JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULLTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENVIRONMENTAL ENGINEERING POST GRADUATE PROGRAM

ASSESSING WATER QUALITY USING PHYSICO-CHEMICAL PROPERTIES AND BENTHIC MACROINVERTEBRATE OF AWETU RIVER

BY: BAHIRU JIHAD

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN ENVIRONMENTAL ENGINEERING

DECEMBER, 2021

JIMMA, ETHIOPIA

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MAIN ADVISOR: Dr. DEJENE BEYENE (PhD)

CO- ADVISOR: Mrs. SEBLEWENGEL MILERGAH (MSc)

DECEMBER, 2021

JIMMA, ETHIOPIA

DECLARATION

I declare that this thesis in title "Assessment of pollution status of Awetu River, using physico-chemical parameters and macroinvertebrate matrices " is my original work and has not been submitted for the award of any degree in Jimma university or elsewhere.

Bahiru Jihad ______________________ ________________________
(Student) Signature Date

As research adviser, I hereby certify that I have read and comment this thesis done under my guidance by Bahiru Jihad Aba Gojem and recommend to be accepted for a fulfilling the requirement for the degree masters of science in Environmental Engineering.

Dejene Beyene (PhD) ____________________ ___________________
(Main Advisor) Signature Date

Seblewengel Milergah (MSc) __________________ ____________________
(Co- advisor) Signature Date

ABSTRACT

The surface water quality is a matter of serious concern today. Rivers due to their role in carrying off the municipal and industrial wastewater and run-off from agricultural land in their vast drainage basins are among the most vulnerable water bodies to pollution. Awetu river is subjected to different types of anthropogenic pressures varying in extent from upstream to downstream, thereby creating spatial variability of water and habitat quality in the stream segment. The main objective of this study was assessing water quality using physicochemical properties and benthicmacroinvertebrate metrics. The assessment were assessed using physicochemical parameters, physical habitat assessment, biotic indices /metrics , human activity by observation as well as macroinvertabretes samples from fifteen sampling sites coded AWS1 to AWS15 along the river using the standard procedures. Six water quality parameters were tested in situ, namely temperature, pH, dissolved oxygen, total dissolved solid, Electric conductivity and Turbidity by employing multi Prob analyzer. Other parameters namely ammonia, total suspended solid, nitrate, nitrite, Ortho phosphate, total Phosphate, total suspended solid, BOD_5 and COD were tested in the laboratory. Benthic macroinvertebrates were sampled at each sampling site using a rectangular frame net (20 × 30 cm) with a mesh size of 300 μm, and identified to the family level following the standard methods in the laboratory. Water quality paramaters were analyzed using standard methods while the habitat quality class was quantified using the qualitative habitat evaluation index(QHEI). Multivariate statistical analyses were computed to describe the macroinvertebrate assembledge. Benthic macroinvertebrate assemblages were determined by, number of taxa, and the total number of individuals, by computing various indices. Detrended correspondence analysis (DCA) was also applied to evaluate the relationship between benthic macroinvertebrate community and physicochemical water parameters. The range values of surface water temperature was 19.6 to 23.6°C, dissolved Oxygen 3.2 to 7.8mg/l, BOD_5 4.5 to 6.7 mg/l, EC 63 to 127μs/cm and NH4 -N 0.29 to 1.33 mg/l. A total of 1621 macroinvertebrates individuals within 33 taxas belonging to 13 orders were identified from the 15 sampling sites. The most abundant orders were: Ephemeroptera 31%, Trichoptera 18%, Odonata 15% and Diptera 10% represented by 14 families. The results revealed that macroinvertebrate distribution varied considerably with the change in anthropogenic activities and habitat conditions in the study area. Upstream sites were found to have significantly better ecological water quality than downstream sites based on indices and metrics. The downstream sites were the most impacted by urbanization, had the poorest water quality scores than upstream sites.

Keywords: Anthropogenic activity, biotic integrity, Macro-invertebrates, physical habitat,

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ACRONYMS& ABBRIVATION

ANOVA	Analysis Of Variance
APHA	American Public Health Association
EPA	Environmental Protection Authority
BOD	Biological Oxygen Demand
BI	Biotic Index
CCA	Canonical Correspondence Analysis
COD	Chemical Oxygen Demand
DCA	Detrendend Correspondence Analysis
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPT	Ephemeroptera, Plecoptera, Trichoptera Index
FBI	Family Level Biotic Index
FDREEPA	Federal Democratic Republic of Ethiopia Environmental Protection Authority
FFG	Functional Feeding Groups
FR	Flow Rate
GPS	Global Positioning System
IBI	Integrated Biotic Index
JiT	Jimma institute of Technology
JU	Jimma University
m a.s.l.	Meter above sea level
MI	Monitering Index
NMA	National Meteorology Agency
NTU	Nephelometric Turbidity Unit
PCA	Principal Component Analysis
pH	Hydrogen ion concentration
RCC	River Continuum Concept
UNEP	United Nation Environmental Protection

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Water is the most important component among the natural resource. The availability of adequate water in terms of quality and quantity is essential to all the forms of life: from very small creature to very complex systems of animals and human being existence. In the past, people only recognized the importance of water from a quantity view point rather than quality (Adewoye *et al*., 2010). Rivers are vital component of the biosphere that contains less than one percent of the world's fresh water with their higher ecological and social significance which are being polluted by indiscriminate disposal of sewerage, industrial waste, Excess of human activities also affecting their physicochemical characteristics and leads to various deleterious effects on aquatic organisms (Murhekar, 2011; Annalakshmi and Amsath, 2012).

Anthropogenic practices have a direct impact on the quality of surface water in aquatic environments in watersheds (*Massoudet et al.*, 2006). Increased water pollution not only degrades water quality but also poses a risk to human health, ecological system balance, economic growth, and social prosperity (Milovanovic, 2007). Discharges of pollutant into the freshwater ecosystem result in a decrease in aquatic life (Sun *et al*., 2018). Thus, uncontrolled waste release from municipal, domestic, agricultural, and industrial facilities may have an effect on the quality of water bodyies (Alie, 2019). Changes in land and water use have resulted from human population increase, posing a growing threat to biodiversity and ecosystem services (Lindborg, 2015; Selemani *et al*., 2018). Physico-chemical and biological diversity are very important to the health of an aquatic ecosystem like rivers and other freshwater systems (Venkatesharaju *et al*., 2010). Currently, the physico-chemical and biological water quality parameters changed from point to point and consequently affect macroinvertebrates composition in a stream or river (Monoj & Padhy, 2013). Therefore it can be inferred the health of river between system and by checking the availability of certain macroinvertebrates (Griffin *et al*., 2015). There is a high probability that the rising temperature due to climate change would negatively affect the water quality of river systems (FAO, 2018). The threat to water quality will be severe in Africa where annual stream flow is the lowest in the world as compared to other continents (Brooks *et al*., 2007). One of the most critical problems of developing countries is the ever increasing population and the progressive adoption of an industry processing based lifestyle that has led to an increasing anthropogenic impact on the ambient environment and river water bodies. In South west Ethiopia, water bodies are the primary dump sites for disposal of wastes, especially the effluents from coffee processing plants containing wide varieties of synthetic and organic wastes that are near them (Alemayehu Haddis and Devi, 2008; Abebe Beyene et al., 2011).

Jimma is one of a town in Southwest Ethiopia with low environmental awareness and inadequate waste management, such as a shortage of waste treatment facilities. As a result, solid and liquid wastes are dumped indiscriminately into the city's rivers, resulting in contamination and human health threats (Haddis et al., 2009). Untreated wastewater and solid wastes generated by inhabitants of Jimma town are directly dumped into the tributaries of Awetu and Boye wetlands (Mereta *et al*., 2013). In addition, river incisions and back erosions as a result of heavy rainfall, steep slopes and deforestation have been contributed to landslides in the catchment (Broothaerts *et al*., 2012). Therefore; the study on assessment of pollution status of Awetu river, using physico-chemical parameters and macro invertebrate metrics is the key to understanding the structure of the assemblages inhabiting them and the correlation between species and the environment. In addition, the response of macroinvertebrates is also important when analyzing invertebrate data for evidence of episodic disturbances or general declines in water quality across multiple streams in study area. Despite alarmingly rising water quality problems in Ethiopia, there is no routine water quality monitoring so far (Ambelu, 2009). Only few studies were conducted to assess status of water pollution on rivers using benthic macroinvertebrates (Beyene et al., 2009). However, the information about the biodiversity of benthic macroinvertebrates in relation to their response towards habitat quality and human impact is limited. Moreover, the lack of research in relation to the response of macroinvertebrate to habitat quality and anthropogenic disturbances in rivers has motivated the current study, whose purpose is to verifying response of macroinvertebrates for habitat quality and anthropogenic disturbance on the Awetu river of Jimma town, Ethiopia.

1.2. Statement of the Problem

In different parts of the world, rivers are the major sources of water to satisfy human needs for: domestic uses, agriculture, energy generation, transport, industries, and recreation (Anbalagan *et al*., 2012). Worldwide problems in ecosystem health and interest to understand the status of biological diversity have increased the demand for ecological information. Although the structure of biotic communities and ecosystem function do not always respond equally to anthropogenic stress; and human induced changes can affects physical structure of stream or fresh water, concentrations of dissolved chemicals in water, living organisms and ecosystem function. Hence, in order to assess ecosystem situation in response to human stressors the measurements of both structural and functional parameters should be considered (Cláudia *et al.*,2013).

Majority of the Ethiopian surface water resources have faced serious quality deterioration that mainly resulted from increasing anthropogenic activities. Furthermore, activities within a catchment are ultimately affect the river draining and affects the users and abusers directly or indirectly (Alemayehu *et al*., 2008). The health of streams and rivers can be influenced by different factors such as their geomorphologic characteristics, hydrological and hydraulic regimes, physicochemical water quality, nature of stream and riparian habitats. Additionally, combined influences of urban development, pollution, bank erosion, deforestation and poor agricultural practices are the major degrading factors of running water. Despite alarmingly rising water quality problems in Ethiopia, there is no routine water quality monitoring so far. Only few studies were conducted to assess effects of urban pollution on rivers using benthic macroinvertebrate. However, the information about the biodiversity of benthic macroinvertebrates in relation to their response towards habitat quality and human impact is limited. In the study area, it is subjected to municipal and domestic sources of pollution.

Like coffee processing industry, illegal car washes are established near the river for easy discharge of the effluent into the river. Among these no one has effluent treatment plant; all of them release untreated effluents into the river. Those activities are jointly posing series pollution problem on the River ecosystem and local communities. In addition to domestic and municipal wastes from hotels and individual households together with toilet discharge join the river. Wastes generated from these sources degrade the river ecosystem together with the physical alterations. But, in this year the town administration by giving attentions and allocate budget and beginning the rehabilitation and construction of channelization work of the River bank of Awetu River.

In Awetu River basin, huge amount of pesticides and fertilizers have been employed and there is no data about the physicochemical and macroinvertabrates, which measures of total organic lodging in river water. Thus, still now no strong water quality research is conduct on River water quality. Hence, current study provides valuable information on the quality of the River. Therefore, there is a need to conduct study over suitability of Awetu River in Jimma town. The present study is the use of physicochemical parameters and macroinvertebrates biometrics to assess biotic integrity and pollution status of the river.

1.3. Objectives of the study

1.3.1. General objective

The general objective of this study is assessing water quality using physicochemical properties and macro invertebrate matrices.

1.3.2. Specific objectives

1. To assess the physicochemical properties of a river water in the study area,
2. To assess macroinvertabrates community assemblage in the study area,
3. To correlate physic-chemical parameter of the River and micro invertebrate metrics,
4. To evaluate the physical habitats status at the sampling sites along the river,

1.4. Research Questions

1. What are the ranges of water quality variation along Awetu River flow?
2. What are the differences in macroinvertabrates community assemblage along the study area?
3. What is the relation between physicochemical parameter of the River and micro invertebrate metrics?
4. What is the status of physical habitat characteristics along the River in study area?

1.5. Significance of the study

Since there is no research that has been attempt on the quality assessment of surface water in this area, data from this study will contribute for the sustainable management of surface water resources in this study area. This study can help to develop and implement effective control methods and intervention strategies for the pollution of streams. Additionally, it provides information evaluating the pollution of the river from anthropogenic disturbance and habitat degradation for further studies. The research will be believed to help in planning interventions to preserve or manage water systems, to ensure its biological integrity. Besides it will helps to define the status and level impact on the environment. The researcher also optimistically believes that, the primary beneficiary of this research will be the community of the study area in general and, a government structure in particular. Furthermore, it will serve as a lighting house for future researches in this particular area. Finally, it will help as a reference or literature for practitioners who are interested on the related issues.

1.6. Scope of the study

The study focuses on analyses of selected physicochemical parameters and on the identification of impact indicator species (macroinvertebrates and habitat quality) as well as pollution status of the river. Selected physicochemical parameters and bioindicators of the impact level helped the study to have a broader view on the impact of anthropogenic activities on the natural environment. The scope of the study was restricted to around 7.45 km stretch of Awetu River and its surroundings up to 30 m from the river bank. All the study areas were selected on the basis of the relative anthropogenic influence that they experience, as well as kinds of pollution the areas were experiencing.

1.7. Limitation of the study

The analysis of water quality, habitat quality and identification of macroinvertebrates needs intensive financial cost, time (dry and wet season) and full laboratory facilities. However, due to time limit and budget constraint the dry season data was not collected, because it was wet (Rainy) season. The other challenge was laboratory facilities to do water quality parameter analysis. Thus, the study was carried out with some of the physico-chemical parameters and water variables measured that need future studies for the remaining water quality parameters like heavy metals.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Quality of River water

Water quality can be defined as a measure of physical, chemical, biological, hydromorphological and aesthetic properties of water (Giri & Qiu, 2016). Chemical and physical assessment is widely utilized to evaluate the extent of pollution of water bodies from industrial and other sources. However, the combination of biological assessment with physico-chemical assessment is the most appropriate means of detecting effects of pollution on the aquatic systems, because it can detect cumulative physical, chemical and biological impacts of adverse activities to an aquatic system (Mandaville, 2002; US EPA, 2002; Davis *et al*., 2003). Water quality provides current information about the concentration of various solutes at a given place and time. Its quality parameters provide the basis for judging the suitability of water for its designated uses and to improve existing conditions (Ali et al., 2004).There is no single or simple measure for water quality. Water may be tested for a few characteristics or numerous natural substances and contaminants depending on their needs. The nature and extent of water pollution is characterized by several physical, chemical and biological parameters (Chitmanat and Traichaiyaporn, 2010). Quality of water can be regarded as a network of variables such as pH, oxygen concentration, temperature, etc. and any changes in these physical and chemical variables can affect aquatic biota in a variety of ways (Kolawole *et al*., 2011).

2.1.1. Physicochemical Parameters

Freshwater body has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geo morphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer (Sarah, 2011). The selection of variables for any water quality assessment programmed depends upon the objectives of the programmed. According to Rangeti *et al.* (2015), the first stage in determining water quality is parameter selection. This is due to the lack of resources, which makes it difficult to monitor all water quality parameters and therefore only few but most crucial parameters should be taken into account. The type of chemical and physical analysis done on each sample is determined by the goal of the study, and available resources (Agency *et al*., 2001). Temperature, dissolved oxygen (DO), TSS (total suspended solids), TDS (total dissolved solids), electrical conductivity, pH (power of hydrogen), nitrate, nitrite, ammonia, Total phosphate, $BOD_{5,}$ COD and Ortho phosphate are selected parameters for this study because mainly they influence the quality of aquatic ecosystems (Chang *et al*., 2019).

