**Jimma University**

**College of Public Health and Medical Sciences**

**Department of Environmental Health Science and Technology**

# Influence of environmental factors on fish and macroinvertebrate assemblages of natural wetlands in the Gilgel Gibe watershed, Southwest Ethiopia

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**Declaration**

I, the undersigned, declare that this research paper is my original work and has not been presented for a degree in any other university and that all sources of materials used for the research paper have been correctly acknowledged.

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## Abstract

*Natural wetlands of Gilgel Gibe watershed in the southwestern Ethiopia have various socioeconomic and ecological values such as habitat for a variety of plant and animal species, and water source for human and livestock consumption. Although these values and services are appreciated, wetlands in the catchment are subject to increasing anthropogenic disturbances. The objective of this study was to determine the effects of these anthropogenic disturbances on water and habitat quality, fish and macroinvertebrate assemblages. A cross-sectional study was carried out from March to April 2014 in three wetlands located in Gilgel Gibe watershed. A total of 23 sites were sampled. Canonical Correspondence Analysis (CCA) and multiple linear regression models were used to identify influencing variables on macroinvertebrate and fish communities. A total of 4,349 macroinvertebrate individuals belonging to 11 orders and 33 families were collected. The most abundant orders were Hemiptera 2478(57%), Coleoptera 557(13%), Diptera 438(10%), Odonata 389(9%) and Ephemeroptera 361(8%) represented by 24 families. 760 different fish specimens were collected. Oreochromis niloticus was the dominant species which accounts 77.5 % followed by Labeo forskalii (18.16 %), Garra dambeensis (3.42), Garra chebera (0.79%) and Labeobarbus intermedius (0.13 %). CCA analysis clearly indicated that environmental factors such as concentration of DO, TSS, ammonium, chloride, turbidity, water temperature, secchi depth, conductivity, water depth, sludge depth and pH influence the structure of wetland fish and macroinvertebrate communities. Furthermore, Macroinvertebrate descriptor was best predicted ($R^2$ = 0.55) by water depth and sludge depth whereas fish descriptor was best predicted ($R^2$ = 0.53) by sludge depth, ammonium and TSS. These variables provided clear interpretations of water quality and habitat deterioration of natural wetlands in the Gilgel Gibe watershed due to human impacts from catchment land use. Therefore, creation of awareness for proper utilization of natural wetlands and their related ecosystem services in the Gilgel Gibe watershed, where wetland resources are being lost at a high rate, and continue to be at high risk due to expansion of agricultural and other development activities. The finding of this study can complement the previous studies on wetlands and surrounding watersheds to prepare a complete monitoring tools and metrics which can give results to make informed decisions for management and restoration of wetland ecosystem.*



**Key Words:** *Fish, Macroinvertebrate, Water quality, Habitat quality and Wetland*

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## Abbreviations

| | |
|---|---|
| APHA | American Public Health Association |
| ASPT | Average Score per Taxon |
| Chl a | Chlorophyll a |
| COD | Chemical Oxygen Demand |
| DO | Dissolved Oxygen |
| EC | Electrical Conductivity |
| FAO | Food and Agriculture Organization of the United Nations |
| LSRCA | Lake Simcoe Region Conservation Authority |
| NTU | Nephelometric Turbidity Units |
| SASS | South African Scoring System |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |
| UNEP | United Nations Environment Program |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| US EPA | United States Environmental Protection Agency |
| WHO | World Health Organization |

# 1. INTRODUCTION

## 1.1 Background

Wetlands are ecosystems or units of the landscape that are found on the interface between land and water. While water is a major factor of wetland definition, soils, vegetation and animal life also contribute to their unique characteristics ( Roggeri 1995; Koetze 1996 ). As a result, it has proved difficult to define wetlands, and over 50 definitions exist (Abebe 2003). The Ramsar convention defined as:

*"Wetlands include a wide variety of habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, and seagrass beds, but also coral reefs and other marine areas no deeper than six meters at low tide, as well as human-made wetlands such as waste-water treatment ponds and reservoirs"*(Ramsar Convention Secretariat 2010). This is the most widely used definition provides significant latitude - how wetlands exist in a whole host of forms and types which enable them to deliver a wide range of ecosystem services that contribute to human well-being, such as fish and fiber, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and, increasingly, tourism. They are described both as 'the kidneys of the landscape' because of the functions they perform in the hydrological and chemical cycles, and as 'biological supermarkets' because of the extensive food webs and rich biodiversity that they support (Mitsch & Gosselink 2007).

Wetlands are distributed all over the world and estimated to cover 6 - 8.6 % of earth's land surface, which is about 12.8 million square kilometer. However, the global extent of wetlands is most likely underestimated, because of lack of concise definition agreed upon commonly by international parties, detailed national inventories and seasonality of some wetland habitats (Millennium Ecosystem Assessment 2005). Although Africa is best known for its savannahs and hot deserts, 4% of its surface area (1.3 million $km^2$) is covered by wetlands (Lehner & Döll 2004).

Ethiopia, with its varied geologic formations and climatic conditions, is endowed with considerable water resources and wetland ecosystems, including twelve river basins, eight major lakes, many swamps, floodplains, and man-made reservoirs (Abunie 2003). As a land locked country, Ethiopia lacks wetlands that are associated with coastal areas; otherwise, all wetland types that exist in different parts of the globe are represented in the country. These include alpine formations, riverine, lacustrine, palustrine and floodplain wetlands. Floodplains are found both in Ethiopia's highlands and lowlands, although they are most common in the North-Western and Western Highlands, Rift Valley and Eastern Highlands. Ethiopia's wetlands make up an estimated 22, 500 $km^2$, which is 2 % of the total landmass of Ethiopia (Abebe 2003).

Wetlands are important microenvironments within the landscape providing many ecological and socio-economic benefits in the Ethiopian highlands where water resources are unevenly distributed. Among the benefits from wetlands are water storage, sediment control, groundwater recharge, stream flow moderation, water filtration and purification, plant and fish products, biodiversity, and wildlife habitat (Dixon & Wood 2003).

## 1.2 Statement of the problem

In more recent biological and human time periods, wetlands have been valuable as sources, sinks, and transformers of a multitude of chemical, biological, and genetic materials. Even if the complex interactions between biotic (fauna and flora) and abiotic (soil, water and topography) components of wetland systems make them amongst the earth's most productive ecosystems, they are also the most threatened (Mitsch & Gosselink 2007). Destruction and modification of wetland has been and is still seen as an advanced mode of development, even at the government level. Wetlands and their value remain little understood and their loss is increasingly becoming an environmental disaster. While rates of wetland loss are documented for the developed world, the limited study of these ecosystems in countries like Ethiopia leaves us with little to say. Wetland loss is palpable wherever major developments like dams, irrigation schemes and conversion projects are present in the developing world (Abebe 2003). While most of the threats that wetlands face result from their misuse, many are also related to unsustainable resource extraction. Extra important reason for their vulnerability is the fact that they are dynamic systems undergoing continual change. Accordingly, many wetlands are temporary features that disappear, reappear and re-create themselves over time (Barbier et al. 1997).

Several people assume that wetlands are common resource to exploit and abundant thereby anyone is entitled to use them. However, a lot of people have not observed wetlands are either drained or lost and need proper management (Finlayson & Davidson 1999; Abebe & Geheb 2003; Millennium Ecosystem Assessment 2005; Mitsch & Gosselink 2007). Humans usually and very dramatically accelerate natural processes often unintentionally but usually in the course of activities like agriculture, industry and urban development. These activities can involve anything from drainage and diverting water, to dredging and loading water sources with toxic chemicals. Practically the most destructive of all activities is mining which permanently destroys the substrate and prevents the natural restoration of a site. Fortunately, Wetlands whose biotic balance has been disturbed can often recover (Williams 1993).

More than 50% of specific types of wetlands in parts of world were destroyed and many others degraded during the twentieth century and 65% of disturbances are of human origin, while the rest from natural origins. Out of these, 73% of disturbances are thought to result from direct human actions; while the remaining 27% are believed to come from indirect sources. The results of wetland loss are broad and disastrous. Humans and other life close to wetlands, and who depend upon them, are the principal to feel the impact of wetland loss (Dugan 1990; Finlayson & Davidson 1999; Abebe 2003; Mitsch & Gosselink 2007).

All too often, wetland functions, including flood protection, nutrient retention, erosion control or sediment retention, will be compromised by well-meant development interventions. While industrialized countries can probably pay for most of these services from tax incomes, this is not so in developing countries, where wetland destruction can have a very serious impact on the livelihoods of the rural poor (Abebe 2003).

Wetlands are rarely damaged by a single stressor. Rather, a mixture of chemical, physical, and biological stressors typically impacts them. Measuring all of the stressors that could affect a wetland in a way that is ecologically meaningful is virtually impossible. The only way to evaluate the cumulative effect of all the stressors is to directly measure the condition of the biological community (Barbier et al. 1997; Baldwin et al. 2005; Uzarski et al. 2005).

Ethiopia’s wetlands are threatened by increasing human population pressure, agricultural encroachment, intensive livestock grazing, deforestation, and construction (Abunie 2003). The few available reports are showing that there is an increasing discharge of liquid and solid waste into the nearby riverine wetlands. Studies done on a limited number of sites of a few riverine wetlands have indicated that water quality of wetland in the periphery of urban environment are getting degraded due to municipal and industrial discharges (Yimer & Mengistou 2010; Mereta et al. 2012; Ambelu et al. 2013).

The wetlands in southwest Ethiopia have various socioeconomic and ecological values such as grazing land, crop cultivation, habitat for a variety of plant and animal species, and water source for human and livestock consumption. Although these values are appreciated, but little understood, investigation on their biodiversity and richness has not yet been undertaken. In response to the rapid degradation of wetlands in Ethiopia, a number of studies on wetland hydrology (Dixon & Wood 2003), wetland ecology based on macroinvertebrate communities (Yimer & Mengistou 2010; Getachew et al. 2012; Mereta et al. 2012; Ambelu et al. 2013; Mereta et al. 2013) and socio-economic aspects (Bekele 2011) have been initiated. However, little is known about the fish assemblage in relation to overall ecological condition of wetlands in Ethiopia. Fish have received little attention as indicators of wetland conditions, but recognition of their ecological significance in wetlands has recently generated considerable interest (Uzarski et al. 2005). Besides, there is no a study which assesses ecology of wetland using the different strength and responses of fishes and macroinvertebrates to the environmental and land use pattern influences at the same sites in Ethiopia.

# 2. LITERATURE REVIEW

## 2.1 Wetland Ecosystem

Wetland ecosystems (including lakes, rivers, marshes, and coastal regions to a depth of 6 meters at low tide) are estimated to cover more than 1,280 million hectares, an area 11.36 times larger than Ethiopia. However, this estimate is known to under-represent many wetland types, and further data are required for some geographic regions (Millennium Ecosystem Assessment 2005).

## 2.2 Values and Functions of wetlands

Wetlands are often considered to be wastelands which are of little use to anyone. They are thought of as nuisances and are associated with problems such as mosquitoes, diseases and floods. They are also regarded as obstacles to human development. As a result they are often converted, usually by drainage, and used for a variety of new uses such as cultivation, grazing or building, especially for industry in urban areas. However, in their natural state wetlands provide a range of ecological and socio-economic benefits. Most of these are lost when the wetlands are drained. This loss of benefits can have serious impacts upon the wellbeing of rural communities (Dixon et al. 2001; Dixon & Wood 2007; Mekonnen & Aticho 2011; Mereta et al. 2012).

Wetlands help maintain the functioning of ecological systems, especially the hydrological system, in many ways such as flood control, ground water recharge with various implications including maintenance of springs, filtration of water flow and sediment trapping (Dixon et al. 2001). Groundwater, often recharged through wetlands, plays an important role in water supply, providing drinking water to an estimated 1.5–3 billion people globally. It also serves as the source water for 40% of industrial use and 20% of irrigation (Millennium Ecosystem Assessment 2005). Wetlands also serve as natural water purification systems. This has crucial practical benefits; for example, Gimbi Town Water Supply Plant is located at the downstream end of Gefar wetland system which is effectively purifying water and reducing the level of sediment in it (Mengistu 2007).

Hailu (2007) sets out an impressive example of wetland services which is the flood regulating and flood control ability of wetlands in highland Illubabor. In earlier decades, before deforestation and wetland drainage intensified in highland Illubabor, there was no history of flooding in the neighboring Gambella Township. However, with increased deforestation and extensive drainage of wetlands in Illubabor highlands flooding has become a major threat to Gambella Township, and until recently dikes were built along the river bank to stop such a threat.

Wetlands also provide important services by treating and detoxifying a variety of waste products and nutrient cycling. Water flowing through a wetland area may be considerably cleaner upon its exit from the wetland. Some wetlands have been found to reduce the concentration of nitrate by more than 80%. Metals and many organic compounds may be adsorbed to the sediments (that is, accumulated on their surface) in the wetlands. The relatively slow passage of water through wetlands provides time for pathogens to lose their viability or be consumed by other organisms in the ecosystem (Millennium Ecosystem Assessment 2005).

Wetlands in various parts of Ethiopia have been drained and used for growing food crops. Studies undertaken in southwestern part of the country including Jimma zone revealed that wetlands have been drained for growing food crops now for more than a century (Dixon et al. 2001; Dixon 2005; Mengistu 2007). According to Bognetteau et al. (2003), the production from wetlands, depending on the size of the household plot and its productivity, provides 8-25% of the yearly food requirement and in some cases where wetland areas are large enough; they contribute up to 50-60% of the household's food security.

Fishery also another important ecosystem services derived from inland waters. Wetland fisheries constitute a very important sector of the local economy and contribute towards the livelihood of tens and thousands of citizens in different parts of Ethiopia, mainly in the Rift Valley and around Lake Tana. Over 60% of Ethiopia's fish supply originates from the Rift Valley Lakes with significant benefits to the local and national economy. The fisheries of the Rift Valley Lakes support over 3,000 families in commercial and subsistence fishing activities and many more in processing, distribution and marketing centers. Additional incomes are obtained through the production, supply and repair of fishing gear, boats and engines (Sissay 2003).

Furthermore, wetlands provide habitat for a diverse assortment of species of fauna and flora. These include fish, bird, mammals, amphibians, invertebrate and plants. Fish are more dependent on wetland ecosystems than any other type of habitat and 40% of known species of fish inhabit inland waters (more than 10,000 species out of 25,000 species globally) (Millennium Ecosystem Assessment 2005). Many wetlands are also renowned because of their birdlife. In Ethiopia, out of a total of 73 Important Bird Areas (IBAs) identified in the country, about 30 (41%) are wetlands, and they support a variety of bird species including some endemics to Ethiopia, as well as worldwide endangered species such as the White Winged Fluff tail. In addition, out of 861 bird species those are believed to exist in the country, 204 (around 25%) are dependent on wetlands (Wondefrash 2003).

## 2.3 Ecological assessment

The sustainable management of aquatic environment requires ecological status assessment based on monitoring of the structure and functioning of aquatic ecosystems. The integrity of wetlands requires the management of indicated factors. To restore and maintain the factors (chemical, physical, and biological integrity of the wetlands) these three parameters should be monitored (Flotemersch et al. 2006). Biological monitoring provides a framework for improving wetland management, protection, and restoration. Bioassessments provide information about a wetland's present biological condition compared to expected reference conditions. By studying biology, wetland scientists can better understand how a wetland's biological community is influenced by the wetland's present geophysical condition and human activities within a watershed. Managers, policymakers, and society at large can use this information to decide if measured changes in biological condition are acceptable and set policies accordingly (Karr & Chu 1999). For instance US EPA is using information from wetland bioassessments to improve many management decisions, including: Strengthening water quality standards, wetland regulatory programs, improving wetland tracking, water quality decisions, and to monitor, protect, and re-store biological condition, evaluating the performance of regulatory, protection, and restoration activities, incorporating wetlands into watershed management and improving risk-based management decisions (Uzarski et al. 2005). Though Ethiopia has several thousands of hectares of wetlands that play critical ecological, economic and socio-cultural roles, the country lacks clearly defined wetland management system. Workable institutional arrangement, wetland policy, strategy and programs are not in place. Human and technical capacity is not adequately developed. Awareness on wetland is very low at all levels, and as a consequence, wetland degradation continued at an alarming rate (Mengistu 2007).

