JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
ENVIRONMENTAL ENGINEERING CHAIR

RIVER WATER QUALITY ASSESSMENT USING PHYSICOCHEMICAL AND BENTHIC MACROINVERTABRATE METRICS: THE CASE OF GILGEL GIBE RIVER, JIMMA ZONE, OROMIA NATIONAL REGIONAL STATE, ETHIOPIA

BY: - ENDALKACHEW ASRAT S/G

A THESIS SUBMITTED TO FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING, JIMMA INSTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS OF THE DEGREE OF MASTERS OF SCIENCE IN ENVIRONMENTAL ENGINEERING

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DECLARATION

As far as my knowledge, the thesis entitled as “River Water Quality Assessment Using Physicochemical and Benthic Macroinvertabrate Metrics: The Case of Gilgel Gibe River, Jimma Zone, Oromia National Regional State, Ethiopia” is only the outcome of research work undertaken by the researcher, Mr. Endalkachew Asrat. Any material used has been duly acknowledged. It is neither in part nor completely been presented for another degree elsewhere.

Endalkachew Asrat ______________ __________________

This thesis report has been submitted for examination with my approval as university supervisor.

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ABSTRACT

The objective of the study was to assess river water quality using physico-chemical and biometrics by means of benthic macroinvertebrate metrics. The study was conducted on the Gilgel Gibe river which covers the area lying between 1678m at Asendabo SS to 1775m at Dedo SS. The Gilgel Gibe river crosses a wide area of farmlands, especially at Dedo sampling sites and is mostly exposed to frequent agricultural runoff from both the left and right side of the river. The samples were collected along the flow of the river from 15 sampling sites (six from Asendabo and nine from Dedo). Two wetland sites were selected as the reference following USEPA protocol, 2002. Physicochemical parameters listed below were analyzed on site by employing HQ40d multi Prob analyzer. Benthic macroinvertabrate metrics were sampled from shallow riffle areas of the river and were identified to the family level following the standard methods in the laboratory. SPPSS version 16, Cannoco and Arc GIS softwares were employed for statistical analysis and mapping of the sampling points. The water samples were analyzed for dissolved oxygen (DO), water Temperature, ambient air temperature, pH, Electrical conductivity (EC), Alkalinity, Chloride, Nitrate (NO_3^- *), Phosphate , total suspended solid (TSS), Turbidity and flow rate. Accordingly; DO (5.18 to 7 mg/l), water temperature (19.1 to 23.9* ^oC*), ambient air temperature (14 to 29.34* ^oC*), pH (7.37 to 8.44), EC (70.4 to 86.9 μs/cm), Alkalinity (30 to 38 mg/l), Chloride (1.999 to 2.999 mg/l),* NO^-_3 *(0.41 to 0.9575 mg/l), phosphate (0.093 to 0.178 mg/l), TSS (113.33 to 700 mg/l) , Turbidity (64.2 to 290 NTU) and the flow rate (0.2 to 0.5 m/s) average values were recorded. In this study the canonical correspondence analysis (CCA) based on the invertebrates assemblages PCA axis 1 explained 25.5% and PCA axis 2 explained 17% of the variability among sites. Following careful analysis, the findings of the study depicts that almost all the parameters on the range of standard values kept for surface water by USEPA. The study was conducted from August 2016 to December 2016.*

Key words: benthic macroinvertabrates, biotic index, physicochemical, tolerance value,
Gilgel Gibe river

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LISTS OF ACRONOMY

ANOVA	Analysis of variance
APHA	American Public Health Association
A.A.EPA	Addis Ababa Environmental Protection Authority
BOD	Biological Oxygen Demand
BI	Biotic Index
CCA	Canonical Correspondence Analysis
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
EDTA	Ethylene-Diamine Tetra-Acetic acid
EPT	Epheromptera Plecoptera Tricoptera
ERA	Ethiopian Road Authority
FBI	Family Level Biotic Index
FISRWG	Federal Interagency Stream Restoration Working Group
FR	Flow Rate
GGASS	Gilgel Gibe Asendabo Sampling Site
GGDSS	Gilgel Gibe Dedo Sampling Site
GPS	Global Positioning System
GW	Ground Water
IBI	Integrated Biotic Index
JiT	Jimma institute of Technology
JU	Jimma University
MCIGR	Macroinvertebrate community index of Gibe river
MI	Monitering index
NB	Nota Bene
NTU	Nephelometric Turbidity Unit
OM	Organic Matter
PCA	Principal Component Analysis
pH	Hydrogen ion concentration
SD	Standard Deviation
SPSS	Statistical Package for Social Science
SS	Sampling Site
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solid
UNEP	United Nation Environmental Protection

USGS	United State Geological Survey
U.S.EPA	United State Environmental Protection
WHO	World Health Organization
WQ	Water Quality
WQI	Water Quality Index

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Water pollution assessment is generally focused towards physical and chemical parameters whereas biological aspects were given little attention until recently. Cairns and Dickson (1971) summarized various reasons for exclusion of biological assessment in water pollution studies. Although physical and chemical methods of assessing water pollution are relatively simple to interpret, biological assessment has many strong merits (CAIRNS, *et al.*, 1976; CAIRNS and VAN DER SCHALIE, 1980). As biological organisms are somewhat interdependent, pollution affecting a particular group of organisms could alter or even destroy the balance of life in an aquatic ecosystem. Since pollutants basically affect living organisms, collection of biological data with physical and chemical data had been emphasized in water pollution assessment (Warren, 1971; Wilhm, 1975; Cairns, *et al.*, 1976, and Cairns *et al.*, 1982).

Having mainly excessive amounts of heavy metals such as Pb, Cr and Fe, as well as heavy metals from industrial processes are of special concern because they produce water or chronic poisoning in aquatic animals (Ellis 1989). High levels of pollutants mainly organic matter in river water cause an increase in biological oxygen demand Kataria *et al*., 1996, chemical oxygen demand, total dissolved solids, total suspended solids and fecal coli form. They make water unsuitable for drinking, irrigation or any other use (Hari 1994).

Effluents are the main source of direct and continuous source input to aquatic ecosystems. Relating observed effects to specific pollutants or even classes of pollutants remains a very difficult task due to the usually unknown, complex and often highly variable composition of effluents. It is recognized that toxic pollutants interfere with organism integrity at the biochemical level and give rise to effects at the individual level and is manifested in reduced ecologically relevant characteristics such as growth, reproduction and survival, and ultimately at the ecosystem level (Agarwal *et al.,* 2011).

Urbanization increases the amount of impervious area and/or amount of disturbed land, which can result in altered hydrology and transport of non-point source pollutants (sediments, nutrients) to rivers (Quinn *et al*., 1978). Such physical alterations combined with massive industrial and residential pollution have taken a heavy damage to non-human aquatic biota (Chu and Karr, 2001).

If watershed vegetation is replaced with impervious surfaces in the form of paved roads, buildings, parking lots, and residential homes and driveways, the ability of the environment to absorb and diffuse the effects of natural rainfall is diminished. These effects are compounded when small streams are channelized (straightened) or piped and storm sewer systems are installed to increase transport of drainage waters downstream. Bank scours from frequently high flow events tends to enlarge urban streams and increase suspended sediment. Scouring also destroys the variety of habitat in streams, leading to destruction of benthic macro invertebrate populations (U.S.EPA, 1999). Urban runoff also carries a potentially toxic cocktail whose cumulative impacts can cause severe impairment to urban streams (Chu and Karr, 2001).

1.1.1. Water Quality Objectives

A major advantage of the water quality objectives approach to water resources management is that it focuses on solving problems caused by conflicts between the various demands placed on water resources, particularly in relation to their ability to assimilate pollution. The water quality objectives approach is sensitive not just to the effects of an individual discharge, but to the combined effects of the whole range of different discharges into a water body. It enables an overall limit on levels of contaminants within a water body to be set according to the required uses of the water. The advantage of the fixed emission approach is that it treats industry equitably requiring the use of best available technology for treating hazardous, as well as a number of conventional, water pollutants wherever the industry is located (Agarwal *et al.,* 2011). This is seen to be a major advantage for transboundary catchment areas where all riparian countries are required to meet the same standards and no country has an unfair trade advantage.

It is generally recognized that water quality objectives, the setting of emission limits based on best available technology, and the use of best environmental practice should all form part of an integrated approach to the prevention, control and reduction of pollution in inland surface waters. In most cases, water quality objectives serve as a means of assessing pollution reduction measures. For example, if emission limits are set for given water body because of best available technology, toxic effects may, nevertheless, be experienced by aquatic communities under certain conditions. In addition, other sensitive water uses, such as drinking-water supplies, may be adversely affected. The water quality objectives help to evaluate, therefore, whether additional efforts are needed when water resources protection is based on using emission limits for point sources according to the best available technology or on best environmental practice for non-point sources (BREHMER *et al., 1960*)

1.1.2. Biological Integrity

Biological integrity has been defined as " the capacity of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr *et al*., 1986). Biological integrity can also be defined as "the wholeness of a living system, including the capacity to sustain the full range of organisms and processes having evolved in a region" (Chu and Karr, 2001). Each organism is adapted to the environmental conditions in its native ecoregion. An environment that supports an assemblage of organisms similar to that produced by long-term evolutionary processes has high biotic integrity. Changes of the environmental condition due to anthropogenic activities cause a decline in biological integrity and can make the environment uninhabitable for appropriate organisms (Rossano, 1996).

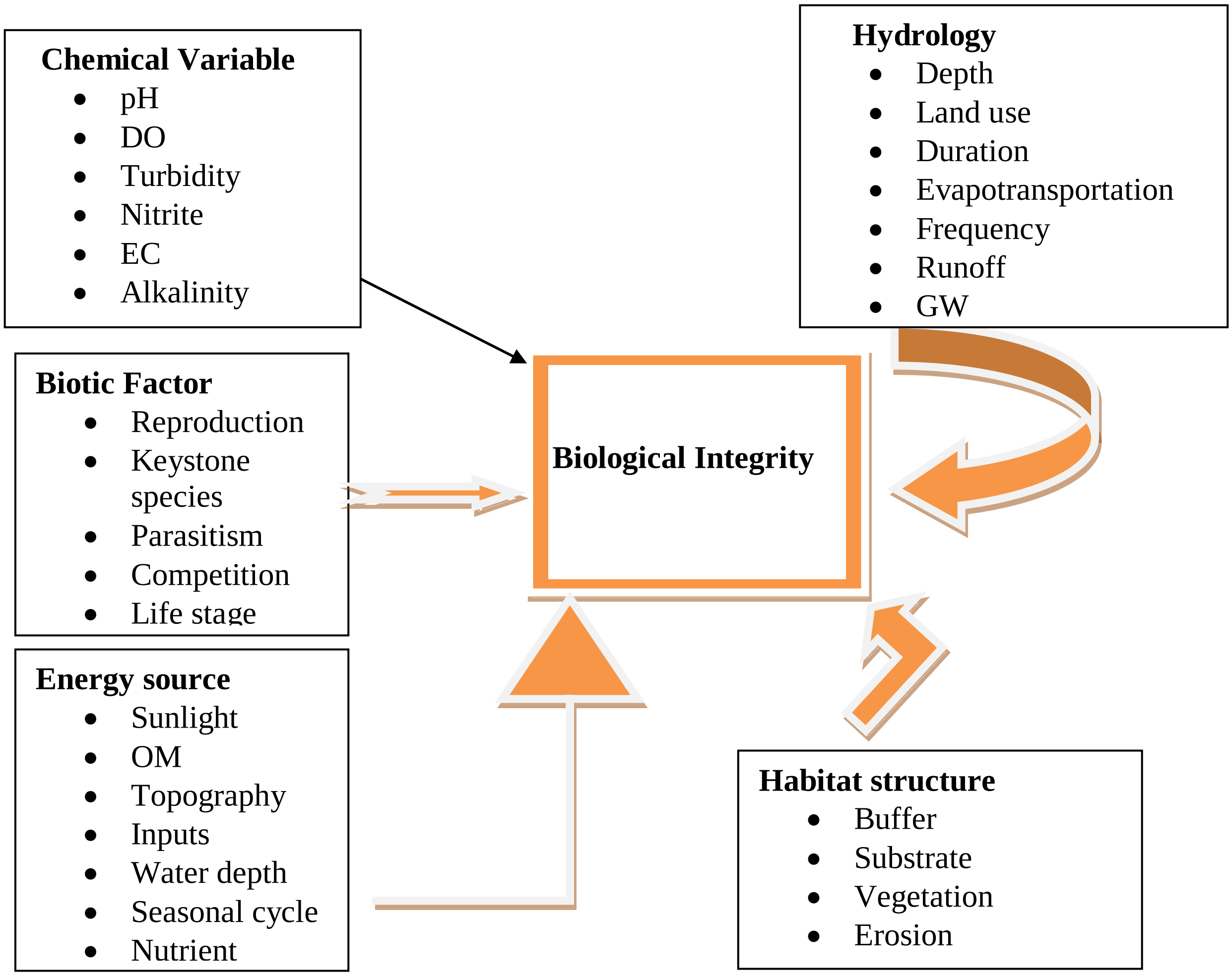

Fig 1: Factors influencing Biological Integrity (U.S. EPA, 2002)

1.1.3. The Integrity of River Ecosystem

Rivers are characterized by unidirectional current with a relatively high average flow velocity ranging from 0.1 to 1m/s (Meybeck and Helmer, 1996). The integrity of river ecosystem refers to its biotic integrity (also called biological integrity). Biotic integrity is also defined “the ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having species composition, diversity and functional organization comparable to that of natural habitats within a region” (Karr and Dudley, 1981). It can be fully characterized by the three major components: hydrology, physico-chemistry and biology. The summary of five attributes of river ecosystem is shown on figure 2 (DeBerry and Perry, 2005).

