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# Ecological studies of benthic macro-invertebrates from a sediment along gradient in the Awash River, Ethiopia.

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**A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Fisheries and Aquatic Science**

# Ecological studies of benthic macro invertebrate along asediment gradient in the Awash River, Ethiopia.

MSc Thesis

BY

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Addis Ababa, Ethiopia.

# Dedication

I dedicate this thesis to my all beloved families, especially my father Mr. Mohammed Seidand my mother Mrs.Workeya Abdulkader for their outstanding support, prayers, encouragement and nurturing conducive environment during my study period.

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# Acronyms

| | |
|---|---|
| **CCA** | Canonical Correspondence Analysis |
| **DO** | Dissolved oxygen |
| **EEPA** | Ethiopia Environmental protection Authority |
| **FSSR** | Fine sediment sensitivity rate |
| **PSI** | Pollution Sensitive Index |
| **RDA** | Redundancy analysis |
| **SRP** | Soluble reactive phosphorus |
| **TP** | Total phosphors |
| **UNEP** | Untied Nation Environmental Program |
| **USEPA** | United State Environmental Protection Agency |

# Abstract

*Macro- invertebrates are good indicators of human land use impacts because they are sensitive to habitat alterations. The present study aimed at assessing the ecological impacts of sediment loading on macro-invertebrates with the view to develop sediment sensitive invertebrate index (PSI) along the gradient of Awash River, Ethiopia. Three sampling sites were selected along the gradient of Awash River for evaluation of physicochemical parameters, soil particle size, organic matter and determination of the richness and diversity of macro-invertebrates. Macro- invertebrates were collected using standard dip net based on Rapid Bio Assessment Protocols for use in streams and wadeable rivers from the same kinds of microhabitats (pools and vegetated areas)and identified to the family level. Alongside, on site of measurement of Physico chemical parameters ($T^o$,DO,pH and Conductivity ) were taken. The results indicated that concentrations of dissolved oxygen, temperature, pH, conductivity, Nitrite and Nitrate showed significant difference among samplingsites (ANOVA),($P < 0.05$). The percentage abundance of families of macro- invertebrates was determined from all sites. Total of 19 families comprising 7,094 individuals were identified from all the sites. The sediment sensitivity result indicated that site one (S1)was moderately sedimented and had the highest family richness, while site three (S3) was heavily sedimented with the least family richness. Macro- invertebrate which indicated moderately sedimented sites are Baetidae and Lepidostomatidae whereas for heavily sedimated site Hydrophilidae and Lymnaeidae were dominant. The study indicated significant effect of different levels of sedimentation on macro-invertebrate community structure.As the sediment emanated from the degraded Awash catchment, there is need toprevent and control the ever-increasing degradation of the water quality of this ecologically and economically important river.*



**Key words:** Awash River, Bio indicators, Macro -invertebrate, PSI; RDA, Sedimentation.

# CHAPTER ONE

## 1. Introduction

Benthic macro invertebrates are among the most used bio indicators due to their sensitivity to environmental changes. Any modification of the streambed by pollutants, deposited sediment and watershed degradation will most likely have a profound effect upon the benthic community (Pawlak, 1999).

Stream invertebrates are strongly influenced by the physical substrate conditions along streambeds (Cummins and Lauff 1969). Benthic macro- invertebrates have been shown to prefer specific streambed particle sizes (Cummins *et al*., 1964), and whole assemblages have been described according to general, physical habitat types (i.e., mud, gravel, bedrock, plant). The array of particle sizes from silt to bedrock interacts with stream hydrologic forces to form benthic habitats, which provide the template upon which overall stream function depends (Hynes, 1970).

Sedimentation involves accumulation of fine sediment both on the surface of the stream layer or within stone substrate" (Naden*et al*., 2003). Sedimentation is one of many factors affecting the ecology streams and rivers ecology in the United States (Waters, 1995). Sedimentation as a main pollutant influenced the biology and role of stream structure in South American streams. (Henley *et al*., 2000) The Chattooga River and many of its tributaries showed signs of degradation due to sedimentation (USEPA, 1999). Since the 1970 $^{s}$ Lowe Yellow River in China decreased in sediment accumulation because of effective conservation activities, low precipitation, trapping by reservoirs. Likewise, Sao Francisco River, Brazil and Chao Phraya River, Thailand indicate lowering in sediment accumulation mainly due to trapping of sediment in reservoirs and irrigation canals. In comparison, Rivers such as Rio Magdalena in Colombia, Fly River in Papua New Guinea and Upper Kolyma River in Russia witnessed an increase in sediment accumulation due to degraded land clearance for agriculture and mining activities (Walling, 2006).