### 2.4 Macroinvertebrate and Fishes for Bio assessment

Bioassessments can help prioritize where to follow up with additional monitoring, help diagnose the causes of degradation, and provide data to make informed management decisions about protecting and restoring wetlands (Mitsch & Gosselink 2007). A variety of taxonomic assemblages, have been employed to assess aquatic ecosystems. Among the biological communities, macroinvertebrate and fish are primary assemblages and sensitive indicators of the relative health of aquatic ecosystems and their surrounding watersheds (Barbour et al. 1999; Flotemersch et al. 2006).

Wetlands, streams, rivers, and lakes are home for many small animals called macroinvertebrates. These animals generally include insects, crustaceans, mollusks, arachnids, and annelids (US EPA 2002). Macroinvertebrates are invertebrates visible to the naked eye that live attached to substrates in very high abundances in most streams and rivers. Many aquatic invertebrates complete their life cycles in wetlands; they are exposed directly to physical, chemical, and biological stressors within the wetland. They are the primary consumers in most systems and are an important link between primary resources and higher trophic levels, including many important recreational and commercial fish. Most macroinvertebrates are relatively sessile, which means they are excellent for use in evaluating site-specific impacts. They have a variety of life cycles, with short-lived and long-lived taxa, and thus provide a way of integrating impacts over a variety of time scales. These organisms are relatively easy to identify to the family level and many are easy to identify to genus. In addition, they are highly variable in terms of their tolerance to different stressors, providing important information for interpreting cumulative stressor impacts. Collection methods are relatively easy, straight- forward, and inexpensive (Barbour et al. 1999; Flotemersch et al. 2006).

Many studies have shown the strength of macroinvertebrate assemblage to assess ecology of wetlands and strong correlation to different environmental predictors (Yimer & Mengistou 2010; Getachew et al. 2012; Mereta et al. 2012; Ambelu et al. 2013; Mereta et al. 2013).

Likewise, fish assemblages are commonly used as indicators of wetland ecological condition because they are a diverse group of organisms that represent a variety of habitat uses. They are relatively longer lived organisms and include many mobile species, so they can potentially integrate effects over longer spatial and temporal scales. The environmental requirements and life histories of many fish species are well understood, meaning that the presence or absence of taxa can often be easily interpreted. Many fish species are consumed by humans and, therefore, they provide an assessment metric that is directly related to human health. In addition, many aquatic life uses are linked to fisheries, providing a direct measure of those uses. Fish are generally easy to collect and to identify to species. Most can be identified in the field and released, unharmed (Barbour et al. 1999; Baldwin et al. 2005; Flotemersch et al. 2006).

Many studies have shown strong associations (i.e., correlations) between fish assemblage integrity results, physical and chemical habitat condition, and human activities that alter stream and river habitat e.g., dams, agriculture, urban development (Passy et al. 2004; Walters et al. 2009; Dejen & Mintesnot 2012; Tessema et al. 2014).

## 2.5 Environmental factors affecting biological systems in the aquatic environment

Natural events and anthropogenic influences can affect the aquatic environment in many ways: synthetic substances may be added to the water, the hydrological regime may be altered or the physical or chemical nature of the water may be changed. Most organisms living in a water body are sensitive to any changes in their environment, whether natural (such as increased turbidity during floods) or unnatural (such as chemical contamination or decreased dissolved oxygen arising from sewage inputs). Individual aquatic organisms have different requirements with respect to the physical and chemical characteristics of a water body. Available oxygen, adequate nutrients or food supply, and the absence of toxic chemicals are essential factors for growth and reproduction (UNESCO/WHO/UNEP 1996).

Different organisms respond in different ways. The most extreme responses include death or migration to another habitat. Less obvious responses include reduced reproductive capacity and inhibition of certain enzyme systems necessary for normal metabolism. Once the responses of particular aquatic organisms to any given changes have been identified, they may be used to determine the quality of water with respect to its suitability for aquatic life (Barbour et al. 1999).

Habitat characteristics are important for classifying wetlands, identifying disturbance gradients and determining their effects, and are the basis for wetlands restoration efforts. Altered habitat structure is considered one of the major stressors to aquatic systems that lead to a loss of biological integrity(Uzarski et al. 2005). Physical habitat variables such as water depth, sludge depth and secchi depth are influential in the assemblage integrity of macroinvertebrate and fish communities in wetlands ecosystem because of its role in influencing water temperatures and dissolved oxygen levels (LSRCA 2006; Ambelu 2009; Mereta et al. 2012).

## 2.6 Significant of the study

Considering that macroinvertebrates and fishes vary in morphological, behavioral, and life history traits, it is not surprising that they have different sensitivities to various stressors. Studies that sample multiple assemblages (e.g., fish, macroinvertebrates, and diatoms) have repeatedly documented different responses to disturbances (Passy et al. 2004; Walters et al. 2009). These patterns suggest that complete and accurate assessment of wetland ecosystem condition should include multiple assemblages. In fact, Carlisle et al. (2008) reported that only half of the sites would have been considered impaired if only one of the three assemblages (fish, macroinvertebrates, or diatoms) were sampled. Furthermore, primary sources of wetland impairment may be missed by using a single assemblage indicator. While combining multiple assemblages into a single index has been recommended (Walters et al. 2009), Recently, Fishes also attract many ecologists for wetland health assessment (Uzarski et al. 2005). The present study was conducted to determine influence of environmental factors on fish and macroinvertebrate assemblage integrity with the view to understand ecological status of natural wetlands in the Gilgel Gibe watershed, Southwest Ethiopia which faced different anthropogenic disturbances. As a result, the finding of this study can complement the previous studies on wetlands and surrounding watersheds to prepare a complete monitoring tools and metrics which can give results to make informed decisions for management and restoration of wetland ecosystem. Besides, it can generate baseline data that may give an insight for future study.

# 3. OBJECTIVES

## 3.1 General objective

- To analyze environmental factors determining fish and macroinvertebrate assemblages integrity with the view to understand ecological status of natural wetlands in the Gilgel Gibe watershed, Southwest Ethiopia, 2014.

## 3.2 Specific objectives

- To examine physicochemical properties of natural wetlands in the Gilgel Gibe watershed
- To assess habitat disturbances of natural wetlands in the Gilgel Gibe watershed
- To determine macroinvertebrate abundance and diversity of natural wetlands in the Gilgel Gibe watershed
- To determine fish abundance and diversity of natural wetlands in the Gilgel Gibe watershed

## 3.3 Research question

What are the environmental factors influencing fish and macroinvertebrate assemblages integrity in natural wetlands of Gilgel Gibe watershed?

# 4. METHODS AND MATERIALS

## 4.1 Study area

The study was conducted in two riverine wetlands (Boye and Kito), and a floodplain wetland (Haro) are located in the Gilgel Gibe watershed, lying between latitudes 7$^{o}$38’N and 7$^{o}$40’N and longitudes 36$^{o}$47’E and 36$^{o}$52’E (Figure 1 and coordinates of each sampling stations are available in annex IX). Totally twenty three sampling points were selected from the three main wetlands i.e. ten from Haro wetland (H1, H2, H3, H4, H5, H6, H7, H8, H9 and H10), four from Boye wetland (B1, B2, B3 and B4) and the rest nine sites from Kito wetland (K1, K2, K3, K4, K5, K6, K7, K8 and K9). The studied wetlands are varying in size ranging from 5 ha to a few

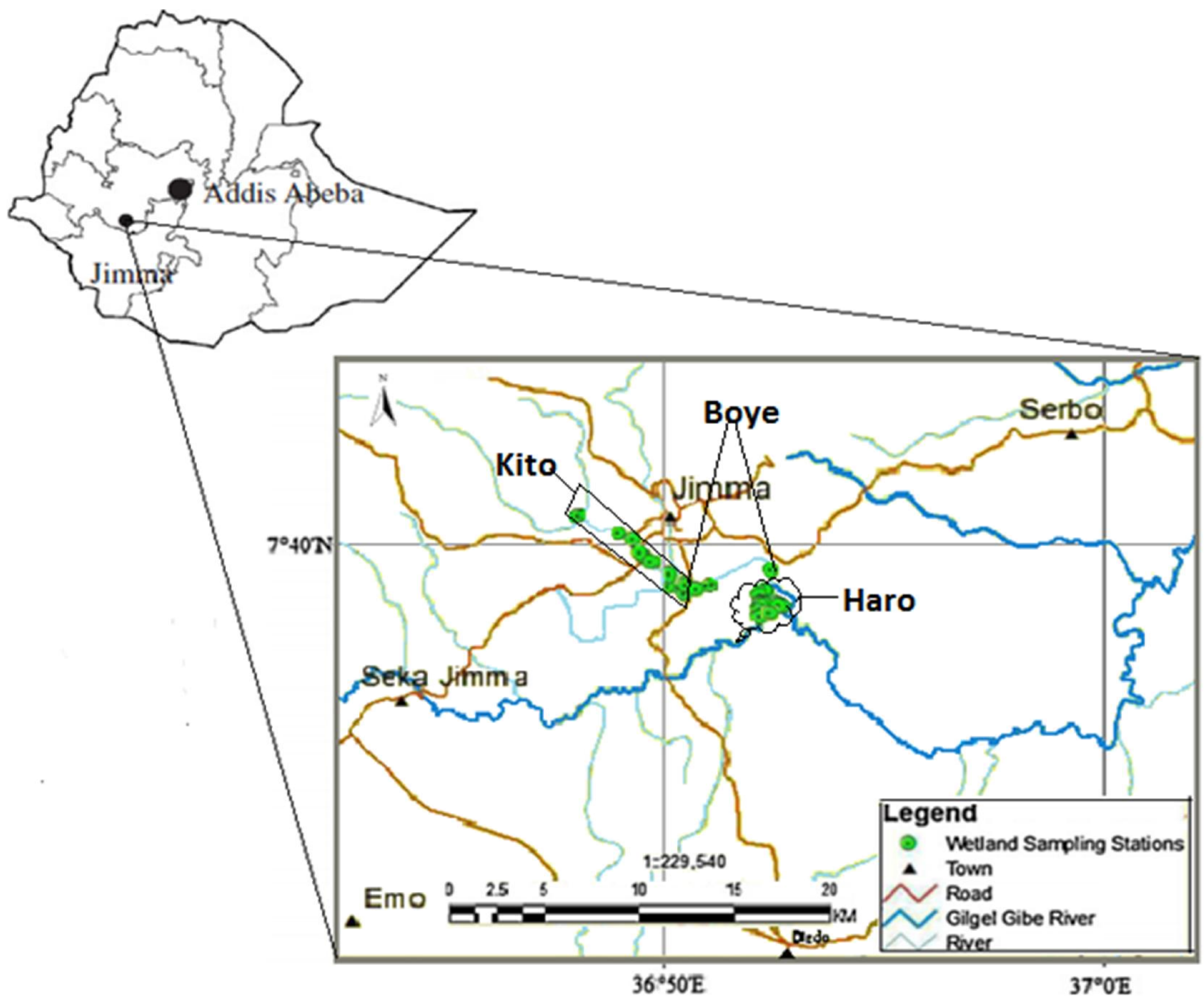


Figure 1: Location of the study area and wetland sampling stations in the Gilgel Gibe watershed, Southwest Ethiopia.

hundred hectares. The mean annual temperature in the area is between 15 ◦C and 22 ◦C, and the mean annual precipitation is between 1800 mm and 2300 mm, with maximum rainfall between June and September and minimum precipitation between December and January (National Meteorological Agency 2013). These wetlands are characterized by high fish and waterfowl abundance (Mereta et al. 2012). The main threats for the wetlands around Jimma are disposal of domestic sewage, drainage, farming, clay mining, removal of riparian vegetation and intensive livestock grazing. Among the riverine wetlands, Kito and Boye receive untreated wastewater generated by the more than 200,000 inhabitants of Jimma town (Mereta et al. 2013).

### 4.2 Sampling sites and sampling frequency

The Sampling criteria were the basis of factors such as: ease of access, availability of open water to set fyke net, variety of habitats, proximity to a local point-source of pollution e.g. Clay mining, a drainage canal or proximity to a non-point source of pollution e.g. a farm. At each site, water samples were taken simultaneously with the fish and macroinvertebrate samples and analyzed for physicochemical parameters during the sampling period. Samples were collected from March to April 2014. To obtain a visual record of sampling sites, digital photographs of wetlands were taken during sampling periods. Furthermore, for integration into a GIS (Geographic Information System) database, longitude and latitude and elevation of each sampling site were recorded using a GPS (global positioning system) unit.

### 4.3 Study design and period

A cross-sectional study was carried out from March to April, 2014 in natural wetlands of Awetu watershed, Southwest Ethiopia.

### 4.4 Sampling and identification

#### 4.4.1 Fish

Fish samplings were conducted using a fyke net with 4.8-mm mesh for one net-night (Uzarski et al. 2005). Nets were set during the day and retrieved after about 24 hours. Catches per effort were recorded. All fish (greater than 20 millimeters total length) collected within the sample were identified (Barbour et al. 1999). Specimen identification were made to species level using relevant taxonomic keys (Golubtsov et al. 1995; Habteselassie 2012). Specimens that cannot be identified with certainty in the field were preserved in a 10% formalin solution and stored in labeled jars for subsequent laboratory identification. Finally, the specimens were labeled and deposited in a 70% ethanol for long-term storage at the Jimma University Environmental Health Laboratory for further use.

### 4.4.2 Macroinvertebrate

Macroinvertebrates were collected at each sampling station using D-frame net of mesh size of 250 µm diameter (Baldwin et al. 2005). Each collection entailed a 5-minute kick sampling over a distance of 10 m (US EPA 2002). Time was allotted proportionally to the cover of different meso-habitats of the wetland such as open water and emergent vegetation. The bottom sediment was disturbed by foot during sampling in order to collect the benthic macroinvertebrates. Macroinvertebrates were sorted in the field, stored into vials containing 70% ethanol and labeled. Afterwards, macroinvertebrates were identified to family level using a stereomicroscope (10× magnification) and the identification key of Gerber & Gabriel (2002) and Bouchard (2004).

### 4.4.3 Water (physicochemical) quality

Dissolved oxygen, electric conductivity, pH and water temperature were measured in the field, at the time biological sampling, using a multi-parameter probe (HQ40d Digital Multi-Parameter, Hach). Chlorophyll a concentration was measured on site using a fluorometer (Turner Design Aquafluor). At each site 2 liter of water were collected and stored on cold box at $4^0$c until return to the Laboratory of Environmental Health at Jimma University. Total phosphorous, total nitrogen and COD were determined after digestions, while the remaining nutrients were analyzed from the filtrate. The kits used for each parameter were LCK 339 (to measure nitrate), LCK 138 (to measure total nitrogen), LCK 349 (to measure orthophosphate and total phosphorous), and LCK 614 (to measure chemical oxygen demand), following the procedures set for each parameter. Chloride concentrations of water samples were determined by the argentometric method (APHA et al. 1995).

### 4.4.4 Estimation of Habitat Disturbance Score (HDS) from catchments land uses

Habitat characteristics were assessed at each sampling station using the USEPA wetland habitat assessment protocol by visual estimate measurement technique (Baldwin et al. 2005). The degree of hydrological modifications (drainage, ditching and filling), habitat alteration (tree removal, tree plantation and grazing), land use patterns (waste dumping, clay mining, and farming) were assessed and quantified based on their intensity (Mereta et al. 2013). A score of 1 was awarded for no or minimal disturbance, 2 for moderate and 3 for high disturbance (Annex VII). The final disturbance score was then computed by summing nine disturbance types. The final disturbance score ranged from 9 to 27 and was divided into five classes: 9-11 = very low, 12-15 = low, 16-19 = moderate, 20-23 =high and 24-27 = very high. Physical variables such as sludge depth, water depth, secchi depth and ambient temperature were measured.

### 4.5 Quality control

There were maintenance, and calibration to ensure consistency and quality of field data. While in the field, the field team were possess sufficient copies of standardized field data forms and chains-of-custody for all anticipated sampling sites, as well as copies of all applicable standard operating procedures (SOPs). The standard procedure for test, identify, analyze, preservation and deposit were followed.

### 4.6 Quality assurance

For the sake of quality assurance, data were assessed carefully using standard operating procedures and identification processes were cross-checked by another expert in order to maintain the reliability of the data set.