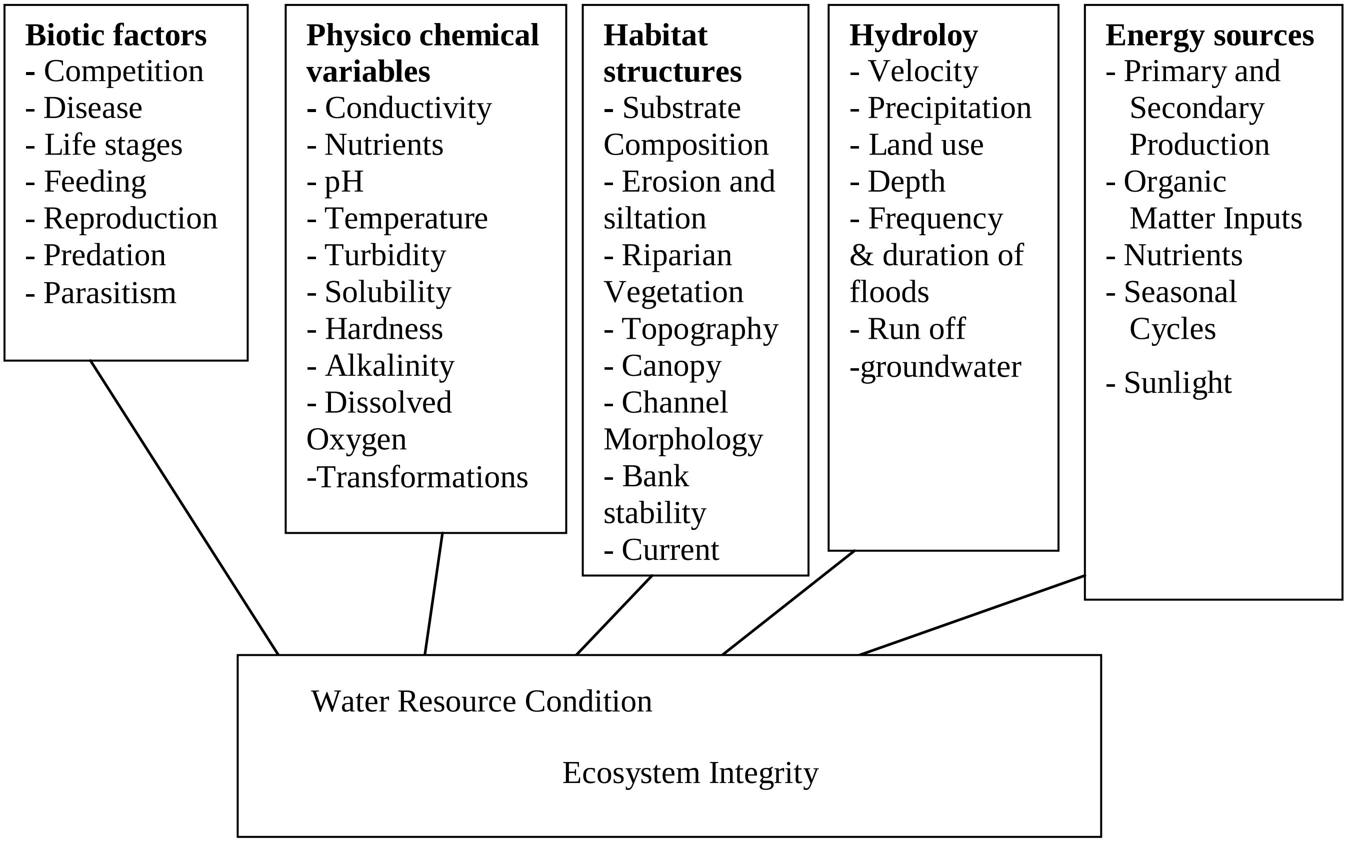

Fig 2: The schematic illustration of components contributing to the integrity of water resources and aquatic ecosystem

1.1.4. The history of benthic macroinvertebrates as indicators of stream water quality

Freshwater macroinvertebrates can be More precisely defined as those invertebrate organisms that live in aquatic habitats at some point in their life cycle and that are trapped by mesh with a gauge between 200 and 500 mm (Rosenberg and Resh 1993). Most of these species are associated with the bottom of the rivers or other stable surfaces, instead of being species that swim freely most of the time. Due to that tendency to inhabit bottoms, they are usually referred to as benthic macroinvertebrates (Hauer and Resh, 1996). The use of community structure of freshwater organisms for biomonitoring can be traced back to the pioneering work of two German scientists, R. Kolkwitz and M. Marsson, in the early 1900s. According to the scientists, restricted occurrence of certain taxa in response to environmental conditions lead to the development of a list of indicator organisms (Cairns and Pratt, 1993). Since then a number of related analytical approaches have evolved. Bioindicator is defined as “a species or group of species that readily reflects the abiotic or biotic state of an environment, represents the impact of environmental change on a habitat, community, or ecosystem, or is indicative of the diversity of a subset of taxa, or of the whole diversity, within an area” (McGeoch, 1998). Benthic macroinvertabrates, as a group, exhibit a relatively wide range of response to chemical and physical water quality stressors and thus can serve as biological indicators of pollution of water. Some of these organisms are tolerant to degraded water quality conditions, while others are pollution sensitive. An unpolluted stream will support a diverse population of macroinvertebrates, with pollution-sensitive species well represented. However, species diversity declines as water quality deteriorates (Peitz, 2003).

Benthic macroinvertabrates can be used to quantify the effects of pollutants on water quality, as they are sensitive to a wide range of variables within a watershed. Pollution affects the community by altering movement, habitat, food quality and oxygen availability. These days, biomonitoring is an integral part of measurements of the total ecological health of a water body and becoming increasingly important tool in water quality monitoring and assessment. It allows overcoming the logistic difficulties of traditional physico-chemical surveys and appearing advantageous from an economic point of view and thus, providing synthetic information in a short time (CAIRNS *et al., 1976)*.

1.1.5. Bioassessment as a Tool to Monitor Water Quality

The health and well-being of the aquatic biota in surface waters is an important barometer of how effectively we are achieving the intent of water quality standards (Yoder and Rankin, 1998). Water bodies exhibit various physical, chemical and biological characteristics, but their conditions are expressed as water quality as a whole. Thus, water quality monitoring program based on the chemical/physical measurements and their conditions omit the ecological concepts from the program (Hawng *et al*., 2006). Often some programs are not protecting rivers or their biological resources because water conservation and management are being implemented as if crystal clean water running down concrete conduits were the goal. As such, assessments of water quality are being implemented to attain only clear water. Water resources are not simply the water; however, their value as resources is beyond the water alone. They also depend on biological components and the underlying biological processes that sustain those species (Barbour *et al.,* 1996)

1.1.6. Potential Biometrics for Effective River Water Quality Assessment

Biological measurements, called metrics, represent elements of the structure and function of the bottom dwelling macroinvertabrate assemblage. Metrics change in some predictable way with increased perturbations (Barbour *et al,* 1996). They include specific measures of diversity, composition and functional feeding group representation and ecological information on tolerance to pollution. Multimetric Indices, such as the IBI (Integrated Biotic Index), incorporate multiple biological community characteristics and measure the overall response of the community to environmental stressors (Karr *et al.,* 1986; Barbour *et al.,* 1995).

1.1.7. Physico-chemical parameters for testing of water.

The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life. Natural water contains different types of impurities are introduced in to aquatic system by different ways such as weathering of rocks and leaching of soils, dissolution of aerosol particles from the atmosphere and from several human activities, including mining, processing and the use of metal based materials (Ipinmoroti and Oshodi 1993, Adeyeye 1994, Asaolu 1997). The increased use of metal-based fertilizer in agricultural revolution of the government could result in continued rise in concentration of metal pollutions in fresh water reservoir due to the water run-off.

Most of the rivers in the urban areas of the developing countries are the ends of effluents discharged from the industries. African countries and Asian countries experiencing rapid industrial growth and this is making environmental conservation a difficult task (Agarwal Animesh 2011). Sea water contains large number of trace metals in very small concentration. This is a challenging matrix for the analytical chemist due to the very low concentrations of many important trace metals (Robertson 1968, Riley).

There are trends in developing countries to use sewage effluent as fertilizer has gained much importance as it is considered a source of organic matter and plant nutrients and serves as good fertilizer (Riordan 1983). Farmers are mainly interested in general benefits, like increased agriculture production, low cost water source, effective way of effluent disposal, source of nutrients, organic matter etc, but are not well aware of its harmful effects like heavy metal contamination of soils, crops and quality problems related to health of the stream they are discharging to.

1.2. Statement of the Problem

Human intervention has significant effects on water quality. Some of these effects are the result of hydrological changes, such as the building of dams, draining of wetlands and diversion of flow. More obvious are the polluting activities, such as the discharge of domestic, industrial, urban and other wastewaters into the watercourse (whether intentional or accidental) and the spreading of chemicals on agricultural land in the drainage basin. In Gilgel Gibe River basin, huge amount of pesticides and fertilizers have been employed and there is no data about the chlorinated hydrocarbon compound, which are the measure of total organic halogen in river water. Hence, current study provides valuable information on the quality of Gilgel Gibe river. The findings can lead to the control of the river and the ground-water pollution (Harmancioglu *et al.*, 2001).

An alarmingly increasing population, uncontrolled urbanization and various anthropogenic activities degrade surface and ground water quality. Water quality degradation for the population and the ecosystem health especially for those people living downstream areas and along the main rivers poses a great threat. The ever increasing settlement of population around the river banks are going presume on the quality of the river water, whereas in Ethiopia this is seriously creating major health risk (Postel and Richter, 2003).

Monitoring of biological communities integrates the effects of different pollutant stressors and provides an overall measure of the aggregate impact of the stressors. Biological communities respond to stresses of all degrees over time and, therefore offer information on perturbations not always obtained with episodic water chemical measurements or discrete toxicity tests.

1.3. Research questions

1. Which physico-chemical water quality parameters are widely available throughout the study sites, with regard to standard values?

2. What are the sources (point/non-point) of pollutants in Gilgel Gibe river at study sites?
3. Which families of bethnic macroinvertabrates are common in study area?
4. Are there variations of both parameters (Physicochemical and benthic macroinvertabrate) at the study sites (Asendabo and Dedo SS)?
5. Is there a difference in benthic macroinvertabrates at reference wetlands and study sites?
6. Does Gilgel Gibe river water quality meet the national and international river water quality standards?

1.4. Objectives of the Study

1.4.1. General Objective

The general objective of the study was to assess the water quality of Gilgel Gibe river by analyzing the physico-chemical parameters and benthic macroinvertabrate assembladges.

1.4.2. Specific Objectives

1. Physico-chemical analysis of samples of water collected from Asendabo and Dedo study sites of Gilgel Gibe river
2. Pinpointing the sources (point/non-point) of pollutants in Gilgel Gibe river at study sites
3. Identification of families of bethnic macroinvertabrates found in study area
4. Investigation of variations of both parameters (Physicochemical and benthic macroinvertabrate) at study sites
5. Comparison of the families of benthic macroinvertabrates at reference wetlands and study sites
6. Evaluation of Gilgel Gibe river water quality with respect to the national and international river water quality standards

CHAPTER TWO

2. LITERATURE REVIEW

Pesticides have different toxic effects on various forms of life and are considered as poisonous to human beings, aquatic ecosystems and animals. If the pesticides introduced into an ecosystem do not have a direct and immediate effect on certain groups of organisms, they may still have indirect toxic effects on them after some time (Ince et al, 1991). The circulation of pesticides in the environment is complex. For example chlorinated hydrocarbon compounds could accumulate in the adipose tissue of the body, give rise to chronic poisoning and other diseases. Among this group of pesticides, Dieldrin is known to pass through the placenta to the foetus and through the mother's milk to babies (Harmancioglu et al, 2001). If huge amount of pesticides and fertilizers of different kinds are used each year and there is not much information about the chlorinated hydrocarbon compounds, the measurement of total organic halogen in river water and the wells along the river could provide valuable information about the quality of water in relation to this aspect. This evaluation could lead to control of the river and the ground water pollution.

In many parts of the developing world, one of the main threats to food security is the degradation of water for drinking, industrial and agricultural uses. Natural resources preservation has a great value for each country. During old days human beings caused much less adverse effect on the environment. Industrialization is unavoidable, but should not destroy the environment. Surface and ground water contamination, not only makes the water supplies useless for drinking water purposes, but also cause the agricultural products to be contaminated with toxic compounds.

2.1. Advantages of Assessing River Water Quality Using Benthic Macroinvertebrate

Recent studies prefer the use of benthic macroinvertabrates over the use of fish, algae, protozoan and other groups of organisms to monitor the quality of water resources for several reasons. Within the biological indicators, macroinvertebrates are one of the most employed groups of organisms. They have a series of advantages as bioindicators that can be summarized as follows (Platts *et al*., 1983; Metcalfe-Smith, 1994 and Plafkin *et al.*, 1989).

1. Macroinvertabrate communities integrate the stresses over time and an ecological measure of fluctuating environmental conditions.

2. Routine monitoring of biological communities can be relatively inexpensive, particularly when compared to the cost of assessing toxic pollutants, either chemically or with toxicity tests.

3. Benthic macroinvertabrate assemblages are made up of species that constitute a broad range on Trophic levels and pollution tolerance, thus providing strong information for interpreting cumulative effects.

4. Small order streams often do not support fish but support extensive macroinvertabrate communities.

5. Benthic macroinvertabrate have well developed methods of data analysis (Rosenberg and Resh, 1993).

6. Benthic macroinvertabrates have well known taxonomy and identification keys.

7. Benthic macroinvertabrates are common and abundant in most streams.

8. Benthic macroinvertabrates are a primary food source for fish, and as such can provide valuable information on the relative health of the fish community.

9. Since most of them have a relatively short life cycle (approximately one year), they will respond to stressors more rapidly than other longer lived components of the community (e.g. fish). Sensitive life stages will respond quickly to stress; the overall community will respond more slowly

10) They generally have long enough life cycles and therefore their characteristics are the result of a relatively recent past, including sporadic episodes difficult to detect with chemical or microbiological analyses.

11. Benthic macroinvertabrates integrate the effects of chemical, physical and biological parameters. Thus, conducting an aquatic biosurvey will increase the likelihood that a degraded condition will be detected, if present.

12. This method is relatively easy to do, inexpensive, produce an abundance of useful information, and is easily reproduced.

13. Communities of macroinvertabrates are sensitive to conditions existent at the moment so changes in the community will be immediate.

14. The status of biological communities is of direct interest to the public as a measure of a pollution free environment.

15. Macroinvertabrates are good indicators of site-specific conditions as most of them have limited migration patterns or are sessile and spend much time clinging to rocks or the stream substrate, and do not move long distances. Thus, they are good indicators of localized water conditions. Their sedentary nature allows spatial analysis of disturbance effects.

16. Sampling of benthic macroinvertabrates under rapid assessment is easy, requires few people and minimal equipment, and does not adversely affect other organisms.

17. Benthic macroinvertabrates are small enough to be easily collected and identified.

18) They can be found in most aquatic habitats, where they are abundant and relatively easy to capture

Table 1: Potential metrics for effective bioassessments

Category	Metrics	Description
Richness measure	Total taxa richness	Total No of individual taxa
	No EPT taxa	No of taxa in the Ephemeptera, Plecoptera and Trichoptera
	No of Ephemeroptera taxa	Number of mayfly taxa
	No. of Plecoptera taxa	Number of stonefly taxa
	No. of Trichoptera taxa	Number of caddisfly taxa
Composition measure	% EPT	%Composition of mayfly, stonefly and caddisfly larvae.
Composition measures	% Ephemeotera	% composition of myfly larvae
	% Chironomidae	% composition of midge larvae
	% Plecoptera	5 composition of stonefly larvae
	Shanon Diversity Index	Sample diversity that incorporates richness and eveness
	Total No of individuals Collected	Abundance of the shredder to the abundance of all other functional groups
Tolerance measure	% Tolerant organisms	% organisms that are highly tolerant to impairment
	% Intolerant Organisms	% organisms that are highly intolerant to impairment
	% Dominant taxon	Dominance of the single most abundant taxon
	% intolerant taxa	%organism that are highly tolerant to impairment
	Hilsenhoff family-level biotic index (FBI)	Uses tolerance values to weight abundance in an estimate of overall pollution. Originally designed to evaluate organic polln.