2.1.1.1. pH

Both high and low pH poses adverse effect on stream biota. Ahmed & Rahman (2000) reported that in most raw water sources pH lies in the range of 6.5- 8.5. The standard value of surface water ranges from 6.5-8.5 (ECR, 2007). The pH of the water is important because affects the solubility and availability of nutrients and how they can be utilized by aquatic organisms. Aquatic organisms are very sensitive to the pH of the aquatic environment because most of metabolic activities are pH dependent. The pH higher than 7 but lower than 8.5 is ideal for biological productivity, while pH lower than 4 is detrimental to aquatic life (Abowei, 2010). Most organisms, including shrimps, do not tolerate wide variations of pH over time and, if such conditions persist, death may occur. Therefore, waters with little change in pH are generally more conducive to aquatic life.

Naturally occurring fresh waters have a pH range between 6 and 9: the concentration range 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 it affects the solubility and availability of nutrients and how they can be utilized by aquatic organisms. It also alters 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 aquatic organisms are pH dependent (Wang *et. al.,* 2002).

2.1.1.2.Temperature

Temperature of water is a very important physical parameter to assess thermal pollution and associated effects on aquatic biota. This is because abnormal water temperature alters chemical reactions, reaction rates and solubility of gases (A.A.EPA, 2005). Benthic macroinvertebrates prefer cold water as cold waters hold more dissolved oxygen than warmer waters. Temperature affects the growth and reproduction of aquatic organisms. If the temperature gets too high or too low, the local population of the species decreases. Temperature also affects water chemistry, which intern affects biological activity. A sudden change in the temperature of river water can lead to a higher rate of mortality of aquatic biota (Fakayode, 2005).

2.1.1.3.Electrical Conductivity

Electrical conductivity (EC) is measuring the ability of water to conduct an electrical current (Carr & Rickwood, 2008). The increase in land use practices in the catchment influences higher TDS. This is also contributing to increase EC. High EC indicates that the water is salty which is not acceptable for macroinvertebrates because some of them cannot tolerate such conditions (Carr & Rickwood, 2008). Inorganic dissolved particles such as nitrate, sulphate, and salt, as well as temperature, influence conductivity in water. Generally, most conductivity in fresh water range from 10 to 1000 μS/cm (WHO, 2011).

2.1.1.4.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.*, 2013). 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 turbidity is influenced either naturally by rainfall runoff or by anthropogenic activities. Wastes from industries influences turbidity. Turbid water affects for photosynthesis by limiting the penetration of light (Carr and Rickwood, 2008).

2.1.1.5.Nitrate –nitrite (NO_3-N)

According to Bwalya (2015), nitrogen-containing elements (nitrates, nitrites) are essential for all biotic processes in the aquatic environment. The increase of nitrate concentration in watercourses is due to anthropogenic activities. When it rains, the runoff from agricultural activities carries fertilizers to the watercourses that cause pollution of water bodies. The increase of nitrate causes excessive algal growth. Upon decomposition excessive algal growth lowers oxygen levels thereby some aquatic organisms that cannot tolerate anaerobic conditions (Mwangi, 2014). Human activities and various land use patterns contribute to high nitrate levels in surface waterways (agricultural runoff, cattle grazing or their waste, washing activities and discharge from sewage) (Mwangi, 2014). Nitrate beyond their acceptable level affects organisms including human beings. Nitrate, on the other hand, is far less harmful than ammonia and nitrite (Romano & Zeng, 2007; Ward, 2009). Similarly, excessive ammonia and phosphorus in water results in an undesirable color, taste, and odor. (Hellar- Kihampa et al., 2013).

2.1.1.6.Total phosphorous and phosphate

Phosphates enter the water ways through both non-point sources and point sources. Nonpoint source (NPS) pollution refers to water pollution from diffuse sources. Nonpoint source pollution can be contrasted with point source pollution, where discharges occur to a body of water at a single location. The non-point sources of phosphates include: natural decomposition of rocks and minerals, storm water runoff, agricultural runoff, erosion and sedimentation, atmospheric deposition, and direct input by animals/wildlife; whereas: point sources may include: wastewater treatment plants and permitted industrial discharges. In general, the non-point source pollution typically is significantly higher than the point sources of pollution. Therefore, the key to sound management is to limit the input from both point and non-point sources of phosphate. High concentration of phosphate in water bodies is an indication of pollution and largely responsible for eutrophication (MacCutheon *et al*., 1983).

2.1.1.7. Oxygen Demand (BOD_5)

According to Bhateria and Abdullah (2015) BOD_5 is the measures of the amount of oxygen that is required by microorganism for aerobic decomposition of organic matter present in water. BOD is an important parameter in aquatic ecosystem since it indicates the status of pollution (Bhateria and Abdullah, 2015). BOD_5 can be affected by human activities in the riparian areas, which destroy the buffering capacity of the river against pollutants emanating from the catchment. The greater the BOD, the more rapidly oxygen is depleted in the water body, because microorganisms are using up the DO (Masese *et al*., 2015).

The five day BOD is the most widely used parameter of organic pollution applied to surface waters. It is the amount of dissolved oxygen taken up by aerobic microorganisms to degrade oxidisable organic matter present in the stream measured a period of five (5) day (EPA, 2005). BOD normally gives an indication of biodegradable organic matter. The determent of high BOD is the same as low dissolved oxygen: aquatic organisms stressed, suffocated, and die.

2.1.1.8. Dissolved oxygen (DO)

Dissolved oxygen is the dissolved gaseous form of oxygen. Oxygen enters water by diffusion from the atmosphere and as by product of photosynthesis by algae and other plants. Loss of dissolved oxygen is caused by respiration, decay by aerobic bacteria and decomposition of decaying sediment (Gupta and Gupta, 2006). Dissolved oxygen is the most important variable that affect water quality as insufficiency of oxygen will allow aquatic organisms to give in to stress, leading to their death or becoming more susceptible to parasites and diseases (King and Jonathan, 2003). The lowest acceptable dissolved oxygen concentration for aquatic life, ranges from 6 mg/l in warm water to 9.5 mg/l in cold water (Carr and Rickwood, 2008). DO is vital to the aquatic organisms as they use it for survival (David *et al*., 2007). Low DO depicts that the aquatic ecosystem is degraded and some organisms that use aerobic conditions will not manage to survive due to lack of oxygen (David *et al*., 2007).

2.2. Pollution of Rivers as a result of anthropogenic activities

Most developments globally have been centered on freshwater habitats, because of their vital role in ecological, economic, social and cultural functions (Reddy, 2014). According to Béné *et al*. (2016), freshwater ecosystems are a vital resource for human survival, supplying clean water, food, livelihoods, and other ecosystem services worth more than $4 trillion yearly. Rivers are one of the most vital sources of freshwater for human life, which contribute water supplies, electricity generation, waste disposal, fishing, irrigation and aesthetic value (Pan *et al*., 2012; Huang *et al*., 2014). However, because to a growing pollution load from polluted runoff water originating from households, land-use changes, and industrial, these freshwater habitats are now endangered all over the world (Banetti & Garrido, 2010; Reddy, 2014). According to Pan *et al*. (2012) and Kibena *et al*. (2014), human activities, such as cattle husbandry, washing, logging, deforestation, and agriculture, all have a part in polluting river systems. As a result, there results untimely destruction of habitat, degradation in water quality, and decreased ecosystem services delivery. freshwaters are some of the most impacted ecosystems on the planet (Carpenter *et al*., 2011). Several human activities associated with the increased of population density such as increased of industrial and domestic effluent load, increased agricultural areas, habitat deterioration, species introduction and dam construction (Arthington *et al*., 2006); Moya, Hughes *et al*., 2011) ; Ruaro *et al*., 2018) affect the ecological integrity of these ecosystems Consequently, the services that they provide. In developing nations, more than 95 percent of urban sewage is discharged untreated into rivers and bays, creating a major human health hazard. Use of this polluted wastewater for irrigation without any treatment causes soil and ground water pollution, which leads to both qualitative and quantitative losses and urban water pollution is growing at alarmingly faster rates (Melaku *et al*., 2005). Human habitation on riverbanks is responsible for the discharge of sewage into the river stream, which the entire pollute length of the river. Industrial units located in and around the outskirts of the city, intensive agricultural practices along the riverside's and indiscriminate disposal of these wastewaters are the major sources of river pollution (Abegaz, 2005).

River ecosystems are extremely sensitive to a variety of human activities (intensive agricultural activities, urban development and industrialization) that introduce point and non-point pollution (Javier *et al*., 2017). The non-point sources of pollution originate from urbanization and agricultural activities that promote nutrient enrichment and pesticide contamination in the surface water (Nowak & Schneider, 2017). These human activities which produce pollutants putting pressures on aquatic ecosystems, by changes in flow patterns, sediment delivery, loss of biodiversity, a decline in the quality of water and habitats, affecting aquatic ecosystems as well as human health (Wang *et al*., 2012; Morrissey *et al*., 2013). According to Ekpo *et al*. (2012), decline in water quality, changes in aquatic biota composition, eutrophication, and a decline or loss of ecological integrity are some of the negative repercussions of human influence on the aquatic environment. Therefore, adequate management of riverine ecosystems needs monitoring, assessing and evaluating the health of streams and rivers condition, by using surveys and other direct measures, to determine the anthropogenic impacts on ecosystem structure and function (Parsons *et al*., 2016).

2.3. The Importance of benthic macroinvertebrates for bio monitoring

Benthic macroinvertebrates are the organisms without backbone or those organisms that could be seen with the naked eyes and are retained in the mesh sizes greater than or equal to 200 to 500 micrometers (Rajele, 2004). Different groups of macroinvertebrates have different pollution tolerance level, which means they can serve as useful indicators of water quality. They may live from several weeks to many years and directly depend on adequate habitat and water quality for survival. As a result, macroinvertebrates can indicate pollution impacts from various, cumulative or multiple sources. Since the invertebrates inhabit the stream bottom, any modification of the stream bed by pollutants, deposited sediment and water shade degradation, will most likely have a profound effect upon the benthic community. These make macroinvertebrates attractive water quality study subjects, with advantages over other community members (Birenesh, 2007)

It is important to recognize that macro-invertebrate communities fluctuate and samples from one point in time may appear quite different from other points in time (E.Kosnicki and W. Sites, 2010). They play significant roles in stream ecosystem. As a group, macro-invertebrates are the primary food source for most stream fishes. Their taxonomic, habitant, and life history diversity insures that an array of food type available to many fish species over the entire annual life cycle.

2.3.1. Measurements of diversity indices

The basic macroinvertebrates metric selection was done based on representing richness, composition and tolerance/intolerance measures were considered for the index development. To be used in the final index, a given metric needed to satisfy the following criteria: Show potential for change associated with habitat degradation, provide unique information (i.e. not be linearly correlated with another metric or metrics) and have measurably different values in known reference sites versus known impaired sites (Royer et al., 2001). The Shannon-wiener diversity indices (H’) is a diversity index that combines taxa richness and community balance (evenness) to characterize species diversity in a community. The H’ requires a count of the total number of individuals and a total count of each of the taxa. This index is an index applied to biological systems by derived from a mathematical formula used in communication area by (Shannon, 1948 and Mandaville, 2002). It’s the most preferred index among the other diversity indices. The index values are between 0.0 – 5.0. Results are generally up to 1.5 – 3.5 and it exceeds 4.5 very rarely. A high H' suggests good benthic habitat and non-impacted water quality. The values above 3.0 indicate that the structure of habitat is stable and balanced; the values under 1.0 indicate that there are pollution and degradation of habitat structure (Gencer and Nilgün, 2010). Diversity within the benthic macroinvertebrates community was described using the Simpson's diversity index (D); its values range from 0, indicating a low level of diversity, to a maximum of 1, while a value closer to 1 is good water quality. The D value which is standing for the dominance index is used in pollution monitoring studies. As D increases, diversity decreases. That way it is effectively used in Environmental Impact Assessment to identify perturbation (Hayal and Seyoum, 2009).

The Equitability or Evenness (E) diversity indices is a measure of macroinvertebrates which represents the relative abundance with which each family is presented in the area. Evenness index is also an important component of the diversity indices. This expresses how evenly the individuals are distributed among the different species. The values are between 0 – 1. When the value is getting closer to 1, it means that the individuals are distributed equally. Evenness near 0 is poor, while a value closer to 1 is good water quality ambient (Muhammad, 2009).

2.3.2. Measurements of biotic indices

2.3.2.1. Family level biotic index (FBI)

FBI is an average of tolerance values of all the macroinvertebrates families in a sample (Hilsenhoff, 1988). FBI is calculated by multiplying the number in each family by the tolerance value for that family, summing the products, and dividing by the total macroinvertebrate in the sample. The family-level tolerance values range from 0 (very intolerant) to 10 (highly tolerant) based on their tolerance to organic pollution. The FBI is then used to evaluate the pollution stats of the water for each sampling sites and the three streams by comparing with the standard used to rate the ecological water quality status. The index is calculated based on the following formula.

$$FBI = \frac{\sum(xi * ti)}{n} \qquad \textbf{[1]}$$

Where **xi** is abundance of taxon **i**, **ti** is the tolerance value of taxon i and **n** is abundance in the sample.

Tolerance values (Table-1) range from 0 to 10 for families and increase as water quality deteriorates. The index was developed by Hilsenhoff (Hilsenhoff, 1988) to summarize the various tolerances 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 1. Evaluation of water quality using the family level biotic index (adapted from Hilsenhoff, (1988) as cited by Mandaville (2002))

Family biotic index	Water quality/	Degree of organic pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	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

2.3.2.2. ETHbios

ETHbios index is the recently developed Ethiopian Biological Score index (ETHbios) was determined to assess the ecological water quality. ETHbios is a rapid, inexpensive, but scientifically sound monitoring method similar to the Biological Monitoring Working Party (BMWP) index, but excludes taxa that do not occur in Ethiopia and includes some endemic species. Such an area-specific index has been developed in a similar way for other African countries and is thus comparable to ETHbios (e.g., the Namibian Scoring System for Namibia, the Okavango Assessment System for Botswana, and the South African Scoring System for South Africa). To calculate ETHbios each family was given a tolerance score, which is based on the literature, and the summation leads to an index value (Aschalew *et al*., 2015). The resulting score of both indices were ascribed to a certain color class Table 2. Additionally, the average score per taxon (ASPT), which is the average sensitivity of the families of the present organisms, was calculated by dividing the index scores by the number of taxa.

Table 2. Water quality classes for the chemical and ecological assessments of the rivers based on ETHbios index (Aschalewu *et al*.,2015)

River quality class	Colur	ETHbios score	ASPT-ETHbios	Interpretation
1	Blue	>115	>6.5	High quality, low level of degradation
2	Green	65-114	5.01-6.4	Good quality, slight ecological degradation
3	Yellow	45-64	4-5	Moderate water quality, significant ecological disturbance
4	Orange	12-44	2.4-3.99	Poor water quality, major degradation
5	Red	<12	<2.4	Bad water quality; heavily degraded

ETHbios was calculated as the sum of sensitivity score of each taxon present in a sample as follows:

$$ETHbios = \sum_{i=1}^{n} Scorei \quad [5]$$

Where *score i* is the score of taxon i and *n* is the number of taxa considering in the calculation.
The average score per Taxon (ASPT) was calculated as ETHbios divided by total number of taxa considered in the calculation.

$$ASPT = \frac{\sum_{i=1}^{n} Score\ i}{n} \quad [6]$$

Where score i is the score of taxon i and n is the number of taxa considered in the calculation.

2.4. Functional feeding groups of Benthic Macroinvertebrates

2.4.1. Shredders

Shredders feed on organic material, such as leaves and woody material, and help to convert this matter into finer particles. They require vegetation growing along a water body, so that plant material falls into the water and slow flowing water so that the plant material is not swept away. Such animals include amphipods, isopods, freshwater crayfish (marron, gilgies, koonacs) and some caddisfly larvae (Miserendino & Masi, 2010).

2.4.2. Collectors/filter feeders

Collectors/Filter feeders feed on fine organic particles that have been produced by shredders, microorganisms and by physical processes. Such animals include mayfly nymph, mussels, water fleas, some fly larvae, and worms (Miserendino & Masi, 2010).

2.4.3. Scrapers

Scrapers graze algae and other organic matter that is attached to rocks and plants. Such animals include snails, limpets and may fly larvae (Marques, et.al., 2012).