In Africa, where a significant portion of the population directly depends on land resources for livelihood, soil erosion and sedimentation are apparent in several countries . Mara River is one of the most important freshwater ecosystems for Kenya and Tanzania and the main source of this Trans – Boundary River being the Mau Forest. The Mau Forest in the upper basin an area equivalent to a third of the forest has been converted to agricultural land and therefore contributed to the degradation and soil erosion leads to loading of sediment in upstream and the impacts from upstream continued downstream (Maldonado, 2010). In Sudan, heavy rain and wind coupled with topographic features such as flat terrain have been identified as the causes of soil erosion and siltation of the Nile and Atbara Rivers, reservoirs, and irrigation canals (Hamad and El-Battahani, 2005).

In Ethiopia Lake Haramaya dried up in recent years because of climate change, overexploitation and siltation (BrookLemma, 2003). High population pressure leads to exploitation of natural resources with improper land resources management practices and poverty resulting in severe soil erosion and sedimentation. Soil erosion is a serious problem in the Ethiopian highlands that has increased sedimentation of reservoirs and lakes. Sediment export rates in the Ethiopian highlands are characterized by important changes in sediment supply to the downstream. Ethiopian highlands carry about 1.3 billion ton/year of sediment to the neighboring countries whereas the Blue Nile alone carries131 million ton/year.Poor upstream watershed management and traditional conservation practices have led to these high rates. Soil erosion and sedimentation are the serious problems where mega hydroelectric dams and large scale irrigation projects are found(Alemu Binyamand KidaneDesale,2015).

In Ethiopia, poor cultivation practices cause soil losses to reach alarming levels of up to 200-300 Mtper hectare per year, already affecting 50 percent of the agricultural areas (UNEP/GRID, 1992). Soil degradation in Ethiopia highlands generally is seen as a major threat to the long run to food security of the country, the high population growth rate (2.2 per cent annually; (World Bank, 1998) and cattle stock expansion steadily increase the pressure on land (World Bank, 1999).

The Awash River which contributes a lot to satisfy water demand and is home for aquatic life forms has become at great risk in the basin. The rapid increase of all kinds of anthropogenic activities in the basin has affected the aquatic ecosystems. As a result, complex interrelationships between socioeconomic factors and natural hydrological and ecological conditions have been identified (BayeSitotaw,2006). The average annual soil loss in the Awash River catchment is in the order of 200- 300 t/ha or 20,000- 30,000 t/km$^2$ (PDRE, 1989).

Removal of vegetation cover through deforestation and overgrazing, repeated tilling of the soil to prepare fine seedbed and lack of adequate soil and water conservation is causing the Kokadam to silt up and inflow to the reservoir is heavily laden with sediments, and this has lowered the water volume from the designed live storage capacity of 1,667 Mm$^3$to 1,186 Mm$^3$at present (i.e., loss of 481 Mm$^3$), which is a loss of 30% of the total storage volume of the reservoir (EEPC, 2002). Efforts to reduce this alarming sedimentation rate has not been recorded; rather the Government has opted to reinstate the reservoir volume by dredging the sediment, and even this effort has not been very successful (Michael, 2001)

The overall objective of the study was, therefore, to assess the ecological impacts of sediment loading on macro-invertebrate and to develop sediment invertebrate index along the gradient of Awash River using macro- invertebrate communities as indicators. This information is important because it helps to assess the level and impacts of sedimentation on rivers. Moreover, it would help to set restoration targets and assess success of river and watershed restoration projects.

## 1.1 Objectives

### 1.1.1 General Objective

To assess the ecological impacts of sediment loading on macro-invertebrate and to develop sediment invertebrate index from sediment gradient along the Awash River.