2.2. Limitation of Assessing river water quality using benthic Macroinvertabrate

There are also characteristics of benthic macroinvertebrates that hinder their effective use and require special considerations (Bode *et al.*, 1990). These are:

1. Qualitative sampling of benthic macroinvertabrates requires large number of samples, which is both labor and many incentive.
2. Factors other than water quality can affect distribution and abundance of Benthic Macroinvertabrates.
3. Seasonal variation may complicate interpretations and comparisons.
4. Propensity of benthic macroinvertabrates to drift may offset advantages of being sedentary.
5. Benthic macroinvertabrates are not sensitive to some perturbations such as pathogens and Trace amount of some pollutants.

The diversity and assemblage of running water macroinvertabrates (shredders, collectors, grazers and predators) reflect shifts in the types and location of resources with stream size and human induced factors. Uncontrolled agriculture, excessive fertilizers and pesticide application alter rivers and their ecological integrity. Land use change such as canalization or damming diversion also contribute to the deterioration of river ecosystems (Meybeck and Helmer, 1996).In general, the effects of human activities on rivers and their ecosystem affect one or more of the five attributes of watersheds and streams: water quality, habitat structure, stream flow patterns, sources of energy and nutrients, and biotic interactions. Several techniques, protocols and indices have been developed to monitor stream quality using changes in species compositions, diversity and functional organization of aquatic insects . The concept of biodiversity (species richness and evenness) is a central theme in community/ ecosystem ecology and can be used to explain other ecosystem properties such as biological productivity, habitat heterogeneity, habitatcomplexity and disturbance. Species diversities are moderate in stable ecosys tems highest in intermediate and low in severely degraded ecosystems (Stevenson *et al.*, 1999).

2.3. Natural Processes Affecting Water Quality

Although degradation of water quality is almost invariably the result of human activities, certain natural phenomena can result in water quality falling below that required for particular purposes. Natural events such as torrential rainfall and hurricanes lead to excessive erosion and landslides, which in turn increase the content of suspended material in affected rivers and lakes. Seasonal overturn of the water in some lakes can bring water with little or no dissolved oxygen to the surface. Such natural events may be frequent or occasional. Permanent natural conditions in some areas may make water unfit for irrigation or for specific uses. Common examples of this are the Stalinization of surface waters through evaporation in arid and semi-arid regions and the high salt content of some groundwater under certain geological conditions. Many ground waters are naturally high in carbonates (hardness), thus necessitating their treatment before use for certain applications.

A number of investigators attempted before to check the quality of water and its physicochemical parameters. Some people give empirical relationship to measure the quality of water but nobody establish a correlation between physicochemical parameters as it pollutes water (Adefemi *et al., 2010).*

2.4. The Physico-chemical parameters

Pollution of a river first affects its chemical quality and then systematically destroys the community disrupting the delicate food web. Diverse uses of the rivers are seriously impaired due to pollution and even the polluters like industry suffer due to increased pollution of the rivers. River pollution has several dimensions and effective monitoring and control of river pollution requires the expertise from various disciplines (S.B. Chapekar *et al.,* 1983).

2.4.1. BOD

BOD is a measure of organic material contamination in water, specified in mg/L. BOD is the amount of dissolved oxygen required for the biochemical decomposition of organic compounds and the oxidation of certain inorganic materials (e.g., iron, sulfites). Typically the test for BOD is conducted over a five-day period (Milacron Marketing Co.).

2.4.2 DO

DO is one of the most important parameter. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc. (Premlata Vikal, 2009). In the progress of summer, dissolved oxygen decreased due to increase in temperature and also due to increased microbial activity (Moss 1972, Morrissette 1978, Sangu 1987, Kataria, 1996). The high DO in summer is due to increase in temperature and duration of bright sunlight has influence on the % of soluble gases (O^2 & CO^2). During summer the long days and intense sunlight seem to accelerate photosynthesis by phytoplankton, utilizing CO2 and giving off oxygen. This possibly accounts for the greater qualities of O2 recorded during summer (Krishnamurthy R, 1990).

2.4.3 Chloride

It is measured by titrating a known volume of sample with standardized silver nitrate solution using potassium chromate solution in water or eosin/fluorescein solution in alcohol as indicator. The latter indicator is an adsorption indicator while the former makes a red colored compound with silver as soon as the chlorides are precipitated from solution.

2.4.4 Nitrate

Nitrate represents the final product of the biochemical oxidation of ammonia. Monitoring of nitrates in water resources are very important because of health effects on humans, animals. Nitrogen is essential for all living things as it is a component of protein. Nitrates represent the final product of the biochemical oxidation of ammonia. Monitoring of nitrates in drinking water supply is very important because of health effects on humans and animals (Salvato, 2003). Nitrogen exists in the environment in many forms and changes forms as it moves through the nitrogen cycle. Nitrogen is the nutrient applied in the largest quantities for lawn and garden care and crop production. In addition to fertilizer, nitrogen occurs naturally in the soil in organic forms from decaying plant and animal residues. In the soil, bacteria convert various forms of nitrogen to nitrate, a nitrogen ion (NO_3^-). This is desirable as the majority of the nitrogen used by plants is absorbed in the nitrate form. However, nitrate is highly leachable and readily moves with water through the soil profile. If there is excessive rainfall or over-irrigation, nitrate will be leached below the plant's root zone and may eventually reach groundwater.

2.4.5. Phosphate

High phosphorus concentration, as phosphates, together with nitrate and carbon dioxide are often associated with heavy aquatic plant growth, although other substances in water also have an effect. Uncontaminated waters contain 0.01 to 0.03 mg/l total phosphorus. Most waterways naturally contain sufficient nitrogen and phosphorus to support massive algal blooms.

2.4.6. Alkalinity

Alkalinity is a measure of the amount of acid (hydrogen ion) water can absorb (buffer) before achieving a designated pH. Alkalinity is a general term used to express the total quantity of base (Bhatnagar and Dev, 2013). Generally water alkalinity is caused by basic species like bicarbonate ion, carbonate ion and hydroxide ion.

2.4.7. pH

Naturally occurring river water have a pH range between 6 and 9: the concentration suitable for the existence of most biological life is quite narrow and critical. Most fresh waters are relatively well buffered and more or less neutral. The pH of the water is important because affects the solubility and availability of nutrients and how they can be utilized by aquatic organisms. It also affects the ionic and osmotic balance of individual organism and determines of the chemical species (and thus the potential toxicity) of numerous elements and molecules (e.g. ammonia) found in water. Aquatic organisms are very sensitive to the pH of the aquatic environment because most of metabolic activities are pH dependent.

2.4.8. River Water Temperature

Temperature of the water is a very important physical parameter to assess thermal pollution and associated effects on aquatic biota. This is because abnormal temperature alters chemical reactions, reaction rates and solubility of gases (A.A. EPA. 2005). Benthic macro invertebrates prefer cold water, as cold water hold more dissolved oxygen than warmer waters, because water molecules are closer together in cold water, which makes it harder for oxygen molecules to escape. The tighter structure is also conducive to a more consistent attraction between the oxygen and water molecules. In addition, temperature affects the growth and reproduction of aquatic organisms. If the temperature gets too high or too low, the local population of a species decreases. Temperature also affects water chemistry, which in turn then affects biological activity. A sudden change of temperature of a river water can too a higher rate of aquatic biota (Fakayode, 2005).

2.4.9 EC

Conductivity shows significant correlation with ten parameters such as temperature , pH value , alkalinity , total hardness , calcium , total solids, total dissolved solids , chemical oxygen demand , chloride and iron concentration of water. Navneet Kumar et al (2010) suggested that the underground drinking water quality of study area can be checked effectively by controlling conductivity of water and this may also be applied to water quality management of other study areas. It is measured with the help of EC meter which measures the resistance offered by the water between two platinized electrodes. The instrument is standardized with known values of conductance observed with standard KCl solution.

2.4.10 Turbidity

Turbidity consists of suspended particles in water and is usually affected by factors such as clay particles, dispersion of plankton organism, particulate organic matters as well as pigments caused by decomposition of organic matter (Bhatnagar *et.al, 201*3). Higher levels of turbidity, water loses its ability to support a diversity of aquatic organisms because suspended particles absorb heat from the sun light and causes oxygen levels to fall and decreases photosynthesis as less light penetrates the water. The combination of warmer water, less light and oxygen depletion makes it impossible for some aquatic life to survive in the river. These factors accompanied with higher amount of organic loading from the farm load could lead resistance of change within the macroinvertabrate community. Turbidity obtained in this work are far more different from findings obtained by other researchers done on other riverss.

2.4.11 TSS

Total suspended solids are made up of carbonates, bicarbonates, chlorides, phosphates and nitrates of metals such as calcium, magnesium, sodium, potassium, magnesium as well as other particles. Total suspended solids are the sum of the dissolved solids and the suspended solids contained in water which include anything from silt and plankton to wastes and sewage. Calcium and magnesium are the major elements, which make hardness of water. These elements contribute to hardness of water. Calcium and magnesium together comprise most natural water hardness.

2.5 Impact of anthropogenic activities on the river

Agricultural non point source (NPS) pollution is the leading source of water quality impacts to river and lakes. Nitrogen from fertilizers, manure, waste and ammonia turns into nitrite and nitrate. Runoff from barnyards, feedlots and cropland carries away manure, fertilizers, ammonia, pesticides, livestock waste, oil, toxins from farm equipment, soil and sediment. High levels of these toxins deplete waters of oxygen, killing all of the animals and fish. Nitrates also soak into the ground. Ammonia, pesticides as well as oil, degreasing agents, metals and other toxins from farm equipment harm and kill aquatic life and animals and cause health problems. Bacteria and parasites from animal waste can get into water which can cause death on aquatic organisms.

2.6 Selection of Reference and Impaired Sites

Reference conditions are established by assessing "minimally" impaired stream sites, as it is rarely possible to find streams with no impairment at all. Reference sites should be established in good examples of the different types of streams found in the region. Regional reference characteristics represent the best attainable conditions for all streams with similar physical characteristics. The *site-specific control* is a segment of the stream being studied that represents the best attainable conditions for that stream. Stream sites are classified into categories that would have similar aquatic communities under ideal conditions. The classification is based on characteristics that are intrinsic to the site (such as elevation, watershed size, stream gradient, soils, geology and other factors), *not* those resultant from human-induced change .The designated wetland sites was taken as reference and impaired based on land use patterns, the degree of habitat degradation as quantified by the USEPA protocol (USEPA, 2002), variables characterizing hydrological modification, and the Prati index as a measure of chemical water quality. The basic Prati index is calculated based on the concentration of ammonium, chemical oxygen demand and oxygen saturation (Prati *et al.*, 1971). A Basic Prati index value of two or less was considered as good water quality and an index greater than two was considered as poor water quality. Land use, habitat alteration and hydrological modifications were quantified based on their intensity in the studied areas (Marshman., *et al.*,2003). A score of 1 was awarded for no or minimal disturbance, 2 for moderate and 3 for high disturbance (Table 1). Based on these criteria, of the 15 samples used for the development of the index, 2 (13.3%) samples were categorized as reference and the remaining 13(86.6%) samples as impaired.

CHAPTER THREE

3. METHODS AND MATERIALS

3.1. Study Area Description

Gilgel Gibe River is the river, which is located 140 Km away from Jimma city and 295 Km from Addis Ababa city and is found on altitude between 1678m above sea level at $GGASS_4$ to 1775 above sea level at $GGDSS_3$. Households residing around the watershed are about 50 households and some of them lead their life farming the land around the river and the rest breading different animals. Gilgel Gibe river crosses a wide areas of farmlands, especially Dedo sampling sites (GGDSS), and are exposed most frequently to agricultural runoff from both the left and the right side of the farmland. The study was conducted from August to December 2016. Fifteen sampling sites were taken, among which two sites were selected as a reference site along the flow of the river to take water samples for physicochemical data and benthic macroinvertabrate samples for bioassessment. Selection criteria were based on minimally degraded physical habitat, the distribution of human activities, pollution sources and the flow regimes. GGASS1 and GGDSS5 were selected as reference sites to compare the induced changes in other sites due to anthropogenic activities. Reference condition was established using best professional judgment and based on guidelines established (Hughes, 1995).

The reference site represents a standard for what the biological assemblage would look like in the absence of human influence (Hughes, 1995). The framework of bioassessment consists of characterizing reference conditions upon which comparisons can be made and identifying appropriate biological attributes with which to measure the condition (Major *et al.*, 2001). On this study, since reference conditions are the expectations on the state of aquatic biological communities (in this case macroinvertebrates) in the absence of human disturbance and pollution, the reference sites selected are those which are anthropogenically undisturbed or minimally disturbed aquatic systems.

Fig 3: Sample preparation (Photo by Fistum and Ibrahim, Aug 2016)

The first sampling station (GGASS) is located in the upper part of the main Gibe river 60km away from Gibe dam and is dominated by bushes and eucalyptus tree. Agricultural debris and fertilizers are the main polluting substances on this station. The river water, especially GGASS3 and GGASS4, serves predominantly the nearby community for bathing purpose. No industrial effluents are being discharged in all the sampling sites. Since sampling site is near to the main road leading to Addis Ababa, economically disadvantaged and homeless people who have no access to clean water, use the water for bathing, washing clothes and feeding their cattle. $GGASS_1$,which is 2 km away from the main highway heading Addis Ababa.