2.4.4. Predators

Predators feed on live prey and are found where smaller collectors and shredders exist. Such animals include dragonfly and damselfly larvae, adult beetles and beetle larvae, some midge larvae and some stonefly larvae (Gamito et. al., 2012). Benthic macroinvertebrate are divided into two groups; temporary fauna, which spend part of their life time in the water (most insect larvae) and permanent fauna, which spent the rest of their life time in the water (Oligochaetes and Leeches). They play a big role in ecosystem functioning and integrity; among these are: nutrient cycling; sediment aeration; influence micro-biological production directly or indirectly through mixing sediment and consumption of diverse benthic resources; can cause fish kills due to accumulation of nutrients in stream sediments with more abundance (Obubu, 2010). They are part of the aquatic food chain and food web; and also give useful information about ecosystem properties like water quality and trophic status. Benthic macroinvertebrates are mostly affected by reduced flow (Dewson et al., 2007a). Low and constant flows alter benthic communities by altering sediment texture, temperature, and dissolved oxygen (Korte, 2010).The availability of habitats for the growth and foraging of many species is also altered (James 2008), especially for taxa with morphological adaptations (e.g., dorsally flattened body) to better resist high velocities, which include Ephemeroptera and Plecoptera (Partnership, 2007).

2.5. The Relationship between water quality and benthic macroinvertebrates

The distribution pattern of biological diversity among taxonomic groups in rivers and streams variations are connected to differences in physical habitat characteristics, water quality (physico-chemical factors), frequency and magnitude of disturbances (Payakka & Prommi, 2014; McGarvey & Terra, 2015). Stressors in an aquatic ecosystem such as physicochemical or habitat degradation lead to diversity decreases, similarly when macroinvertebrates diversity decreasing, which has also a great potential to affect taxonomic composition (Gaskill, 2014). Pollution and sedimentation are considered as the major contributors to the decline of macroinvertebrates by changing the movement and quality of food and water as well as the interstitial spacing with the sediment regime (Akaahan *et al*., 2014). That is why Kithiia (2012) and UNEP (2012) stated that the ecological balance, normal functioning, and population dynamics of the aquatic environment along the river's passage are all affected by water quality degradation. According to various investigators, macroinvertebrates have varying tolerance levels to fluctuations in environmental conditions due to human activities that may lead to changes in assemblages and biodiversity of the macroinvertebrates (Akaahan *et al*., 2014; Bere et al., 2014).

Species are extremely sensitive to certain alterations, some species are moderately susceptible to pollution, with others having the ability to withstand a wide range of contamination, and therefore inform on their use as water quality indicators (Odume *et al*., 2012; Adu *et al*., 2016). Trichoptera and Coleoptera taxa are more sensitive to human disturbance or pollution than others and hence good indicators of degraded habitat and important for taxa biomonitoring in many types of freshwater habitats (Olomukoro & Dirisu, 2014; Houghton, 2015). Some groups such as Baetidae and Caenidae are tolerant to human disturbances (Lakew & Moog, 2015). The EPT Index can be used to detect water quality status by using aquatic insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). The EPT Index is based on the assumption that high-quality rivers and streams contain the most species diversity (Akaahan *et al*., 2014; Masese & Raburu, 2017).

In general, a healthy aquatic environment is dependent on water's physicochemical and biological features, which give important information about the ecosystem's available resources for supporting life (Thirupathaiah *et al*., 2012). Macroinvertebrates are the most abundant and diverse species in stream and river ecosystems, and they are also the most vulnerable to poor water quality, as evidenced by their composition, variety, and quantity (Adeogun & Fafioye, 2011). Here it is important that today's environment if not properly managed would lead to an unsustainability in environmental resources.

2.6. Habitat quality modification and their relationships with macroinvertebrates

According to Bere *et al*. (2014), habitats can be defined as a certain area that helps to understand the function of the ecosystem within a known ecosystem. Whereas, habitat quality is described as the occurrence of riverine and riparian biodiversity features, including diversity, rarity and suitability for individual species or biological assemblages. Anthropogenic activities of habitat and water quality alteration have an impact on the composition, distribution, and diversity of benthic macroinvertebrates in a river system (McGarvey & Terra, 2015). Currently, in Africa forested streams are continuously being degraded for agricultural land use and other purposes and these also affecting stream channel, altering riparian habitat and stream flows by increasing inputs of pollutants (Ndaruga *et al*., 2004). These effects are reflected through a decline in habitat indexes, habitat quality, bank stability and disruption of aquatic terrestrial linkage (Allan *et al*., 2012; Niculae *et al*., 2013). As a result, habitat availability, features, and appropriateness are regarded significant determinants in determining the physiology, development, local abundance, and structure of species assemblages, as described by Leahy (2016). Suitable environments, in other words, are thought to promote an individual's fitness by boosting food availability while lowering predation risk and metabolic expenditure (Gosselain *et al*., 2005).

A longitudinal physical habitat evaluation gives scientifically valuable information on the availability of biotopes for macroinvertebrates, as well as the quality, quantity, and variety of these habitats (Nichols, 2012). Variation in habitat features like as channel shape, riparian vegetation, and stream bed sediment composition can assist predict where certain management interventions would be most beneficial and may be used to track mitigation strategies once they are implemented in the ecosystem. (Miller *et al*., 2010).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Study sites descriptions

This study was conducted in the Awetu River, situated in Southwest Ethiopia and lying between latitudes 7°37'N and 7°53'N and longitudes 36°46'E and 37°43'E. Elevation of this sub-catchment area ranges between 1,700 and 2610 m a.s.l. The mean annual temperature ranges between 15°C and 22°C, and the mean annual precipitation ranges between 1500 mm and 2300 mm, with maximum rainfall from June to early September and minimum precipitation occurs between December and January (NMA, 2012). The stream bisects the center of the Jimma town to make its outlet southward and plays an important role on the day-to-day life of the town and surrounding population. The landscape is topographically heterogeneous, consisting of Afromonte forest cover. The riparian forest in the urban stream catchment has been severely affected by high levels of human activity at the riverbanks and the presence of exotic riparian species such as Eucalypts globules. The stream is predominantly surrounded by urban area in down- and middle sections, with only a small percentage of agricultural land use. The upstream section had good riparian corridor, covered with natural native vegetation. To obtain a representative data the river was divided into three streams orders (longitudinal sections) based on gradient, geomorphology and the level of branching system namely upper, middle and down streams. A total of Fifteen (15) sampling sites were selected along 7.45 KM reach of Awetu stream stretch, distributed upstream (AWS 1 to AWS 5), middle (AWS 6 to AWS 10), and downstream (From AWS 11 to AWS 15), Along a downstream increased nutrient pollution and habitat degradation gradient (Figure 1). Sampling Sites AWS 1, AWS 2, and AWS 3, have canopy cover and highly diverse riparian vegetation including eucalyptus species; sites AWS 4, AWS 5 and AWS 6 has light anthropogenic disturbance like grazing, swimming, light agriculture, and small weirs, and sites AWS9 to AWS 15 has a distinct odor and color with strong bank channelizing and flow regulation characterized with input of raw municipal wastewater effluent, carwash effluent, and municipal solid waste.

Table 3. Coordinates, elevation, sampling points and characteristics

Sampling Point	Coordinates		Elevation (MASL)	Description of sampling points	Sampling points characteristics
	X	Y			
AWR`1	260253	851995	1753	Reference site	Agriculture and forest
AWS2	260917	851787	1738	Municipality nursery of Seto	Agriculture and shurbs
AWS3	260532	851571	1732		Shurbs and Grassing
AWS4	260510	850938	1731	Furustale birdge	Car Washing, Bathing,
AWS5	260228	850767	1719	Shonkoree	Agriculture, bathing
AWS6	260451	850256	1712	Mobile fuel station and wet coffee processing	Agriculture, fuel station, water extraction
AWS7	260624	850336	1712	Mabrat hayilsebstation	Agriculture, car washing
AWS8	260867	849919	1712	JUCA nursery	Agriculture , car washing
AWS9	261049	849584	1710	Seto bridge near Beteseb school	car washing, bathing , waste damping
AWS10	261168	849075	1716	OSSA (behind the public library)	Residents, damping wastes
AWS11	261286	848672	1712	Awetu menafesha	Coffee processing, car washing , discharging of sewage
AWS12	261222	8484008	1712	Back of stadium	car washing , bathing, discharging of sewage
AWS13	261230	847638	1710	Bishishe bridge	Waste damping, discharging of sewage
AWS14	261832	846722	1716	Old kera (Abatior)	waste dumping, liquid discharge
AWS15	261989	846083	1699	Bore bridge	car washing, bathing ,

Fifteen sample stations including reference site (AWR1) was selected along the flow of the river to take water samples for physico-chemical data and macro invertebrates sample for bioassessments. Selection criteria were based on minimally degraded physical habitat, the distribution of human activities, pollution sources and the flow regimes.

References (AWR1) were selected as reference site to compare the induced change in other sites due to different activities. Reference condition was established using best professional judgment and based on guide lines established by Hughes (1995). A reference site represents a standard for what the macro invertebrate assemblage would look like in the absence of human influence (Hughes, 1995). The remaining 14 sites (AWS2 to AWS15) were selected on the basis of prominent land use in the stream catchment, discharge of point and non-point pollutants.

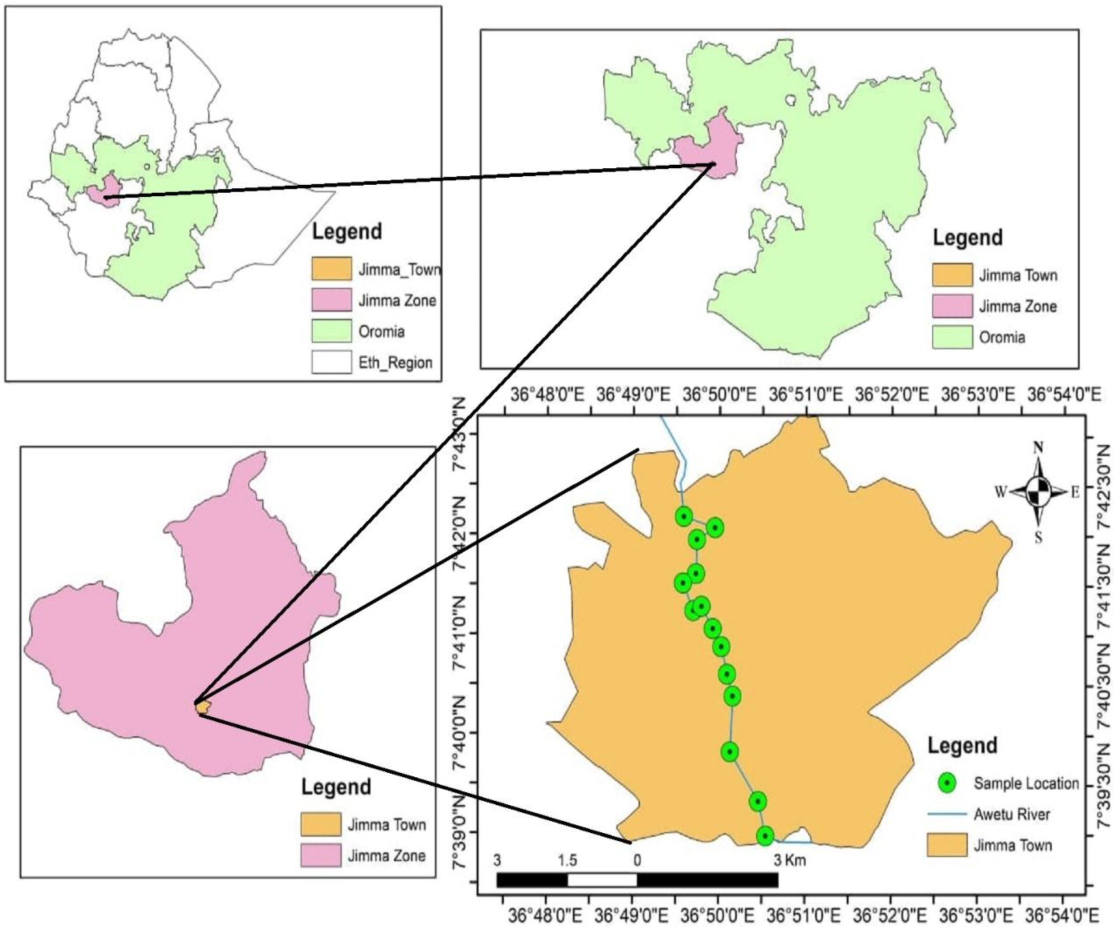

Figure 1. Study area and locations of sampling stations on the Awetu River

3.1.1 Research design

Sampling was done starting from 7th July 2021 to July 30th 2021. Sampling was done within wet season due to predictable climate change during the study period. Before field sampling started, a preliminary survey was carried out to obtain the representative sampling stations. Sampling stations along the river were selected based on purpose and accessibility, physical proximity, habitat diversity and riparian land uses for the collection of water samples and macroinvertebrates. Each sampling station was marked using a Geographical Positioning System (GPS) to be sure that samples were collected from the same place at each sampling time and divided into four biotopes namely; riffle, pool, run and marginal vegetation to obtain representative data. The sampling of physico-chemical parameters was carried out from various biotopes (riffle, run and pool). Whereas, macroinvertebrates were collected from riffle, run, pool and marginal vegetation biotopes in each station, as well as habitat quality characteristics were also evaluated through visualization. A 300 m long stretch upstream of the river at each station was used as a unit for sampling macroinvertebrates and habitat assessments.

3.2. Sampling and laboratory analysis of physico-chemical parameters

3.2.1. Physico-chemical parameters and morphological variables

At each sampling site, in-situ measurements of dissolved oxygen (DO), electrical conductivity (EC), pH, Turbidity and Water temperature (T°) were measured by using multi-probe meter (HQ30d Single Input Multi-Parameter Digital Meter, Hach). For the physicochemical analysis which was done in the laboratory, 1.0 L of unfiltered water samples were collected from each site by inserting clean polyethylene plastic bottle, and facing it in opposite direction of the current flow. The collected samples were kept in an ice-box and transported to Jimma University, Environmental Health Science, and Technology laboratory, within six hours after collection. In the laboratory, samples were placed in a deep freezer until further processing and analysis was done.

The hydro-morphological variables such as velocity, width and depth of the river were measured by using a flow meter and tape measure respectively. The depth was measured along the width of the river at a minimum of five points and the width also was measured three times in each sampling station.

3.2.2 Nutrients

Water samples were collected on July 07, 2021. In each sampling site, three 500 mL water samples were filtered (Whatman GF/F) and stored in clean bottles. At the same time unfiltered 1- L samples were collected using clean bottles. The filtered and unfiltered samples were stored in an ice box (below 4 °C) and transported to Environmental Health Laboratory unit at Jimma University, within 1 to 6 h for analysis. Biological oxygen demand (BOD_5) was measured based on oxygen consumed in a 5-d test period (5-d BOD or BOD_5) at 20^0C after arrival of sample to the laboratory (APHA, 1998). Total phosphorus (TP), was determined from unfiltered samples. Water samples were filtered using Whatman glass microfibre filter having a pore size of 0.45µm and transferred to a 150 ml of polyethylene bottles for the analysis of nitrate (NO_3-N), ammonia (NH_4-N), and orthophosphate (PO_4-P). Spectrophotometer was used to read the concentration of each parameter.

3.3. Benthic Macro invertebrates Field Sampling

Benthic Macro invertebrates were collected at each sampling site using a rectangular frame net (20 × 30 cm) with a mesh size of 300 µm. Each collection needed a 10-minute kick sampling over a distance of 10 m. Time is allotted proportionally to the cover of different habitats of the sites such as bare edge, open water, and emergent and submerged vegetation.