### 1.1.2 Specific Objective

- To collect macro-invertebrates from upstream, mid-stream and downstream sites and compare their abundance and diversity among the sites.
- To determine sediment particle size and organic matter in the study sites.
- To determine variation of physicochemical parameter along the sediment gradient.
- To calculate sediment sensitive benthic macro-invertebrate index (PSI) along the gradient with the view to adopt the PSI for other rivers in Ethiopia.

## 1.2 Research Questions

The main hypothesis of the study is "There is no difference in physicochemical, sediment and macro-invertebrate structure along the sediment gradient in the Awash River). Specific questions are:

1. Are there any difference in micro invertebrate abundance and diversity between the three sites?
2. Are there any difference in sediment particle size and organic matter between the three sites?
3. Are there any different in the level of physicochemical parameter between the three site-s?
4. Are there any different in the level of physicochemical parameter between the three site-s?
5. Can we use sediment invertebrates to develop a PSI index?

# CHAPTER TWO

## 2. Literature Review

### 2.1. Macro Invertebrates and Stream Ecosystem Assessment

Benthic macro- invertebrates are central apparatuses of river ecosystems. They play an important role in trophic dynamics by cycling nutrients and providing food for higher trophic levels such as fish and birds. As such, they are considered to provide good indicators of long-term environmental changes due to their limited range and long-term persistence. A better understanding of macro- invertebrate assemblages is of great significance to river ecological assessment and management (Pan *et al..,* 2013).

According to De Pauw and Hawkes (1993) and Bode *et al., (*1996) some of the advantages of using benthic macro-invertebrates in bio monitoring and stream ecology studies are: -

- ✓ They are large enough to be seen with the unaided eye, making them relatively easy to identify and inexpensive to collect;
- ✓ They are relatively abundant; and hence there is little danger of depleting sparse populations through sampling.
- ✓ Small order streams often do not support fish but do support extensive macro- invertebrate communities.
- ✓ As a group, macro- invertebrate communities are sensitive and respond to both natural and man-induced changes in their environment.
- ✓ Taxa (family, genus or species) differ in their tolerance to pollutants; particular taxa make useful “indicators" of conditions. In other words, there are a large number of taxa, and different stresses produce different macro- invertebrate communities.

- ✓ Most of the species that make up the benthic community are more-or-less confined to a specific area and exhibit little movement out of the area, in contrast to zooplankton or fish whose distribution is greatly affected by currents and wave action.
- ✓ Since benthic macro‑ invertebrates retain (bioaccumulate) toxic substances, chemical analysis of them will allow detection where levels are undetectable in the water resource.
- ✓ Sampling of macro‑ invertebrates is easy, requires few people and minimal equipment, low cost and does not adversely affect other organisms.

In Ohio, Yoder and Rankin (1995) indicated that costs (per evaluation) for ambient monitoring using benthic‑ invertebrates are low (US $824) compared to chemical and physical water quality (US$ 1,653) and bioassays (US$ 3,573-$ 18,318). So, biological monitoring can provide an estimate of all deleterious influences on lotic habitats but it may be particularly useful in developing countries as it frequently has low cost and technical requirements (Thorne and Williams, 1997).

On the contrary, Barbour *et al*., (1996) explained the disadvantages of using macro‑ invertebrates as bio indicators as follows:

- ✓ Benthic macro‑ invertebrates do not respond to all impacts;
- ✓ Seasonal variations may prevent comparisons of samples taken in different seasons;
- ✓ Drifting may bring benthic‑ macro invertebrates into waters in which they would not normally occur.
- ✓ Certain groups are difficult to identify to the species level

In this respect, biological monitoring using macro‑ invertebrates as indicator is considered as the most appropriate means of detecting impacts on rivers and lakes. The ecological impacts of siltation (especially its impacts on macro‑invertebrates) are not well studied in Ethiopia, although there is a wide recognition of its impacts on lake and reservoir level (e.g. Dagnachew and Tenalem, 2005; Haregeweyn*et al.,* 2012). In fact, as SeyoumMengistou (2006) noted, little attention is given in Ethiopia to invertebrate research in general and riverine invertebrates in particular and most of the available studies focus on lakes.

Biological communities and physical habitat are closely linked in ecosystems. River stratum diversity, shoreline complexity, vertical meandering, riverbed sediment heterogeneity and other morphological characteristics create a rich diversity in river habitats and biological communities. River morphological diversity has laid an important foundation for maintaining the diversity of river biological communities (DesaleKidaneand BinyamAlemu,2015).