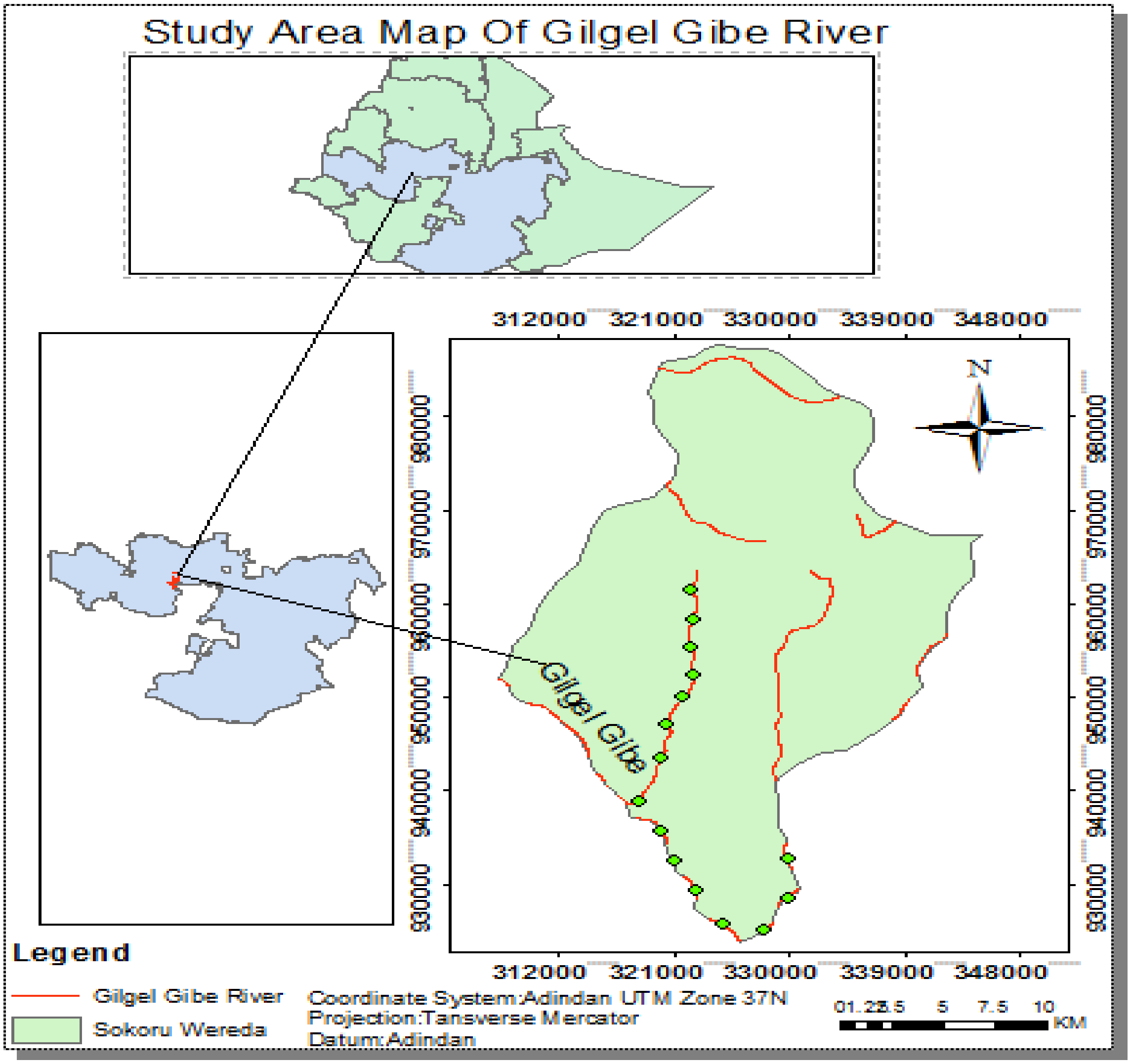

Fig 4: Map Of the study area

3.2. Research design

Water and macro invertebrate samples were collected within the study period in triplicate between August and December 2016. Sampling was conducted at two sampling stations, fifteen sampling sites, six in the western part of the river, which in Asendabo sampling stations. The remaining Nine sites in Dedo sampling stations. In the later sampling stations, informal settlement and over grathing activities are abundantly practed than the first sampling station, Asendabo SS

3.3. Study variable

In this research there were two main types of variable that is conducted while assessing the river water quality using physic chemical parameter determination and using macroinvertabrate Metrics.

3.3.1 Independent variable

The Physico chemical parameters: pH, Turbidity, TSS, EC, Chloride, Conductivity, Temperature, Alkalinity, DO, BOD, Nitrate, Phosphate and Total Hardness was analyzed.

3.3.2. Dependent variable

The macro invertebrate assemblages

3.4. Data collection procedure

At each sampling site where benthic macroinvertabrates were collected, water samples were also taken concurrently with biological sampling in a 1-liter clean polypropylene bottles that have been pre-washed and thoroughly rinsed with deionized water. Other measuring equipments like, Benthic Macroinvertebrate Field Data Sheet, Thermometer, bucket, forceps, standard kick-net, waders (chest-high or hip boots), rubber gloves (arm-length), 95% ethanol, GPS, dip net(D-frame or rectangular), and Surber, taken from Jimma University Environmental health, science and technology laboratory, were calibrated and maintained their consistency, especially prior to reaching the laboratory.

3.5. Data processing and Analysis

The collected water samples and the macroinvertabrate were transported to Jimma for analysis of physicochemical parameters. The samples were kept in a refrigerator at 4^{o}C until analyzed for the parameters. Physical /Chemical parameters such as pH, temperature, electrical Conductivity (EC), DO, Flow rate (FR) were measured at the time of sampling in the field using Portable water quality measuring equipment (HQ40d Multiprobe). Water samples were collected in triplicates from each location. The pH sample was measured with a portable pH meter that has been previously calibrated with standard buffer solutions of pH 4, pH 7 and pH = 10. Electrical conductivity (EC) was measured with Conductivity meter that has been calibrated with standard conductivity buffer solution.

Dissolved oxygen (DO) was measured at each site with a portable DO meter. Temperature was also measured in situ, using a handheld degree Celsius digital thermometer. Current flow (Flow rate) was measured at each site where benthic macroinvertabrate and water samples were collected with a handheld standard mechanical flow meter as the number of counts per 10 seconds. While the remaining parameter like NO_3^- and PO_4^{3-} were analyzed using DR-5000 Spectrometric method, TSS was measured using gravimetric method and the remaining parameters determined using titrimetric method and other parameters; TSS, Nitrate (NO_3^-), Phosphate, Alkalinity and Chloride was determined by titrimetric method following the instructions with them. BOD_5 was determined following APHA (2005) instruction. All the reagents and chemical used for the analysis were analytical laboratory grade. Specimen vials were grouped by sites and date placed in jars with small amount of alcohol (97%) and tightly capped.

3.6. Macroinvertebrate Field Sampling

Benthic macro invertebrate samples were collected from shallow riffle areas of Gilgel Gibe river with a surber sampler frame net (mesh size=500 µm: sampling area= $0.9m^{2)}$ sampling in accordance with the methods for assessing surface waters (Peterson *et al.*, 1999). All sites were assessed within the reach of 200m that must be walked in entirety to collect enough samples of representatives' benthic macro invertebrates. During sampling, the bottom sediment was disturbed by long stick in order to dislodge and consequent scoop up of the benthic macroinvertebrate. To minimize disturbance of a site prior to sampling, samples were collected from the most downstream reach of the river at a site first and then progressing upstream until two samples were collected for the site. A 100 m reach representative of the characteristics of the stream should be selected. Whenever possible, the area should be at least 100 meters upstream from any road or bridge crossing to minimize its effect on stream velocity, depth, and overall habitat quality. There should be no major tributaries discharging to the stream in the study area Plafkin et al. 1989.

Before sampling, the physical/chemical field sheet was checked/ written to document site description, weather conditions, and land use. After sampling, review this information for accuracy and completeness. Drawing a map of the sampling reach was also don , as this map should include in-stream attributes (e.g., riffles, falls, fallen trees, pools, bends, etc.) and important structures, plants, and attributes of the bank and near stream areas. Arrow was used to indicate the direction of flow, this indicate the areas that were sampled for macroinvertebrates on the map. Estimate "river mile" for sampling reach for probable use in data management of the water resource agency. Hand-held Global Positioning System (GPS) for latitude and longitude determination taken at the furthest downstream point of the sampling reach has a paramount importance for the study too. At each sampling site, two samples were usually taken and the duration of each sampling was 10 minutes to maintain consistency. All riffle and run areas within the 100-m reach are candidates for sampling macroinvertebrates. A composite sample is taken from individual sampling spots in the riffles and runs representing different velocities. Generally, a minimum of 2 m^2 composited area is sampled.

Fig 5: sampling of macroinvertabrate from the first sampling station, GGASS

All rocks were picked up and scraped to dislodge the attached invertebrates. For each sample a 1-m^2 area was marked off and the river water was vigorously disturbed to uniform depth 3 times with stiff stick so that the dislodged invertebrates were washed downstream in to the net by the current. The surber net was then turned inside out and invertebrates attached to the fabrics were picked from the net with forceps and transferred to a labeled vial, which is rinsed and filled with 97 % alcohol.

Four sweep samples were taken over the length of the reach of a pool (a single jab sweep samples consists of forcefully thrust the scoop net into a pool for an approximately a linear distance of 1.5m). The characteristics representative benthic macroinvertebrate samples collected from the microhabitats (Pools and riffles) were finally pooled in to a single sample for each site.

The samples were transferred to plastic bottle and preserved with addition of 97 % alcohol for later sorting and identification at family level.

Fig 6: Sorting Macro invertebrates on site, GGDSS

3.7. Data quality assurance

Since the outcome of the result is of paramount importance, in general, for the country, Ethiopia, and specifically, the local residents who are leading there life by breading and farming activities, prior to the collection of the data that is going to be analyzed, a full permission was asked from the local administration, also awareness for the communities was created concerning Why the research is performed.

3.8. Sorting and identifying Macro invertebrates Laboratory

Samples of benthic macroinvertabrate were taken beginning from August till December, 2016 from two sampling stations; at fifteen (15) sampling sites of Gilgel Gibe River. On return to the laboratory, samples were rinsed through a 500 μm mesh sieve, identified to the family level under a dissecting compound microscope, and enumerated after thorough identification as given in Bode, *et al.*, 1973. Water quality of the selected sites was identified by comparing the calculated values to the reference water quality conditions (Hilsenhoff, 1998; Weber, 1973), and (Plafkin, *et al.,* 1989). Identification was done with the help of keys from literature for Tropical Africa, a field guide for Aquatic Invertebrates of South Africa, a guide to aquatic macroinvertabrates of the upper mid west (Bouchard, 2004). Each macroinvertabrates found in the sample was enumerated and recorded on the data book using a tally counter to keep track of cumulative count.

Fig 7: Sorting macroinvertabrates on site, DDSS6

3.9. Statistical data analysis

Spearman bivariate correlation analysis was used to relate benthic macroinvertabrate metrics to physicochemical parameters. To determine if significant differences exist between reference and study sites with regard to physico chemical parameters, one-way ANOVA was performed. This analysis was performed on all physicochemical data. All statistical analysis were done using Microsoft office excel (version 13 Inc, 2003), SPPS statistical software (Version 20: SPSS Inc, 2013), (ArcGIS version 10.1 Inc, 2012) and Canonical correspondence analysis was done using a software named Canoco.

CHAPTER FOURE

4. RESULTS AND DISCUSSION

4.1 Results

4.1.1 Physicochemical Parameters

Physicochemical data supplemented with bioassessment are critical for evaluating the health of a river, and in turn, their results are essential to provide the information of disturbed systems to be restored (Ramakrishnan, 2003). Unlike the biological assessment of water quality, where the incidence intensity of pollution is based on the degree to which the community attributes of indicator of organisms deviate from its expected natural diversity, the physicochemical assessment is usually based on a comparison of the measurements made with water quality criteria or with standards derived from such criteria (Gupta, 2001).

Fig 8: Analyzing the physico-Chemical Parameters in the Laboratory

4.1.2 BOD

In the present study, there were differences in BOD_5 between the two sampling stations, GGASS and GGDSS. Except GGASS2 & GGASS4, GGDSS5, GGDSS6, GGDSS8 and GGDSS9 in all the sampling sites BOD is below the standard value set for surface water (5mg/l). The highest level of BOD was recorded at the second sampling stations, GGDSS4 (7.81 mg/l) where farmers around the riverbank/ catchment exercise agricultural activities using synthetic fertilizers. The lowest value was registered at both sampling stations GGDSS5 (4.99) and GGDSS9 (4.13mg/l) and GGASS1 (5.11 mg/l).

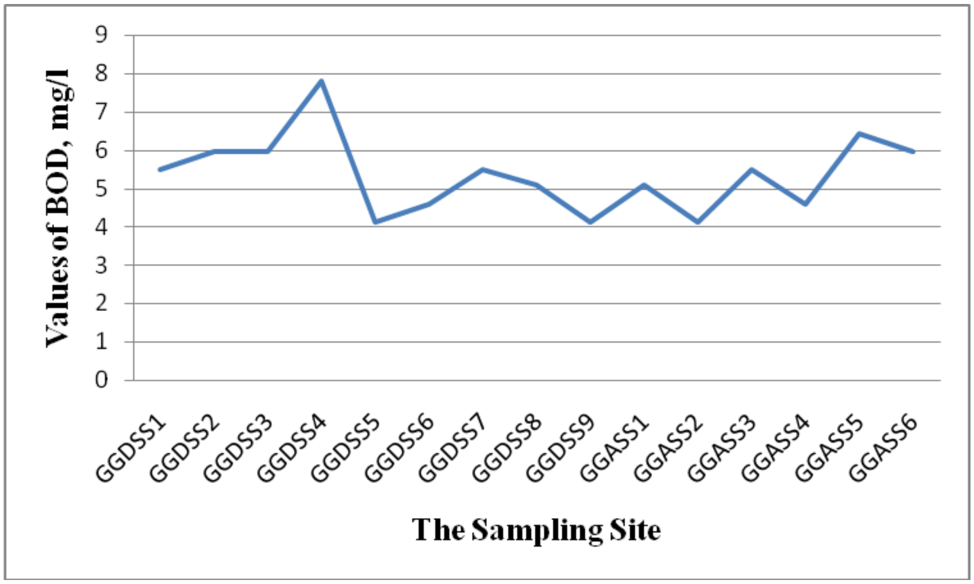

Fig 9: Mean value of BOD5 in Gilgel Gibe River

4.1.3 Dissolved Oxygen (DO)

When the algae decompose, DO concentration declines. Significant change of DO was observed in all over the fifteen sampling site (5.18 to 7.0 mg/l) and this is probably due to the entrance of fertilizers from the farmland, around the riverbank, to the river and hence it reaches the plant and let them end up in decomposition. In addition, the activities practiced around the river basin, like car washing, defecation and the likes could have to low DO level in Gibe river.

The average DO value of the river water was found 6.31 mg/l. The values of DO of different stations showed in Appendex 1. The optimum value of DO for good water quality is >5 mg/l. In both stations the DO values recorded was in accordance with the optimum values for good water quality, but in the second sampling station (DSS4 & DSS6), DO values were found a little bit higher, 7mg/l. The higher DO values in the study area indicate lower microbial load and no or less pollution of the river water or the river has a good potential to recover from anthropogenic disturbance.