Macroinvertebrate samples were conducted from each riffle and runs sample sites. In the field, the mesh net with the collected sample was then carefully turned inside out and shaken gently in a white plastic container filled with water was washed leaves, twigs, rocks and other debris were taken out of the collected sample through a 500 µm sieve. The specimen bottles were well labeled for better and reliable information. The sorted was preserved in a 80% ethanol and transported to laboratory of Environmental Health Sciences and Technology Department, Jimma University for later sorting and identification (Barbour et al., 1999; Bouchard, 2004; Kobingi et al., 2009).

3.4. Assessment of habitat quality

The habitat quality of the sample sites were assessed by using the Fluvial Habitat Index (IHF) and the Quality of the Riparian Corridor Index (QBR). Theses indices are the best indices currently available for the purpose of such study, and they have also been commonly used by water agencies and consultancies in tropical region and elsewhere (Barquın et al., 2011). The IHF evaluates in-stream habitat heterogeneity and considers seven items related to substrate, current velocity and depth, shadow, presence of elements of heterogeneity and aquatic vegetation. The final IHF score is the sum of the scores obtained for each item. The higher the habitat heterogeneity of a stream, the better the final IHF score indicating little impacts (Barquınet al., 2011). In our study, the final IHF score decreased in a downstream direction indicating degradation of habitat quality. The QBR index is an easy-to-use field method for assessing the habitat quality of riparian forests. The index is based upon four main aspects of the riparian area being studied, and unlike indices currently in use which assess the water quality itself or the habitat directly adjacent to the stream; the QBR index assesses a site's entire floodplain. It generates a score that can then be used to contrast sites, to compare sites to ideal conditions, or to assess the success of impacts of human activities over time. The QBR classifies the riparian corridor quality into five classes. Class-I (QBR $\geq$ 95), riparian habitat in natural condition, excellent quality; class II (90 > QBR > 75), some disturbance, good quality; Class III (70 > QBR > 55), disturbance important, fair quality; Class IV (50 > QBR > 30), strong alteration, poor quality; class V (QBR $\leq$ 25), extreme degradation, bad quality. Natural riparian corridors without alteration increases habitat complexity, improve the quality and quantity of leaf litter inputs, and maintain water temperature which results in increased habitat quality and is translated to higher QBR score (Castela et al., 2008). In contrast, building of dams, channelization of streams, agricultural conversion, and urban development destroy natural vegetation and floodplains, and alter flooding cycles for the riparian area, which will result in low scores.

3.5. Laboratory work and analyses

3.5.1. Nutrients

From each water sample nitrate, phosphate, TDS, ammonia-nitrogen and BOD_5 were analyzed by following the procedures outlined in APHA et al. (1999) to determined level of ecological disturbance of nutrient. The methods are presented in Table 3.

Table 4 Water quality parameters determination methods and instruments used (Adapted from Rhonda et al, 2006)

Water physicochemical parameters	**Unit**	Methods and instruments used
Phosphate	Mg/L	Stannous Chloride method (UV-Vis) Spectrophotometer at 690nm)
Nitrate	Mg/L	Phenoldisulphonic acid method (UV-Vis spectrophotometer at 410nm)
Ammonia	Mg/L	Nesselerization method (UV-Vis spectrophotometer at 425nm)
Total Dissolved Solids (TDS)	Mg/L	TDS dried at 180 ˚C (drying at oven)
Biological Oxygen Demand	Mg/L	Volumetric method

3.5.2. Sorting and identifying macroinvertebrates in laboratory

In the laboratory, the collected sample were transferred into a petridishes containing sufficient amount of water, agitated and sieved with 500 µm mesh size to discard the mud and retain the macroinvertebrates. This was repeated until all the macroinvertebrates were washed from the mud. The samples were then transferred to petridishes to easily pick them up using forceps. Benthic macroinvertebrates were identified up to their family level. This was carried out at the Jimma University Department of Environmental Health Sciences & Technology laboratory unit using standard systematic keys (Macan 1979; Edington and Hildrew 1981; Bouchard 2004). Even the damaged MIs were identified by examining closely both head and tail. The identification process was cross-checked by another expert in order to maintain the confidence of the data set.

Margalef diversity index (Margalef 1968), Simpson index (Simpson 1949), Shannon index (Shannon 1948) and evenness was calculated to identify macroinvertebrate diversity and the even distribution of macroinvertebrate families in all stations of the River.

3.6. Statistical analysis

Pearson correlations were performed between bio-assessment indices and physic-chemical variables to determine the sensitivity of each index to specific variables. Statistical analyses were performed using Excel and Statistical Package for Social Sciences (SPSS) version 26. Canonical Correspondence Analysis were done using Paleontological Statistics software package for education (PAST 3) version 3.18. In addition, to compare the three streams post-hoc comparisons were made with the STATISTICA® software package version 7.1.

3.7. Data analyses

3.7.1 Physical-chemical parameters, morphological variables and nutrients.

Data for physical-chemical parameters, morphological variables and nutrients were analysed using descriptive statistics and presented as mean. Pearson correlation coefficient was carried out to determine the relationship between each parameter and nutrients in the river. Principal component analysis (PCA) was used to summarize variation in physico-chemical parameters and benthic macroinvertebrate metrics among sites. Detrended correspondence analysis (DCA) was used to determine the appropriate response model (linear or unimodal) for benthic macroinvertebrate data. The performed DCA gives a gradient length less than three standard deviations, implying that taxa abundance exhibit linear response to environmental gradients. Macroinvertebrate abundance data were log transformed $\log(x + 1)$ prior to analysis to obtain homogeneity of variance. Furthermore, CCA analysis was performed to evaluate the relationship between measured environmental variable and species data. The statistical significance of eigenvalues and species–environment correlations generated by the CCA were tested using Monte Carlo permutations. All the multivariate analysis was performed using CANOCO version 4.5 software (ter Braak and Smilauer). The macroinvertebrate community structural and functional composition were described per site as total number of individuals, family richness, total number of EPT taxa (Ephemeroptera + Plecoptera + Tricoptera), % Ephemeroptera individuals, % Diptera individuals, % Chironomidae individuals, %

Oligochaeta individuals, and the FFGs (collectors, predators, scrapers and shredders). The Marglef's index (M), Simpson's diversity index (1/d), and Shannon's diversity (H') index. FBI and ETHbios was also calculated for each sites.

3.7.2. The Benthic Macroinvertebrate Assemblages

The benthic macroinvertebrate diversity, richness, composition, abundance and functional feeding groups were determined from each sampling station and sampling occasion; To evaluate the diversity indices & evenness benthos species were calculated by respective formula as follow:- Macro-invertebrate assemblages as biological indicators of the river water bodies for each sampled stations were pooled to furnish the values of measuring diversity indices (Shannon-Wiener index (H'), Simpson's index (D) and Equitability index (E) were used to determining species diversity, taxa richness; and evenness respectively as described in the subsequent subsections.

3.7.2.1. Shannon Diversity Index

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

$$\boldsymbol{H'} = \sum \mathbf{pilog}(\mathbf{pi}) \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

Where, H´ is the standard symbol for the maximum Shannon index, and pi is the proportion of i'th species. i = an index number for each species present in a sample.

3.7.2.2. Simpson's diversity index (D)

Diversity within the macroinvertebrate community was described using the Simpson's diversity index (D). The Simpson Index (D), with values ranging from 0 to 1, is the probability that if two selections are made randomly from a collection of organisms, they will be individuals of the same families. This index places relatively little weight on rare families and more weight on common families. Its values range from 0, indicating a low level of diversity, to a maximum of 1 for high level of diversity (Mandaville, 2002). This index is calculated as follows:

$$D = 1 - \sum_{i=1}^{s} pi2 \qquad [3]$$

Where: D = Simpson's diversity index, and Pi = the proportion of the total individuals in a sampling of s families.

3.7.2.3. Evenness

Evenness was calculated for macroinvertebrates as the ratio of diversity with the maximum possible diversity for the number of species (Tanya *et al*., 2014). The formula is:

$$E = H'/H'max \qquad [4]$$

Where, H' is Shannon index, and H 'max= maximum possible Shannon's diversity

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. Physicochemical of water quality parameters

The values of the physic-chemical examination of samples from the different sites are shown in Table 5 Values showed considerable variability among the sites.

4.1.1. Temperature

Surface water temperature is an indispensable ecological factor that regulates the physiological behavior and distribution of aquatic organisms (macroinvertebrates). Lower temperature is reported to reduced metabolism and growth of macroinvertebrates (Tapan *et al.*, 2014). The water temperatures ranged from 19.6°C to 23.6°C during the study period. The lowest water temperature of 19.6°C was recorded in station AWS7 while the highest value 23.6 °C was recorded in station AWS4. The surface water temperature range in this study may be attributed to the atmospheric temperature that was obtained in the data collection. According to WHO (2006), temperatures of surface waters generally range from 5–30°C for the protection of the aquatic species. Beyond this standard temperature affects the distribution, survival and food chain of aquatic organisms by influencing the amount of oxygen that is available for an aquatic organism and their metabolic rates (Mohamed *et al.*, 2009). Therefore, according to the above range surface water temperature in Awetu River was acceptable.

4.1.2. pH

pH values vary from a minimum of 6.2 and a maximum of 6.72. The highest value was found in station AWS4, while, the lowest value was obtained at station AWS14 (downstream of the river). The low pH value measured at station AWS14 might be related to the inflow, waste disposal, and decomposition of organic material such as leaf litter in this site, as well as inputs from surface runoffs during the rainy season. Whereas, relatively high pH value recorded at station AWS4 might be due to the discharge of fertilizers and various wastes to sampling point. Because pH affects biological and chemical processes in the water body, as well as the solubility and availability of nutrients and their consumption by aquatic species, the pH of water is an essential element in determining its quality (George et al., 2012).

Naturally occurring freshwaters have a pH range between 6.0 and 8.0 suitable for aquatic organisms (Osman & Kloas, 2010). As a result, levels outside of this range indicate that the variety of aquatic biota inside the water body decrease owing to physiological stress, resulting in lower reproduction and growth. For instance, pH values that are too high (above 9.5) or too low (below 4.5) might create hazardous circumstances for aquatic life, alterations in the ionic and osmotic balance of individual, change in community structure and lethal effects on organisms (WHO, 2006). Therefore, based on the above range pH in Awetu River was in a suitable condition.

Table 5. The values of measured physicochemical properties of the study sites in Awetu river

	Reference		Study site													
	AWR1	AWS 2	AWS 3	AWS 4	AWS 5	AWS 6	AWS 7	AWS 8	AWS 9	AWS 10	AWS 11	AWS 12	AWS 13	AWS 14	AWS15	Mean
Width (m)	8	7.4	6.3	5.2	6	3.5	4	8	5.2	9.6	5	4.6	6	6	4.5	5.9533
Depth (m)	0.6	0.65	0.75	0.8	0.6	1.4	1.45	1.5	1.4	2	1.5	1.7	1.75	1.7	1.8	1.3067
Velocity (m/s)	0.3	0.32	0.35	0.25	0.34	0.3	0.12	0.23	0.11	0.09	0.3	0.2	0.15	0.17	0.11	0.2227
Temprature (^{o}C)	21.7	21.5	22.4	23.6	22.3	20.1	19.6	21.4	20.7	21	21.3	022.5	22.5	21.4	21.2	21.547
pH	6.5	6.5	6.6	6.72	6.39	6.58	6.54	6.71	6.61	6.4	6.61	6.44	6.28	6.2	6.27	6.49
EC (µS/cm)	63	66	65	66	69	73	78	75	80	84	87	88	116	120	127	83.8
DO (mg/L)	7.31	7.32	7.16	6.89	7.17	7.73	7.83	7.4	7.45	7.09	7.31	7.01	6.32	4.89	3.26	6.8093
TDS (mg/L)	32	33	33	33	35	37	39	38	40	42	44	44	58	60	63	42.067
Turbidity (NTU)	805	571	442	386	325	326	322	313	315	261	453	630	583	517	274	434.87
Amb. Temprature	30.5	31	31.2	30	26	23	21	24	23	24	26	27	30	27	26.5	26.68
PO_4^{3-}-P (mg/L)	0.82	0.45	0.52	0.4	0.39	0.44	0.55	0.45	0.4	0.44	0.67	0.85	0.74	0.74	0.59	0.5633
TP (mg/L)	1.72	1.36	1.52	1.71	1.08	1.36	1.18	0.85	1.31	0.94	1.3	1.37	1.41	0.98	1.26	1.29
NH_4^{+} -N (mg/L)	1.33	1.063	1.166	0.951	0.674	0.738	0.567	0.455	0.486	0.345	0.438	0.427	0.408	0.4	0.298	0.6497
TSS (mg/L)	276.8	219	135	96	130	110	152	48	143	43	121	231	180	105	41	135.39
NO_3^{-} -N (mg/L)	0.65	0.55	0.64	0.52	0.46	0.37	0.74	0.74	0.4	0.35	0.58	0.8	0.55	0.63	0.52	0.5667
BOD_5 (mg/L)	6.1	6	6	5.9	6	5.6	5.4	5.4	5.5	5.4	5.2	5.1	5	4.7	4.5	5.4533
COD (mg/L)	86	64	64	54	48	64	32	32	32	54	64	32	32	32	24	47.6

4.1.3. Electrical conductivity (EC)

Electrical conductivity (EC) showed significant difference between the reference and impacted sites. Electrical conductivity values in Awetu river varied between 63-127 µS/cm (Table 4.0). The lowest value was recorded at station AWS3 and the highest value was at AWS15 where every effluent of Jimma town and upstream agricultural wastes were discharged to Awetu and reached at the study area with stipend run off. EPA standard for EC in surface waters is 1000µs/cm (EPA, 2003). Based on this limit, the Awetu River is suitable for aquatic life in relation to electrical conductivity recorded in this study. High electrical conductivity is an indicator of saline conditions (Deepa *et al*., 2016). On the other hand, the large amounts of water received during the wet season contribute to dilution effects and a subsequent lowering of EC. The increment of EC value towards downstream side of the river indicates that, due to increase in salinity content of river water across the flow direction. The salinity increment was resulted from entry of waste from surrounding of river bank.

4.1.4. Dissolved oxygen (DO)

The dissolved oxygen (DO) varied significantly among sites ($P < 0.05$) and the values were between 3.2 to 7.8 mg/L. The maximum value was observed in station AWS7. Whereas, the minimum value was recorded at station AWS15 near Boye wetland. Reduced aquatic plant activities such as photosynthesis, the presence of rich organic matter, and the change of other factors such as depth and temperature might all have contributed to low DO concentrations at site AWS15. Similar findings were also reported by Zang et al. (2011), who indicated that as pH decreases, dissolved oxygen decreases and according to Kuligiewicz et al. (2015), DO being temperature dependant changes along the river due to biological processes like photosynthesis, respiration, and decomposition of organic matter. As a result, aquatic biota survival, development, and mobility are all heavily reliant on the availability of an appropriate dissolved oxygen levels. This is due to the activities practiced around the river basin, like car washing, defecation and the likes could have to low DO level in Awetu River. The level of DO in this catchment was found to be as low as 3.2 mg/L, a lower level than the EPA guideline of 5 mg/L, which is the minimum requirement to support aquatic life.

4.1.5. Total suspended solids (TSS)

The present study shows that the average value of TSS varies from 41 to 276 mg/L. These values might be attributed to the surface runoff and disposals of domestic sewage. Higher values recorded at reference sampling site AWR1 and AWS12 could be attributed to the surface runoff, and disposals of domestic sewage locally. While, the lowest value was measured at station AWS15. These values were found to be greater than the acceptable limits of surface waters (< 50mg/l) especially the downstream that has the largest value. Total Suspended Solids (TSS) is an indication of the amount of erosion that took place upstream. The concentration of TSS in this study is due to the level of surface run off to Awetu River. Bilotta and Brazier (2008) as cited by Steve et al. (2015) reported that excess TSS increased the rate of drift of benthic fauna in surface water. Based on the finding by Bilotta and Brazier (2008) as cited by Steve et al., (2015), the TSS concentration in Awetu River during the course of this study may contribute to the drift of the benthic fauna (macroinvertebrates). The increase in TSS concentration of river water across downstream sample site was due to load of wastes from surrounding area while route of river.