## 2.2. Sources of Sediment

Sources of sediment are defined as either channel sources, which derive sediment from within the stream channel, or non-channel sources, which originate outside of the stream channel. Channel derived sediments are sourced from banks and channel margins, point bars, fines stored in interstitial pore spaces or sequestered in vegetation, and pools or backwater areas. Outside of the stream channel, sources of sediment encompass leaf and litter fall, biological pseudo feces, exposed or unvegetated soils, landslides, particles from atmospheric deposition, and in general, anthropogenic activities. Transport of non-channel sediment to the water body depends on the source of sediment as well as the path of transport, which is highly variable. Stream derived sediment transport is less varied, and depends on hydrological and hydraulic characteristics, such as stream discharge and stream bed stability (Wiitala,2013).

Sediment arrives in aquatic systems due to soil erosion, which is influenced by climatic (precipitation rate, temperature), geologic (soil type) and topographic conditions (slope gradient and length) as well as by the catchment vegetation cover (Wischmeier and Smith, 1978).

Aquatic resources have been degraded because of non-point source pollution and alterations of stream channels, riparian areas and entire stream catchments. Monitoring using macro invertebrate’s assemblage can give an indication of past as well as present conditions in addition, biological monitoring is valuable for determining natural and anthropogenic influences on river resources because biota iteratively respond to stress from multiple spatial or time scales and several pathways including habitat and water chemistry (Rezvan,2011).

In Ethiopia, soil destruction and nutrient reduction has been one of the most important environmental problems). High population pressure relaying on natural resources united with poor land resources management practices and poverty resulted in severe soil destruction and sedimentation, this in turn has been a serious threat to national and household food security (Desale Kidane and Binyam Alemu, 2015).

Anthropogenic actions that increase sediment loads to rivers and streams include: agriculture, forestry operations, mining, road construction, dam reservoirs and urban runoff these agriculture has been identified as the greatest contributor of sediment to streams and rivers (Waters, 1995; Zweig, 2000). The removal of riparian vegetation to increase crop production area and increase livestock access decrease bank stability causing erosion and increased fine sediment inputs. Floodplain lands are highly productive and cultivation of row-crop increases the amount of soil exposed to erosion and thus fine sediments in surface run-off (Waters ,1995).

Ethiopia has the largest livestock population in Africa and the tenth largest in the world estimated to consist of 35.4 million cattle, 11.4 million sheep and 9.6 million goats (EPA, 2003). Currently only 4.07 million hectares or 3.56% of the land mass of Ethiopia is covered by forest (MoARD, 2004).

Deforestation is increasing at an alarming rate estimated to be 62,000 ha/year (World Bank, 2001) and hence furthering the rate soil erosion. The cost of land degradation in Ethiopia is estimated to be 2 to 3 percent of the agricultural GDP (World Bank, 2007). Unproductive land followed by crop lands and perennial crops with an estimated soil loss rat of 42 tons/ha/yr and 8 tons/ha/yr respectively. The rate of soil loss from grazing land, land not under cultivation and, wood and shrub land is estimated to be 5 tons/ha/yr each while the lowest rate is estimated to be 1 ton/ha/yr from land covered by forests. Based on these estimates, an annual soil loss of 1.5 billion tons has been calculated. About 10% of the soil lost from the catchments in the form of erosion end in rivers and is transported downstream (UNESCO, 2008).

Flooding, as a natural phenomenon is not new to Ethiopia. One of the expected causes of flooding is poor watershed area protection. Poor watershed area protection can be due to less understanding of upstream land users and downstream water users about watershed area protection and their impact. For unprotected watershed area the rainfall directly changes to runoff and then to flooding and its effect results in social and economic damage (Ayele Getachew,2014)

## 2.3. The Impact of Sediment on Benthic Macro-Invertebrates

The increased supply of sediment to the river channel negatively affects the in stream habitat and the associated biological communities (Allan 2004; Beechie*et al.*, 2013). Fine sediment (i.e. grain size below 2mm) is especially known to negatively affect the biota by changing the physicochemical environment in rivers and streams Figure 1.