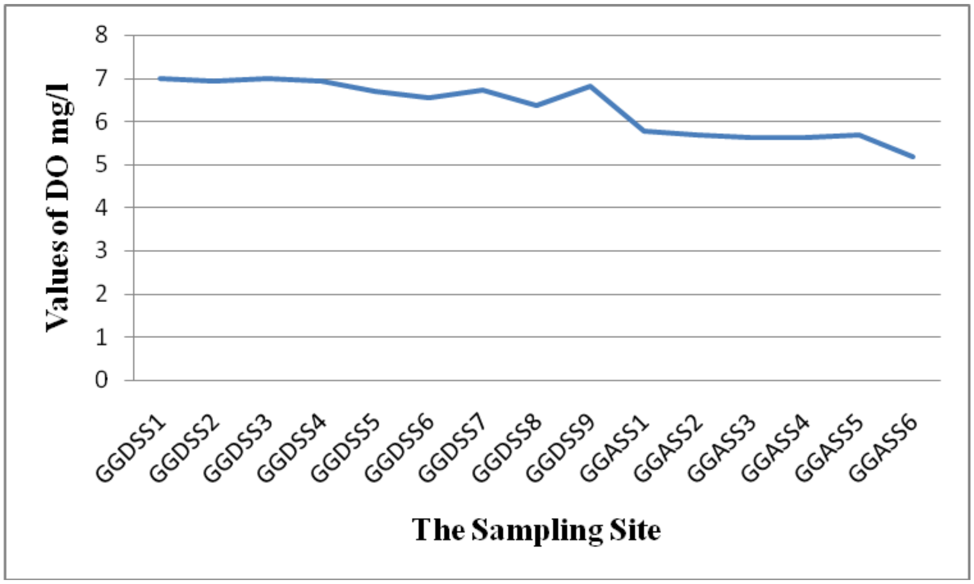

Fig 10: Mean value of DO in Gilgel Gibe River

4.1.4 Chloride

The findings of chloride ions in both sapling stations (GGASS & GGDSS) are shown in Appendex1 The WHO guideline for chloride ion is 250 mg/l. A goal of less than 200mg/l is recommended. Irrigation water should contain less than 200 mg/l. The minimum concentration of chloride ion recorded on both sites by consuming 0.6ml titrant was 0.999 mg/l (GGDSS2 and GGDSS7) and the maximum concentration of chloride recorded by consuming 0.6ml titrant was 2.999 mg/l (GGASS1, GGASS3 & GGASS4). These values are in line with both the WHO and EPA guideline values recommended for surface water quality, either for irrigation or for any other functions. The slow flow of the river, discharge of agricultural runoff and higher temperature of the downstream cause such conditions of dramatic change of chloride between sampling sites.

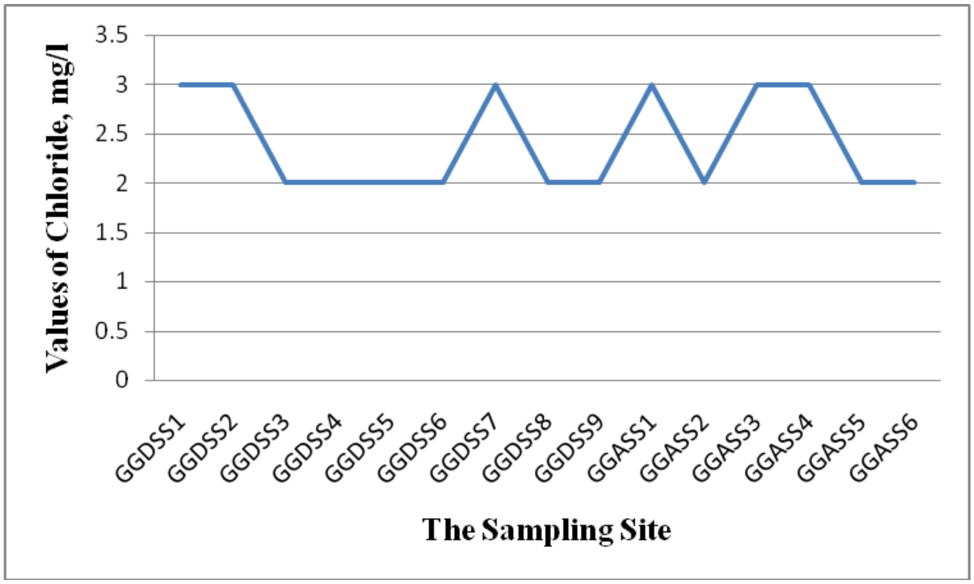

Fig 11: Mean value of Chloride in Gilgel Gibe River

4.1.5 Nitrate

The average value of nitrate ion observed on the study site was 0.64 mg/l and is less than 3 mg/l, which does not indicate significant man –made contribution (Pringle *et al*., 2000).

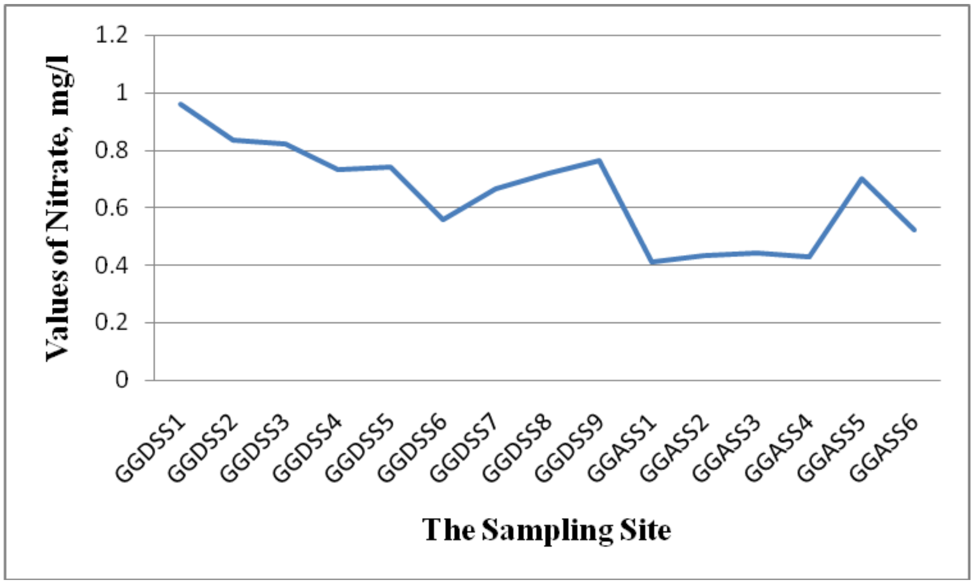

Fig 12: Mean value of Nitrate in Gilgel Gibe River

4.1.6 Phosphate

In this study, there was no as such significance change between all the fifteen sampling sites in the level of phosphate. The average concentration ranged between 0.093 mg/l (GGDSS3) to

0.185 mg/l (GGASS3). The higher levels of phosphorus observed on GGASS was most certainly due to the incorporation of different fertilizer and detergents incorporated by both the local widespread farming activities and different car washing activities, consecutively, in to the river water and aquatic organisms food chain. There is no legal water quality standard for the determination of phosphate in river water, but it is generally accepted that total phosphorus levels must be below about 0.10mg/l to prevent downstream eutrophication. (U.S. EPA, 2005).

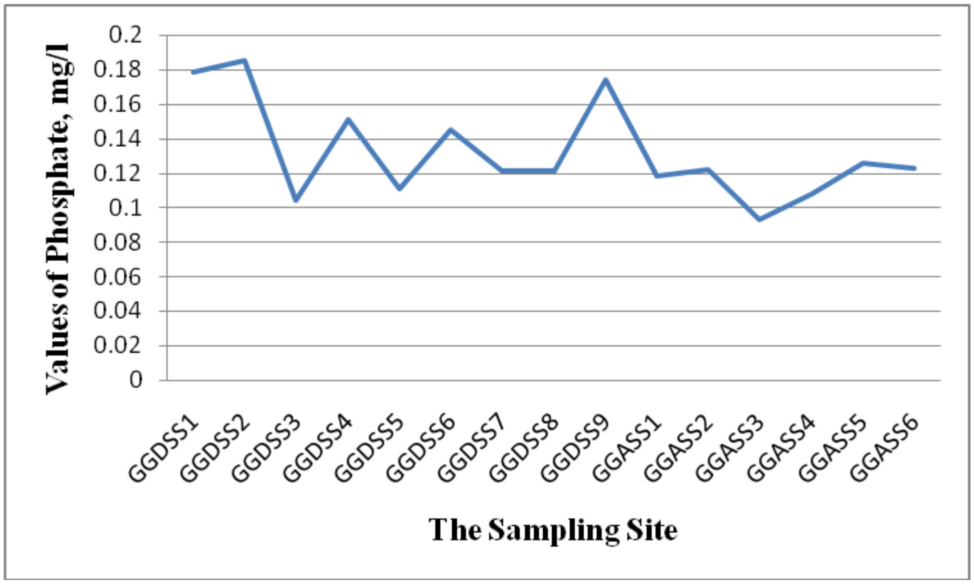

Fig 13: Mean value of Phosphate in Gilgel Gibe river

4.1.7 Calcium hardness

It is measured by complexometric titration with standard solution of ETDA using Patton's and Reeder's indicator under the pH conditions of more than 12.0. These conditions are achieved by adding a fixed volume of 4N Sodium Hydroxide. The volume of titre (EDTA solution) against the known volume of sample gives the concentration of calcium in the sample.

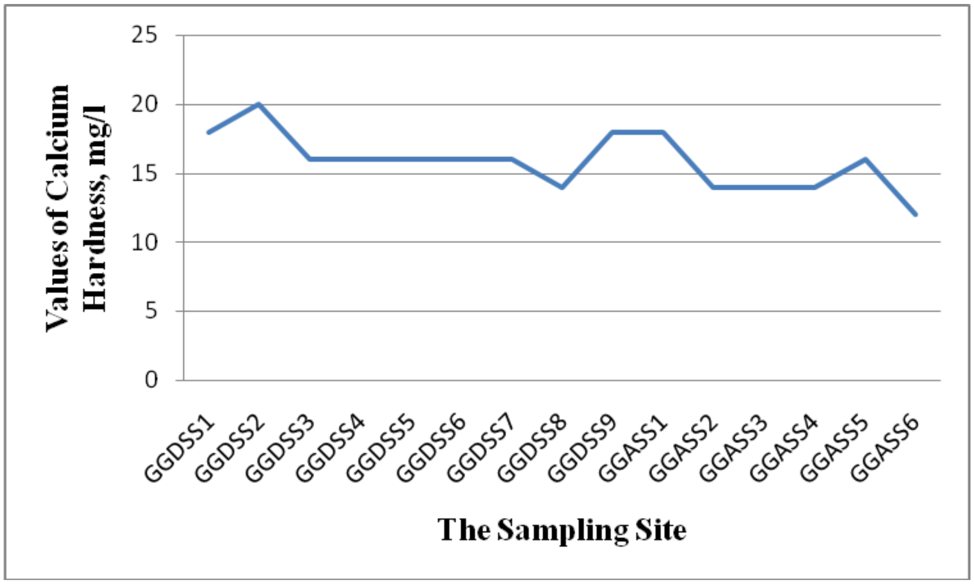

Fig 14: Mean value of Calcium in Gilgel Gibe river

4.1.8 Alkalinity

Based on the findings of the study, by using 1.5ml, 1.6 ml, 1.7 ml, 1.8 ml and 1.9 ml of titrant, the alkalinity of Gibe river water is more or less lower and similar throughout the sampling stations, ranging from 30 mg/l (at GGASS2) and 38 mg/l (at GGDSS1).

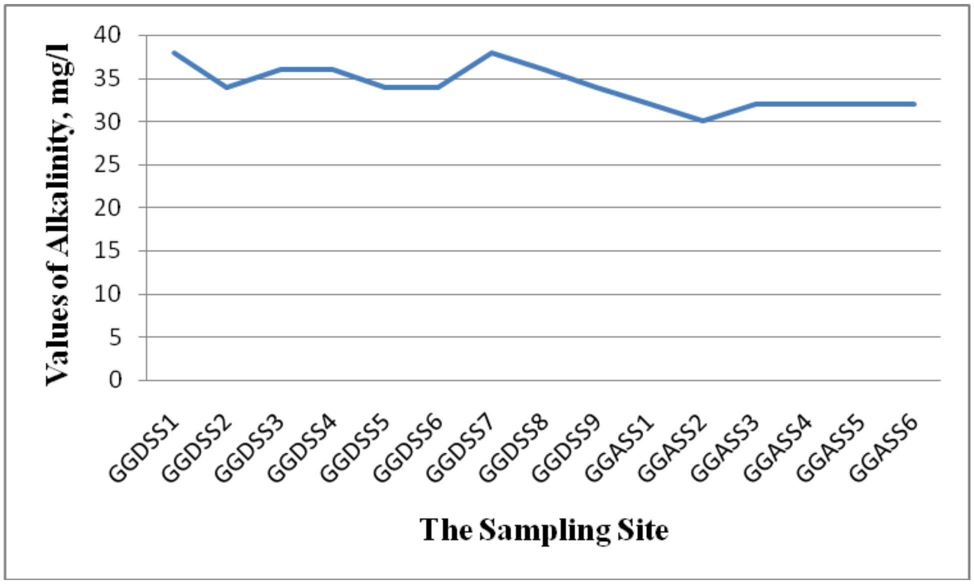

Fig 15: Mean value of Alkalinity in Gilgel Gibe river

4.1.9 pH

In this study, the pH level of the river ranged from 7.37 (GGASS6) to 8.44 (GGDSS9) which is neutral and slightly alkaline. pH is most important in determining the corrosive nature of water. Lower the pH value higher is the corrosive nature of water. pH was positively correlated with electrical conductance and total alkalinity(Guptaa 2009). The reduced rate of photosynthetic activity the assimilation of carbon dioxide and bicarbonates which are ultimately responsible for increase in pH, the low oxygen values coincided with high temperature during the summer month. Various factors bring about changes the pH of water. The higher pH values observed in some of the study site suggests that carbon dioxide, carbonate-bicarbonate equilibrium is affected more due to change in physico-chemical condition (Karanth 1987).