### 4.7 Data analysis

Taxa richness, abundance, shannon diversity index (Shannon 1948), simpson diversity index (Simpson 1949) and margallef diversity index (Gamito 2010) were used to measure diversity of fish and macroinvertebrate. Family level biotic index (FBI) (Hilsenhoff 1988), SASS and ASPT (Dickens & Graham 2002) were calculated based on the sensitivity score given to each macroinvertebrate family to indicate ecological status (see annex III for detail).

The data were analyzed using ordination and regression techniques. Principal component analysis (PCA) based on the first and second components were used to determine the most important variables in showing distinction between sampling sites. On the other hand, environmental and macroinvertebrate data (twenty macroinvertebrate taxa were selected based on their frequency of occurrence) as well as environmental and fish data have been analyzed by canonical correspondence analysis (CCA) to identify influencing variables on macroinvertebrate and fish communities. The CANOCO for windows software package version 4.5 (Ter-Braak & Smilauer 2002) was used to undertake the PCA and CCA analysis. Before running CANOCO, the biological and environmental data were transformed using *square root* and *log(x+1)*, respectively except for pH.

Using a transformed data, multiple regression analysis were also performed to analyze the existence of linear relationship between biological data and the environmental variables by stepwise selection method to identify the best environmental predictors using SPSS software package version 20.

Box plots were made using SPSS software package version 20 to visualize the impact of different levels of habitat disturbance on fish and macroinvertebrate community.

### 4.8 Ethical consideration

The study was conducted after getting permission from ethical committee of Jimma University, college of public health and medical sciences.

### 4.9 Dissemination plan

The final result of this study will be presented to Jimma University public health and medical science, department of Environmental health science and technology, and Publication in national and international journals will also be considered.

# 5. RESULT

## 5.1 Physic-chemical characteristics

The values of the physic-chemical examination of samples from the different sites are shown in Table 1 and annex I. Values showed considerable variability among the sites. The water temperature ranged from 21.7 to 32.5 °C. The turbidity level was ranging from 7.3 to 119 NTU. The pH values of all water samples were from neutral to nearly strong basic (7.42–10.69). The highest value of OP was 0.24 mg/L (at Haro site H7) and the highest value of $NO_3^-$ was 1.09 mg/L which was recorded at Kito site K1.

Table 1: Summary statistics of physicochemical characteristics of water samples from natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014. Min= minimum, Max = maximum and SD = Standard deviation

| Site name | Haro | | | | Boye | | | | Kito | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N ( number of sampling sites) | 10 | | | | 4 | | | | 9 | | | |
| | Min | Max | Mean | SD | Min | Max | Mean | SD | Min | Max | Mean | SD |
| pH | 8.0 | 10.7 | 9.5 | 0.96 | 7.6 | 8.2 | 7.9 | 0.27 | 7.4 | 8.41 | 8.0 | 0.30 |
| Ambient Temperature ($^0$C) | 25.0 | 31.5 | 27.6 | 2.23 | 22.0 | 29.0 | 26.0 | 3.56 | 22.0 | 27.0 | 24.6 | 1.96 |
| Water Temperature ($^0$C) | 26.4 | 32.5 | 28.9 | 1.81 | 23.3 | 24.8 | 23.8 | 0.71 | 21.7 | 29.3 | 23.5 | 2.31 |
| DO (mg/L) | 2.5 | 13.5 | 8.4 | 3.65 | 1.1 | 5.0 | 2.5 | 1.84 | 1.1 | 8.3 | 3.1 | 2.44 |
| Oxygen Saturation (%) | 37.1 | 230.1 | 135.8 | 62.13 | 15.3 | 73.2 | 36.1 | 27.22 | 14.8 | 133.5 | 46.2 | 39.19 |
| Conductivity (µs/cm) | 16.0 | 276.0 | 176.5 | 69.40 | 115.9 | 231.0 | 149.3 | 54.76 | 72.7 | 154.1 | 127.4 | 24.42 |
| Turbidity (NTU) | 21.7 | 78.8 | 47.6 | 18.68 | 11.0 | 37.9 | 23.0 | 11.74 | 7.7 | 119.0 | 54.1 | 48.82 |
| Secchi depth (cm) | 6.0 | 20.0 | 10.9 | 4.44 | 10.0 | 23.0 | 16.0 | 6.48 | 15.0 | 65.0 | 31.9 | 17.14 |
| Chlorophyll a (µg/L) | 13.3 | 19.2 | 15.4 | 2.26 | 12.4 | 16.3 | 13.4 | 1.91 | 12.0 | 15.7 | 12.7 | 1.17 |
| COD (mg/L) | 35.4 | 124.0 | 82.6 | 35.81 | 20.8 | 46.1 | 35.7 | 10.94 | 9.7 | 73.6 | 33.3 | 23.03 |
| Chloride (mg/L) | 4.0 | 9.0 | 7.0 | 1.63 | 6.0 | 12.0 | 8.5 | 2.65 | 3.0 | 5.0 | 4.2 | 0.83 |
| NH4- (mg/L) | 0.03 | 0.1 | 0.1 | 0.03 | 0.1 | 0.2 | 0.1 | 0.06 | 0.0 | 0.3 | 0.1 | 0.09 |
| TSS (mg/L) | 58.0 | 144.0 | 89.3 | 30.66 | 59.0 | 70.0 | 65.8 | 5.32 | 33.0 | 240.0 | 102.1 | 72.85 |
| TN (mg/L) | 2.05 | 5.1 | 3.1 | 0.88 | 1.7 | 3.7 | 2.6 | 0.98 | 0.02 | 11.0 | 4.4 | 3.33 |
| TP (mg/L) | 0.2 | 0.7 | 0.4 | 0.15 | 0.2 | 0.3 | 0.3 | 0.03 | 0.2 | 0.4 | 0.3 | 0.06 |
| OP (mg/L) | 0.02 | 0.2 | 0.1 | 0.08 | 0.03 | 0.1 | 0.04 | 0.01 | 0.03 | 0.1 | 0.06 | 0.02 |
| $NO_3$- (mg/L) | 0.1 | 0.2 | 0.1 | 0.05 | 0.1 | 0.3 | 0.2 | 0.11 | 0.02 | 1.1 | 0.4 | 0.36 |
| water depth (cm) | 24.0 | 71.0 | 48.4 | 19.24 | 64.0 | 75.0 | 67.3 | 5.19 | 35.0 | 120.0 | 67.1 | 23.36 |
| sludge depth (cm) | 35.0 | 70.0 | 55.5 | 12.31 | 18.0 | 81.0 | 41.8 | 27.43 | 5.0 | 85.0 | 45.4 | 28.91 |

**Principal component analysis of environmental variables**

A PCA bi-plot showed that there was a clear distinction among sampling sites (Figure 2). Conductivity, orthophosphate, sludge depth, pH and chloride were strongly positively correlated with H6, H7, H8, H9 and H10, whereas TN, TSS, turbidity, chlorophyll a and DO were positively correlated with H3, H4, H5, and K8 sampling sites. Water depth, Nitrate-N and Ammonium-N were correlated with B1, B2, K1, K2, K3 and K5 sampling sites, whereas secchi depth solely was correlated with H1, H2, B3, B4, K4, K6, K7 and K9 sampling sites.

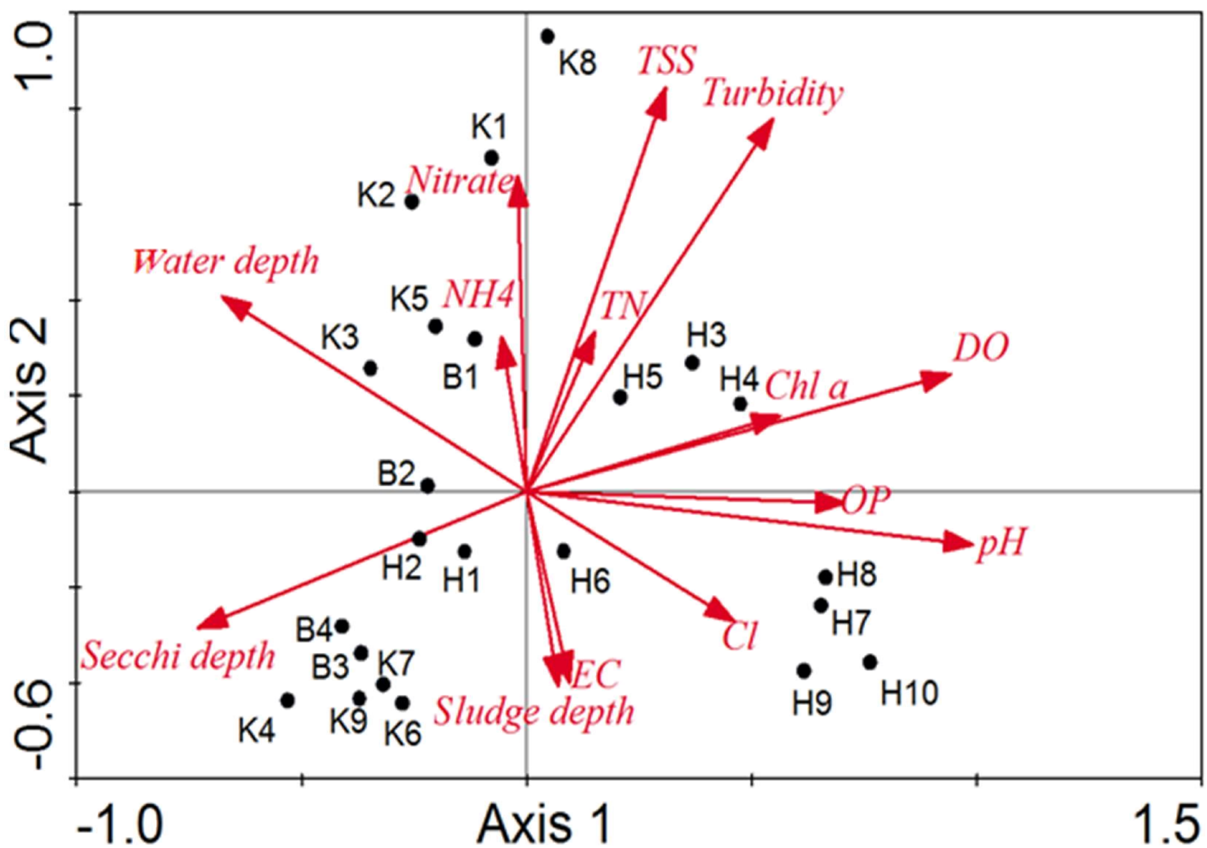


Figure 2: PCA bi-plot of environmental variables in 23 sampling sites of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014. (75.4 % variance of explained by axis 1 whereas 9.1% variance explained by axis 2)

## 5.2 Macroinvertebrate community

A total of 4,349 macroinvertebrate individuals belonging to 11 orders and 33 families were collected. The most abundant orders were Hemiptera 2478(56.98%), Coleoptera 557(12.81%), Diptera 438(10.07%), Odonata 389(8.94%) and Ephemeroptera 361(8.3%) represented by 24 families. These families were accounted more than 97% of the overall macroinvertebrate abundance (Table 2).

Table 2: Percentage of macroinvertebrates order of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014

| Site code | % Ephemeroptera | % Coleoptera | % Hemiptera | % Odonata | % Diptera | % Decapoda | % Gastropoda | % Pelecypoda | % Aranae | % Hirunae | % Trichoptra |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **H1** | 51.61 | 8.06 | 12.90 | 24.19 | 3.23 | 0 | 0 | 0 | 0 | 0 | 0 |
| **H2** | 16.67 | 13.33 | 33.33 | 30.00 | 6.67 | 0 | 0 | 0 | 0 | 0 | 0 |
| **H3** | 33.14 | 5.71 | 33.14 | 24.00 | 2.86 | 0 | 0.57 | 0.57 | 0 | 0 | 0 |
| **H4** | 42.50 | 0 | 28.75 | 17.5 | 11.25 | 0 | 0 | 0 | 0 | 0 | 0 |
| **H5** | 44.26 | 0 | 27.87 | 21.31 | 1.64 | 0 | 4.92 | 0 | 0 | 0 | 0 |
| **H6** | 4.17 | 6.71 | 69.91 | 8.33 | 7.18 | 0 | 3.47 | 0 | 0.23 | 0 | 0 |
| **H7** | 14.32 | 8.18 | 71.36 | 1.79 | 4.09 | 0 | 0.26 | 0 | 0 | 0 | 0 |
| **H8** | 2.51 | 1.96 | 78.21 | 5.03 | 10.89 | 0 | 1.40 | 0 | 0 | 0 | 0 |
| **H9** | 4.79 | 2.24 | 85.62 | 2.24 | 3.51 | 0 | 0.64 | 0.96 | 0 | 0 | 0 |
| **H10** | 2.60 | 2.92 | 92.21 | 0.32 | 0.97 | 0 | 0.32 | 0.32 | 0 | 0.32 | 0 |
| **B1** | 2.23 | 35.20 | 28.49 | 0.56 | 30.17 | 0 | 2.79 | 0 | 0 | 0.56 | 0 |
| **B2** | 0 | 28.46 | 26.02 | 0 | 45.53 | 0 | 0 | 0 | 0 | 0 | 0 |
| **B3** | 0 | 40.00 | 43.33 | 8.89 | 3.33 | 0 | 0 | 0 | 2.22 | 2.22 | 0 |
| **B4** | 0 | 78.38 | 8.11 | 3.60 | 0.90 | 0 | 5.41 | 0 | 3.60 | 0 | 0 |
| **K1** | 17.39 | 10.87 | 0 | 50.00 | 4.35 | 2.17 | 0 | 0 | 0 | 0 | 15.22 |
| **K2** | 18.37 | 31.97 | 13.61 | 29.25 | 4.76 | 0 | 0 | 1.36 | 0 | 0.68 | 0 |
| **K3** | 14.77 | 23.49 | 20.81 | 20.81 | 5.37 | 0 | 6.04 | 5.37 | 3.36 | 0 | 0 |
| **K4** | 0 | 28.47 | 11.81 | 4.17 | 50.69 | 0 | 1.39 | 1.39 | 2.08 | 0 | 0 |
| **K5** | 17.57 | 8.11 | 6.76 | 14.19 | 51.35 | 0 | 1.35 | 0 | 0.68 | 0 | 0 |
| **K6** | 0 | 30.00 | 65.45 | 0.91 | 0 | 0 | 0.91 | 0 | 0 | 2.73 | 0 |
| **K7** | 0.94 | 10.38 | 59.91 | 22.17 | 0.47 | 0 | 1.89 | 1.89 | 0 | 2.36 | 0 |
| **K8** | 0 | 1.29 | 94.84 | 3.50 | 0.37 | 0 | 0 | 0 | 0 | 0 | 0 |
| **K9** | 2.20 | 28.57 | 28.57 | 0 | 37.36 | 0 | 1.10 | 0 | 0 | 2.20 | 0 |
| **Total %** | **8.30** | **12.81** | **56.98** | **8.94** | **10.07** | **0.05** | **1.33** | **0.48** | **0.37** | **0.34** | **0.32** |

### 5.2.1 Diversity measures

Table 3 explains the different values of the diversity measures at different sampling sites. Macroinvertebrate abundance ranged from 30 (at site H2) to 543 (at site K8) animals per sample at the sites, and taxa richness at the sites ranged from 6 (at site B2) to 19 families (at site H6). The Shannon diversity index of macroinvertebrate was lowest at H9 (0.936) and H10 (0.810). But in the other sites it ranged from 1.063-2.368. The Simpson diversity index of macroinvertebrates communities were between 0.332 and 0.880. The values of Margallef diversity index of macroinvertebrate was between 1.039 –3.234. The lowest value was at site B2 while the highest value was at site H2.