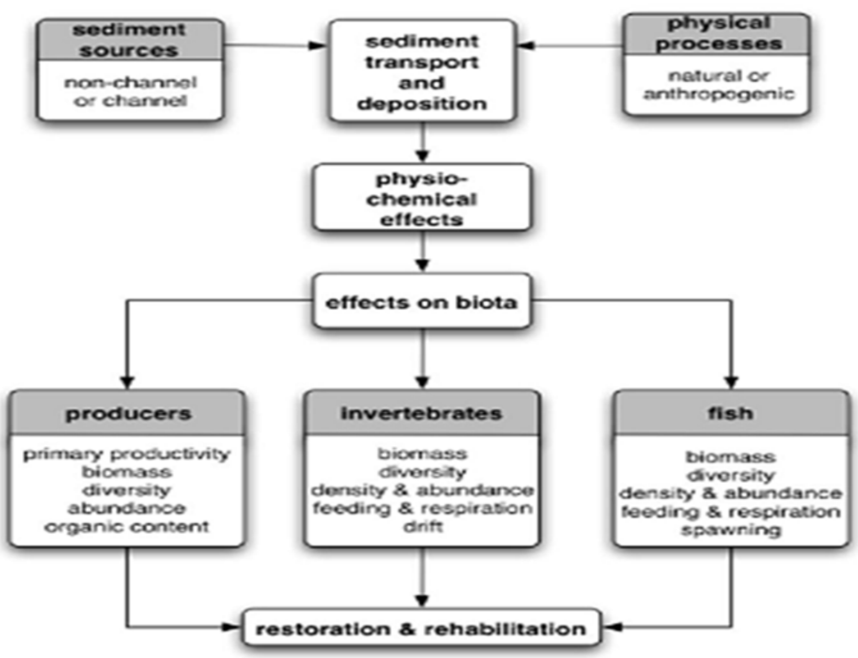

**Figure 1: A holistic overview of effect of fine sediment on the biota in lotic ecosystem (Wood &Armitage, 1997)**

Fine sediment disturbs in-stream biota including macroinvertebrates through several pathways impacts include damage to body parts, clogging of respiratory and filtering organs, habitat loss due to filling of interstices between substrates, burial, oxygen depletion, changes in quantity and quality of food, and drift as a result of sediment deposition or substrate instability (Wood and Armitage, 1997; Jones *et al.,* 2012). Although drift is a normal aspect of the macroinvertebrate life, the downstream displacement can occur in large numbers as a result of increased flow and sediment discharge (Gibbins*et al*., 2007). However, fine sediment does not affect all macroinvertebrates to the same extent. Some, because of their morphological, physiological or behavioural characteristics, can thrive in river channels affected by fine sediment (Extence*et al.,* 2013). For example, in an experiment involving four taxa, different sediment size classes and burial levels, Wood *et al.,*(2005) observed that while the nymphs of the *Plecopetra Nemouracambrica* freed themselves from all sediment types and burial levels, the nymphs of *Baetisrhodani* remained buried.

## 2.4. Benthic Macro Invertebrate Indicators for Sedimentation

Streams and the inhabitant biota are, therefore, good pointers of land use impacts in a watershed because they are very much connected to the catchment and integrate the impacts over time (Maloney and Feminella, 2006). Macro‑ invertebrates have been found to be particularly useful in this respect because they have limited movement and different disturbance tolerance levels which enable them to integrate environmental changes and make it possible to compare differences between sites with varying levels of disturbance (Barbour *et al*., 1999). In addition most macro‑invertebrates have distinct microhabitat preference dictated by hydraulics and substrate type Beisel, *et al.* (1998); Baptista*et al.,*(2001); Day *et al*., 2003; Lamouroux*et al*., (2004), an attribute which make them the biota of choice for assessing hydro morphological changes. For example, *Simuliidae* are found attached to stone or submerged vegetation in moderately to fast flowing water, where they filter their food from the water column and get fresh supply of dissolved oxygen (Day *et al*., 2003). (Buss, *et al.* 2004) found that, along an environmental gradient from natural to degraded sites, filterers including *Simuliidae* disappeared following an increase in the level of siltation downstream.