4.1.6. Total dissolved solids (TDS)

In the present study the average values for TDS ranged from 32 to 63 mg/L. Station AWS15, which is located downstream of the river, had the highest value, whereas, AWS2, AWS3 and AWS 4 had the lowest value. Variations in TDS may be due to the inflow of domestic effluent discharges, animal and agriculture wastes are examples of the types of sources that may contribute to increased TDS concentrations in the sampling sites. This result agreed with Davie (2008) who stated that the higher level of TDS indicated that the water body may be polluted via natural or anthropogenic sources. TDS levels recorded in the entire sample points were below the WHO guideline of 1000 mg/l for the protection of fisheries and aquatic life (WHO, 2004). Ethiopian standard to TDS limit is 30 mg/l to the protection of aquatic species (FDREEPA and UNIDO, 2003).

4.1.7. Water turbidity

The average turbidity values ranges from 261 to 630 NTU. The highest turbidity observed at AWS12 probably due to the extreme and sudden runoff to the river water. The statistical analysis indicates that water at site AWS12 (630 NTU) is significantly different from the other sampling sites. This might be due to daily disturbance of the river by washing of different vehicles and surface runoff (Alemayehu, 2001). Turbidity values obtained for the Awetu River at all fifteen sampling sites are higher than WHO, (2008) which suggests 5 NTU for the purpose of surface water. Stream bank cultivation along the river banks disturbs the banks which became weak and when it rains the soil is washed away into the river thereby increasing turbidity. In this study high turbidity values indicate the possible presence of microorganisms, clay, silt and other suspended solids in water, which affects its aesthetic value by causing it to appear cloudy.

4.1.8. Orthophosphate ($PO_4{}^{3-}$- P)

Phosphate is a nutrient for plant growth and a fundamental element in the metabolic reaction of plants and animals. Phosphate is a major pollutant that causes eutrophication in surface waters. Akaahan et al. (2014) stated that inorganic phosphate of more than 0.5 mg/l is an indicator of organic pollution. In this study, The average concentration ranged from 0.39 mg/l to 0.85 mg/l. The higher levels of phosphorus observed on AWS12 was most certainly due to the incorporation of different fertilizers and detergents by both the local widespread farming and car washing activities, consecutively, in to the river water and aquatic organisms food chain. The source of phosphate to Awetu River might be the decomposition of organic matter, atmospheric precipitation, urban runoff, and drainage from agricultural land, in particular from land on which fertilizers have been applied (FDREEPA and UNIDO, 2003).

4.1.9. Total phosphorus (TP)

Total phosphorus for Awetu River water ranged from 0.94 to 1.72 mg/L. Higher values for total phosphorous at AWS4 could be due to disposal of phosphate with domestic sewages and surface runoff from phosphate containing fertilizers (Korostynska et al., 2012). The source of TP might be the entry of agricultural fertilizers and pesticides from the watershed to the river and other human activities such as cleaning activities and discharge of various wastes. 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 0.10 mg/l to prevent downstream eutrophication (U.S. EPA, 2005). Excess phosphate enters the system; it can lead to eutrophication and therefore producing less desirable effects in aquatic systems. Phosphate/Phosphorous concentration in this study were above the permissible value (0.4 m/L), might affect benthic macroinvertebrates.

Various studies (Pradhan 2005; Shrestha *et al*. 2008) have concluded that water pollution in the urban areas is mainly related to the municipal sewage system. This has been further supported in our study by the identification of ortho-phosphates and total phosphorus as major influencing factors in downstream. Sewage, municipal waste and fertilizers have been contributing to the higher concentration of phosphorus as has the domestic use of laundry detergents (Karafistan et al. 2002; Kannel *et al*. 2007)

4.1.10. Nitrate-nitrogen (NO_3 -N)

The concentration of nitrates-nitrogen can be used as indication of level of micronutrients in water bodies and has ability to support plant growth. High concentration of nitrate favore growth of phytoplankton. The concentration of nitrate -nitrogen in Awetu River water ranged from 0.35 to 0.8 mg/L. The slightly elevated nitrate-nitrogen in some sites (AWS7, AWS8, AWS12 and AWS14) was found during flooding where the flood brings nutrients from wide array of the catchment area. Agriculture is likely a result of higher fertilizer application in watersheds with more cropland, and/or increased nitrate retention and removal in watersheds (Fisher 2000). Nitrate N is an oxidized, inorganic form of nitrogen in water. Nitrogen is a necessary nutrient for plant growth. Too much phosphorus and nitrogen in surface waters contributes to nutrient enrichment, increasing aquatic plant growth and changing the types of plants and animals that live in a stream. The values obtained from the fifteen sites were significantly different among each other for NO_3 –N concentrations. Higher amount of both NO_3 -N was observed in downstream stations, especially at AWS12 and AWS14. This might be due to agricultural fertilizer runoff, sewage from the domestic areas, wastes from animal and humans as well as the prevalence of anthropogenic activities.

4.1.11. Ammonium-nitrogen (NH_4^+-N)

The concentrations of NH_4^+ -N recorded ranged from 0.29 to 1.33 mg/L. The levels of ammonia-nitrogen were higher than the WHO standards for surface water in most of sampling stations (0.5 mg/L) particularly in station AWS1, AWS6, and AWS15. Thus, it can be toxic to some aquatic organisms. The source of ammonia in the study area might be due to the application of fertilizer in the watershed, sewage discharge (domestic activities) and the biological degradation of manure (WHO, 2011). Ammonia is a harmful contaminant found in sewage, liquid manure, and liquid organic waste, and it occurs naturally in water bodies as a result of the breakdown of nitrogenous waste in the soil and water, biota excretion, nitrogen gas reduction in water by microorganisms, and gas exchange with the atmosphere. As a result, it can be used to diagnose the condition of natural water bodies like rivers (Deepa *et al*., 2016).

4.1.12. Chemical oxygen demand (COD)

There were significant differences in COD between the reference site AWS1 and the rest sampling sites. Average COD concentration for Awetu River is ranged from 16.02 to 32.53 mg/L, higher than the WHO (2008) value. The high COD values observed in this study were alarming and suggests that both organic and inorganic contaminants from municipal and agricultural activities are entering into the water system. This is undesirable as continuous discharge of untreated effluent can negatively impact the quality of the river water and subsequently cause harm to aquatic life (Igbinosa *et al.,* 2012).

4.1.13. Biological Oxygen Demand (BOD_5)

BOD_5 represents the amount of oxygen that microbes need to stabilize biologically oxidizable matter in five days. It is found to be more sensitive test for organic pollution (WHO, 2006). There were no significant differences in BOD_5 between the reference site and impacted sites. BOD5 ranges between 4.5-6.1 mg/l (Table 4.0). The highest BOD_5 (6.1mg/l) was observed at reference site (AWS1) the lowest (4.5 mg/l) was at station AWS15. Large quantities of organic matter can reduce the chemical and biological quality of surface water and result in biodiversity of aquatic communities and microbiological contamination that can affect the quality of water. BOD_5 was lower in all water samples taken during the wet season, likely reflecting dilution effects by runoff and precipitation. Generally, the BOD5 levels recorded in the sampling points except AWS14 and AWS15 were higher than the 5 mg/l standard limit of WHO and Ethiopian EPA to the protection of aquatic species (FDREEPA and UNIDO, 2003; WHO, 2007).

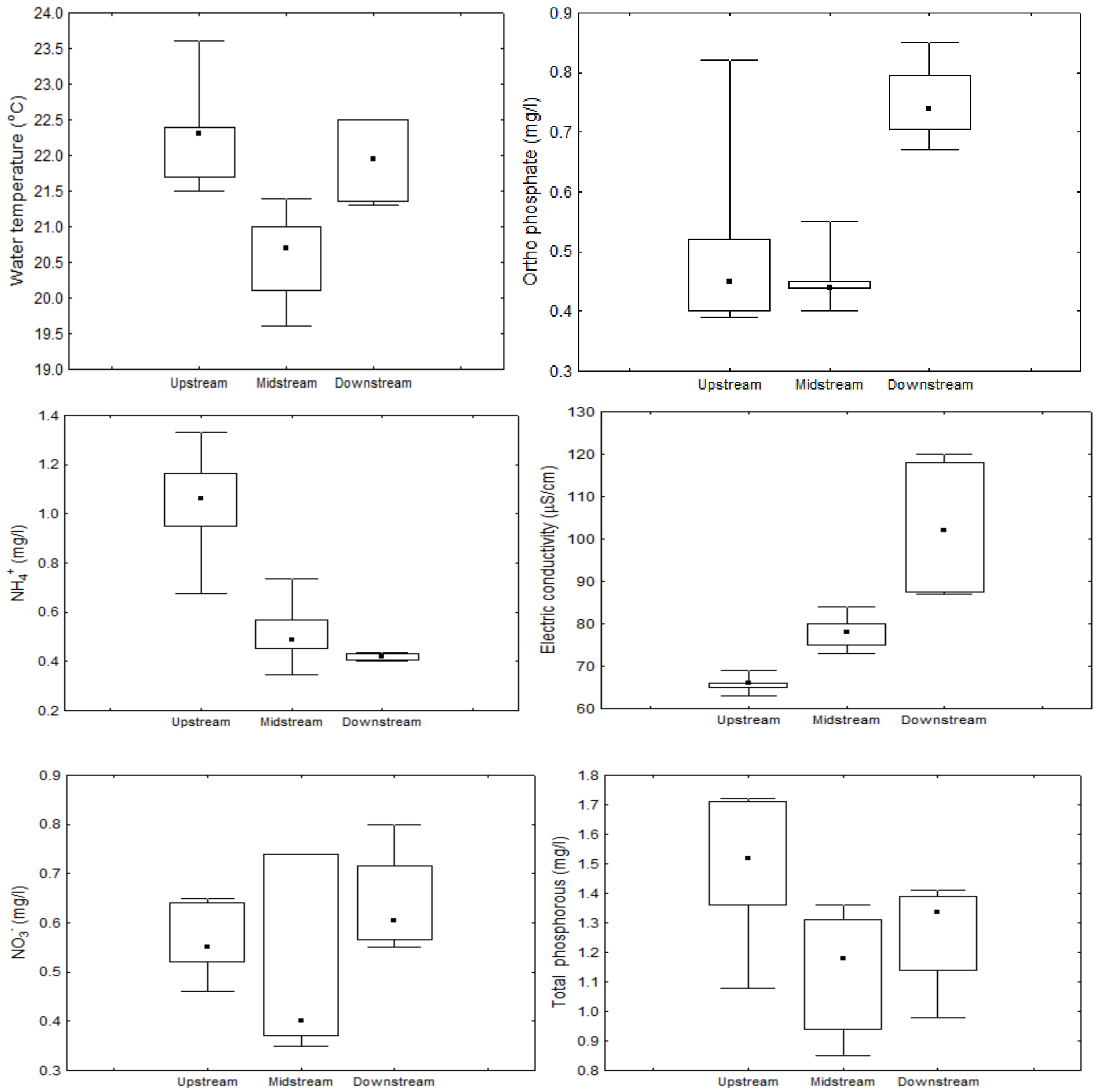

Figure 2. Boxplots of the different stations (upstream, midstream and downstream) for the variables temperature, PO43- (orthophosphate), NH4+ (Ammonium-nitrogen), EC (electrical conductivity), TDS (total dissolved solids), BOD5 (Biological oxygen demand), NO3- N

Box and whisker plots of some selected parameters identified by spatial variation (upstream, midstream and downstream) were constructed to evaluate different patterns associated with spatial variations in river water quality (Fig. 2). Mean Electric conductivity of the river shows a steady increase with the river course. This is due to the presence of high amount of dissolved inorganic substances in their ionized form.

Trends for pH, BOD_5, NH_4–N, and NO_3–N suggest for high load of dissolved organic matter in the midstream and downstream. The COD and BOD_5 values in the middle and downstream of the river increase significantly, which may be due to the high effluent discharge from storm drainage, car washing and flushing of sewage directly into the river by the residents. The PO_4^{3-} concentration is found to be higher in the downstream region of the river. This high value of PO_4^{3-} may be the result of agricultural runoff and detergents from car washing activities.

4.2. Hydro-morphological Variables

According to the result in (table 4), the highest depth value (2.0m) was observed in a station AWS10. While, the lowest (0.6 m) was in station AWS1 and AWS5. There were no statistically significant variations in depths between sampling sites. However, the main source for depth variation could be the availability of canopy cover to the topography, the bank stability, riparian vegetation protection, gradient of the area and types of substrate composition found there. This is true in station AWS10 which has higher canopy cover and bank stabilities than others. This agrees with Cunningham & Schalk (2011), who proposed that the low water depth might be linked to significant water evaporation and low water input from rain and runoffs. The highest width value (9.6m) was measure in downstream of the river (station AWS10) and the lowest (3.5 m) in upstream (station AWS6). This result agrees with river continuum concept. This variation probably might be due to the status of channel stability, bank vegetation protection, various human activities, and vulnerability to sediment deposition, slope differences and the contribution of other tributaries in the watersheds. The maximum (0.35 m/s) velocity value was measured at site AWS3 and minimum (0.09 m/s) in AWS10. Differences in velocity could be because of the shape of channels, slope, and the wideness of channels and the composition of substrates. For instance, the highest velocity found where the area had a steep slope and in narrow channels. Whereas, the lowest velocity appeared in the gentle slope and wide channels. This idea also verified by the river continuum concept (RCC) which states that the velocity of water decreased from headwater (narrow channel) to downstream (wide channel). Dietz & Clausen (2008) also observed that stations which had enough cobble and gravels substrates leads to swift velocity of the water. Whereas, silt and sand substrates can have low water flow.

Table 6. Correlation between physic-chemical parameters among the selected sites of Awetu River

	Temp.	pH	EC	DO	TDS	Turbid	A.Tem	$PO4_3$	TP	NH_4^+	TSS	NO_3	BOD_5	COD
T (^oC)	1													
pH	.009	1												
EC	-.071	-.763**	1											**
DO (mg/L)	-.128	.689**	-.829**	1										
TDS (mg/L)	-.071	-.763**	1.000**	-.825**	1									
Turbidity	.371	-.179	-.060	.072	-.056	1								
A.Temp (^oC)	.761*	-.116	-.074	-.181	-.074	.667**	1							
PO_4^{3-} -P	.152	-.461	.439	-.281	.445	.760**	.310	1						
TP (mg/L)	.428	.273	-.315	.130	-.319	.537*	.618*	.230	1					
NH_4^+ -N	.278	.399	-.717**	.390	-.717**	.475	.601*	-.073	.687**	1				
TSS	.171	-.027	-.303	.354	-.303	.857**	.448	.532*	.581*	.538*	1			
NO_3	.150	.075	.014	.023	.016	.457	.160	.577*	.033	.078	.364	1		
BOD_5 (mg/L)	.212	.585*	-.939**	.714**	-.939**	.172	.299	-.418	.425	.837**	.385	-.126	1	
COD(mg/L)	.107	.355	-.657**	.463	-.651**	.406	.423	-.024	.518*	.785**	.385	-.192	.72**	1

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

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

4.2. Correlation Matrix among selected physico-chemical parameters of Awetu river quality characteristics

In order to find out the relationship among physico-chemical parameters of the river water samples, correlation coefficients were worked out and a large number of significant correlations were found. The statistical analysis of correlation matrixes of the physico-chemical parameters are summarized in (Table 6). Water temperature and ambient temperature revealed high positive correlation at ($P<0.01$). But, temperature was negatively correlated with DO (-0.12), EC (-0.07) and TDS (-0.71) at ($p<0.01$). On the other hand BOD_5 strongly correlated with DO and NH_4^+ ($P<0.05$). But BOD_5 was highly correlated with EC and TDS at ($P>0.05$). Turbidity showed that high positive significant correlation with PO_4^{3-}-P and

TSS at ($P<0.05$). Turbidity also exhibited decreased or increased in their values and also reverse for DO and pH values. The turbidity was a striking characteristic to know the physical status of a river. The suspended particles, soil particles, discharged effluents; decomposed organic matter, TDS as well as the microscopic organisms increase the turbidity of water, which interferes with the penetration of light. EC indicated that high negative significance correlation with DO (-0.84), NH_4^+ (-0.71) and BOD_5, pH (-0.9) at ($P<0.05$). EC was a measure of capacity of a substance or solution to conduct electricity. This shows that with increased or decreased in the values of EC; TDS, TSS, TS, BOD_5, COD, TN, NO_3-N, NH_3-N, Orth-P.