Table 3: The abundance, richness and diversity indices of macroinvertebrate community of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014 (H'= Shannon H' Log base 10, H max = H max log base 10, J'= Evenness or Equitability, 1-D= Simpson diversity (1-D) and M= Margallef)

| Site code | H' | H max | J' | 1-D | M | Taxa richness | Abundance |
|---|---|---|---|---|---|---|---|
| H1 | 1.700 | 2.398 | 0.709 | 0.699 | 2.423 | 11 | 62 |
| H2 | 2.278 | 2.485 | 0.917 | 0.880 | 3.234 | 12 | 30 |
| H3 | 1.855 | 2.398 | 0.774 | 0.802 | 1.936 | 11 | 175 |
| H4 | 1.856 | 2.303 | 0.806 | 0.772 | 2.054 | 10 | 80 |
| H5 | 1.689 | 2.303 | 0.733 | 0.737 | 2.189 | 10 | 61 |
| H6 | 1.768 | 2.944 | 0.601 | 0.649 | 2.966 | 19 | 432 |
| H7 | 1.225 | 2.398 | 0.511 | 0.557 | 1.675 | 11 | 391 |
| H8 | 1.211 | 2.565 | 0.472 | 0.496 | 2.041 | 13 | 358 |
| H9 | 0.936 | 2.565 | 0.365 | 0.356 | 2.088 | 13 | 313 |
| H10 | 0.810 | 2.485 | 0.326 | 0.332 | 1.920 | 12 | 308 |
| B1 | 1.862 | 2.708 | 0.688 | 0.783 | 2.699 | 15 | 179 |
| B2 | 1.511 | 1.792 | 0.843 | 0.720 | 1.039 | 6 | 123 |
| B3 | 1.879 | 2.485 | 0.756 | 0.796 | 2.445 | 12 | 90 |
| B4 | 1.816 | 2.303 | 0.789 | 0.776 | 1.911 | 10 | 111 |
| K1 | 1.590 | 2.197 | 0.724 | 0.708 | 1.769 | 9 | 92 |
| K2 | 2.308 | 2.639 | 0.874 | 0.878 | 2.605 | 14 | 147 |
| K3 | 2.368 | 2.833 | 0.836 | 0.877 | 3.197 | 17 | 149 |
| K4 | 1.416 | 2.303 | 0.615 | 0.654 | 1.811 | 10 | 144 |
| K5 | 1.858 | 2.773 | 0.670 | 0.735 | 3.002 | 16 | 148 |
| K6 | 1.427 | 2.079 | 0.686 | 0.707 | 1.489 | 8 | 110 |
| K7 | 1.969 | 2.773 | 0.710 | 0.812 | 2.800 | 16 | 212 |
| K8 | 1.063 | 2.303 | 0.462 | 0.575 | 1.429 | 10 | 543 |
| K9 | 1.742 | 2.398 | 0.727 | 0.762 | 2.217 | 11 | 91 |

### 5.2.2. Biotic indices

**Family level biotic index**

The family level biotic index showed significant variation among the studied sites. Eight sties (H1, H5, H6, B7, H8, H9, H10 and B4) were categorized as fair water quality, ten sites (H2, H3, H4, B1, B2, K2, K4, K5, K6 and K9) categorized as fairly poor water quality and four sites (B3, K1, K3 and K7) were under poor water quality. Kito site 8 fall under very poor or sever water quality status as shown figure 3.

**South Africa Scoring System**

South African Scoring System (SASS) and Average Score per Taxa (ASPT-SASS) value of the studied sites show that all were fall under poor or largely modified status as shown figure 3.

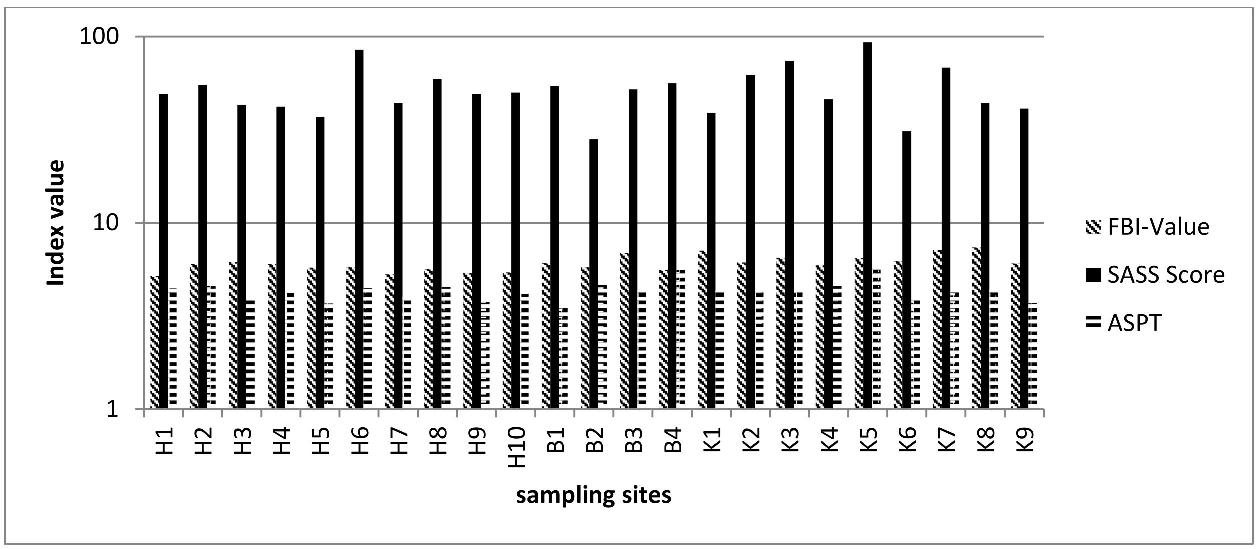


Figure 3: Family level biotic index/FBI/, South Africa Scoring System/SASS/and Average Scoring per Taxa/ASPT/ of macroinvertebrates of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014. Y-axis is in logarithmic scale

**Dominant Taxa**

The most dominant taxa in the studied sites was Corixidae (seven sites) followed by Chironomidae (Five sites), Baetidae and Dytiscidae each dominated four sites, Coenagrionidae (two sites) and the rest one site was dominated by Naucoridae.

### 5.2.3 Relationship between macroinvertebrate community and environmental predictors

The species-environment correlation coefficients of the first and second axes of the CCA bi-plot were 0.997 and 0.918 respectively. The cumulative percentage variance of species-environment relation explained by the first two axes is 48.9%. From this bi-plot, the first axis was positively correlated with the water depth (r= 0.76), habitat disturbance score (r= 0.46), and secchi depth (r= 0.51). Dissolved oxygen (r= -0.84), water temperature (r= -0.85), chlorophyll a (r= -0.46), COD (r= -0.73), Op (r= -0.63) and pH (r = -0.80) were negatively correlated with CCA axis 1. CCA axis 2 was positively correlated with dissolved oxygen (r= 0.34) and total suspended solid (r= 0.57), and negatively with secchi depth and habitat disturbance score with r= -0.33 and r= -0.34, respectively (Figure 4).

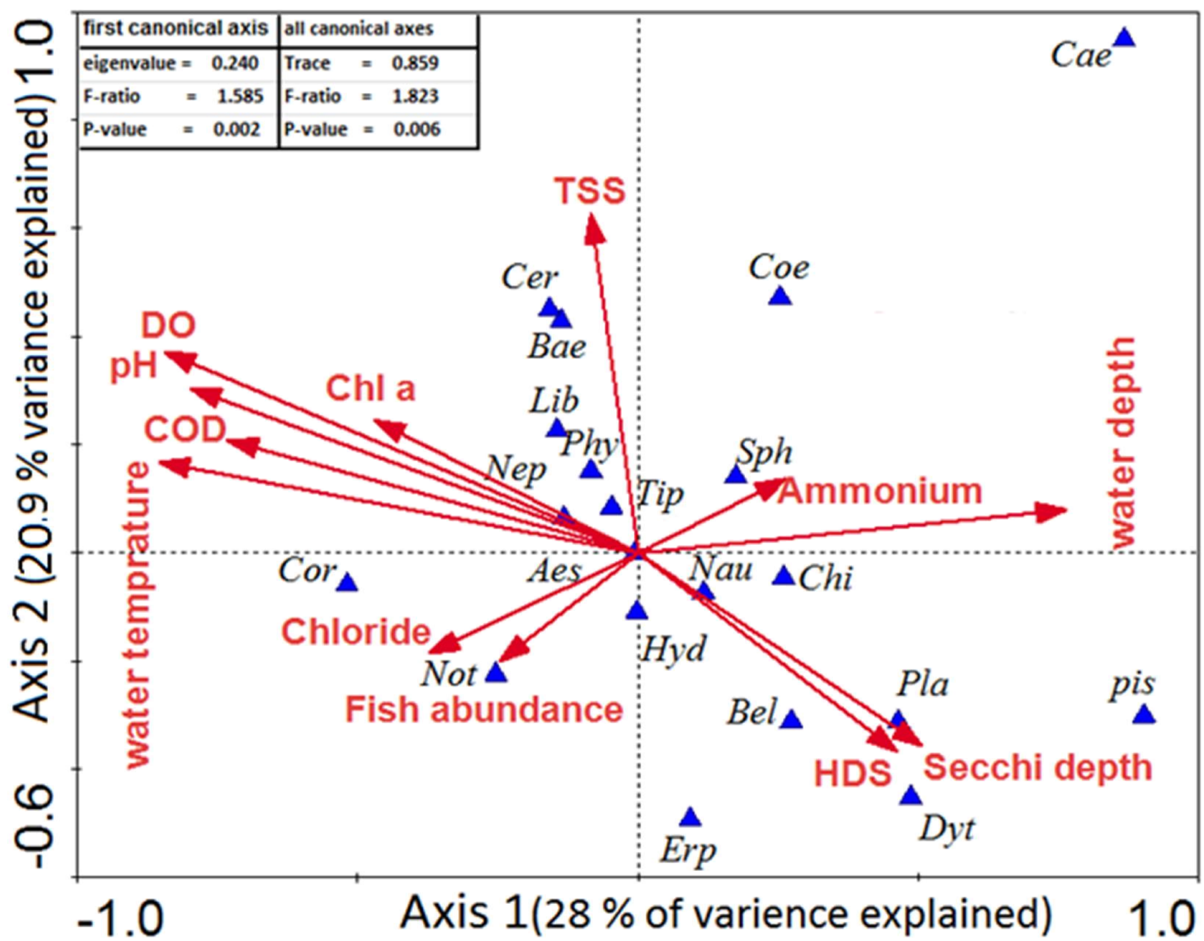


Figure 4: CCA of macroinvertebrate communities and influencing environmental variables in natural wetlands of Gilgel Gibe watershed, southwest Ethiopia, 2014. (Full name of macroinvertebrates displayed in annex III)

Multiple linear regression model between macroinvertebrate community and environmental variables showed significant variations ($p < 0.05$) by water depth and sludge depth which explained 54.6% of the variance in descriptor(Table 4 and see annex IV for detail). Predicted versus observed values of macroinvertebrate abundance is shown in Figure 5.

Table 4: Regression summary of macroinvertebrate community prediction using *log(x+1)* transformed values of environmental predictors of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014

| Model (N=23) | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| (Constant) | 1723.524 | 289.366 | | 5.956 | **.000** |
| water depth | -640.592 | 125.602 | -.794 | -5.100 | **.000** |
| sludge depth | -253.132 | 73.925 | -.533 | -3.424 | **.003** |

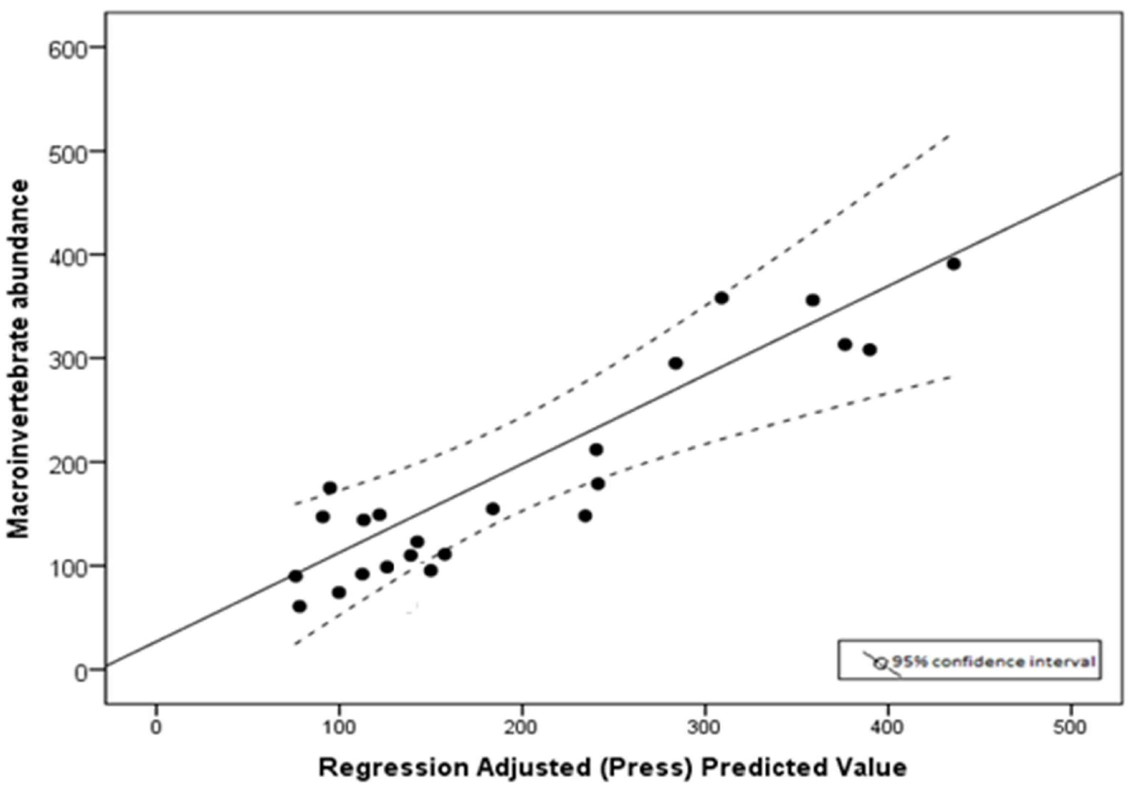


Figure 5: Predicted versus observed values of macroinvertebrate abundance using *log(x+1)* transformed values of environmental predictors of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014. Regression summary: adjusted $R^2 = 0.546$, $p < 0.000142$.

## 5.3 Fish community

### 5.3.1 Fish species composition

Five fish species were collected from the different study sites. The species collected were: *Oreochromis niloticus*, *Labeo forskalii, Garra chebera, Garra dambeensis* and *Labeobarbus intermedius* grouped under family Cichlidae and Cyprinidiae. Except *Oreochromis niloticus,* all fishes collected belong to Cyprinidiae.

A total of 760 different fish specimens were collected. *Labeo forskalii* was the second dominant species which accounts 18.16 % next to *Oreochromis niloticus* (77.5 %). *Garra dambeensis*, *Garra chebera* and *Labeobarbus intermedius* constituted 3.42, 0.79 and 0.13 %, respectively (figure 6).