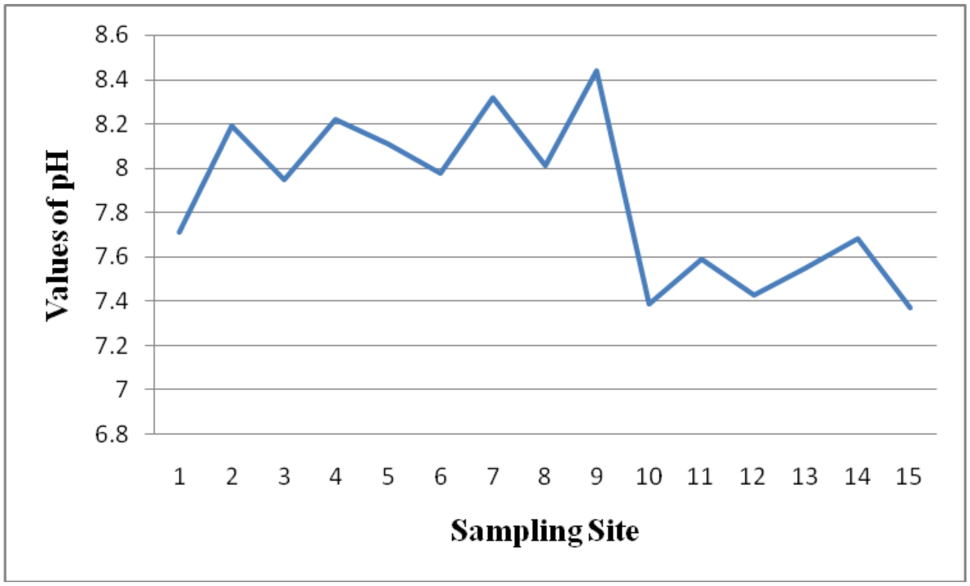

Fig 16: Mean value of pH in Gilgel Gibe River

4.1.10 The River Water Temperature

Among the stations the highest temperature was observed at GGDSS8 (23.9 ^{O}C) and lowest at GGDSS3 (19.1^{O}C). The fluctuation in river water usually depends on the season, geographic location, sampling time and temperature of effluents entering the stream (Ahipathy and Puttaiah, 2006). The standard value of temperature of river water is 20 ^{o}C - 30 ^{o}C (ECR, 1997).

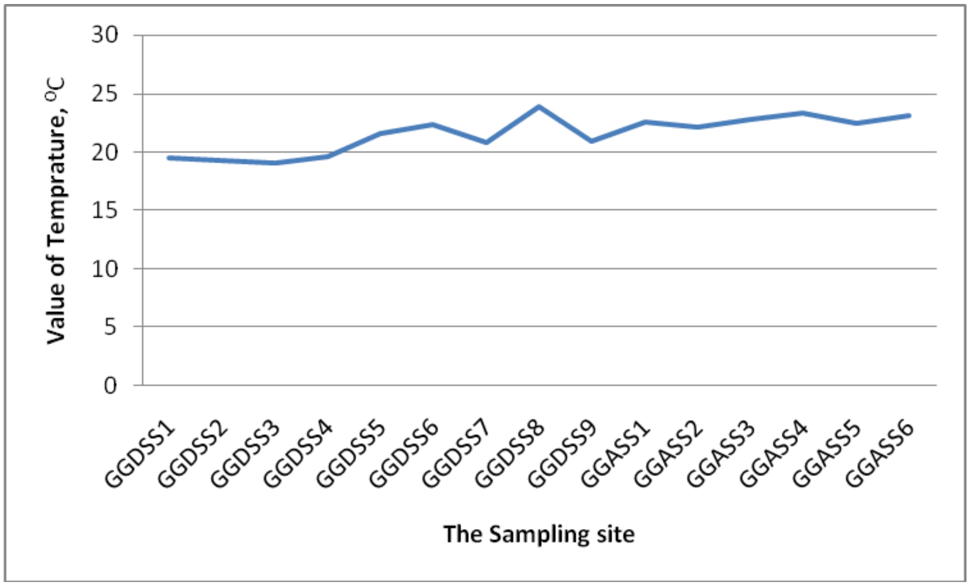

Fig 17: Mean value of water temperature in Gilgel Gibe River

4.1.11 Electrical Conductivity (EC)

The highest EC (86.9 µS/cm) found at the first sampling station, GGASS3, and likewise the lowest EC (70.4 µS/cm) found at GGASS2 are since both beyond the standard value set for the limit of surface water. The average value for EC in GGASS was 74.46 µS/cm and the average value in GGDSS 75.05 µs/ cm. These values are not above the permissible limit set for EC (300 µs/cm) the standard value which indicates there is no problem of pollution of the river.

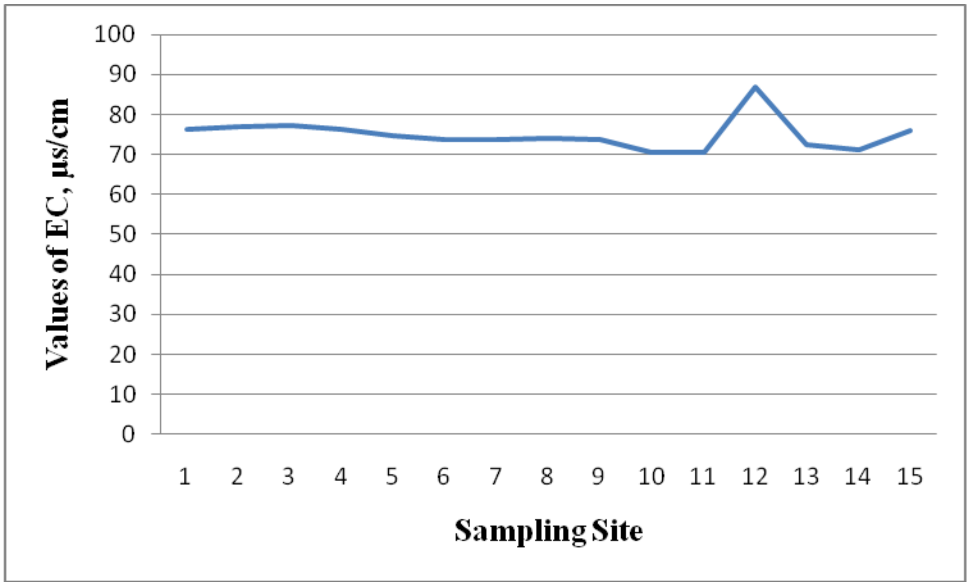

Fig 18: Mean value of EC in Gilgel Gibe river

4.1.12 Turbidity

Turbidity obtained in this work ranged between 64.2 NTU (GGDSS7) and 290.0 NTU (GGSS1). The highest Turbidity observed in GGSS1 is probably due to the extreme and sudden runoff addition to the river water.

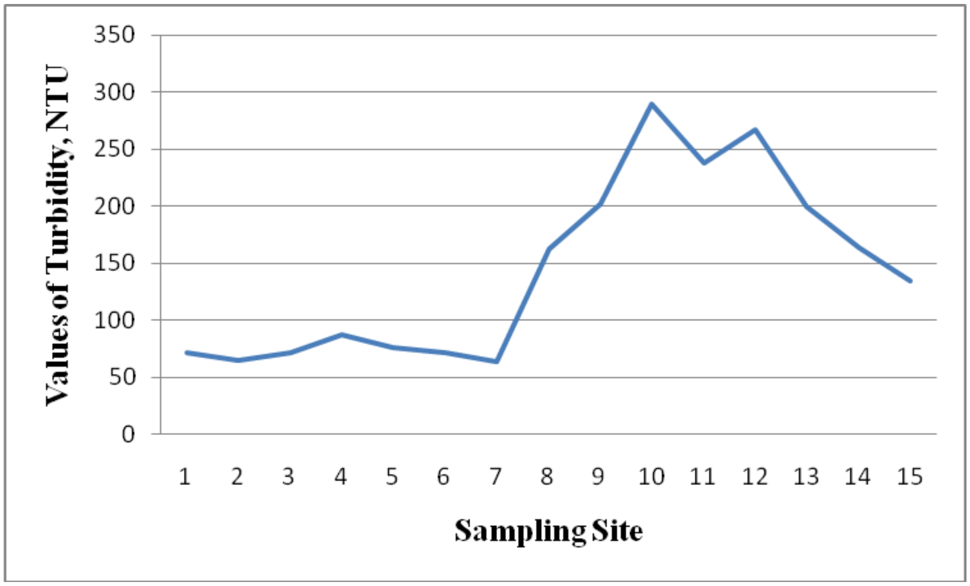

Fig 19: Mean value of Turbidity in Gilgel Gibe river

4.1.13 Flow rate of the river

Current flow rate is measured at each site where benthic macroinvertabrate and water samples were collected with a hand held mechanical flow meter (Model 2030R). Since flow rates are fundamental property of streams that affects everything from temperature of the water and concentration of various substances in the water to the distribution of habitats and organisms throughout the stream, it should be measured appropriately. One of the most important parameters, which affect the degree of the water pollution is the flow of the river. If the amount of the pollutants, discharged into the river is constant, high flows in the river would increase dilution and would lower pollution. Calculation and estimation of the degree of the river pollution could be performed if the amount of the pollutants and the discharge of the river are known. There are non point sources of pollution along the river basin, which could affect the estimation and the degree of the pollution. In this study, even if the majority of the study sites have more or less similar flow velocity, on average it can be said that the river flow velocity is 0.37 m/s.

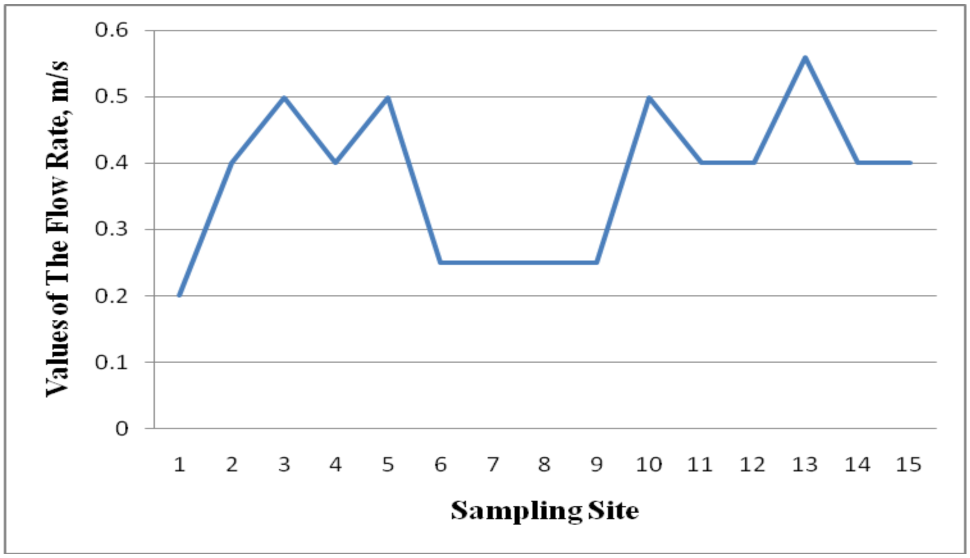

Fig 20: Mean value of The flow rates in Gilgel Gibe river

4.1.14 Total suspended solids (TSS)

The levels of total suspended solids recorded in the river were higher than the ambient standards for surface waters (< 50mg/l). The elevated levels of suspended solids concentration in Gilgel Gibe river could result discharge of farming debris, especially around GGASS sampling stations. The highest level was 700mg/l recorded in GGDSS9 and the lowest level was 113.3mg/l recorded in GGDSS6 and GGDSS7.

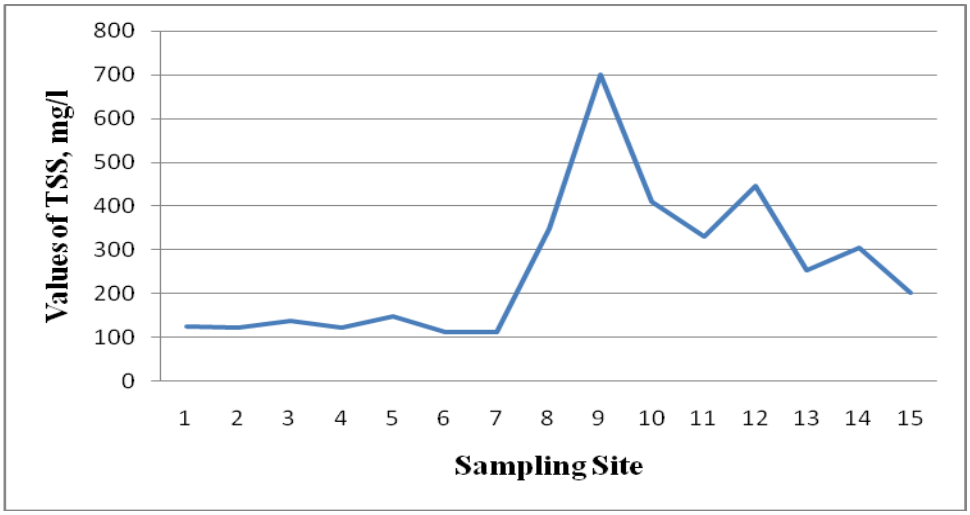

Fig 21: Mean value of TSS in Gilgel Gibe river

4.2. Benthic Macroinvertabrates

A total of 1132 macroinvertabrates representing 39 families and 6 higher order taxa were collected from fifteen study areas throughout the study period on the two sampling stations, GGASS and GGDSS. The minimum and maximum number of macroinvertabrates and the type of the invertebrate fetched are Philopotaminadae (1) and Athercidae (1) and Caenidae 309 consequently both at similar sampling stations (GGDSS). Caenidae (27%), the most abundant and Coinagrionidae (17%) are the smaller proportion of macroinvertabrate tallied among all the impacted sites. Results of the canonical correspondence analysis (CCA) based on the invertebrates assemblages with respect to environmental variables. PCA axis 1 explained 25.5% and PCA axis 2 explained 17% of the variability among sites. (NB: those, which explain the correlation by <10% is not needed (removed/ congested) (Fig. 19). Among the sorted and identified families the following are the common species found in all the fifteen (15) sampling sites; Chironomidae, Velidae, Heptagenidae, Coinagronoidae, Caenidae and Belostomatidae