4.2. Macroinvertebrates abundance and composition

4.2.1. Benthic macroinvertabrates

A total of 1621 macroinvertabrates individuals belonging to 11 orders, and 33 families were collected during the sampling period along the stretch of Awetu stream. From the 11 orders encountered, *Ephemeroptera* was the dominant taxa group with relative abundance of 43% followed by *Odinata* 18.3% and *Diptera* 14%. *Caenide* was the most abundant family (399 individuals), followed by *Baetidae* (345 individuals), *Ceonagrionidae* (253 individuals), *Chironamidae* (198 individuals), *Vellidae* (88 individuals), then *Beloctomatidae* (62 individuals). Among the sorted and identified families the following are the common species found in all the fifteen (15) sampling sites; *Caenidae*, *Betidae, Ceonagridae* and *Chironomidae.* This could be attributed to increased inputs of organic nutrients, which could have resulted in an increase in the population of benthic macroinvertebrates as well as their ability to tolerate high pollution levels.

Macroinvertebrates were found in all sampling sites, most macroinvertebrate taxa richness was found at site AWS7 (15 families), followed by AWS6 (14 families), AWS4 (13 families), and AWS3 (12 families), while fewer taxa (6 families) were collected at AWS6, and AWS15 (Table.7).

Many taxa including *Coenagrionidae, Corixidae, Naucoridae, Gerridae, Gyrinidae, Dytiscidae*, *Notonectidae*, *Elmidae and Psphenidae* were collected exclusively from upstream sites in low numbers. Higher taxa diversity has been attributed to good ecosystem condition and ability of the resident taxa to adapt to the prevailing conditions (Patrick et al., 2014).

Generally, taxa richness tended to decline down streams. This might have been due to the presence of relatively higher pollution in this site due to various human activities such as the washing of motorbikes, clothes, bathing laundry activities, grazing, animal wastes, and agricultural inputs.

Chironomids are most abundant species of diptera taxa with value of 198. This species is most commonly present in sample sites of AWS12, AWS13 AWS14 and AWS15 in which the sample sites are known by holding different types of wastes and organic loads from the surrounding area. Chironomids are much tolerant for pollution with having tolerance value of eight. They can even stay longer in highly polluted areas. Higher tolerance of the blood red chironomidae is due to its pigment that helps the organism to get oxygen from the atmosphere hence the name “blood red” (Barbour *et al*., 1999; Bouchard, 2004).The relative abundance (95 %) for taxon groups of EPT% were recorded in station AWS5 (upstream) and the lowest (13.3%) was in station AWS15 (downstream). The decreasing abundance of intolerant taxa in station AWS15 could be attributed to poor water quality, habitat quality, food availability, and the extent of anthropogenic activities.

Table 7. The diversity indices of benthic macro invertebrates collected from the sampling sites along Awetu River

Diversity Indices	AWS 1	AWS 2	AWS 3	AWS 4	AWS 5	AWS 6	AWS 7	AWS 8	AWS 9	AWS10	AWS 11	AWS 12	AWS 13	AWS 14	AWS 15
Abundance	14	11	12	13	6	14	15	8	12	13	12	12	10	12	8
Family richness	144	74	79	140	69	87	177	74	120	163	171	75	113	62	75
Taxa richness (Margalef Index)	2.61	2.32	2.51	2.42	1.18	2.91	2.7	1.62	2.28	2.35	2.13	2.54	1.9	2.66	1.62
Shannon- wiener Index (H)	1.84	1.71	1.88	1.69	1.01	1.85	1.59	1.38	1.55	2.19	1.65	1.72	1.78	1.78	1.56
Simpson's dominance Index (D)	0.76	0.74	0.79	0.73	0.52	0.73	0.67	0.63	0.69	0.86	0.74	0.76	0.77	0.73	0.71
Evenness Index	0.45	0.77	0.6	0.4	0.34	0.45	0.31	0.49	0.39	0.6	0.4	0.3	0.55	0.48	0.59
No. of EPT Taxa	57	62	53	106	66	20	44	53	81	42	100	46	35	12	10
ETHbios	81	64	73	67	34	61	80	37	44	54	46	54	37	33	36
FBI	3.6	4.03	4.4	5	4.2	7.54	7.6	6.8	6.8	6.3	6.07	6.02	6.83	7.1	6.9
% EPT	39.5	83.7	40.9	67	95	22.9	24.9	71.6	67.5	25.7	58.4	61	30.9	19.3	13.3

4.2.3. Biological indices and metrics

4.2.3.1. 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. The ability to quantify diversity in this way is an important tool to understand community structure. Based on the species richness and species abundance (the number of individuals per species), the more species you have the more diverse area.

A. Shannon diversity index (H')

The result indicated that value of the Shannon-Wiener diversity index (H′) in the sampling stations varied from 1.01 to 2.19. The highest value (2.19) was observed in station AWS10, followed by 1.88 in station AWS3. Whereas, the lowest (1.01) was recorded in station AWS5. There were minimal variations in ShannonWiener diversity between sampling stations. The main reason could be the availability of quality and quantity of food sources, trophic structure, and the level of environmental stress for each site. This result agreed with Morphin-Kani & Murugesan (2014), who suggested that the high macroinvertebrate diversity could be an indication of a good environment and very low diversity showing the environment is under some lack of habitat availability.

B. Simpson diversity index

Simpson's diversity index (1-D) in Awetu River varied from 0.52 (AWS5) to 0.86 (AWS10). The highest (0.86) value was observed in station AWS10 and the lowest (0.52) was in AWS5. This probably due to few macrohabitats observed in station AWS5 and it is vulnerable to other invasion due to being open. This recorded value in Awetu River more than the given range indicated the presence of almost a high level of diversity. The Shannon-Wiener Index (H′) and Simpson's diversity index (1-D) showed the same trend at each sampling station. However, they had an inverse relation to Dominance (D).

C. Margaleff diversity index

Margalef's richness index was observed in the range of 1.18 to 2.66. Relatively the highest Margalef richness index was 2.66 followed by 2.61and 2.19 which were found in station AWS14, AWS1, and AWS6, respectively. Whereas, the lowest (1.18) was recorded in station AWS5. This could be due to the presence of several macrohabitats in station AWS14, particularly riffles, marginal areas, and pools, which may have favored the availability of more niches for macroinvertebrates' existence, as well as the absence of major anthropogenic activities such as deforestation, grazing, and washing activities. In the same way, the highest taxa richness was found in station AWS7 (15), AWS6 (14) and AWS1 (14). While the lowest (6) was in station AWS5. The variation among sites might was due to the level of environmental stress in the area via increased human activities for example in station AWS1 the degree of human activities was minimal.

D. Family level biotic index

Helsenhoff FBI was used to assess the pollution status of the river using macroinvertebrates and the result is presented in Table 7. FBI varied from 3.6 at AWS1 to 7.6 at AWS8 among the sites where specimens were collected and relatively the highest value recorded at mid-stream sites . When the three stream categories are compared with respects to their FBI mean values (AWS8, AWS9 and AWS10) were categorized as "poor" and (AWS12, AWS13 and AWS14) were categorized as "very poor" water quality classes indicating severe organic pollution according to the FBI category. Site AWS3 and AWS4 impacted sites fall under "good" water quality class. The sites (AWS1) were categorized as "excellent" water quality class as shown in (Table 7).

4.2.3 Functional feeding group of macroinvertebrates and ecosystem attributes

The functional feeding groups in Awetu River were dominated by Predators (44.48%), followed by collector- gathere (41.27%), scraper (4.71%), collector- filterer (3.08%) and shredders (0.92%). The results of this study showed that there was diversified functional feeding groups (FFGs) in Awetu River including gathering-collectors, filtering- collectors, predators, shredders and scrapers (Table 8). This is because of the differential distribution of energy inputs and change in river morphology over time which included variations in channel characteristics (presence of rapids, riffles, plant cover and water flow) and provided rise to a diversity of substrates and microhabitats, which in turn determine the arrangement of FFGs in lotic environments. The results have shown that functional feeding groups was dominated by predators, gatherer, and filterer respectively. On the other hand, the abundance of shredders feeding group was the least. Regarding the spatial distribution, the highest percentage of predators' composition (84%) was observed in downstream (station AWS15) and the lowest (3.7%) in station AWS5. On the other hand maximum percentages of collector-gatherer (70.2%) recorded in AWS2 and AWS8, but the lowest percentage (13.3%) at AWS15. Whereas, the lowest percentage for shredders (0.56%) and scrappers (0.56%) were observed in station (AWS7). The percentage of collector- filterer (CF) varied in the range of 0.56% (stationAWS7) to 15.9% in station AWS3. The difference in predators between sites could be due to the availability of prey like mayflies in each site and the presence or absence of riparian vegetation. However, some predators for example, Odonata use vegetation as a hunting ground for food (prey) and resting positions especially for the less mobile species (Koneri *et al*., 2017). This finding agrees with the river continuum concept the abundance of predator may depend on prey availability and in turn predator abundance also affects prey populations. Favretto *et al*. (2014), reported that the predator functional group can be found with high abundance in anthropic environments.

Table 8. Functional feeding groups on benthic macroinvertebrate

Categories	AW1	AW2	AW3	AW4	AW5	AW6	AW7	AW8	AW9	AW10	AW11	AW12	AW13	AW14	AW15	Mean
%Predators	62.5	12.1	56.8	28.18	3.7	70.1	73.4	27	28.3	42.3	35.6	33.3	50.4	59.6	84	44.4853
%Scrapers	0.69	5.4	2.27	1.81	9.2	1.14	0.56	2.7	2.5	30.6	0.58	1.3	0	12.9	0	4.77667
% Filters	3.47	10.8	15.9	3.63	0	0	0.56	1.35	0.83	1.22	0	0	2.65	3.2	2.66	3.08467
%Gatherers	35.4	70.2	22.7	22.7	85.1	28.7	14.6	70.2	68.3	25.7	63.1	64	14.2	20.9	13.3	41.2733
%Shredders	0.69	1.35	2.27	0.9	1.85	0	0.56	0	0	0	0.58	1.3	1.5	2.85	0	0.92333

4.3 The relationship between water quality and benthic macroinvertebrates

Based on the canonical correspondence analysis (CCA) the relationship between the physicochemical parameters and macroinvertebrates communities is illustrated in Figure 3. The first and the second canonical axes explained 69.1% (eigenvalue of 0.602) and 82% (eigenvalue of 0.113) of the variation in the macroinvertebrates data respectively. The macroinvertebrates and physicochemical correlation of the first axis were statistically significant in a Monte Carlo permutation test ($P < 0.05$). The result on canonical correspondence analysis (CCA) showed the relationship between benthic macroinvertebrates taxa (biological indexes) and water quality parameters. This showed that macroinvertebrates act as bioindicators. Furthermore, most EPT taxas such as *Caenidae*, *Betidae* and *Heptagenidae* were abundant in upstream stations (From AWS1 to AWS5). This could be the presence of high dissolved oxygen in upstream sites and suitability of habitat for very sensitive macroinvertebrates. Whereas, total phosphors, TSS and nitrate-nitrogen are negatively correlated with EPT taxas. Axis one has a great correlation with the environment. The ecological indicators ETHbios, Family rechness and Evennes were positively correlated with TSS, TP and NO_3-N. On the other hand, a negative correlation of BOD_5, pH and NH_4. Regarding biological communities, the presence of most pollution sensitive taxa (e.g., *Hydropsychidae, Caenidae, and Heptageniidae*) were associated with high levels of DO or a low oxygen Prati index. On the other hand, pollution resistant taxa (e.g., *Haplotaxidae, Culicidae, Physidae, and Hydrophylidae*) were more abundant in waters with high nutrient levels. The family richness, evenness and Shannon index revealed that high significant dependence on TSS, NO_3 -N and TP. This suggests that a local increase in pH and DO was responsible for increase in the richness of benthic macro-invertebrates. At same time, highly significant negative correlation of BOD_5 and COD affected taxa richness and all diversity indices. This implies that, an increase in BOD_5, COD and NH_4^+ was responsible for decrease in the richness of benthic macroinvertebrates. Generally, in this study, benthic macroinvertebrates were influenced by the location of the sampling site (upstream or downstream) and also by the sources of anthropogenic activities or land uses.

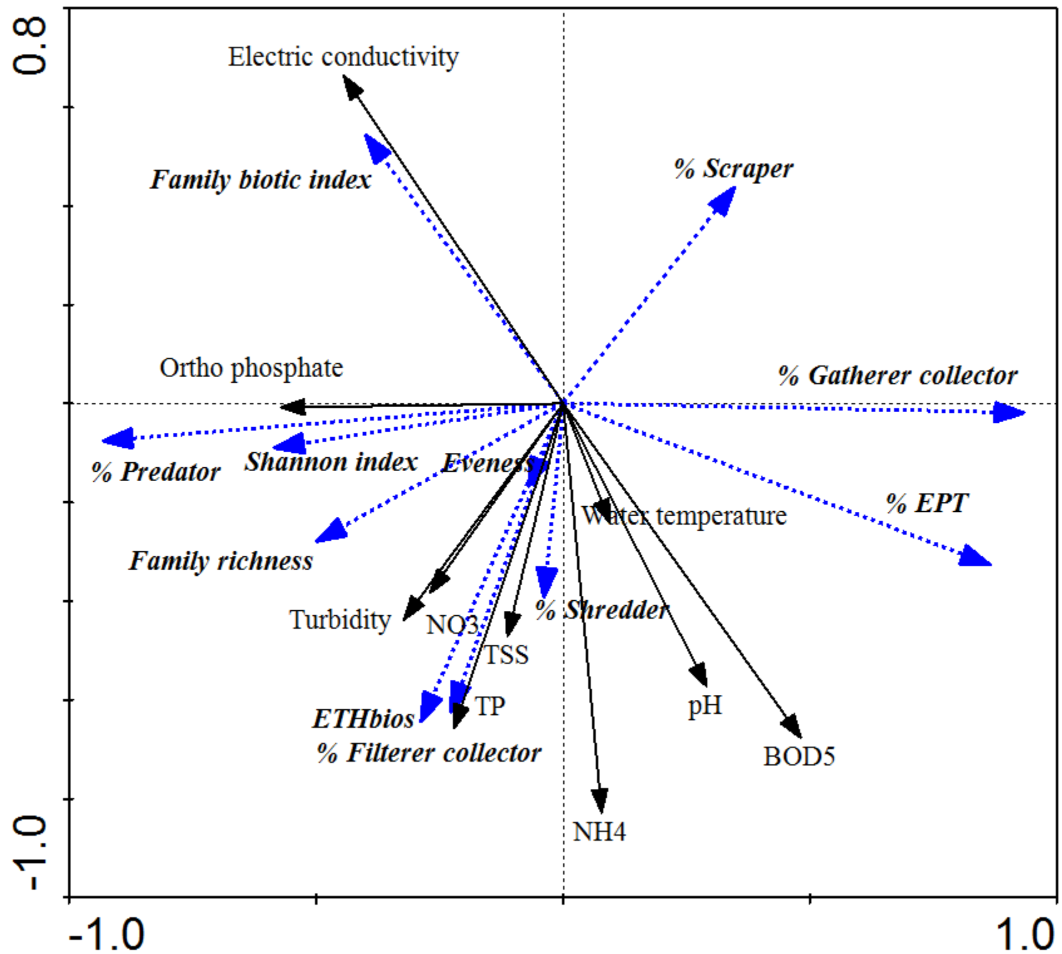

Figure 3. Detrended correspondence analysis (DCA) based on the invertebrates assemblages with respect to environmental variable