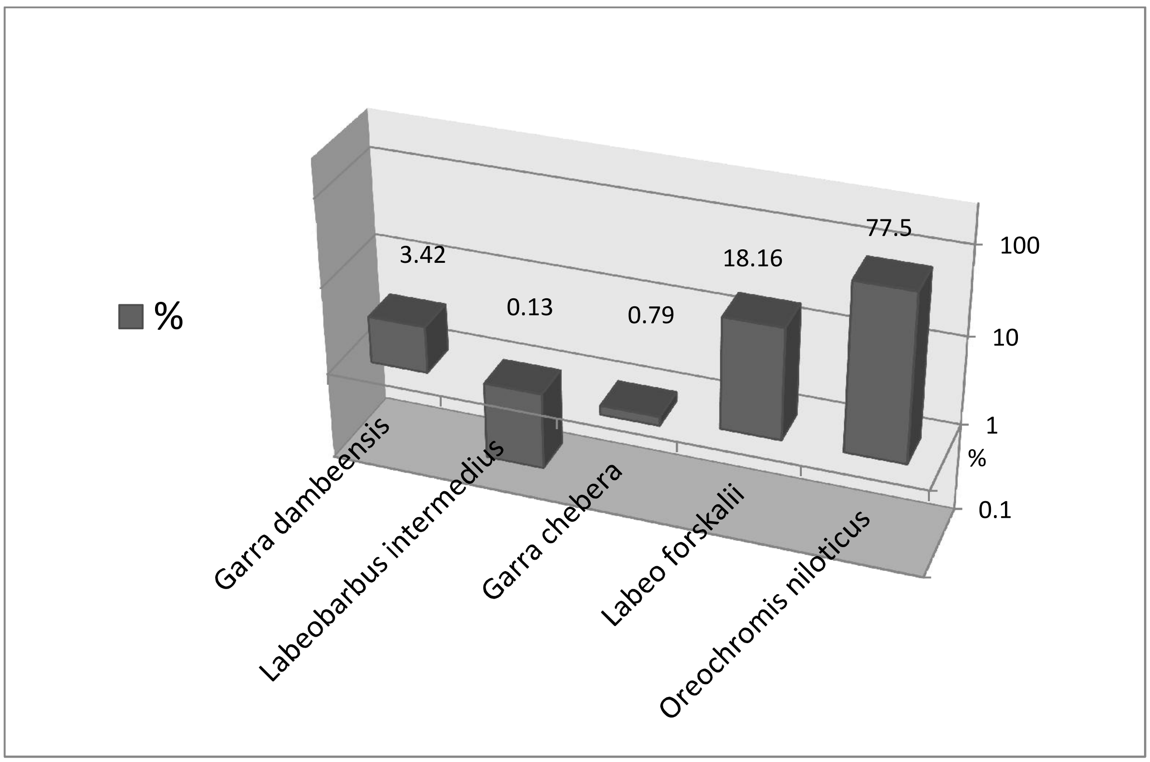


Figure 6: Fish species composition (%) of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014

### 5.3.2 Fish diversity measures

Table 5 explains the different values of the diversity measures at different sampling sites. Fish abundance ranged from 3 (at site K9) to 280 (at site K8) animals per sample at the sites, and taxa richness at the sites ranged from 1 (at sites H7, H8, B1, K2, K4, K7, K8 and K9) to 4 species (at site K3). The Shannon diversity index of fish communities was significantly low at all sites except K5 (1.094) and K3 (1.169) sites where fishes were found with better diversity. The Simpson diversity index of fish communities were between 0.0 and 0.675. The values of Margallef diversity index of fishes were between 0.0 and 0.869. The lowest value was at sites H7, H8, B1, K2, K4, K7, K8 and K9 while the highest value was at site K1.

Table 5: The abundance, richness and diversity indices of fish community in natural wetlands of Gilgel Gibe watershed, southwest Ethiopia, 2014 (H'= Shannon H' Log base 10, H max = H max Log base 10, J'= Evenness or Equitability, 1-D= Simpson diversity (1-D) and M= Margallef)

| Site name | H' | H max | J' | 1-D | M | Abundance | Taxa richness |
|---|---|---|---|---|---|---|---|
| H1 | 0.530 | 0.693 | 0.764 | 0.346 | 0.455 | 9 | 2 |
| H2 | 0.666 | 0.693 | 0.961 | 0.473 | 0.390 | 13 | 2 |
| H3 | 0.673 | 0.693 | 0.971 | 0.480 | 0.311 | 25 | 2 |
| H4 | 0.678 | 0.693 | 0.977 | 0.484 | 0.284 | 34 | 2 |
| H5 | 0.382 | 0.693 | 0.551 | 0.223 | 0.260 | 47 | 2 |
| H6 | 0.562 | 0.693 | 0.811 | 0.375 | 0.721 | 4 | 2 |
| H7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 10 | 1 |
| H8 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 5 | 1 |
| H9 | 0.176 | 0.693 | 0.254 | 0.081 | 0.260 | 47 | 2 |
| H10 | 0.673 | 0.693 | 0.971 | 0.480 | 0.621 | 5 | 2 |
| B1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 10 | 1 |
| B2 | 0.637 | 0.693 | 0.918 | 0.444 | 0.558 | 6 | 2 |
| B3 | 0.683 | 0.693 | 0.985 | 0.490 | 0.514 | 7 | 2 |
| B4 | 0.094 | 0.693 | 0.135 | 0.037 | 0.252 | 53 | 2 |
| K1 | 0.943 | 1.099 | 0.859 | 0.580 | 0.869 | 10 | 3 |
| K2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 12 | 1 |
| K3 | 1.169 | 1.386 | 0.844 | 0.675 | 0.779 | 47 | 4 |
| K4 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 8 | 1 |
| K5 | 1.094 | 1.099 | 0.996 | 0.664 | 0.542 | 40 | 3 |
| K6 | 0.069 | 0.693 | 0.099 | 0.025 | 0.230 | 78 | 2 |
| K7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 7 | 1 |
| K8 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 280 | 1 |
| K9 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 3 | 1 |

**Dominant Fish Taxa**

The most dominant taxa in the studied sites was *Oreochromis niloticus* (18 sites) followed by *Labeo forskalii* (4 sites) and the rest one site was dominated by *Garra chebera*.

### 5.3.3 Relationship between fish community and environmental predictors

The species-environment correlation coefficients of the first and second axes of the CCA bi-plot were 0.941 and 0.931 respectively. The cumulative percentage variance of species-environment relation explained by the first two axes is 73.2%. From this bi-plot, the first axis was positively correlated with the ammonium (r= 0.21) and habitat disturbance score (r= 0.25). Dissolved oxygen (r= -0.47), turbidity (r= -0.37) and pH (r= -0.21) were negatively correlated with CCA axis 1. CCA axis 2 was positively correlated with ammonium (r = 0.52), secchi depth (r = 0.46) and total nitrogen (r= 0.45), and negatively with sludge depth, pH, total phosphorous and dissolved oxygen with r = -0.48, r= -0.24, r = -0.28 and r= -0.25, respectively (Figure 7).

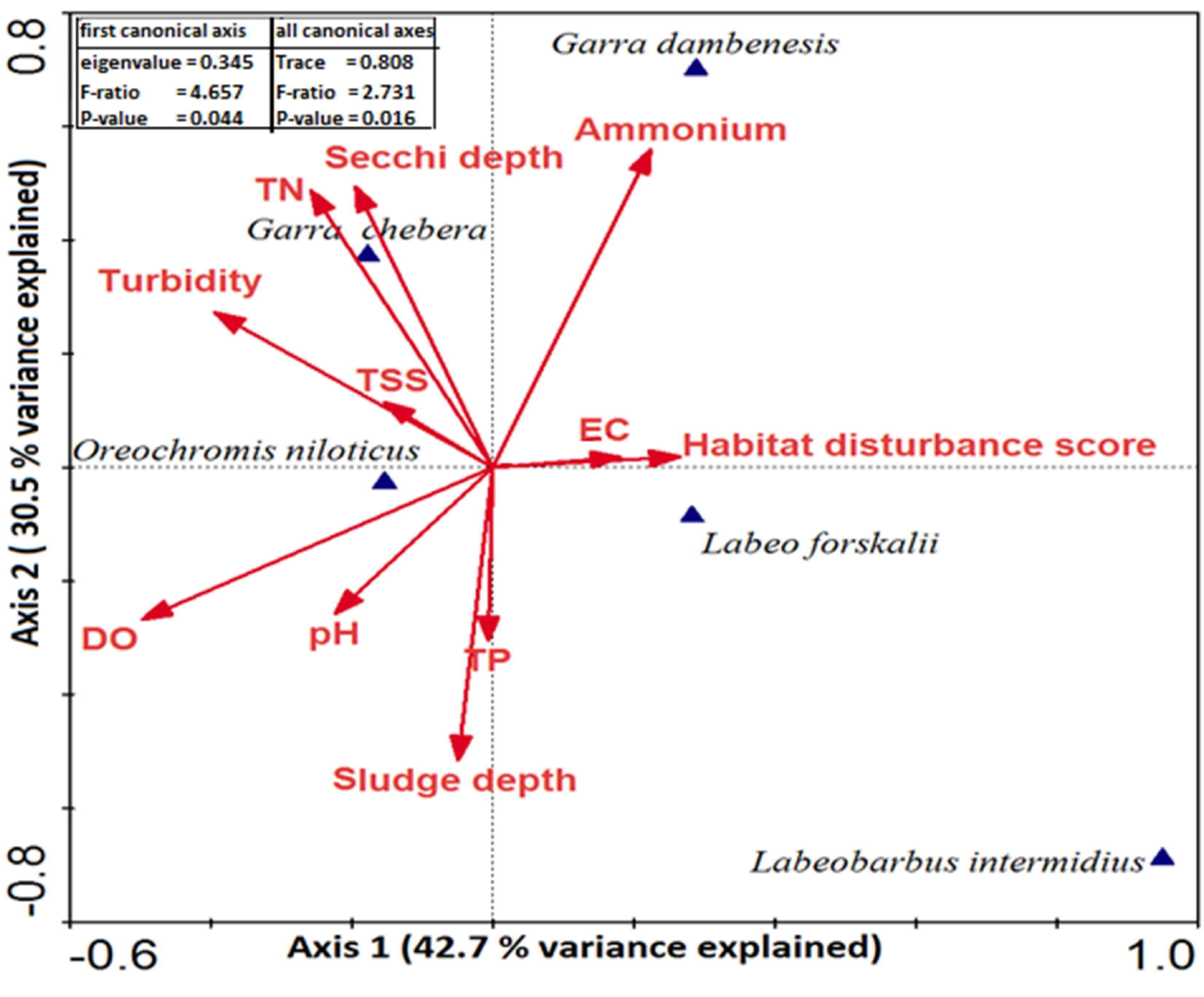


Figure 7: CCA bi-plot showing the distribution of fishes and influencing environmental variables in natural wetlands of Gilgel Gibe watershed, southwest Ethiopia, 2014.

Multiple linear regression model between fish community and environmental variables showed significant variations ($p < 0.05$) by sludge depth, ammonium and total suspended solid which explained 53.4% of the variance in descriptor (Table 6 and see annex V for detail). Predicted versus observed values of fish abundance is shown in Figure 8.

Table 6**:** Regression summary of fish community prediction using *log(x+1)* transformed values of environmental predictors of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014

| Model | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| (Constant) | 217.991 | 106.671 | | 2.044 | **.055** |
| sludge depth | -185.480 | 38.888 | -.920 | -4.770 | **.000** |
| Ammonium | -1755.342 | 455.617 | -.758 | -3.853 | **.001** |
| TSS | 102.088 | 41.366 | .369 | 2.468 | **.023** |

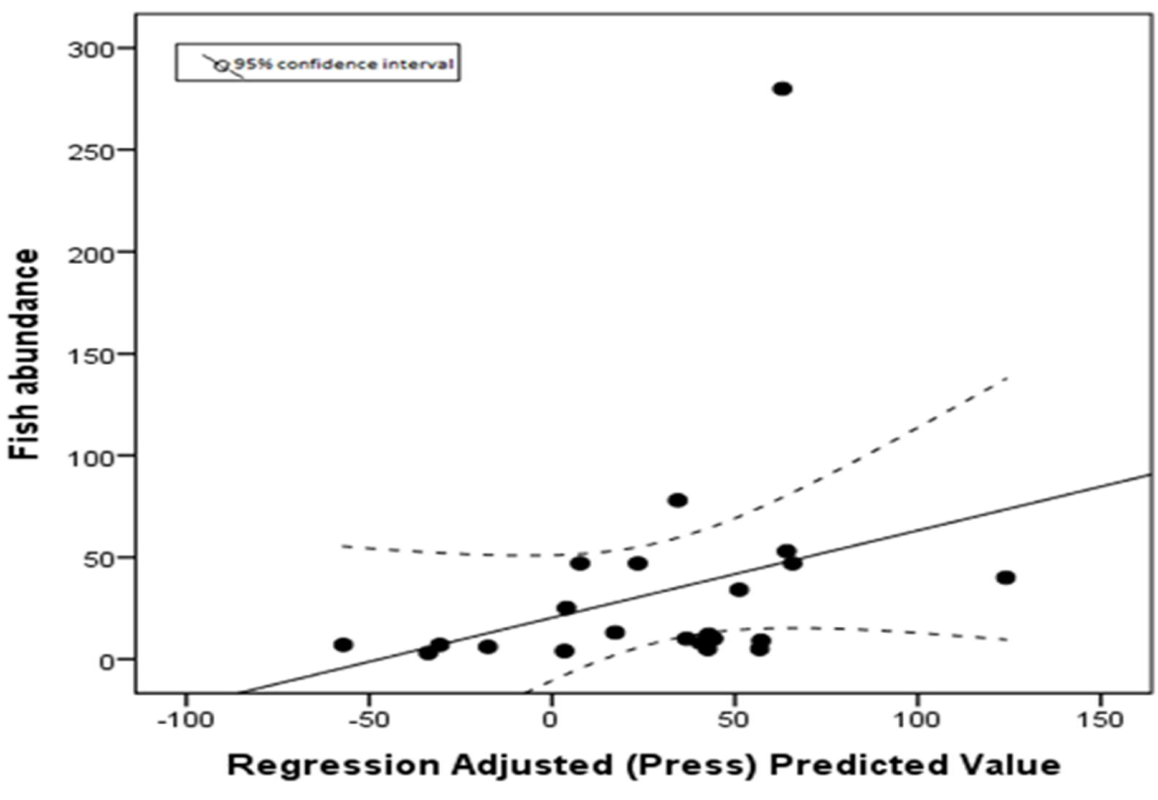


Figure 8: Predicted versus observed values of fish abundance using *log(x+1)* transformed values of environmental predictors of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014. Regression summary: adjusted $R^2 = 0.534$, $p < 0.005$.

## 5.4 Habitat quality

### 5.4.1 Habitat Disturbance Score from catchment land use

Habitat disturbance score of studied sites was fall under three habitat classes which were low (at 12 sites), moderate (at 8 sites) and the rest three sites fall under high disturbance class (Table 7).

Table 7: Habitat disturbance scores and classes of natural wetlands in the Gilgel Gibe watershed, southwest Ethiopia, 2014

| **Site code** | **Habitat Disturbance Score** | |
|---|---|---|
| | **Score** | **Class** |
| H1 | 13 | Low |
| H2 | 13 | Low |
| H3 | 16 | Moderate |
| H4 | 12 | Low |
| H5 | 12 | Low |
| H6 | 13 | Low |
| H7 | 14 | Low |
| H8 | 13 | Low |
| H9 | 13 | Low |
| H10 | 13 | Low |
| B1 | 18 | Moderate |
| B2 | 17 | Moderate |
| B3 | 16 | Moderate |
| B4 | 22 | High |
| K1 | 15 | Low |
| K2 | 18 | Moderate |
| K3 | 12 | Low |
| K4 | 12 | Low |
| K5 | 23 | High |
| K6 | 17 | Moderate |
| K7 | 19 | Moderate |
| K8 | 16 | Moderate |
| K9 | 20 | High |

Habitat disturbance score categorization criteria: 9-11 = very low, 12-15 = low, 16-19 = moderate, 20-23 =high and 24-27 = very high (Mereta et al. 2013).

### 5.4.2 Impacts of habitat disturbances on macroinvertebrates and fish assemblages

Box- and Whisker plots showed that macroinvertebrate diversity metrics were better in showing the effect of habitat variation in the study area than fish metrics (figure 9).