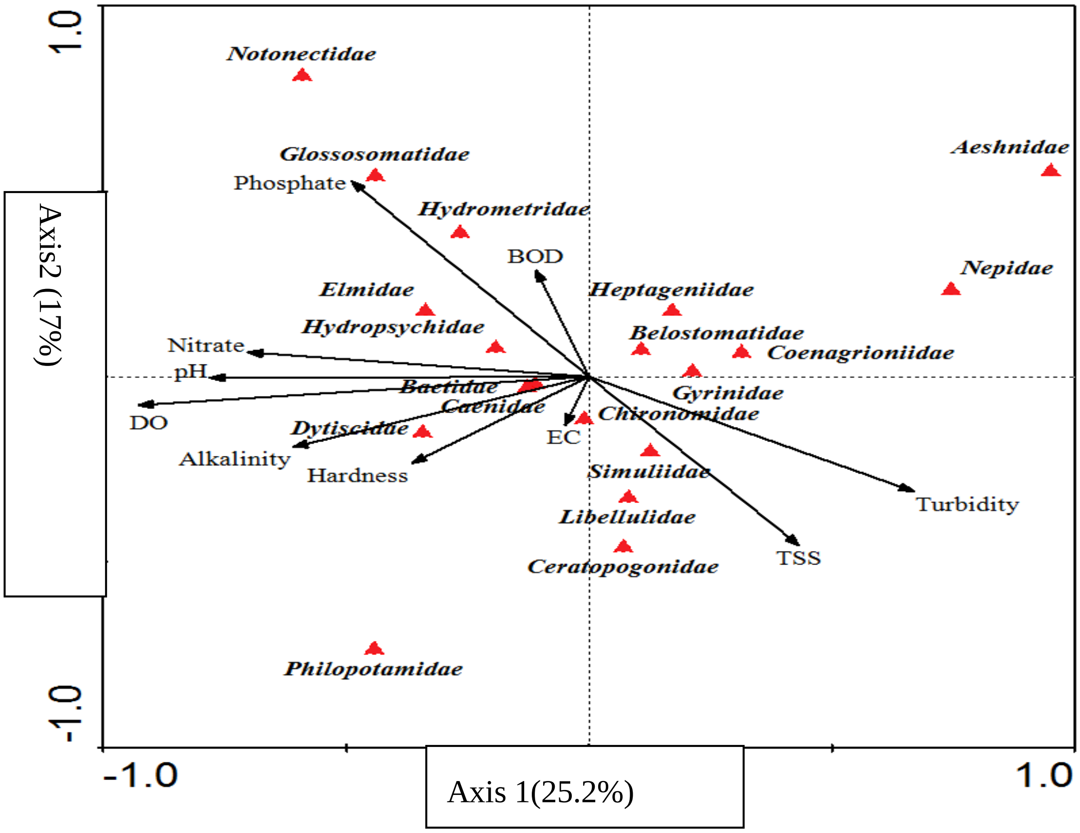

Fig 22: Canonical correspondence analysis (CCA)

As it is indicated in the figure above, at axis one Coenagrioniidae, Simulidae, Ceratopogonnidae, Chironomidae, Heptagenidae, Libelluliidae, Gyrinidae and Belostomatidae are positively corilated with the ingredient of Turbidity and TSS, whereas hardness, alkalinity, BOD and nitrite are negatively correlated with axis one. Axis one has a great correlation with the environment.

4.3. Diversity indices

A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composition than simply species richness (i.e., the number of species present); they also take the relative abundances of different species into account. By considering relative abundances, a diversity index depends not only on species richness but also on the evenness, or equitability, with which individuals are distributed among the different species .Its importance is, diversity indices provide important information about rarity and commonness of species in a community (Barbour *et al*., 1999). The ability to quantify diversity in this way is an important tool for biologists trying to understand community structure. Based on the species richness (the number of species present) and species abundance (the number of individuals per species), the more species you have, the more diverse the area is. Shannon index is an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled. The Simpson index is a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity (Liu *et al.,* 2008).

Table 2: Diversity indices of the Benthos macroinvertabrates

	Sites														
	A_1	A_2	A_3	A_4	A_5	A_6	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
Marglef's index, M	2.7	1.6	2.0	1.1	0.9	1.9	2.3	1.6	3.0	2.2	3.4	1.4	1.6	1.8	1.2
Simpson's diversity index, 1/d	0.9	0.7	0.6	0.4	0.4	0.1	0.6	0.7	0.7	0.5	0.9	0.8	0.7	0.4	0.5
Shannon-Wiener Diversity Index (H)	2.8	1.6	2.1	1.6	1.2	1.1	1.6	2.4	1.8	1.9	3.3	1.5	1.5	1.6	1.4
Pielou's index, J	0.9	0.8	0.9	0.9	0.9	0.5	0.7	0.8	0.7	0.8	0.8	0.8	0.7	0.7	0.8

NB: A= (GGASS) , D= (GGDSS)

Diversity indicates the quality of the water, either good or bad water quality. As it is indicated in table 3 Simpson's diversity index (D) takes values from zero (0) to one (1). It shows good diversity or bad diversity. Always values approaching one has good diversity, it has good water quality which means pollution and stress tolerant organisms live together (it has ecologically good water quality). Shanon Weber diversity index, H, takes numbers above one, 1 up to 10, the higher the score the better water quality, hence good diversity. Good diversity is coupled with good water quality. The diversity is less means, the sensitive taxa are diminished because of the bad water quality. Shanon weber index does not consider evenness. Pierlou's index, J, this indicates evenness, the higher the value, more even it is, it also measures abundance. The other one is Marglef's index, M, this is a measures of biodiversity, species richness. Pierlou's index and Marglef's index shows almost similar meaning, both calculate species richness. This means, individual occurrences (species evenness and species richness) will be taken in to consideration. The higher the value of this index, it has good water quality.

4.3.1. Simpson's Diversity Index (D)

Diversity within the benthic macroinvertebrate community was described using the Simpson's diversity index ("D"), which was calculated as:

$$D = 1-\sum_{\iota=1}^{s} (p_i)^2$$

Where "pi" is the proportion of individuals in the "i^{th}" taxon of the community and "s" is the total number of taxa in the community. This index places relatively little weight on rare species and more weight on common species (Barbour *et al*., 1996). Its values range from 0, indicating a low level of diversity, to a maximum of 1-1/s.

Table 3: Simpson's Diversity Index

Index	Sampling sites														
	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4	D5	D6	D7	D8	D9
Simpson's diversity, D	0.9	0.7	0.6	0.4	0.4	0.1	0.6	0.7	0.7	0.5	0.9	0.8	0.7	0.4	0.5

From Simpson's diversity index, the finding of the study indicates that since the values for the index ranges between zero (0) and one (1), almost half of the study area (A1-A3, D1-D3, D5-D7) have good diversity, that means stress and pollution tolerant species are living together, hence the river has good water quality.

4.3.2. Shannon-Wiener Diversity Index (H)

The Shannon-Wiener Diversity index (H) is commonly used to calculate aquatic and terrestrial biodiversity. This index was calculated as:

$$H = -\sum (p_i)(\log_2 p_i)$$

Where "p_i" is the proportion of individuals in the "i^{th}" taxon of the community and "s" is the total number of taxa in the community. As the number and distribution of taxa (biotic diversity) within the community increases, so does the value of "H".

Table 4: Shannon diversity index

Index	Sampling sites														
	A1	A2	A3	A4	A5	A6	D1	D2	D3	D4	D5	D6	D7	D8	D9
Shannon diversity Index (H)	2.8	1.6	2.1	1.6	1.2	1.1	1.6	2.4	1.8	1.9	3.3	1.5	1.5	1.6	1.4

The Shannon-wienner diversity index (H) takes a number greater than one (between one and ten). The higher the score, the better the water quality, and hence good diversity. In general, good diversity is coupled with good water quality. Here all the results depicted that the water has somehow dropped, since all the values are far from the standard value for good water quality, which is in fact a number close enough to 10. The sites A1, A3, D2, D3 - D5 has relatively good diversity with respect to other study sites. Hence, only the stated study sites got good water quality that showed us that it could support or accommodate both pollution tolerant and sensitive macroinvertatbrates.

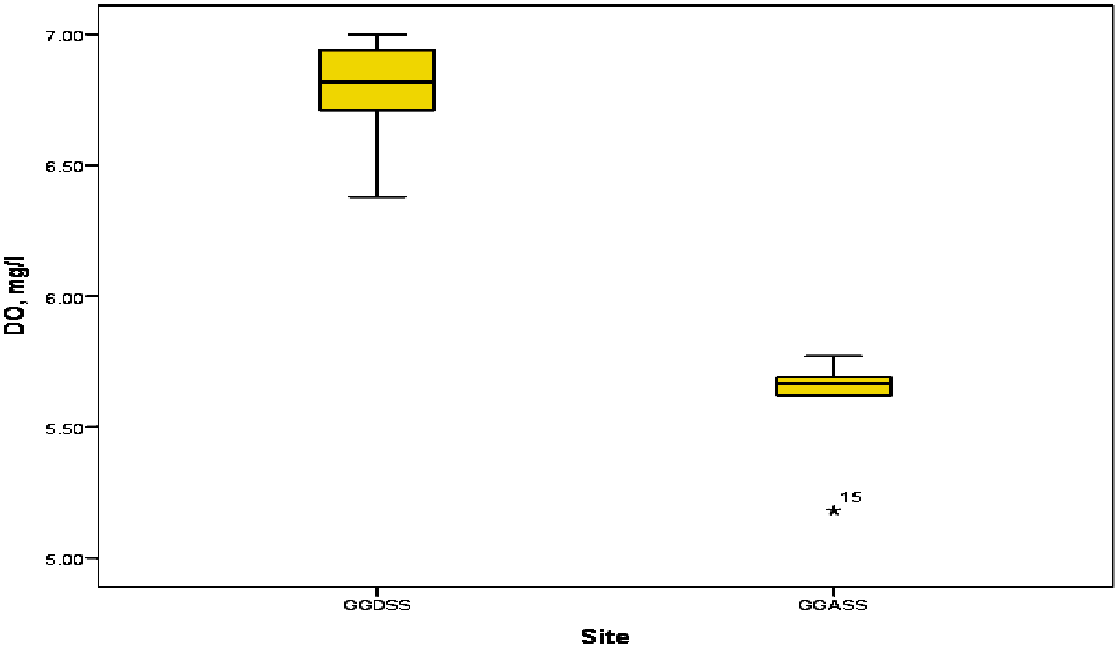

Fig 23: Box plot analysis of DO at the sampling stations

4.4 Metrics Selection

The multimetric approach uses a number of community attributes, which are known to be responsive to stream degradation due to human impacts (Karr *et al*.,, 1999). A number of metrics and indices were chosen that best describe the macroinvertabrates community at each sampling site of Gilgel Gibe River. Candidate Metrics (Table 4) representing richness measure (such as Total taxa richness), Tolerance measures (such as % tolerant taxa) and composition measures (such as % single most tolerant taxa) were considered for the index development for Gilgel Gibe River. Trophic measures (feeding Guilds) were not considered in index development as different functional feeding groups might present within the same family. In order for a metric to be selected for index development, it must have been able to discriminate between the study and reference sites. Invertebrate community attributes were selected as metrics based on:

1) Their ability to distinguish between reference and test sites
2) A significant relationship with disturbance
3) Their contribution of non-redundant information (not be linearly correlated with another metric or metrics)
4) Reliability and easy quantification from field samples (Karr *et al*., 1999; Jackson *et al*., 2000)

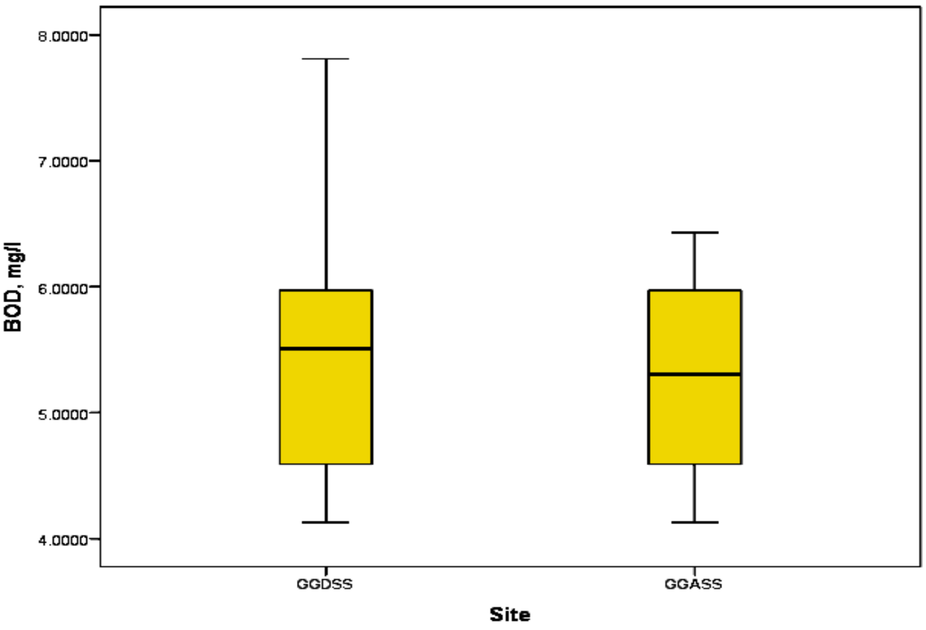

Fig 24: Box plot analysis of BOD at the sampling sites

4.5. Statistical Analysis

Tolerance values (Table-6) range from 0 to 10 for families and increase as water quality decreases. The index was developed by Hilsenhoff (Hilsenhoff, 1988) to summarize the varioustolerances of the benthic arthropod community with a single value. The Modified Family Biotic Index (FBI) was developed to detect organic pollution and is based on the original species-level index (BI) of Hilsenhoff. Tolerance values for each family were developed by weighting species according to their relative abundance.

In unpolluted streams, the FBI was higher than the BI, suggesting lower water quality was, and in polluted streams it was lower, suggesting higher water quality. 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. Thus, the FBI usually indicates greater pollution of clean streams by overestimating BI values and usually indicates less pollution in polluted streams by underestimating BI values. The FBI is intended only for use as a rapid field procedure. It should not be substituted for the BI; it is less accurate and can more frequently lead to erroneous conclusions about water quality (Hilsenhoff, 1988).

Table 5: Tolerance Values for Macroinvertebrates

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

(**source:** Resh *et al.*, 1996. Using data from Hilsenhoff, 1988)

4.6 Screening Candidate Metrics

Candidate metrics underwent a series of data reduction steps to come up with core metrics used to construct the IBI for the river. Metrics with too many low values at reference sites were rejected, as they could not able to reveal changed conditions. Those metrics that satisfied the first criterion were analyzed next by bivariate correlation analysis of SPSS statistical software package to evaluate the redundancy in information provided from the metrics and how well each metrics could discriminate between impaired and reference sites. The central goal was to select metrics that maximize the detection of stresses while minimizing the noise of natural variation.

Metrics were considered strong discriminator power if the difference between impaired and reference sites were significant (Spearman $R^2 = 0.95$, $p < 0.05$). Thus, metrics were maintained provided that a significant relationship exists between impaired and reference sites (Spearman/ $R^2/ > 0.95$, p,0.05) Ideally, every metric would show a response along a gradient of disturbance, but due to the varaiblity of sites of intermediate quality, a linear response is not always attainable (Mc Cormick *et. al.,*2001). In order to attain a robust set of metrics, some metrics were retained for redundancy testing that showed a significant response in the correlation. Metrics that are highly correlated with each other and show graphically linear relationship convey approximately the same information.