4.4. The habitat quality assessment and their relationships with benthic macroinvertebrates

4.4.1. Physical habitat quality

Based on the rapid bio assessment protocols the habitat measurement characteristics shown in (Table 9). The anthropogenic impacts were reflected in the IHF and QBR indices scores as well, which decreased from site AWS2 to AWS15, showing a gradient of impacts from upstream to downstream. These findings were consistent with (Haddis *et al.*, 2014) observation which identified increased degree of anthropogenic impacts in the riparian corridor of Awetu stream. Overall, upstream sites (AWS1, AWS2, AWS3 and AWS4) had good water and habitat quality when compared with downstream sites which are characterized by increased in nutrient concentration and habitat degradation. Measures of the structural integrity were sensitive to water quality and have detected the differences in water and habitat quality among sites. The sites are differed in habitat quality showing gradient of habitat degradation from upstream to downstream. Sampling station from (AWS1 –AWS3) had a native riparian corridor and high substratum heterogeneity with a minimal human alteration, site AWS4 and AWS5 has natural channel and good aquatic vegetation cover as well as good substratum heterogeneity with medium human alteration (grazing, swimming, and bathing), site from AWS6 to AWS10 crossed light agricultural area with strong human alteration (farming, bathing, washing clothing's, native forest removal and channelizing) whereas sites AWS11 to AWS15 were severely altered by human activities (channelization, removal of native riparian vegetation, municipal wastewater effluent input, municipal solid waste dumping, and car wash effluent input). The QBR index clearly classified the riparian corridor quality of the studied stream sites into four classes: sample site of upstream (AWS1-AWS3) with a total score of 80 QBR, that indicates the site had riparian habitat in some disturbance condition with good quality; sample site AWS4 to AWS7 scored 55 total QBR score means that the site had important disturbance with fair habitat quality ; site AWS8, AWS9 and AWS10 had strong alteration indicates poor habitat quality and the last five sites (AWS11, AWS12, AWS13, AWS14 and AWS15) recorded < 25 total QBR score, had extreme degradation with bad habitat quality (Table 9). The habitat quality of the 15 sampling sites evaluated by QBR and IHF indices agreed with the benthic macroinvertebrate diversity of the sites. Degradation of water and habitat quality causes predictable changes on macroinvertebrate community structure. For instance, reduction of macroinvertebrate diversity is found in streams affected by urbanization (Beyene *et al*., 2009). Indeed, sites located in upstream areas with native riparian vegetation, higher diversity of habitats and good water quality, showed greater taxonomic richness (reflected by the biotic index and derived metrics). In contrast, a decreased taxonomic richness and a correspondingly lower Shannon Diversity and Simpson's diversity index were observed in downstream sites.

Table 9. Habitat quality of the study sites evaluated by Fluvial Habitat Index (IHF) and Quality of the Riparian Corridor Index (QBR) in Awetu stream.

	AWS1	AWS2	AWS3	AWS4	AWS5	AWS6	AWS7	AWS 8	AWS 9	AWS 10	AWS 11	AW S12	AWS 13	AWS1 4	AW S15
Fluvial Habitat Index (IHF)															
Embeddedness in riffles/sedimentation in pools	20	20	20	20	15	15	15	15	15	15	10	15	10	10	10
Frequency of riffles	8	8	8	10	10	10	10	8	8	10	10	10	10	10	10
Composition of the substrate	20	20	20	14	14	14	14	14	14	8	8	8	8	8	8
Velocity/depth combinations	8	8	8	8	6	6	4	6	6	6	4	4	4	4	4
Percentage of shadow in the stream	5	3	7	3	3	3	10	10	3	5	5	3	5	5	3
Elements of heterogeneity	6	8	8	6	6	6	6	6	4	4	6	4	4	4	4
Aquatic vegetation cover and diversity	20	20	20	20	15	15	15	15	15	15	15	15	15	15	15
Final IHF Score	87	87	91	81	69	69	74	74	65	63	58	59	56	56	54
Quality of the Riparian Corridor Index (QBR															
Degree of cover of the riparian corridor	25	25	25	10	10	10	5	10	10	5	5	5	5	5	5
Structure of the vegetation	25	25	25	10	10	10	10	10	5	10	5	5	5	5	5
Quality of vegetation cover	20	20	20	20	10	10	20	10	10	10	5	0	0	0	0
Degree of naturalism of the channel	25	25	25	20	25	25	25	5	5	5	5	5	5	0	0
Final QBR score	95	95	95	60	55	55	60	35	30	30	20	5	15	10	10

QBR score is the sum of the scores of the four items that compose it. QBR < 25, extreme degradation; 70 > QBR > 55, beginning of important alteration; QBR > 95, riparian vegetation without alterations as defined by (Colwell, 2007).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The increasing levels of pollutants in study area were as a result of agricultural, urban and domestic waste discharges that make an issue of concern on water quality, habitat and quality of aquatic environment. On the basis of this assessing water quality using physicochemical properties and macroinvertebrate matrices of Awetu River has been done and reached on conclusions. From the results of this study shown that, the water qualities of the study area were varied from excellent to fair on the downstream direction due to increase in the pollution levels as evidenced by high water turbidity, low species richness, composition and diversity of the benthic macroinvertabrates fauna. This was a result of natural forces and an increase on anthropogenic activities affected and its biological systems were impaired due to various human impacts. Measures of most of the physico-chemical parameters, biotic index and benthic macroinvertebrate community matrices all indicated severe water pollution and associated ecological impairment in the impacted sites. The results indicate that the quality of water varies from station to station. A conclusion of the findings are given below.

The water temperature of Awetu River ranged between 19.6ºC to 23.6ºC. The electrical conductivity (EC) of water is affected by the suspended impurities and the amount of ions in the water. The highest conductivity 127µs/cm of the river water was observed in the last sampling station AWS15. The minimum conductivity 66µs/cm was observed at AWS2 sampling station; this could be due to the reduction of suspended impurities. The turbidity in river was lowest at the sampling site AWS10, which is 261 NTU. Moreover, the maximum turbidity observed in the river was on the AWS12 sampling station, which is 630 NTU. Total suspended solids (TSS) may affect water quality. Water with high TSS was generally poorer portability. TSS was observed maximum 231 mg/l in AWS12 and minimum 43mg/l in AWS10. Awetu River contained higher dissolved oxygen (DO) at AWS7; followed by a gradual decrease to downstream its lowest values at sampling station AWS15. Ammonia and Phosphorous showed a general increase downstream this was attributed to the existence of agricultural fields in close proximity to river banks. Dissolved Oxygen was generally higher in upstream than downstream where most of the catchment activities occur.

Macroinvertebrate analysis was the other assessment mechanism. The diversity indices were able to capture water quality impairment. The mean abundance of upper stream of the river water was dominated by pollution sensitive tax richness (Ephemeroptera, Trichoptera, Plecoptera and Coleoptera), while dawn stream of effluent discharges were readily recovered by pollution tolerant families (*Chironomidae, Simulidae, leeches*). Moreover, the result shows that as habitat and water quality are degraded, number and percentage of EPT decreased. Major possible activities which have affected the studied rivers might be agriculture, forest clearance and waste dumping were causes of macroinvertebrate impairment. Furthermore, most EPT taxas such as *Caenidae, Betidae* and *Heptagenidae* were abundant in upstream stations (From AWS1 to AWS5). This could be the presence of high dissolved oxygen in upstream sites and suitability of habitat for very sensitive macroinvertebrates. Whereas, total phosphors, TSS and nitrate-nitrogen are negatively correlated with EPT taxas. The results have shown also that there was a high diversity of FFGs namely: predators, gathering-collectors, filtering- collectors, shredders and scrapers. Predators were the most dominant particularly in dawn stream sites. However, shredders were the least. Based on functional feeding group ratios ecosystem attributes in Awetu river were heterotrophic, a non-functioning riparian area, plentiful of particulate organic matter and overburdened with predators. Thus, this study also concluded that the composition of benthic macroinvertebrates functional feeding groups and ecosystem attributes were affected by the human activities near the river such as agriculture, grazing, deforestation and washing activities which lead to natural habitat quality deterioration and soil erosion.

Physical habitat information for this study, determined that aquatic habitat features, including channel morphology, riparian condition, stream bank stability, in stream cover, and substrate, have been degraded by human disturbances. In general according to this study, the anthropogenic activities towards rivers, the habitat quality deterioration and the water quality are happen to be in a complex relationship so that when the anthropogenic activity reduces the habitat quality, it intern degrade the bio indicator community diversity that result in poor water quality. The macroinvertebrate based indices and metrics were found to be robust methods in understanding the relationship between habitat quality, anthropogenic activity and river water quality.

5.2. Recommendations

Awetu River used for a variety of purposes such as, cattle drinking, car washing, domestic purposes and recreational part of the town without prior treatment. For sustainable management of this water resource, based on the findings of the study, the following recommendations are forwarded to environmental protection agencies at different levels and other concerned administrative and/or non-governmental bodies should take strict as well as technical measures.

- To minimize the deterioration of the aquatic ecosystem in this area the current Awetu River rehabilitation project of river side along with watershed management should be continued.
- Enforcement of law and propagating environmental education to the community with special target to those contributors of the present degradation could be one solution.
- To maintain habitat and water quality, the riparian area of Awetu River should be free from agricultural activities if possible.
- Creating awareness on waste handling and disposing system in the community to save a fast deteriorating water bodies is highly recommended.
- The impacted sites should be protected against the increasing anthropogenic impacts and remedial actions should be taken to protect the remaining pristine river segments and to restore the degraded rivers on the standard of these rivers.
- Also recommend further study including the wet and dry seasons to see the effect of season by including larger sampling area coverage

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APPENDIX

Annex I

Annex 1. Stream assessment form

1. DD/MM/YYY--
2. Site code------------------------------------ name of stream ---------------------------------
3. Stream description--

   ----
4. Altitude (m)------------------------------------ coordinates -----------------------------------
5. Ambient temperature (^{0}C)--------------------------- water temperature (^{0}C)-----------
6. Do(mg/1)-------------%---------------EC (µs/cm)----------------pH-----------------------
7. Velocity (m/s)---------------------water depth (m)----------------discharge (m^3/s)----
8. Turbidity (NTU)----------- color-----------------smell--------------------------------------

   Habitat assessment

9. River bank width (m)---------------------------- Bank height (m)-------------------------
10. Riverbed (%)

a. Bed rock--------e gravel--------I sticks--------------------------------

b. Boulder---------f sand ----------j branches --------------------------

c. Cobble ----------g silt-----------k loges--------------------------------

d. Pebble ----------h detritus--------------

11. Riparian vegetation

a. Trees>10m-----------------------d. grass-------------------------------------

b. Trees<10m--------------------e bare land ---------------------------------

c. Shrubs---

12. Width riparian vegetation right----------------------------------- left----------------------
13. Canopy cover--
14. Protection riparian vegetation right------------------------------ left----------------------
15. %pool--
16. % riffle--

a. Water appearances

17. Sinuosity---

18. Slope--

19. List the available anthropogenic disturbance --

    ----

20. Upstream land use--

21. Adjacent land use right----------------------------------- left--------------------------------

22. Farming distance from the river bank--

23. Take picture (picture number)--

24. Anthropogenic activities

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

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

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

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

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

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

g. Car washing -------------------------------

h. Waste dumping -------------------------------

i. Swimming -------------------------------

Annex 2 A. Fluvial Habitat Index

Sampling site
Date
Operator

1. **Embeddedness in riffles and runs- sedimentation in pools**

Riffles	Stone , pebbles and gravel imbibed in fine sediment in 0-30%	10	
	Stones, pebbles and gravel embebed in fine sediment in 30-60 %	5	
	Stones, pebbles and gravel embebed in fine sediment in >60 %	0	
Pools	Sedimentation 0-30%	10	
	Sedo,emtatopm 30-60%	5	
	Sedimentation > 60%	0	

TOTAL (Only one score from pools or from riffles)

2. **Riffle frequency**

High frequency of riffles , Ratio : distance between riffles / stream width< 7	10	
Medium , Ratio: distance between rifles / stream width 7-15	8	
Ocassuibak.Ratio : distance between riffles /Stream width 7-15	6	
Scarce or null, laminar flow Ratio: distance between riffles / stream width > 25	4	
Only pools	2	
TOTAL (Only one score)		

3. **Substrate composition** **score**

% Boulders and stones	1-10%	2	
	>10%	5	
% pebbles and gravels	1-10%	2	
	>10%	5	
% Sand	1-10%	2	
	>10%	5	
% Silt and clay	1-10%	2	
	>10%	5	

TOTAL (Some of scores from Each class of Substrate)

4. Velocity / depth regime

4 classes present. Slow- depth, slow- shallow, fast- depth and fast – shallow.	10	
Only 3 of 4 regimes	8	
Only 2 of 4 regimes	6	
Only 1 regime	4	
	TOTAL (only one socre)	

5. Shading of river bed

Shaded with some open areas	10	
Completely shaded	7	
Large open areas	5	
Not shaded	3	

6. Heterogeneity components

Leaf litter	>10%or<75% <10%or<75%	4	
Presence of branches and wood in the stream		2	
Tree roots in the banks		2	
Natural dams		2	
		2	
TOTAL (Sum of scores of each class)			

7. Aquatic vegetation cover

% plocon + mosses	10-50% <10% or >50%	10 5 10	
% pecton	10-50%	5	
% phanerogams + Charales	<10%or >50% 10-50%	10 5	
TOTAL (Sum of Scores of each class)			

Total (Sum of Scores of each class

Annex 2 B. QBR index from

Riparian habitat quality assessment from

Score of each part cannot be negative or exceed 25

1	Site Name	
2	Observer	
3	Longitude	
4	Latitude	
5	Altitude	

Total riparian cover
part 1 score

Score	
25	>80% of riparian cover (excluding annual plants
10	50-80% of riparian cover
5	10-50% of riparian cover
0	<10% of riparian cover
+10	If connectivity between the riparian forest and the woodland is total
+5	If the connectivity is higher than 50%
-5	Connectivity between 25 and 50%
-10	Connectivity lower than 25%

Cover quality part 2 score

score	
25	>75% of tree cover
10	50-75% of tree cover or 25-50% tree cover but 25% covered by shrubs
5	Tree cover lower than 50 % but shrub cover at least between 10 and 25 %
0	Less than 10% of either tree or shrub cover
+10	At least 50 % of the channel has helophytes or shrubs
+5	If 25-50 % of the channel has helophytes or shrubs
+5	if trees and shrubs are in the same patches
-5	If trees are regularly distributed but scrubland is > 50%
-5	If trees and shrubs are distributed in separate patches without continuity
-10	Trees distributed regularly and scrubland <50%

Cover quality score part 3

Score		Type 1	Type 2	Type 3
25	>75% of tree cover			
10	50-75% of tree cover or 25-50 % tree cover but 25% covered by shrubs			
5	Tree cover lower than 50% but shrub cover at least between 10 and 25 %			
0	Less than 10% of either tree or shrub cover			
+10	At least 50% of the channel has helophytes or shrubs			
+5	If 25-50% of the channel has helophytes or shrubs			
+5	If trees and shrubs are in the same patches			
-5	If trees are regularly distributed but scrubland is >50%			
-5	If trees and shrubs are distributed in separate patches without continuity			
-10	Trees distributed regularly and scrubland <50%			
Final score is sum of all level scores				

Appendix 3 Values of physico-chemical parameters on different sampling site of study area