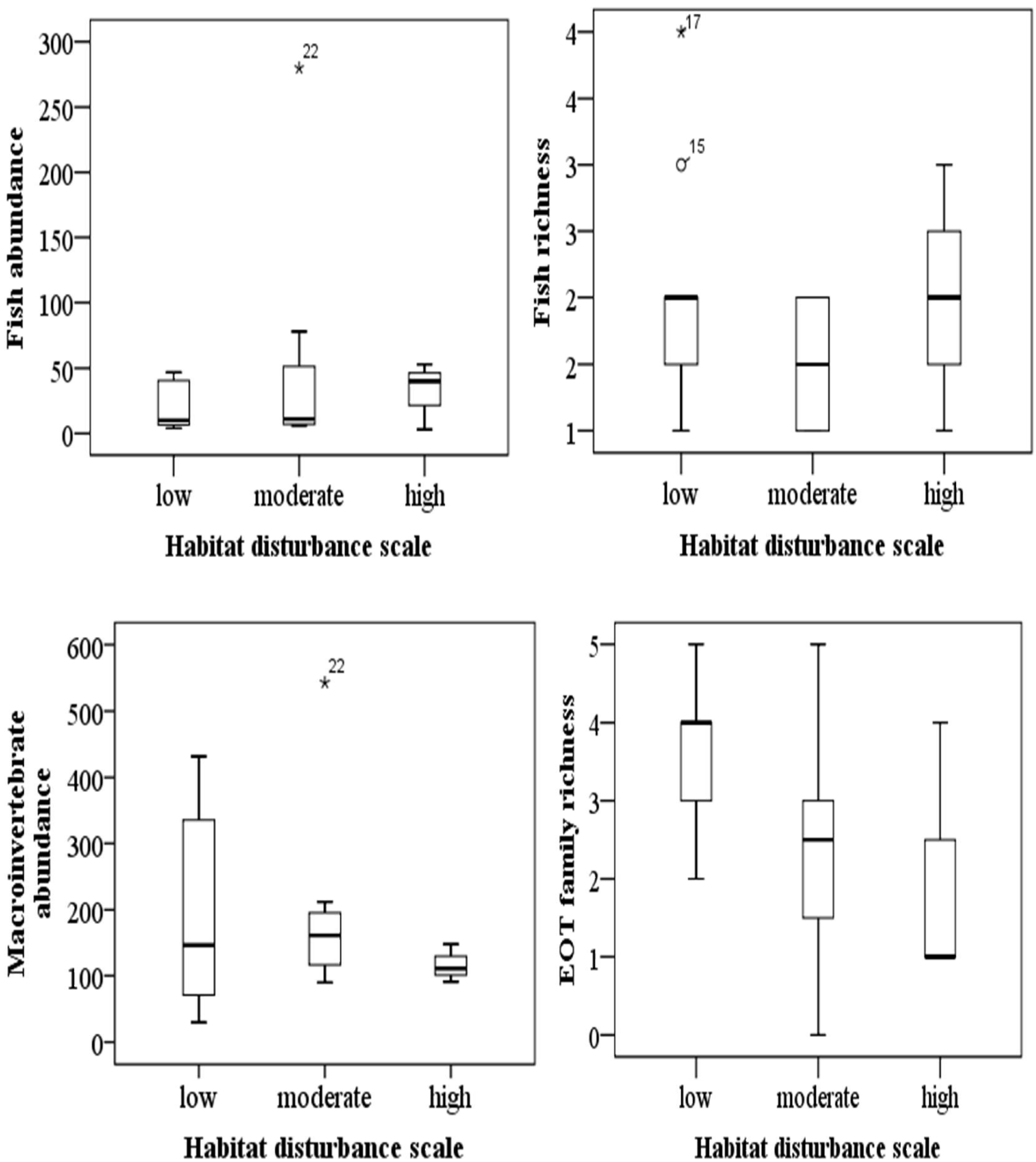


Figure 9: Box- and whisker plots of fish and macroinvertebrate metrics along habitat disturbance scale. Boxes represent interquartile ranges (25-75 % percentiles), black line between box represent median numbers and range bars show maximum and minimum values (EOT = Ephemeroptera, Odonata, and Trichoptera and, 22 = K8, 15 = K1 and 17 = K3).

## 6. DISCUSSION

The ecological status and functions of wetland ecosystems in Ethiopia are poorly studied and documented. However, the wetland ecosystem in the country provides many ecological functions which maintain and protect nature and systems which benefit people through services such as maintenance of water quality, flow and storage, flood control, nutrient retention and microclimate stabilization (Mengistu 2007). Despite their value, wetlands are very fragile ecosystems threatened by human interventions. Altering the wetland environment through waste discharge and other misuses can potentially degrade wetlands and undermine their capacity to provide services in the future (Mitsch & Gosselink 2007). In this study, Macroinvertebrate and fish diversity, habitat condition and water quality were heavily affected by anthropogenic activities, which carried out on the whole components and the surrounding area of natural wetlands in the Gilgel Gibe watershed, south west Ethiopia. The high COD, nutrient (P & N), TSS and low DO values appear to be mainly due to organic pollution from animal excrements, agricultural and sewage discharges from Jimma town and surrounding villages. Other studies conducted in Ethiopia (Getachew et al. 2012; Mereta et al. 2012; Ambelu et al. 2013) and Selected Catchments of Lake Victoria (Jones et al. 2011) also found that the main causes of water quality deterioration and biodiversity decline in wetlands were activities associated with tillage, overgrazing, clearance of vegetation and dumping of liquid and solid waste.

From the PCA results (figure 2), there was a clear distinction between sampling sites due to variation among the physic-chemical variables. The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body. In this study, pH values (Table 1) were remained within acceptable ranges of surface water standards in most sites but some sites from Haro floodplain wetland were recorded above 9 which may be caused by the photosynthesis and respiration cycles of algae in eutrophic waters and runoff from agricultural activities. When streams become excessively acidic or alkaline, the change can adversely impact the biota. As those fish and macroinvertebrates unable to tolerate the altered conditions decline, tolerant organisms increase in numbers due to a lack of competition for food and habitat. This results in an unhealthy biological community dominated by a few tolerant taxa. Elevated pH can also cause the toxicity of other pollutants. For example, above a pH of 9 (depending on temperature), ammonia becomes un-ionized and toxic to aquatic life (UNESCO/WHO/UNEP 1996).

The concentration of dissolved oxygen, phosphate, nitrogen, chloride and TSS weren't within acceptable ranges of surface water standards in most sites (Table 1). Among 23 sampling sites, DO measured at 13 sites were Low (< 5 mg/L). The reason might be the process of biodegradation of sewage in the wetland which can cause an initial rapid decline in oxygen concentration in the water resulting from microbial respiration during self-purification. However, microbial activity also leads to an increase in nutrient content. Wetlands with higher nutrients may have low DO concentration by promoting plant growth and sometimes other harmful substances are formed such as hydrogen sulphide or ionized ammonia. Phosphate also becomes available following the biological decomposition of domestic sewage and this might be the cause for high concentration of phosphate or in general nutrients measured in most sampling sites of natural wetlands in the Awetu watershed. Such changes form the basis of water quality assessments using biota as indicators of the intensity of pollution (UNESCO/WHO/UNEP 1996; US EPA 2002; Baldwin et al. 2005; Mitsch & Gosselink 2007).

Biodiversity indices like Shannon and Simpson indices were used in order to estimate the level of ecological disturbances of natural wetland in the Awetu watershed. These indices can be used in order to show relative differences from one sampling site to other sites with the same aquatic system or at the same site over the time period (Kratzer & Batzer 2007).

Shannon diversity index(Shannon 1948) is the most used metric to measure heterogeneity. As a diversity index, it expresses the average degree of uncertainty of predicting the taxon of an individual picked at random from a community. Uncertainty increases both as the number of taxa increases and as the individuals are distributed more equally among the collected taxa. Unlike the Simpson index, it is sensitive to the addition or the loss of rare taxa. The values were commonly ranges from 1.5 to 3.5, rarely exceeding 4.5. Values above 3.0 indicate that habitat structure is stable and balanced and values under 1.0 indicate the presence of pollution and degradation of habitat structure and, water quality (Kratzer & Batzer 2007). Based on these criteria, shannon diversity index of macroinvertebrate was lowest at H9 (0.936) and H10 (0.810). But in the other sites it ranged from 1.063-2.368 (Table 3). Furthermore the shannon diversity index of fish communities was significantly low at all sites except K5 (1.094) and K3 (1.169) sites where fishes were found with better diversity (Table 5) and none of the study sites exceed 1.5 and 3 index value for fish and macroinvertebrate communities respectively, indicating the presence of elevated levels of pollution and degradation of habitat structure and water quality(Walters et al. 2009).

The family biotic index calculated based on macroinvertebrate showed organic pollution level in all sites of natural wetlands. Although this biotic index was originally formulated to provide a single 'tolerance value' which is the average of the tolerance values of all species within the benthic arthropod community (Hilsenhoff 1988), these results showed that the index responded well to loading of organic pollutants. The FBI score is increasing with increasing perturbation. These results occurred because the more intolerant genera and species in each family predominate in clean streams, whereas the more tolerant genera and species predominate in polluted streams (Barbour et al.1999). On the basis of these criteria, all sites macroinvertebrate family scored high family biotic index value (Figure 3) and all the sites were severely deteriorated by anthropogenic activities.

SASS is a biomonitoring system adapting from South Africa River to give an indication of water quality. This done by looking at the macroinvertebrates present in the system adding a value derived from the species tolerance to pollution, with the most sensitive species having high score while the most tolerant providing low score (Dickens & Graham 2002). Based on this criteria, most of macroinvertebrate species were most tolerance and having low scoring value and it indicated that all sites water quality were severely deteriorated by anthropogenic activities since all sites were categorized under category D bellow <79 scoring value as shown from Figure 3.

The CCA bi-plot of environmental variables and macroinvertebrates showed clear relationship between macroinvertebrate community and environmental variables. From this bi-plot, the first axis was correlated with the water depth, habitat disturbance score, dissolved oxygen, water temperature and pH. CCA axis 2 was more correlated with total suspended solid and secchi depth (Figure 4). On the other hand, tolerant macroinvertebrate communities like Chironomidae, Dytiscidae, Naucoridae and Belostomatidae positively correlated with high disturbance score and negatively correlated with fish abundance since they are food source for juvenile tilapia fishes. Similarly a linear relationship was found between environmental variables and macroinvertebrate abundance. Macroinvertebrate communities showed significant variations ($p < 0.05$) by water depth and sludge depth which explained 54.6% of the variance in descriptor (Table 4 and see annex IV for detail).

Water depth was the principal factor influencing the occurrence and abundance of macroinvertebrate communities of natural wetlands in the Gilgel Gibe watershed because of its role in influencing water temperatures and dissolved oxygen levels and which is in agreement with study conducted in Canada (LSRCA 2006). Besides which might be an indication of the loss of water component of natural wetlands and changing into a grazing field due to pollution from animal excrements, agricultural and wastewater directly discharged from Jimma town and surrounding villages (Ambelu 2009; Mereta et al. 2012; Ambelu et al. 2013). The most abundant orders were Hemiptera, Coleoptera, Diptera, Odonata and Ephemeroptera represented by 24 families (Table 2). These families were accounted more than 97% of the overall samples, all of them belonging to families called generalists. This group uses a variety of food resources, including detritus, plants, epiphytic algae and other organisms (Barbour et al. 1999) and is able to resist disturbance when food resources change. Thus, sludge depth was the second predictor variable which influences macroinvertebrate community. Similar scenario were notified in Spain where macroinvertebrate assemblages showed significantly nested patterns, with those in sediment rich locations consisting of a subset of those in locations with little fine sediment (Buendia et al. 2013).

The CCA bi-plot of environmental variables and fishes showed also a clear relationship between fish community and environmental variables. From this bi-plot, the first axis was correlated with the ammonium, dissolved oxygen habitat disturbance score, turbidity and pH. CCA axis 2 was more correlated with ammonium, secchi depth and sludge depth (Figure 7). On the other hand, *Oreochromis niloticus* was strongly correlated with DO, pH and sludge depth whereas *Garra dambeensis* strongly correlated with Ammonium. *Garra chebera* was more correlated with turbidity, TSS, secchi depth and total nitrogen whereas *Labeo forskalii* and *Labeobarbus intermedius* were slightly correlated with conductivity, total phosphorous and habitat disturbance score. Multiple linear regression model between fish community and environmental variables showed significant variations ($p < 0.05$) by sludge depth, ammonium and total suspended solids which explained 53.4 % of the variance in descriptor (Table 6 and see annex V for detail).

Sludge depth, ammonium and total suspended solids were the most important environmental variables determining the presence or absence of fish taxa. These variables were selected predictor in regression model and also correlated with the axes that explain the largest amount of variation in CCA analysis. Sediment provides spawning habitat, refuge from predators, and locations to search for food, among other benefits, therefore insufficient sediment may impact biota. However excess sediment (both Suspended sediments and deposited sediments) becomes a concern for water quality and biota when the natural cycle of sedimentation is altered, either by increasing or decreasing natural levels (Jones et al. 2012). While agricultural practices, such as raising livestock and row-crop cultivation, are the largest contributor of sediments, forestry and mining are also sources. Other anthropogenic activities, including dredging, hydrologic and hydraulic alterations, and urban development, also alter natural sedimentation and deposition cycles (Wilber & Clarke 2001).

Sediment can cause physical and chemical problems for the biological integrity of water bodies. Physically, suspended sediment increases turbidity and limits UV penetration. In great excess, bed load sediment can smother the stream bed and alter channel morphology by reducing stream depth or eliminating heterogeneous habitats (Walser & Bart 2006). Sediment with large quantities of organic matter can deplete oxygen levels through decay (Jones et al. 2012). Besides sludge depth (deposited sediment) and total suspended solid (suspended sediment), Ammonium ($NH4^+$-N) was an important parameter affecting the composition of fish community since the measured concentration values in present study were generally above the maximum allowable range for fish and aquatic life (0.005-0.025 mg/L) (UNESCO/WHO/UNEP 1996).

The natural wetlands in the Gilgel Gibe watershed are composed of three habitat classes which were low (at 12 sites), moderate (at 8 sites) and the rest three sites fall under high disturbance class (Table 7). Hydrological modifications (drainage, ditching and filling), habitat alteration (tree removal, tree plantation and grazing) and land use patterns (waste dumping, clay mining, and farming) were some of the causes of habitat deterioration in the natural wetlands (Mereta et al. 2012; Ambelu et al. 2013; Mereta et al. 2013). In this study, Box- and Whisker plots showed that macroinvertebrate diversity metrics were better in showing the effect of habitat variation in the study area than fish metrics (figure 9). This could be due to variation in morphological, behavioral, and physiological response of communities to environment. For instance, fish are capable of mobility, behavioral response to reduced dissolved oxygen (Ekau et al. 2010) and elevated water temperature (Dallas 2008). Besides, most of the sites (at 18 sites) were dominated by *Oreochromis niloticus* (Nile Tilapia) which is a tropical species predominantly cultured worldwide. In Ethiopia, the species contributed more than 60% of the annual total fish landing and it is the most preferred variety (Dejen & Mintesnot 2012). According to FAO 2009(cited by (Dejen & Mintesnot 2012)), *Oreochromis niloticus* prefers to live in shallow water and its lower and upper lethal temperatures are 11-12 $^{o}$C and 42 $^{o}$C, respectively. *Oreochromis niloticus* an herbivorous fish feeding on phytoplankton and detritus of plant origin. On the other hand, juveniles are omnivores and feed on a mixture of algae, zooplankton and insects. All those things favor this species to be the abundant and dominant among the collected fishes throughout sampling sites (neglecting HDS variation) of natural wetlands in the Gilgel Gibe watershed. Besides, the absence of predator *Clarias gariepinus*(catfish) might be the reason for better representation in the studied wetlands (Tadesse 2011).

# 7. CONCLUSION AND RECOMMENDATION

## 7.1 Conclusions

In conclusion, it is appropriate to recall general research question of this study about what are the environmental factors influencing fish and macroinvertebrate assemblage integrity of natural wetlands in the Gilgel Gibe watershed. The results analyzed using both ordination diagrams and multiple linear regression models clearly indicated that environmental factors such as concentration of DO, TSS, ammonium, chloride, turbidity, water temperature, secchi depth, conductivity, water depth, sludge depth and pH influence the structure of wetland fish and macroinvertebrate communities. Furthermore, Macroinvertebrate descriptor was best predicted ($R^2 = 0.546$) by water depth and sludge depth whereas fish descriptor was best predicted ($R^2 = 0.534$) by sludge depth, ammonium-N and total suspended solid. These variables provided clear interpretations of water quality and habitat deterioration of natural wetlands in the Gilgel Gibe watershed due to human impacts.

Furthermore, habitat changes better explain by macroinvertebrate metrics than fishes and primary sources of wetland impairment may be missed by using a single assemblage indicator. While combining multiple assemblages into a single index has been recommended (Walters et al. 2009), the finding of the present study argue that sampling multiple assemblages and separately examining causal pathways will lead to a better understanding of the multiple mechanisms by which environmental impacts wetland ecosystems. The suite of stressors will, in combination, provide the best indicators of disturbance and, in turn, the most comprehensive management recommendations.

## 7.2 Recommendations

Since the natural wetlands in the Gilgel Gibe watershed is located in Omo-Gibe river basin and a main source of surface water and ground water recharge, hence they serve as a water source for the surrounding vegetation, the environmental changes due to the direct and indirect effects of agricultural land use, liquid and solid waste disposal, cattle-raising, and other anthropogenic pressures may have local and regional impacts (Yimer & Mengistou 2010; Mekonnen & Aticho 2011; Mereta et al. 2012; Ambelu et al. 2013). Therefore, based on the study findings the following recommendations are forwarded:

- The finding of this study can complement the previous studies on wetlands and surrounding watersheds to prepare a complete monitoring tools and metrics which can give results to make informed decisions for management and restoration of wetland ecosystem.

