

Appendix-4. P-value for Pearson Correlation Coefficients and r-value for Linear Regressions of (H-FBI and TR) with physico-chemical parameters where, ($P < 0.05$ show significance and r- value in the interval $-1 < r < 1$)

	H-FBI		TR	
	r-value	P-value	r-value	P-value
pH	0.792	**0.030**	0.130	0.403
Temp	-0.448	0.186	0.472	0.172
Condu	-0.831	**0.020**	-0.029	0.478
TDS	-0.877	**0.011**	-0.052	0.461
Nitrate	-0.335	0.258	-0.182	0.362
Phosphate	-0.860	**0.014**	-0.179	0.367

Appendix-5. Overall composition and distribution of benthic macro-invertebrates collected from Hawassa Lake sampling sites.

Taxa and their common name	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**Total of a group**	**Toler value of taxa**
Ephemeroptera (Mayflies)								
Baetidae	0	7	12	5	1	13	38	4 moderate
Caenidae	0	1	1	33	5	0	40	7 high
Metretopodidae	0	4	0	0	0	0	4	4 moderate
Leptophlebiidae	0	0	13	0	0	0	13	2 low
Polymitarcyidae	0	0	2	0	0	0	2	2 low
Ephemerellidae	0	0	0	3	0	0	3	1 low
Heptagenildae	0	0	0	0	0	4	4	4 moderate
% contribution for the lake	**0**	**11.5**	**27**	**39**	**6**	**16.3**	**104**	

Plecoptera (Stone flies)								
Perlidae	0	0	2	0	0	0	2	1 low
Capniidae	0	0	1	0	0	0	1	1 low
% contribution for the Lake	**0**	**0**	**100**	**0**	**0**	**0**	**3**	
Trichoptera (Caddisflies)	0	0	0	0	0	0	**0**	
Odonata (Damselflies and Dragonflies)								
Calopterygidae	7	18	4	16	7	12	64	5 moderate
Coenagrionidae	4	23	1	6	10	13	57	9 high
Lestidae	7	51	4	1	9	13	85	9 high
Corduliidae	2	7	0	1	18	8	36	7 high
Aeshnidae	1	0	0	0	0	0	1	3 low
Gomphidae	0	4	4	0	0	1	9	1 low
Libellulidae	0	0	1	0	0	0	1	7 high
Macromiidae	0	0	0	0	0	2	2	7 high
% contribution for the Lake	**8.24**	**40.4**	**5.5**	**9.4**	**17.25**	**19.2**	**255**	

Hemiptera (True bugs)								
Naucoridae	12	21	65	135	33	9	275	5 moderate
Notonectidae	71	43	10	5	5	37	171	undetermined
Gerridae	1	2	0	0	0	0	3	undetermined
Pleidae	25	1	0	0	3	0	29	undetermined
Mesoveliidae	2	0	0	0	0	0	2	5 moderate
Hydrometridae	0	14	0	0	6	0	20	undetermined
Corixidae	0	0	0	0	13	10	23	9 high
% contribution for the Lake	**21.2**	**15.5**	**14.3**	**26.8**	**11.5**	**10.7**	**523**	
Diptera								
Chironomidae	19	17	11	4	15	40	106	8 high
% contribution for the Lake	**17.9**	**16**	**10.4**	**3.8**	**14.1**	**37.7**		
Stratiomyidae	1	2	0	1	0	1	5	8 high
Syrphidae	1	0	0	0	0	0	1	10 high

Coleoptera								
Hydrophilidae	7	0	0	0	0	0	7	5 moderate
Elmidae	1	0	0	1	0	0	2	5 moderate
Gyrinidae	0	1	5	0	0	3	9	4 moderate
Metheles	0	1	0	0	0	0	1	undetermined
Muscidae	0	0	0	1	0	0	1	6 moderate
% contribution for the Lake	**40**	**10**	**25**	**10**	**0**	**15**	**20**	
Gastropoda								
Pleuroceridae	2	29	96	60	13	34	234	6 moderate
Physidae	4	173	183	61	80	17	518	7 high
Planoribidae	14	6	18	0	1	13	52	7 high
Bithyniidae	0	0	0	0	1	0	1	8 high
Viviparidae	0	31	0	1	0	0	32	7 high
% contribution for the Lake	**2.4**	**28.5**	**35.5**	**14.6**	**11.3**	**7.65**	**837**	
Hirudinea (Leeches)	0	6	0	6	1	1	14	10 high

% contribution for the Lake	**0**	**43**	**0**	**43**	**7**	**7**	**14**	
NO.Taxa	**18**	**22**	**18**	**17**	**17**	**18**	**38**	
H-FBI	**4.96**	**6.70**	**7.22**	**6.05**	**6.90**	**6.93**		
TOTAL	**182**	**462**	**436**	**340**	**221**	**231**	**1872**	

H-FBI (Hilsonhoff Family level Biotic Index)

PICTURES OF STUDY AREA

PLATE -1 Tikur Wuha River round Hawassa lake entry

PLATE -2 (a &b) Tikur Wuha (Black Water) Sampling areas (site-1)

PLATE-3 Sampling by D- net from(site-2) PLATE-4 Sampling by Ekman grab from (site-3)

PLATE -5 (a-f) - Show Main get (site-3)

PLATE-6 (a-c) Buffer area adjacent to site-3

PLATE-7   Site-4 (Wabeshebelle -2 site)

PLATE-8 (a-d) Site-5 (Amora gedel or Gudumalle site)

PLATE-9 (a-f) Site -6 (At the back of Hawassa University Referal Hospital)

PLATE- 10 (a&b) Site-6 (Septic Tanks of Referral Hospital)

PLATE-10 (a&e) Vegetations of Hawassa Lake