## 2.5. Benthic Macro-invertebrate Metrics

Biological impairment of the benthic community may be assessed by the use of metrics or indices including community, population and functional parameters. Metrics measure different components of the community structure and have different ranges of sensitivity to stress. It is advisable, therefore, to use several metrics because an integrated approach provides more assurance of a valid assessment (Klemm*et al*., 1990). Many different indices have been used in the evaluation of benthic macro-invertebrate communities in order to summarize information. Three basic types of indices (diversity, taxa richness) are mostly employed to assess river health (Rosenberg and Resh, 1993). A few of the more useful metrics in identifying the effects of sediment deposition are briefly described below(Logan,2004) .

### 2.5.1. Family–level Richness (RICH)

This metric is a diversity measure that evaluates the number of different families found in a sub sample. It reflects the health of the community as a measurement of the variety of families present. Generally this metric increases with increasing water quality, habitat diversity, and habitat suitability (Barbour *et al*., 1999). However, some pristine headwater streams may be naturally unproductive, supporting only a very limited number of taxa (Rosenberg and Res*h,* 1993).

### 2.5.2. Shannon Diversity Index (SDI)

The SDI is a diversity index that combines taxa richness and community balance (evenness) to characterize species diversity in a community. The SDI requires a count of the total number of individuals and a total count of each of the taxa. The combination of abundance and richness in this index is designed to indicate the state of the macro– invertebrate community (Rosenberg *et al.,* 1993). A community has low SDI if only a few taxa are present, or if only a few taxa are abundant. In contrast, a community exhibits high diversity if many taxa are present and they score in equal or nearly equal numbers. A high SDI suggests good benthic habitat and non-impacted water quality.

### 2.5.3. Sediment sensitive index (PSI)

The PSI index is a pressure-specific bio monitoring tool, designed to identify the impacts of deposited fine sediment. Fine sediment is defined as the load of silts and clays, which have diameters smaller than 0.0625 mm. The tool was developed using previous literature and expert knowledge of invertebrate morphological/physiological traits that are associated with either sensitivity or tolerance to fine sediment, in order to select and assign species to one of four Fine Sediment Sensitivity Ratings (FSSRs)it requires a log abundance category to be estimated for all taxa identified in a sample (1–9, 10–99, 100–999 and 1000+ individuals present).The tool thus has a sound biological basis and is linked to ecological niche theory. The sensitivity ratings are used to assign abundance-weighted scores, which are then used to calculate. PSI scores ranging from zero (heavily sedimated) to one-hundred (un-sedimated) and given that rivers vary in their natural sediment conditions the lower the ratio, the greater the sedimentation stress). This approach allows direct comparisons to be made spatially between sites on the same river and from different catchments/region s and also enables comparison between different types of fine sediment impacts (e.g., construction activities and bank erosion) or recovery (e.g., following natural spates or river restoration activities) (Extence*et al*., 2011).

# CHAPTER THREE

# 3. Materials and Methods

## 3.1. Description of the Study Area

This study was conducted in the Awash River basin, which extends from its source at Ginchi up to Lake Abbe. It is surrounded by the Abay basin, Omo basin and Rift Valley lakes basin in the north and west, southwest and south, respectively. The Awash basin includes the central part of the country where the most densely populated and most industrialized towns are located. Important commercial towns, like Addis Ababa and Mojo are found within this basin. Therefore, socio-economic developments are growing faster and wider in the basin than anywhere else in Ethiopia.

Habitat in each sampling sites was characterized according to Barbour *et al*. (1999).The first sampling site (**S-I**) was located about 50 km south-west of Addis Ababa, near Awash Bello town. There is small natural vegetation and scattered *Eucalyptus* trees which are planted at the river bank. The second and third sampling sites (**S-II**) and (**S-III**)were located at 100 km and 150 km, respectively, south-east of Addis Ababa, In those sampling sites, agricultural activities are intense including river water abstraction for irrigation using motor pumps.

## 3.2. Sampling

The samples were taken from the three sampling sites beginning from Dec to Jan, 2016, during the dry season. The sampling sites selection was based on the method stated in objective (Klemm *et al*., 1990). The detailed description of the study sites is presented in Table 1 and the map of the study area in Fig. 3.