- Further longitudinal studies:

    1. covering both wet and dry seasons are recommended to examine the environmental influence on macroinvertebrate and fish communities
    2. Also on the ecological significance of morphometric measurements and meristic counts difference among fishes are recommended.

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## Annexes

I: Physicochemical parameters of water samples from 23 sampling sites of natural wetlands of Gilgel Gibe watershed, southwest Ethiopia, 2014

| Site name | pH | Amb T($^0$c) | Water T($^0$c) | DO (mg/L) | DO Sat(%) | EC (µs/cm) | Turbidity (NTU) | Secchi Depth (cm) | Chl_a (µg/L) | COD (mg/L) | Cl (mg/L) | $NH_4$ (mg/L) | TSS (mg/L) | TN (mg/L) | TP (mg/L) | OP (mg/L) | $NO_3^-$ (mg/L) | water depth (cm) | sludge depth (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H1 | 8.22 | 26 | 29.1 | 3.99 | 63.5 | 141.7 | 21.7 | 20 | 13.3 | 35.4 | 4 | 0.028 | 58 | 2.54 | 0.238 | 0.03 | 0.064 | 60 | 57 |
| H2 | 7.97 | 25 | 26.4 | 2.45 | 37.1 | 149 | 22.2 | 16 | 13.51 | 39.1 | 5 | 0.071 | 62 | 3.44 | 0.236 | 0.02 | 0.113 | 67 | 61 |
| H3 | 9.56 | 25 | 26.5 | 8.35 | 126.9 | 16 | 58.1 | 7 | 18.78 | 54.7 | 9 | 0.137 | 110 | 2.05 | 0.491 | 0.12 | 0.108 | 69 | 54 |
| H4 | 9.76 | 28 | 28.3 | 8.89 | 139.6 | 167.3 | 78.8 | 6 | 17.61 | 110 | 6 | 0.098 | 144 | 3.88 | 0.676 | 0.1 | 0.113 | 58 | 51 |
| H5 | 9 | 26 | 28.3 | 6.74 | 105.8 | 167.9 | 60.6 | 10 | 19.16 | 95.9 | 7 | 0.103 | 136 | 2.96 | 0.603 | 0.23 | 0.12 | 71 | 63 |
| H6 | 8.74 | 31.5 | 29.5 | 5.8 | 93.1 | 276 | 28.4 | 9.5 | 13.43 | 41.9 | 7 | 0.095 | 86 | 2.68 | 0.255 | 0.05 | 0.093 | 50 | 70 |
| H7 | 10.37 | 28 | 29.3 | 11.58 | 185.7 | 203.7 | 53.1 | 12 | 14.18 | 97.1 | 8 | 0.125 | 82 | 3.37 | 0.432 | 0.24 | 0.213 | 25 | 35 |
| H8 | 10.31 | 29 | 30.7 | 11.57 | 195.3 | 232.5 | 60 | 6 | 14.5 | 124 | 8 | 0.041 | 81 | 5.1 | 0.339 | 0.12 | 0.22 | 30 | 60 |
| H9 | 10.24 | 27 | 28.6 | 11.4 | 180.9 | 206.9 | 43.7 | 10.5 | 14.83 | 105 | 9 | 0.073 | 69 | 3.03 | 0.358 | 0.08 | 0.195 | 24 | 69 |
| H10 | 10.69 | 30.5 | 32.5 | 13.51 | 230.1 | 204 | 49.4 | 12 | 14.44 | 123 | 7 | 0.103 | 65 | 2.36 | 0.43 | 0.14 | 0.158 | 30 | 35 |
| B1 | 8.15 | 29 | 24.8 | 4.97 | 73.2 | 115.9 | 37.9 | 11 | 12.43 | 41 | 7 | 0.187 | 70 | 3.67 | 0.223 | 0.05 | 0.333 | 65 | 18 |
| B2 | 8.08 | 29 | 23.9 | 2.74 | 39.7 | 120.6 | 26.1 | 20 | 12.44 | 20.8 | 9 | 0.201 | 64 | 3.11 | 0.271 | 0.04 | 0.259 | 75 | 30 |
| B3 | 7.75 | 24 | 23.3 | 1.07 | 15.3 | 129.8 | 16.9 | 23 | 12.55 | 46.1 | 6 | 0.125 | 59 | 1.68 | 0.301 | 0.03 | 0.118 | 64 | 81 |
| B4 | 7.57 | 22 | 23.3 | 1.12 | 16.1 | 231 | 10.97 | 10 | 16.29 | 34.7 | 12 | 0.066 | 70 | 1.81 | 0.238 | 0.04 | 0.122 | 65 | 38 |
| K1 | 8.17 | 25 | 23.7 | 5.9 | 85.5 | 134.4 | 115 | 16 | 12.19 | 33.3 | 4 | 0.132 | 240 | 3.06 | 0.277 | 0.04 | 1.09 | 63 | 62 |
| K2 | 7.75 | 26 | 22 | 3.46 | 49.4 | 112.6 | 116 | 17 | 12.7 | 25.7 | 3 | 0.07 | 157 | 2.2 | 0.292 | 0.05 | 0.598 | 60 | 80 |
| K3 | 7.76 | 24 | 21.7 | 2.03 | 28.2 | 137.2 | 49.5 | 26 | 12.16 | 13.5 | 4 | 0.099 | 66 | 5.09 | 0.236 | 0.04 | 0.14 | 83 | 27 |
| K4 | 7.42 | 22 | 21.9 | 1.06 | 14.8 | 136.7 | 11.23 | 65 | 12.15 | 18.5 | 5 | 0.036 | 44 | 1.83 | 0.407 | 0.03 | 0.021 | 65 | 55 |
| K5 | 8.22 | 25.2 | 23.6 | 1.85 | 26.6 | 151.2 | 37.7 | 26 | 12.02 | 31.1 | 4 | 0.298 | 105 | 5.94 | 0.234 | 0.04 | 0.15 | 120 | 5 |
| K6 | 8.11 | 22.9 | 23.6 | 2.36 | 34 | 154.1 | 13.91 | 35 | 11.98 | 9.7 | 5 | 0.003 | 33 | 3.05 | 0.255 | 0.04 | 0.082 | 60 | 55 |
| K7 | 7.8 | 22 | 22.6 | 1.97 | 27.8 | 127.4 | 7.73 | 35 | 12.83 | 73.6 | 3 | 0.089 | 57 | 11 | 0.219 | 0.09 | 0.419 | 35 | 85 |
| K8 | 8.41 | 27 | 29.3 | 8.34 | 133.5 | 72.7 | 119 | 15 | 15.67 | 69.6 | 5 | 0.106 | 175 | 7.25 | 0.209 | 0.09 | 0.664 | 55 | 10 |
| K9 | 7.89 | 27 | 23.5 | 1.24 | 15.7 | 120.5 | 16.36 | 52 | 12.19 | 24.8 | 5 | 0.19 | 42 | 0.015 | 0.255 | 0.08 | 0.149 | 63 | 30 |

**II:** Overview of the identified macroinvertebrate taxa as well as their frequency of occurrence in all 23 samples

| Order | Family | family code | frequency of occurrence | Frequency of occurrence (%) |
|---|---|---|---|---|
| **EPHEMEROPTERA** | Baetidae | Bae | 17 | 73.91 |
| | Caenidae | Cae | 5 | 21.74 |
| **COLEOPTERA** | Dytiscidae | Dyt | 15 | 65.22 |
| | Elmidae | Elm | 2 | 8.70 |
| | Gyrinidae | Gyr | 3 | 13.04 |
| | Helodidae | Hel | 2 | 8.70 |
| | Hydraenidae | Hyd | 4 | 17.39 |
| | Hydrophilidae | Hyd | 16 | 69.57 |
| **HEMIPTERA** | Belostomatidae | Bel | 13 | 56.52 |
| | Corixidae | Cor | 19 | 82.61 |
| | Gerridae | Ger | 2 | 8.70 |
| | Hydrometridae | Hyd | 1 | 4.35 |
| | Nepidae | Nep | 8 | 34.78 |
| | Naucoridae | Nau | 20 | 86.96 |
| | Notonectidae | Not | 19 | 82.61 |
| | Pleidae | Ple | 3 | 13.04 |
| **ODONATA** | Aeshindae | Aes | 11 | 47.83 |
| | Libellulidae | Lib | 16 | 69.57 |
| | Coenagrionidae | Coe | 18 | 78.26 |
| **DIPTERA** | Ceratopogonidae | Cer | 7 | 30.43 |
| | Chironomidae | Chi | 21 | 91.30 |
| | Culicidae | Cul | 4 | 17.39 |
| | Tipulidae | Tip | 5 | 21.74 |
| | Stratiomyidae | Str | 1 | 4.35 |
| **DECAPODA** | Potamonautidae | Pot | 1 | 4.35 |
| **GASTROPODA** | Lymnaeidae | Lym | 3 | 13.04 |
| | Physidae | Phy | 11 | 47.83 |
| | Planorbidae | Pla | 6 | 26.09 |
| **PELECYPODA** | Sphaeriidae | Sph | 7 | 30.43 |
| **ARANAE** | Pisauridae | Pis | 6 | 26.09 |
| **HIRUNAE** | Erpobdellidae | Erp | 7 | 30.43 |
| | Heamopidae | Hea | 2 | 8.70 |
| **TRICHOPTERA** | Hydropsychidae | Hyd | 1 | 4.35 |

### III: Biotic indices

#### Family level biotic index

Family level biotic index (Hilsenhoff's) index was calculated based on the scores given to each taxon

Family level biotic index scoring value

| S/N | Order | Family | Score | Reference |
|---|---|---|---|---|
| 1 | **EPHEMEROPTERA** | Baetidae | 4 | Barbour et al,1999 |
| | | Caenidae | 7 | Barbour et al,1999 |
| 2 | **COLEOPTERA** | Dytiscidae | 5 | Barbour et al,1999 |
| | | Elmidae | 4 | Barbour et al,1999 |
| | | Gyrinidae | 5 | Barbour et al,1999 |
| | | Helodidae | 5 | Barbour et al,1999 |
| | | Hydraenidae | 5 | Barbour et al,1999 |
| | | Hydrophilidae | 5 | Barbour et al,1999 |
| 3 | **HEMIPTERA** | Belostomatidae | 10 | Barbour et al,1999 |
| | | Corixidae | 5 | Barbour et al,1999 |
| | | Gerridae | 5 | Barbour et al,1999 |
| | | Hydrometridae | 5 | Barbour et al,1999 |
| | | Nepidae | 8 | Barbour et al,1999 |
| | | Naucoridae | 5 | Barbour et al,1999 |
| | | Notonectidae | 10 | Barbour et al,1999 |
| | | Pleidae | 5 | Barbour et al,1999 |
| 4 | **ODONATA** | Aeshindae | 3 | Barbour et al,1999 |
| | | Libellulidae | 9 | Barbour et al,1999 |
| | | Coenagrionidae | 9 | Barbour et al,1999 |
| 5 | **DIPTERA** | Ceratopogonidae | 6 | Barbour et al,1999 |
| | | Chironomidae | 6 | Barbour et al,1999 |
| | | Culicidae | 8 | Barbour et al,1999 |
| | | Tipulidae | 3 | Barbour et al,1999 |
| | | Stratiomyidae | 8 | Barbour et al,1999 |
| 6 | **DECAPODA** | Potamonautidae | 8 | Barbour et al,1999 |
| 7 | **GASTROPODA** | Lymnaeidae | 6 | Barbour et al,1999 |
| | | Physidae | 8 | Barbour et al,1999 |
| | | Planorbidae | 7 | Barbour et al,1999 |
| 8 | **PELECYPODA** | Sphaeriidae | 8 | Barbour et al,1999 |
| 9 | **ARANAE** | Pisauridae | 8 | Barbour et al,1999 |
| 10 | **HIRUNAE** | Erpobdellidae | 8 | Barbour et al,1999 |
| | | Heamopidae | 10 | Barbour et al,1999 |
| 11 | **TRICHOPTERA** | Hydropsychidae | 4 | Barbour et al,1999 |

**Evaluation of water quality using the family-level biotic index** (Hilsenhoff 1988)

| 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 | substantial pollution likely |
| **5.76-6.50** | Poor | substantial pollution likely |
| **7.26-10.00** | Very poor | Severe organic pollution likely |

**Evaluation of water quality using South Africa Scoring System/SASS/** (Dickens & Graham 2002)

| SASS | ASPT | ecological category | category name | Description |
|---|---|---|---|---|
| **137-166** | 8.2-9 | A | Natural | unmodified natural |
| **108-137** | 7.4-8.2 | B | Good | natural with few modification |
| **79-108** | 6.6-8.2 | C | Fair | moderately modified |
| **<79** | <6.6 | D | Poor | largely modified |

South African Scoring System (SASS) index was calculated based on the scores given to each taxon

South Africa Scoring System value

| S/N | Order | Family | Score | Reference |
|---|---|---|---|---|
| 1 | **EPHEMEROPTERA** | Baetidae | 4 | Dickens & Graham, 2002 |
| | | Caenidae | 6 | Dickens & Graham, 2002 |
| 2 | **COLEOPTERA** | Dytiscidae | 5 | Dickens & Graham, 2002 |
| | | Elmidae | 8 | Dickens & Graham, 2002 |
| | | Gyrinidae | 5 | Dickens & Graham, 2002 |
| | | Helodidae | 12 | Dickens & Graham, 2002 |
| | | Hydraenidae | 8 | Dickens & Graham, 2002 |
| | | Hydrophilidae | 5 | Dickens & Graham, 2002 |
| 3 | **HEMIPTERA** | Belostomatidae | 3 | Dickens & Graham, 2002 |
| | | Corixidae | 3 | Dickens & Graham, 2002 |
| | | Gerridae | 5 | Dickens & Graham, 2002 |
| | | Hydrometridae | 6 | Dickens & Graham, 2002 |
| | | Nepidae | 3 | Dickens & Graham, 2002 |
| | | Naucoridae | 7 | Dickens & Graham, 2002 |
| | | Notonectidae | 3 | Dickens & Graham, 2002 |
| | | Pleidae | 4 | Dickens & Graham, 2002 |
| 4 | **ODONATA** | Aeshindae | 8 | Dickens & Graham, 2002 |
| | | Libellulidae | 4 | Dickens & Graham, 2002 |
| | | Coenagrionidae | 4 | Dickens & Graham, 2002 |
| 5 | **DIPTERA** | Ceratopogonidae | 5 | Dickens & Graham, 2002 |
| | | Chironomidae | 2 | Dickens & Graham, 2002 |
| | | Culicidae | 1 | Dickens & Graham, 2002 |
| | | Tipulidae | 5 | Dickens & Graham, 2002 |
| | | Stratiomyidae | 2 | Dickens & Graham, 2002 |
| 6 | **DECAPODA** | Potamonautidae | 3 | Dickens & Graham, 2002 |
| 7 | **GASTROPODA** | Lymnaeidae | 3 | Dickens & Graham, 2002 |
| | | Physidae | 3 | Dickens & Graham, 2002 |
| | | Planorbidae | 3 | Dickens & Graham, 2002 |
| 8 | **PELECYPODA** | Sphaeriidae | 3 | Dickens & Graham, 2002 |
| 9 | **ARANAE** | Pisauridae | 8 | Dickens & Graham, 2002 |
| 10 | **HIRUNAE** | Erpobdellidae | 8 | Dickens & Graham, 2002 |
| | | Heamopidae | 3 | Dickens & Graham, 2002 |
| 11 | **TRICHOPTERA** | Hydropsychidae | 6 | Dickens & Graham, 2002 |

**IV**: Regression summary of macroinvertebrate prediction using *log(x+1)* transformed values of environmental predictors of natural wetlands of Gilgel Gibe watershed, southwest Ethiopia, 2014