	AWS1	AWS 2	AWS 3	AWS 4	AWS 5	AWS 6	AWS 7	AWS 8	AWS 9	AWS 10	AWS 11	AWS 12	AWS 13	AWS 14	AWS 15
Width (m)	8	7.4	6.3	5.2	6	3.5	4	8	5.2	9.6	5	4.6	6	6	4.5
Depth (m)	0.6	0.65	0.75	0.8	0.6	1.4	1.45	1.5	1.4	2	1.5	1.7	1.75	1.7	1.8
Velocity (m/s)	0.3	0.32	0.35	0.25	0.34	0.3	0.12	0.23	0.11	0.09	0.3	0.2	0.15	0.17	0.11
Temprature (oC)	21.7	21.5	22.4	23.6	22.3	20.1	19.6	21.4	20.7	21	21.3	22.5	22.5	21.4	21.2
pH	6.5	6.5	6.6	6.72	6.39	6.58	6.54	6.71	6.61	6.4	6.61	6.44	6.28	6.2	6.27
EC (µS/cm)	63	66	65	66	69	73	78	75	80	84	87	88	116	120	127
DO (mg/L)	7.31	7.32	7.16	6.89	7.17	7.73	7.83	7.4	7.45	7.09	7.31	7.01	6.32	4.89	3.26
TDS (mg/L)	32	33	33	33	35	37	39	38	40	42	44	44	58	60	63
Turbidity (NTU)	805	571	442	386	325	326	322	313	315	261	453	630	583	517	274
Ambiant Temprature	30.5	31	31.2	30	26	23	21	24	23	24	26	27	30	27	26.5
PO43- -P (mg/L)	0.82	0.45	0.52	0.4	0.39	0.44	0.55	0.45	0.4	0.44	0.67	0.85	0.74	0.74	0.59
TP (mg/L)	1.72	1.36	1.52	1.71	1.08	1.36	1.18	0.85	1.31	0.94	1.3	1.37	1.41	0.98	1.26
NH4 + -N (mg/L)	1.33	1.063	1.166	0.951	0.674	0.738	0.567	0.455	0.486	0.345	0.438	0.427	0.408	0.4	0.298
TSS (mg/L)	276.8	219	135	96	130	110	152	48	143	43	121	231	180	105	41
NO3 - -N (mg/L)	0.65	0.55	0.64	0.52	0.46	0.37	0.74	0.74	0.4	0.35	0.58	0.8	0.55	0.63	0.52
BOD 5 (mg/L)	6.1	6	6	5.9	6	5.6	5.4	5.4	5.5	5.4	5.2	5.1	5	4.7	4.5
COD (mg/L)	86	64	64	54	48	64	32	32	32	54	64	32	32	32	24

Annex 3. Biotic indices

Table 13. The tolerance score used for the evaluation of water quality using the family – level blotic index (Hilsenhoff, 1988)

S/N	Order	Family	Tolerance	Reference
1	Ephemeroptera	Baetidae	4	Barbour et al,1999
		Caenidae	7	Barbour et al,1999
		Ephemerlidae	1	Barbour et al,1999
		Heptagenidae	4	Hauer & lamerti 1996
		Tricorythidae	6	Barbour et al ,1999
2	Plecoptera	Perlidae	1	Hauer & Lamberti 1996
		Chloroperlidae	1	Hauer & Lamberti 1996
3	Tricoptera	Lepidostomatidae	1	Hauer & Lamberti 1996
		Sericostomatidae	4	Barboure et al, 1999
		Philopotamidae	3	Barboure et al, 1999
		Limnephilidae	3	Hauer & Lamberti 1996
		Brachycentridae	4	Hauer & Lamberti 1996
		Hydropsychidae	1	Hauer & Lamberti 1996
4	Odonata	Aeshnidae	4	Hauer & Lamberti 1996
		Coenagrionidae	3	Hauer & Lamberti 1996
		Gomphidae	9	Hauer & Lamberti 1996
		Lestidae	9	Hauer & Lamberti 1996
		Libellulidae	9	Hauer & Lamberti 1996
		Protoneuridae	9	Hauer & Lamberti 1996
5	Coleopteran	Dytiscidae	3	Bode et al., 1996
		Elimide	5	Hauer & Lamberti, 1996
		Gyrinidae	4	Bode et'al 1996
		Helodidae	4	Bode et'al 1996
		Hydrometridae	5	Hauer & Lamberti 1996
		Hydrophilidae	4	Hauer& lamberti 1996

6	Hemiptera	Gerridae	4	Hauer& lamberti 1996
		Corixiidae	5	Bode et al ., 1996
		Mesoveliidae	10	Barbour er at 1999
		Naucoridae	5	Barbour er at 1999
		Notonoctidae	1	Barbour er at 1999
		Nepidae	3	Barbour er at 1999
		Veliidae	6	Barbour er at 1999
		Pleidae	5	Barbour er at 1999
		Belostomatidae	10	Barbour er at 1999
7	Basommatophora	Physidae	8	Barbour er at 1999
		Lymnaeidae	5	Barbour er at 1999
8	Veneroida	Sphaeridae	8	Barbour er at 1999
9	Oligochates	Lumbriculidae	5	Barbour er at 1999
10	Rhynchobdella	Hirudinidae	10	Barbour er at 1999
11	Dipteral	Syrphidae	10	Barbour er at 1999
		Tabanidae	6	Barbour er at 1999
		Tipulidae	3	Hauer & Lamberti 1996
		Simulidae	6	Bode et al .1996
		Psychodidae	10	Hauer & Lamberti 1996
		Chironomidae	8	Hauer & Lamberti 1996
12	Decapoda	Potamonautidae	10	Hauer & Lamberti 1996
13	Unionoida	Unionidae	8	Barbour et al, 1996
S/N	Order	Family	Tolerance Score	Reference
1	Ephemeroptera	Baetidae	4	Dickens & Graham ,2002
		Caenidae	6	Dickens & Graham ,2002
		Ephemerlidae	15	Dickens & Graham ,2002
		Tricorythidae	13	Dickens & Graham ,2002
		heptagenidae	9	Dickens & Graham ,2002
2	plecoptera	Perlidae	12	Dickens & Graham ,2002

		Chloroperlidae	14	Dickens & Graham ,2002
3	Tricoptera	Lepidosomatidae	10	Dickens & Graham ,2002
		Leptoceridae	6	Dickens & Graham ,2002
		Sercostomatidae	13	Dickens & Graham ,2002
		Philopotamidae	10	Dickens & Graham ,2002
		Limnephilidae	8	Dickens & Graham ,2002
		Brachycentridae	13	Dickens & Graham ,2002
		Hydropsychidae	4	Dickens & Graham ,2002
4	Odonata	Aeshnidae	8	Dickens & Graham ,2002
		Coenagrionidae	4	Dickens & Graham ,2002
		Gomphidae	6	Dickens & Graham ,2002
		Lestidae	8	Dickens & Graham ,2002
		Libelluide	4	Dickens & Graham ,2002
		Protoneuridae	8	Dickens & Graham ,2002
5	Coleopteran	Dytiscidae	5	Dickens & Graham ,2002
		Elimidae	8	Dickens & Graham ,2002
		Gyrinidae	5	Dickens & Graham ,2002
		Helodidae	12	Dickens & Graham ,2002
		Hydrometridae	5	Dickens & Graham ,2002
		Hydrophilidae	5	Dickens & Graham ,2002
6	Heniptera	Gerridae	5	Dickens & Graham ,2002
		Corixidae	3	Dickens & Graham ,2002
		Mesoveliidae	5	Dickens & Graham ,2002
		Naucoridae	7	Dickens & Graham ,2002
		Notonoctidae	3	Dickens & Graham ,2002
		Nepidae	3	Dickens & Graham ,2002
		Veliidae	5	Dickens & Graham ,2002
		Pleidae	4	Dickens & Graham ,2002
		Belostomatidae	3	Dickens & Graham ,2002
7	Basommatophora	Physidae	3	Dickens & Graham ,2002

		Lymnaeidae	3	Dickens & Graham ,2002
		Sphaeridae	3	Dickens & Graham ,2002
		Lumbriculidae	1	Dickens & Graham ,2002
		Hirudinidae	3	Dickens & Graham ,2002
		Syrphidae	1	Dickens & Graham ,2002
		Tabanidae	5	Dickens & Graham ,2002
		Tipulidae	5	Dickens & Graham ,2002
		Simulidae	5	Dickens & Graham ,2002
		Potamonautidae	10	Dickens & Graham ,2002
		Unionide	8	Dickens & Graham ,2002

Annex 4. Abundance and composition of the macroinvertebrates in Awetu stream

Taxa (Order & Family)	AWS1	AWS 2	AWS3	AWS4	AWS5	AWS6	AWS7	AWS 8	AWS9	AWS10	AWS11	AWS12	AWS 13	AWS 14	AWS15	No. of taxa
Coleoptera																
Elmidea	1	1	1	2	1						1	1	2			**10**
Gyrinidae	2		1													**3**
Dytiscidae							1					1				**2**
Lumbricidae						4	1	2				1	3			**11**
Diptera																
Chironimidae	2			1	1	3	17	11	7	3	30	13	45	29	36	**198**
Cullcidae							1		1	2			3	2	2	**11**
Tipuhidae														2		**2**
Syrphidae						1	1		1		8	1	14	1		**27**
Decapoda																
Potamidae	_	2		1		1										**4**
Ephemeroptra																
Caenidae	32	28	23	49	17	10	22	42	59	24	27	25	22	10	9	**399**
Baetidae	19	22	22	51	44	9	21	8	22	18	73	21	12	2	1	**345**
Heptagenidae	1	4	1	2	5	1	1	2				1				**18**
Hemiptera																
Coroxidae										8				1	2	**11**
Beloctomatidae						8	6			23	3		7	4	11	**62**
Gerridea	5	1		2												**8**
Nepidea	2					1	1				1					**5**
Notonectidae										4	1		2	1	10	**18**
Naucoridea	1	2	2	2		1	2									**8**
Velidea	57	5	5	12			1	1	3	2	1	1				**88**
Odinata																
Aeshnidae										2						**2**
Calopteryidae	3		1		1	1	4		1		3	1				**15**
Coenagridea	11		12	5		41	95	7	20	23	22	8	3	2	4	**253**
Gomphidea			1	3												**4**
Libellulidea	3		3	6		4	3		2	4		1				**26**

Taxa (Order & Family)	AWS1	AWS 2	AWS3	AWS4	AWS5	AWS6	AWS7	AWS 8	AWS9	AWS10	AWS11	AWS12	AWS 13	AWS 14	AWS15	No. of taxa
Plicopetra																
Nemouuridea		1														**1**
Trichptera																
Hydropsychidea	5	7	7	4				1								**24**
Sphariide																
Sphariidae		1														**1**
Arhynchobdellidae																
Hirudinae						2			1							**3**
Moluscus																
planorbidae										16						**16**
Physidae									2	34	1			7		**44**
Hydrobidae									1					1		**2**
Total # of Taxa	**144**	**74**	**79**	**140**	**69**	**87**	**177**	**74**	**120**	**163**	**171**	**75**	**113**	**62**	**75**	**1621**
	14	11	12	13	6	14	15	8	12	13	12	12	10	12	8	31

Annex 6 Results of biotic index and FFG of benthic macroinvertebrate on each sample sites.

Site	FR	Abundance	Shannon	Simpson	Eveness	ETHbios	HBI	EPT	Predadator	Scraper	Filter Collector	Collector gathore	Shreder
AW1	14	144	1.84	0.76	0.45	81	3.6	39.5	59.50	0.69	3.47	35.65	0.69
AW2	11	74	1.71	0.74	0.77	64	4.03	83.7	12.10	5.45	10.80	70.10	1.55
AW3	12	79	1.88	0.79	0.6	73	4.4	40.9	56.86	2.27	15.90	22.70	2.27
AW4	13	140	1.69	0.73	0.4	67	5	67	68.17	3.80	3.63	22.70	1.70
AW5	6	69	1.006	0.52	0.34	34	4.2	95	3.70	9.20	0.00	85.25	1.85
AW6	14	87	1.85	0.73	0.45	61	7.54	22.9	70.10	1.14	0.06	28.70	0.00
AW7	15	177	1.59	0.67	0.31	80	7.6	24.9	83.35	0.56	0.56	14.97	0.56
AW8	8	74	1.38	0.63	0.49	37	6.8	71.6	26.00	2.70	1.30	70.00	0.00
AW9	12	120	1.55	0.69	0.39	44	6.8	67.5	28.30	2.50	0.20	69.00	0.00
AW10	13	163	2.19	0.86	0.6	54	6.3	25.7	42.52	30.60	1.22	25.66	0.00
AW12	12	75	1.72	0.76	0.3	54	6.02	61	33.30	1.30	0.00	64.00	1.40
AW13	10	113	1.78	0.77	0.55	37	6.83	30.9	80.40	0.00	3.90	14.20	1.50
AW14	12	62	1.78	0.73	0.48	33	7.1	19.3	59.70	12.90	3.65	20.90	2.85
AW15	8	75	1.56	0.71	0.59	36	6.9	13.3	84.00	0.00	2.70	13.30	0.00

Annex 7 : Diversity index values of macro invertebrates on each sample sites.

Diversity Indices	AWS 1	AWS 2	AWS 3	AWS 4	AWS 5	AWS 6	AWS 7	AWS 8	AWS 9	AWS10	AWS 11	AWS 12	AWS 13	AWS 14	AWS 15
Abundance	14	11	12	13	6	14	15	8	12	13	12	12	10	12	8
Family richness	144	74	79	140	69	87	177	74	120	163	171	75	113	62	75
Taxa richness (Margalef Index)	2.61	2.32	2.51	2.42	1.18	2.91	2.7	1.62	2.28	2.35	2.13	2.54	1.9	2.66	1.62
Shannon- wiener Index (H)	1.84	1.71	1.88	1.69	1.01	1.85	1.59	1.38	1.55	2.19	1.65	1.72	1.78	1.78	1.56
Simpson's dominance Index (D)	0.76	0.74	0.79	0.73	0.52	0.73	0.67	0.63	0.69	0.86	0.74	0.76	0.77	0.73	0.71
Evenness Index	0.45	0.77	0.6	0.4	0.34	0.45	0.31	0.49	0.39	0.6	0.4	0.3	0.55	0.48	0.59
No. of EPT Taxa	57	62	53	106	66	20	44	53	81	42	100	46	35	12	10
ETHbios	81	64	73	67	34	61	80	37	44	54	46	54	37	33	36
HBI	3.6	4.03	4.4	5	4.2	7.54	7.6	6.8	6.8	6.3	6.07	6.02	6.83	7.1	6.9
% EPT	39.5	83.7	40.9	67	95	22.9	24.9	71.6	67.5	25.7	58.4	61	30.9	19.3	13.3

Annex 8

Figure 4. In-situ measurement of physicochemical parameters

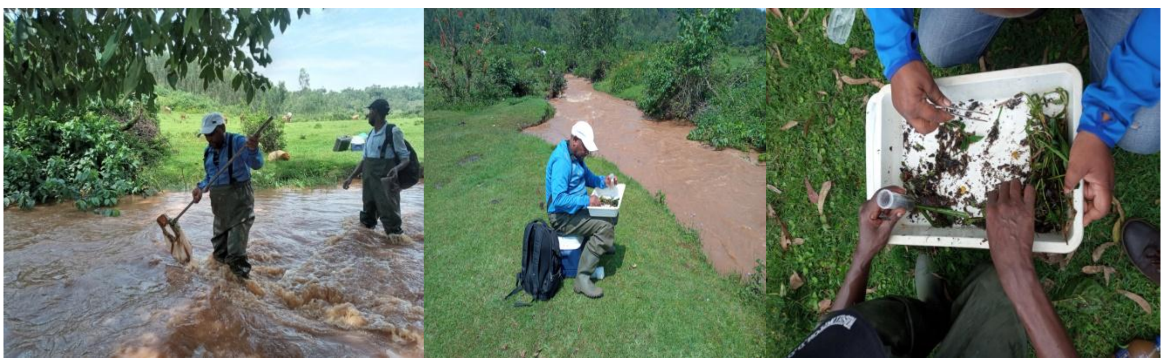

Figure 5. Collection of macroinvertebrate samples at the study area

Figure 6. Analyzing the physico-chemical parameters in the laboratory

Figure 7. Sorting and identification of macroinvrtebrates in to their family level.