Table 6: Evaluation of water quality using FBI

Sites	FBI	Water quality
GGASS1	4.95	Good
GGASS2	6.05	Fair
GGASS3	7.99	Poor
GGASS4	7.99	Poor
GGASS5	8.39	Poor
GGASS6	6.21	Fairly poor
GGDSS1	8.81	Very poor
GGDSS2	7.35	Very poor
GGDSS3	6.25	Fairly poor
GGDSS4	6.33	Fairly poor
GGDSS5	5.55	Fair
GGDSS6	4.87	Good
GGDSS7	6.05	Fairly poor
GGDSS8	7.17	Poor
GGDSS9	3.25	Excellent

NB: GGASS= Gilgel Gibe Asendabo Sampling Site
GGDSS=Gilgel Gibe Dedo Sampling Site

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results obtained from analysis of water samples of Gilgel Gibe river are shown in Appendix 1 and Appendix 2. The reported values refer to the mean value of water samples collected in different sites at different areas along the stretch of Gibe river. The results indicate that the quality of water varies from location to location. A summary of the findings is given below.

The water temperature of Gibe river ranged between 19.1 ºC to 23.9 ºC. The electrical conductivity of water is affected by the suspended impurities and the amount of ions in the water. The highest conductivity 86.9 µs/cm of the Gibe water was observed in the first sampling station, Asendabo SS. the conductivity decreased and minimum conductivity 70.4 µs/cm was observed at similar sampling station, this could be due to the reduction of suspended impurities. The turbidity in Gibe river was lowest at the second sampling station, Dedo SS, which is 64.2 NTU. Moreover, the maximum turbidity observed in the river is seen on the same sampling station, Dedo SS, which is 290 NTU. Total suspended solids may affect water quality. Water with high Total suspended solids generally is of inferior potability. Total suspended solids were observed maximum 700 mg/l in Dedo SS and minimum 113.33 mg/l in Dedo SS. The pH of Gibe river was slightly alkaline. It ranged from 7.37 to 8.44.

Gibe river water contained lower dissolved oxygen, followed by a gradual increase to its lowest values in the second sampling station. The higher concentrations of dissolved oxygen in the second sampling station were probably due to low water temperature, no turbidity and increased photosynthetic activity of the green algae found on the submerged stones and pebbles. The maximum 7 mg/l oxygen content of water was recorded in the second sampling station and minimum 5.18 mg/l in the Asendabo SS. From Dedo SS the water of Gibe river starts becoming turbid which reduces the photosynthetic activity of the algae and thus decreases oxygen concentration. B.O.D. was maximum 7.81 mg/l in Dedo sampling station and minimum 4.13 mg/l in Asendabo SS. Total alkalinity throughout the study period ranges from 32 mg/l to 38mg/l in. The alkalinity due to carbonates was more or less nil. Maximum calcium 20 mg/l was found in Dedo SS. Minimum calcium 12 mg/l was found in Asendabo SS. Similarly, maximum magnesium 34 mg/l was found in Dedo SS and minimum magnesium 2 mg/l in Asendabo SS. Concentration of Calcium was always greater than that of magnesium. The hardness was higher in the Dado SS (50 mg/l) and lower in Dedo SS (20 mg/l). Calcium ions make major contribution to the hardness of river water. Phosphate was highest in Dado SS (0.183 mg/l) and lowest in Asendabo SS. (0.093 mg/l). The chloride was observed maximum (2.99 mg/l) variable and seen on both stations, minimum (1.99 mg/l) in similarly observed on both the sampling sites. The ordination analysis, the Canoco explains in Axes one the species Environment correlation 96% and Axes two explains 99%, which means Axes one is positively correlated with the ingredient of Turbidity and TSS. Whereas; Alkalinity, hardness, nitrate and BOD_5 are negatively correlated with axis one. Phosphate is positively correlated with Axis two. The pH has no correlation with any one of the axes.

Water characteristics differed significantly among sites (one-way ANOVA: F=5.44, P=0.02). The mean concentrations of ammonia, nitrate, chloride, $BOD_{5,}$ conductivity and turbidity were more elevated at all sites when compared with the standard values set by WHO and EPA. Turbidity was elevated in the first sampling station, GGASS, and on $GGDSS_{7,}$ $GGDSS_8$ and $GGDSS_9$ of the second sampling station. Except turbidity, all the parameters studied did not showed variations. The bio Oxygen demand (a measure of Organic Pollution) at the most affected site reached 35.1 mg/L that is about 15-folds above the recommended level (2.2mg/L) for surface water (Table 2). Furthermore, Evaluation of the water quality using the FBI, the collected data was found to be on varied values (Table 6). $GGASS_1$ and $GGDSS_6$ get a score, which is of good water quality, but probability of organic pollution. Whereas $GGASS_2$ & $GGDSS_5$ which is on the range of Fair and substantial pollution is expected. GGASS3, GGASS4, GGASS5 and GGDSS8 there is very likely substantial water pollution.

5.2 Recommendation

Based on the findings of the study, the following recommendations are forwarded for different stakeholders.

Since the demand of modern life may interfere with the Phosphorus cycle, more than any other, with the exception of the modern massive release of carbon dioxide, the mining of phosphorus is mainly to make fertilizer that is spread on farm land in generous quantities and hence this activity carried in to water ways by erosion and storm runoff. One consequence is over stimulation or overload of nitrogen and phosphorus in rivers and lakes that will cause eutrophication, a condition of excessive algae and weed growth and oxygen depletion by consuming the dead and dying algae, hence DO level will decline and it threaten the aquatic organisms in the river.

The communities around the river basin are advised not to exercise farming to the extent of the river and must practice plantation to create buffer zone. Community based watershed management excuted by the government must be continued at all levels of the communities living around the river basin. The government must create awareness on bio farming. Unsuitable way of exploring and using river water (example washing cars, clothes and discharging wastes) by the community must be managed. Further studies need to be conducted in order to know the seasonal variations of Gilgel Gibe river water quality. othe physicochemical and morphological analyses are recommended to be studied.

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APPENDEXES

Appendix 1: Mean value of Gilgel Gibe river water quality parameters

Parameter	SITE			
	GGDSS		GGASS	
	Mean ± SD D1+…D6	Standard error of mean	Mean ± SD A1+…A9/9	Standard error of mean
T^o	20.80 ± 1.62	0.54	22.77 ± 0.43	0.18
pH	8.1 ± 0.22	0.07	7.5 ± 0.12	0.05
EC	75.8 ± 1.51	0.50	74.47 ± 6.42	2.62
DO	6.79 ± 0.21	0.07	5.6 ± 0.21	0.09
Turbidity	97.08 ± 49.87	16.62	215.67 ± 60.14	24.55
Amb. T^o	22.85 ± 6.26	2.09	16.62 ± 2	0.82
Alk	35.56 ± 1.67	0.56	31.67 ± 0.82	0.33
Chlorine	2.33 ± 0.5	0.17	2.5 ± 0.55	0.22
Mg	11.78 ± 9.08	3.03	9 ± 4.52	1.84
Ca	28.44 ± 8.59	0.58	14.67 ± 2.07	0.84
TSS	16.67 ± 1.73	65.47	324.89 ± 91.83	37.49
Nitrate	215.55 ± 196.4	0.04	0.49 ± 0.11	0.04
Phosphate	0.75 ± 0.11	0.01	0.12 ± 0.01	0.01
BOD	5.41 ± 1.14	0.38	5.29 ± 0.86	0.35

Appendix 2: T-test for Equality of Means

	t-test for Equality of Means						
						95% Confidence Interval of the Difference	
	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp	-2.865	13	0.013	-1.96667	0.68646	-3.44967	-0.48366
PH	6.066	13	0.000	0.60167	0.09919	0.38737	0.81596
EC	0.279	13	0.784	0.61111	2.18771	-4.11516	5.33738
DO	10.607	10.958	0.000	1.18722	0.11193	0.94076	1.43369
Turbidity	-4.000	9.401	0.003	-118.58889	29.64910	-185.22609	-51.95169
Ambient	2.335	13	0.036	6.23222	2.66870	0.46684	11.99760
Alkalinity	5.263	13	0.000	3.88889	0.73896	2.29247	5.48531
Chloride	-0.598	10.142	0.563	-0.16667	0.27889	-0.78689	0.45355
T. Hard	1.425	12.326	0.179	4.77778	3.35291	-2.50623	12.06179
Calcium	1.957	9.484	0.080	2.00000	1.02198	-0.29403	4.29403
TSS	-1.449	12.036	0.173	-109.33500	75.44153	-273.65285	54.98285
Nitrate	4.491	11.079	0.001	0.26333	0.05863	0.13440	0.39227
Phosphate	2.127	13	0.053	0.02833	0.01332	-0.00045	0.05711
BOD	0.241	12.710	0.813	0.12500	0.51760	-0.99580	1.24580

Appendix 3: Royal Commission Classifications of rivers

Approximate BOD5, PPM	Classification
1	Very clean
2	Clean
3	Fairly clean
5	Doubtful
10	Bad

(**source:** Klein 1971)

Appendix 4: Pearson correlation coefficient for selected physico chemical parameter.

	To	pH	EC, µS/cm	DO, mg/l	Turbidity, NTU	Ambient, oc	Alkalinity, mg/l	Chloride, ml	TSS, mg/l	Nitrate, mg/l	Phosphate, mg/l	BOD, mg/l
T^o	1.00											
pH	-.54*	1.00										
EC, µS/cm	0.19	0.07	1.00									
DO, mg/l	-.8**	.826**	0.09	1.00								
Turbidity, NTU	.614*	-.585*	0.04	-.695**	1.00							
Ambient, oc	0.17	.647**	0.24	0.34	0.30	1.00						
Alkalinity,	-.58*	.613*	0.15	.800**	-.704**	0.36	1.00					
Chloride, ml	0.10	0.23	0.25	0.03	0.16	0.28	0.12	1.00				
TSS, mg/l	0.39	0.09	0.01	0.31	.783**	0.11	0.42	0.07	1.00			
Nitrate, mg/l	.730**	.625*	0.09	.814**	-.716**	0.19	0 .74**	0.12	0.30	1.00		
Phosphate, mg/l	-.546*	0.48	0.13	.550*	0.39	0.12	0.34	0.05	0.04	.607*	1.00	
BOD, mg/l	0.40	0.03	0.28	0.13	0.31	0.46	0.30	0.00	0.39	0.30	0.13	1.00

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

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

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Appendix 5: Macroinvertabrate Diversity and Abundance

Site code	Macroinvertabrate Diversity	Abundance	Tolerance value
GGASS1	Belostomatidae	6	10
	Caenidae	3	7
	Ceratopogonidae	4	6
	Chironomidae	12	8
	Coinagrionidae	38	9
	Gyrinidae	3	4
	Hydrometridae	1	-
	Hydrophilidae	2	5
	Hydropsychidae	1	4
	Libellulidae	1	9
	Nepidae	1	5
	Simulidae	8	6
	Veliidae	1	6
GGASS2	Baetidae	15	4
	Belostomatidae	4	10
	Caenidae	13	7
	Coinagrionidae	33	9
	Hydropsychidae	3	4
	Heptagenidae	6	4
	Simulidae	3	6
	Veliidae	1	6
GGASS3	Belostomatidae	9	10
	Caenidae	3	7
	Chironomidae	7	8
	Coinagrionidae	23	9
	Hydropsychidae	2	4
	Gyrinidae	9	4
	Hydrophilidae	2	5
	Libellulidae	11	9
	Simulidae	13	6
	Veliidae	6	6
GGASS4	Baetidae	19	4
	Chironomidae	3	8
	Coinagrionidae	29	9
	Caenidae	12	7
	Heptagenidae	9	4
	Veliidae	12	6
	Belstomatidae	5	10
GGASS5	Chironomidae	3	8
	Coinagrionidae	50	9

	Heptagenidae	7	4
GGASS6	Aeshnidae	2	5
	Beatidae	2	4
	Belstomatidae	2	10
	Chironomidae	1	8
	Caenidae	2	7
	Gyrinidae	6	4
	Heptagenidae	2	4
	Nepidae	2	5
	Veliidae	3	6
GGDSS1	Aphididae	1	-
	Baetidae	36	4
	Belostomatidae	3	10
	Caenidae	16	7
	Chironomidae	2	8
	Coinagrionidae	1	9
	Elmidae	1	4
	Hydropsychidae	2	4
	Heptagenidae	4	4
	Simulidae	1	6
	Veliidae	4	6
GGDSS2	Baetidae	5	4
	Belstomatidae	2	10
	Caenidae	28	7
	Chironomidae	6	8
	Coinagrionidae	1	9
	Dyticidae	2	5
	Elmidae	2	4
	Geridae	2	4
	Hydrometridae	3	-
	Glossosomatidae	1	0
	Hydrophilidae	1	5
	Hydropsychidae	7	4
	Mesoveliidae	5	5
	Nematoda	4	-
	Noctonoctidae	12	10
	Veliidae	3	6
	Athericidae	1	-
	Baetidae	10	4
	Belostomatidae	2	10
	Caenidae	37	7
	Ceratoponidae	2	6
	Chironomidae	10	8
	Dyticidae	3	5
	Elmidae	1	4

GGDSS3	Simulidae	2	6
	Heptagenidae	1	4
	Hydropsychidae	1	4
	Nematoda	5	-
	Philopotaminadae	1	-
	Veliidae	2	6
GGDSS4	Baetidae	17	4
	Caenidae	33	7
	Chironomidae	6	8
	Corixidae	1	5
	Glossosomatidae	1	0
	Heptagenidae	8	4
	Hydrometridae	2	-
	Hydropsychidae	14	4
	Oligochata	3	-
	Simulidae	1	6
	Veliidae	7	6
GGDSS5	Baetidae	17	4
	Belstomatidae	3	10
	Coinagrionoidae	2	9
	Veliidae	5	6
GGDSS6	Caenidae	49	7
	Chironomidae	3	8
	Aphididae	1	-
	Hydropsychidae	4	4
	Halodidae	2	5
	Hydrophilidae	6	5
GGDSS7	Belstomatidae	6	10
	Caenidae	33	7
	Elmidae	8	4
	Gyrinidae	3	4
	Hydropsychidae	7	4
	Velidae	3	6
	Baetidae	17	4
	Belstomatidae	3	10
	Caenidae	38	7

	Coinagrionidae	7	9
GGDSS8	Chironomidae	4	8
	Hydropsychidae	4	4
	Libelilludae	4	9
	Velidae	3	6
	Baetidae	26	4
	Caenidae	24	7
	Chironomidae	10	8
	Coinagronoidae	3	9
GGDSS9	Corixidae	1	5
	Dyticidae	2	5
	Geridae	1	5
	Halodidae	2	5
	Hydropsychidae	2	4
	Veliidae	6	6