**Model Summary**[c]

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .588[a] | .346 | .315 | 112.49675 |
| 2 | .767[b] | .588 | .546 | 91.52712 |

a. Predictors: (Constant), water depth

b. Predictors: (Constant), water depth, sludge depth

c. Dependent Variable: Macroinvertebrate abundance

**ANOVA**[a]

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 140565.917 | 1 | 140565.917 | 11.107 | .003[b] |
| | Residual | 265765.909 | 21 | 12655.519 | | |
| | Total | 406331.826 | 22 | | | |
| 2 | Regression | 238787.556 | 2 | 119393.778 | 14.252 | .000[c] |
| | Residual | 167544.270 | 20 | 8377.213 | | |
| | Total | 406331.826 | 22 | | | |

a. Dependent Variable: Macroinvertebrate abundance

b. Predictors: (Constant), water depth

c. Predictors: (Constant), water depth , sludge depth

**Coefficients**[a]

| Model | | Unstandardized Coefficients | | Standardized Coefficients | T | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 1019.590 | 250.298 | | 4.074 | .001 |
| | water depth | -474.676 | 142.429 | -.588 | -3.333 | .003 |
| 2 | (Constant) | 1723.524 | 289.366 | | 5.956 | .000 |
| | water depth | -640.592 | 125.602 | -.794 | -5.100 | .000 |
| | sludge depth | -253.132 | 73.925 | -.533 | -3.424 | .003 |

a. Dependent Variable: Macroinvertebrate abundance

**Excluded Variables[a]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics |
|---|---|---|---|---|---|---|
| | | | | | | Tolerance |
| | fish | .111[c] | .700 | .492 | .159 | .849 |
| | Habitat disturbance scale | -.104[c] | -.599 | .556 | -.136 | .711 |
| | pH | -.038[c] | -.180 | .859 | -.041 | .482 |
| | Ambient Temperature | .169[c] | 1.056 | .304 | .235 | .798 |
| | Water Temperature | .167[c] | .919 | .370 | .206 | .633 |
| | DO | .191[c] | 1.017 | .322 | .227 | .583 |
| | Oxygen saturation | .196[c] | 1.075 | .296 | .239 | .613 |
| | Conductivity | -.118[c] | -.767 | .452 | -.173 | .890 |
| | Turbidity | .177[c] | 1.207 | .242 | .267 | .942 |
| 2 | Secchi depth | -.129[c] | -.851 | .406 | -.192 | .906 |
| | Chlorophyll a | .074[c] | .498 | .624 | .113 | .967 |
| | COD | -.001[c] | -.008 | .994 | -.002 | .562 |
| | Chloride | .015[c] | .095 | .926 | .022 | .915 |
| | NH4- N | -.140[c] | -.711 | .486 | -.161 | .545 |
| | TSS | .209[c] | 1.487 | .153 | .323 | .981 |
| | TN | .149[c] | .987 | .336 | .221 | .900 |
| | TP | -.099[c] | -.651 | .523 | -.148 | .913 |
| | OP | -.026[c] | -.149 | .883 | -.034 | .726 |
| | $NO_3$-N | .114[c] | .777 | .447 | .176 | .981 |

a. Dependent Variable: Macroinvertebrate abundance

b. Predictors in the Model: (Constant), water depth

c. Predictors in the Model: (Constant), water depth , sludge depth

**V**: Regression summary of fish prediction using *log(x+1)* transformed values of environmental predictors of natural wetlands of Gilgel Gibe watershed, southwest Ethiopia, 2014

**Model Summary[d]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .469[a] | .220 | .183 | 52.13397 |
| 2 | .685[b] | .469 | .416 | 44.08356 |
| 3 | .773[c] | .598 | .534 | 39.35817 |

a. Predictors: (Constant), sludge depth

b. Predictors: (Constant), sludge depth, NH4-N

c. Predictors: (Constant), sludge depth , NH4-N, TSS

d. Dependent Variable: Fish abundance

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 16077.992 | 1 | 16077.992 | 5.915 | .024[b] |
| | Residual | 57076.965 | 21 | 2717.951 | | |
| | Total | 73154.957 | 22 | | | |
| 2 | Regression | 34287.745 | 2 | 17143.872 | 8.822 | .002[c] |
| | Residual | 38867.212 | 20 | 1943.361 | | |
| | Total | 73154.957 | 22 | | | |
| 3 | Regression | 43722.715 | 3 | 14574.238 | 9.408 | .001[d] |
| | Residual | 29432.242 | 19 | 1549.065 | | |
| | Total | 73154.957 | 22 | | | |

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | T | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 187.444 | 64.406 | | 2.910 | .008 |
| | sludge depth | -94.486 | 38.848 | -.469 | -2.432 | .024 |
| 2 | (Constant) | 397.187 | 87.526 | | 4.538 | .000 |
| | sludge depth | -181.899 | 43.526 | -.903 | -4.179 | .000 |
| | NH4- N | -1530.611 | 500.022 | -.661 | -3.061 | .006 |
| 3 | (Constant) | 217.991 | 106.671 | | 2.044 | .055 |
| | sludge depth | -185.480 | 38.888 | -.920 | -4.770 | .000 |
| | NH4- N | -1755.342 | 455.617 | -.758 | -3.853 | .001 |
| | TSS | 102.088 | 41.366 | .369 | 2.468 | .023 |

a. Dependent Variable: Fish abundance

**Excluded Variables[a]**

| Model | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics |
| --- | --- | --- | --- | --- | --- |
| | | | | | Tolerance |
| pH | -.105[d] | -.691 | .498 | -.161 | .949 |
| Ambient Temperature | -.109[d] | -.698 | .494 | -.162 | .891 |
| Water Temperature | -.027[d] | -.174 | .864 | -.041 | .894 |
| DO | -.069[d] | -.395 | .698 | -.093 | .731 |
| Oxygen saturation | -.078[d] | -.443 | .663 | -.104 | .720 |
| Conductivity | -.226[d] | -1.549 | .139 | -.343 | .927 |
| Turbidity | -.175[d] | -.625 | .540 | -.146 | .279 |
| Secchi depth | .130[d] | .724 | .478 | .168 | .677 |
| Chlorophyll a | .159[d] | .951 | .354 | .219 | .761 |
| COD | .022[d] | .133 | .895 | .031 | .835 |
| Chloride | .035[d] | .231 | .820 | .054 | .986 |
| TN | .035[d] | .214 | .833 | .050 | .811 |
| TP | -.092[d] | -.560 | .582 | -.131 | .820 |
| OP | .021[d] | .138 | .892 | .033 | .929 |
| $NO_3$-N | .165[d] | .853 | .405 | .197 | .577 |
| water depth | -.017[d] | -.105 | .917 | -.025 | .814 |
| Habitat disturbance scale | .254[d] | 1.459 | .162 | .325 | .660 |
| Macroinvertebrate abundance | .178[d] | 1.126 | .275 | .257 | .838 |

a. Dependent Variable: Fish abundance

b. Predictors in the Model: (Constant), sludge depth

c. Predictors in the Model: (Constant), sludge depth, NH4-N

d. Predictors in the Model: (Constant), sludge depth, NH4-N, TSS

**VI: Wetland assessment protocol sheet**

General information

1. DD/MM/YYY--------------------------------------------------Time------------------
2. Name of wetland------------------------------------Sampling station------------------
3. Altitude (M) ---------------------------------- coordinates-----------------------------
4. Weather condition----------------------------------------------------------------------------
5. Previous day rain history-------------------------------------------------------------------------
6. Photo number----------------------------------------------------------------------------------------
7. Size of site under assessment (ha) --------------------------------------------------------------
8. Size of total wetland (ha) ----------------------------------------------------------------------------

Notes and or sketch of the site

| |
|---|
| |

Physico-Chemical parameters (Field)

9. Ambient Temperatures ($^0$c) -------------------------------pH------------------------------------
10. Water temperature ($^0$c) ---------------------DO (mg/l) ------------------ EC (µS/cm) ----------
11. Turbidity (NTU) ------------------------------Transparency (cm) -------------------------------
12. Chlorophyll a (ABS) ------------------------ (0.1309*ABS+11.274) ------------------- (µg/l)
13. Color---------------------------------------- odor -----------------------------------------------

Physic-Chemical parameters (laboratory)

14. COD ------------------------------------------
15. Chloride -------------------------------------------- $NH_4$ -------------------------------------------
16. TSS ----------------------------------------------TN -------------------------------------------

17. OP -----------------------------------------------TP------------------------------------------

18. $NO_3$ -------------------------------------------------

Hydrological assessment

19. Wetland geographic setting --------------------------------------------------------------------

a. Riverine -------------------------------------------------------------------------------------

b. Depressional ---------------------------------------------------------------------------------

c. Meandering flood plain----------------------------------------------------------------------

d. Other---------------------------------------------------------------------------------------------

20. Site setting/degree of isolation from other wetland

a. The site is connected upstream and downstream with other wetland

b. The site is only connected upstream with other wetlands

c. The site is only connected downstream with other wetlands

d. Other wetlands are nearby (within 0.25 mile) but not connected

e. The wetland site is isolated

21. Free water depth (cm)

a. Minimum ------------- b. maximum--------------------- Average--------------------

22. Sludge depth

a. Minimum---------------b. Maximum----------------------Average--------------------

23. Soil type

a. Organic------------------------------------------------------------------------------------------

b. Mineral------------------------------------------------------------------------------------------

c. Both organic and mineral--------------------------------------------------------------------

24. Apparent hydro period

a. Permanently flooded

b. Seasonally flooded

c. Saturated (surface water seldom present)

d. Artificially flooded

e. Artificially drained

25. Hydrological modified

a. Ditch inlet and outlet----------------------------- d. culverts---------------------------------

b. Drainage -------------------------------------------- e. filling or bulldozing------------------

c. Storm water input---------------------------------- f. others specify--------------------------

Land use

26. Adjacent land use pattern

a. Agriculture tilled------------- e. road-------------------

b. Pasture------------------------- f. commercial---------------

c. Native vegetation------------- g. industrial------------------

d. Residential area--------------- h. recreational---------------

Habitant assessment

27. Hydrophytic vegetation coverage (%)

a. Woody plants---------------------------- e. floating macrophyte-----------------------

b. Water grass------------------------------- f. periphyton---------------------------------

c. Emerged macrophyte------------------- g. filamentous algae-------------------------

d. Submerged macrophyte----------------- h. other specify------------------------------

28. Wetland fauna

a. Fish ------------------------------ c. invertebrates--------------------------------

b. Birds (ducks) ---------------------------------------- d. others-----------------------------------

29. Anthropogenic activities wetland upland

a. Cultivation -------------------------------------- ---------------------------------

b. Tree removal -------------------------------------- ---------------------------------

c. Shrub removal ---------------------------------------- ---------------------------------

d. Tree plantation ---------------------------------------- ---------------------------------

e. Grazing ---------------------------------------- ---------------------------------

f. Grass cutting ---------------------------------------- ---------------------------------

g. Brick manufacture ----------------------------------------- ---------------------------------

h. Car washing ----------------------------------------- --------------------------------

i. Clay mining/pottery -------------------------------------- ------------------------------

j. Waste dumping -------------------------------------- ------------------------------

k. Fishing ------------------------------------- ------------------------------

l. Swimming -------------------------------------- ------------------------------

30. Other potential threats

a. Agricultural biocides----------------------------------------------------------------------------

b. Point source pollution--------------------------------------------------------------------------

31. Wetland ecological state

a. Unmodified, natural-----------------------------------------------------------------------------

b. Largely natural with few modification-------------------------------------------------------

c. Moderately modified----------------------------------------------------------------------------

d. Largely modified---------------------------------------------------------------------------------

e. Seriously modified-------------------------------------------------------------------------------

f. Critical/extremely modified--------------------------------------------------------------------

32. Any additional comments

-------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------

**VII: Criteria used for designating reference and impaired (degraded) wetland sites. A score of 1 was awarded for no or minimal disturbance, 2 for moderate disturbance and 3 for high disturbance**(Mereta et al. 2013)

| Disturbance | | Score = 1 | Score = 2 | Score = 3 |
|---|---|---|---|---|
| Habitat alteration | Grazing | Minimal grazing | Moderate grazing | Intensive grazing |
| | Vegetation removal | <10% vegetation Removal | 10–50% of vegetation Removal | >50% vegetation removal |
| | Tree plantation | No tree plantation or plantation at > 50 m | Tree plantation at < 50 m but not in the wetland | Tree plantation in the wetland |
| Land use | Farming | No farming or farming at > 50 m from the wetland | Farming in a distance of < 50 m from the wetland | Farming in the wetland it self |
| | Clay mining | No clay mining | Clay mining > 50 m | Clay mining in the wetland or < 50 m |
| | Waste dumping | No waste dumping | Waste dumping near the Wetland | Active sign of waste dumping in the wetlands |
| Hydrological modification | Draining and ditching | No draining, nor Ditching | Draining nearby < 50 m | Draining in the wetlands |
| | Filling | No filling | Filling near the wetland | Filling in the wetland |
| | Water abstraction | No dewatering | Dewatering near wetland | Dewatering in the wetland |

**VIII**: **Laboratory procedures**

1. **Determination of Chloride**(APHA et al. 1995)

**Argentometric Method**

1. Measure the appropriate sample volume for the indicated chloride range using the following table and transfer to a 250 ml Erlenmeyer flask or porcelain casserole.

| Sample volume ml | Alkalinity range mg/l as $CaCO_3$ |
|---|---|
| 100 | 1-50 |
| 50 | 51-100 |
| 25 | 101-200 |
| 10 | 201-500 |

2. Bring the total volume to 100 mL with distilled water if the sample size is less than 100 mL

3. Prepare a color comparison blank by placing distilled water in a similar flask and the volume must be equal to that of the sample

4. Add 1 mL potassium dichromate indicator solution to the blank and the sample; and Mix

5. To the color comparison blank carefully add from a burette drop by drop silver nitrate titrant until the yellow color changes to a brownish tinge.

6. Record the mL silver nitrate titrant consumed.

7. If the sample turns yellow, gradually add silver nitrate titrate from a burette. Shake the Flask continuously and continue adding the titrant until the sample turns the same Orange- red color as in the color comparison blank.

8. Record mL silver nitrate titrant consumed.

9. Calculation:

$$\text{mg Cl/L} = \frac{(\text{A-B}) \times \text{N} \times 35{,}450}{\text{Ml of sample}}$$

Where: A= ml titration for sample B= ml titration for blank, and

N= normality of silver nitrate Mg NaCl/L = (mg Cl/L) x 1.65

Note: Directly titrate sample in the pH range 7 to 10. Adjust sample pH to 7 to 10 with $H_2SO_4$ or NaOH if not in this range.

For highly colored samples clarification with aluminum hydroxide suspension is necessary

If sulfide, sulfite thiosulphate is present, add 1 ml hydrogen peroxide and stir for 1 minute.

**2.Determination of Total suspended solids (Gravimetric method)**

1) Dry the clean evaporating dishes in the oven for 1 hour at 103-105 $^{o}$C and cool in a desiccator.
2) Note down the empty weight of the dish (W1).
3) Pour a measured portion (50 to 100 mL) of the well-mixed sample into the dish and evaporate the contents by placing the dish on a steam bath.
4) Transfers the dishes to an oven maintained at 103–105°C and dry it for 1 hour.
5) Allow the dish to cool briefly in air before placing it, while still warm in a desiccator to complete cooling in a dry atmosphere.
6) Weigh the dish as soon as it has completely cooled (W2).
7) Weight of residue = $\frac{(\text{W2} - \text{W1})\ \text{mg} \times 1000}{\text{Ml of sample}}$.

**IX: Coordinates of sampling sites in natural wetlands of Gilgel Gibe watershed, southwest Ethiopia, 2014.**

| site code | x | y |
|---|---|---|
| H1 | 36.88026 | 7.642225 |
| H2 | 36.87824 | 7.642133 |
| H3 | 36.87223 | 7.643106 |
| H4 | 36.87077 | 7.642994 |
| H5 | 36.87126 | 7.641817 |
| H6 | 36.87051 | 7.639911 |
| H7 | 36.87192 | 7.638458 |
| H8 | 36.87053 | 7.637511 |
| H9 | 36.87119 | 7.637983 |
| H10 | 36.8711 | 7.639356 |
| B1 | 36.84707 | 7.649125 |
| B2 | 36.85289 | 7.650842 |
| B3 | 36.85523 | 7.654258 |
| B4 | 36.8751 | 7.656225 |
| K1 | 36.79822 | 7.676628 |
| K2 | 36.81756 | 7.671381 |
| K3 | 36.82336 | 7.668631 |
| K4 | 36.82589 | 7.66335 |
| K5 | 36.83047 | 7.659531 |
| K6 | 36.83634 | 7.654589 |
| K7 | 36.83609 | 7.649989 |
| K8 | 36.84257 | 7.646928 |
| K9 | 36.84256 | 7.648383 |