**Table 1. Description of the sampling sites**

| Site Name | Altitude(m) a.s.l | Coordinates Latitude | Longitude |
|---|---|---|---|
| Site one (SI) | 2054 | 08$^{0}$50 '49.9 'N | 038$^{0}$24 '41.6 " |
| Site two (II) | 1580 | 08$^{0}$24 '22.0 'N | 039$^{0}$01 '12.1 " |
| Site three(III) | 1587 | 08$^{0}$19 '10.5 'N | 039$^{0}$05 '02.5 " |

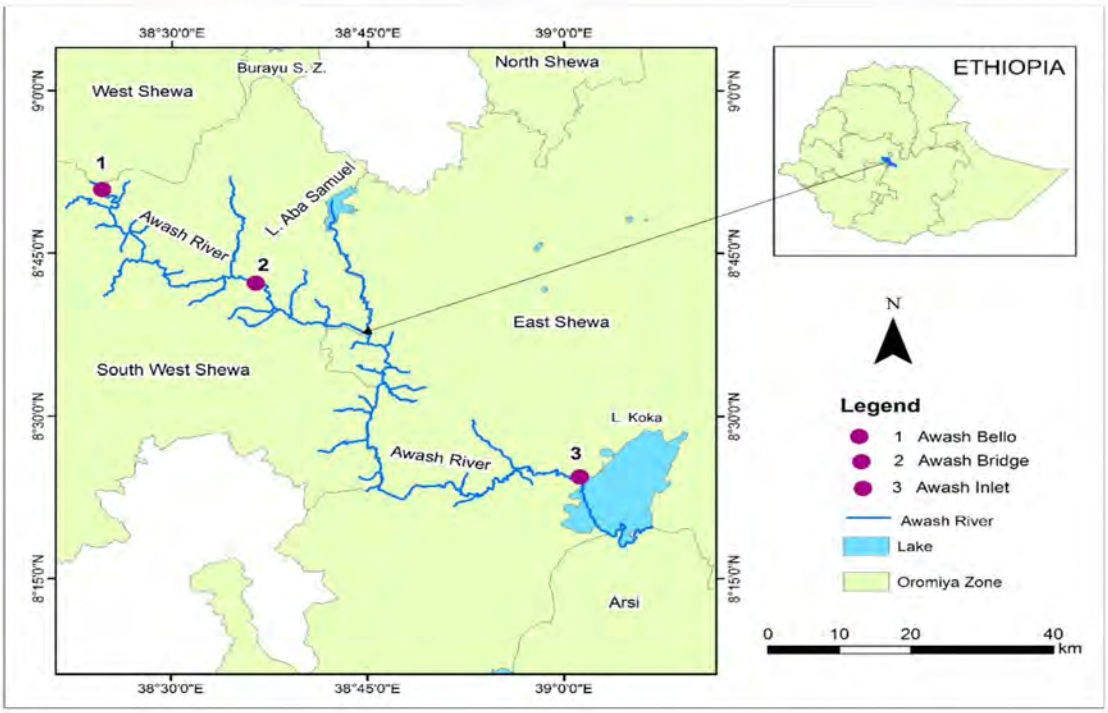


Figure 2**:** Map showing of Awash River with sampling stations


Figure **3**: Habitat Structure of the three sampling sites.

## 3.3. Data Collection

### 3.3.1. Macro invertebrate and Sediment Data Collection

Samples were taken from three sites along the Awash River (upstream, mid-stream and downstream).In all sites, the same kinds of microhabitats (pools and vegetated areas) were found. From the pools and vegetated areas macro-invertebrates were sampled using standardized Metal frame D-net of area 90x90cm (500-µm mesh) at the specified locations. The net was held in one position on the stream bottom, and the stream bed was agitated by hand kick directly upstream of the net to dislodge the organisms (Hayslip , 2007).In the field the collected samples were sieved (using a 500 µm mesh size sieve) to remove sediments and debris and put into the specimen bottle, preserved with 70% ethanol(Resh and Jackson 1993). Then in the laboratory macro-invertebrate samples were enumerated and identified to the familylevel using a dissecting microscope and taxonomic keys from literatures for tropical Africa (Durand, 1981) and other temperate keys (Merritt and Cummins, 1999).

The remaining sediment samples from each sampling site were preserved and brought to laboratory for soil analysis (Particle size distribution–boulder, sand, clay, silt and organic matter content of each site).

### 3.3.2. Physicochemical Data Collection

In *situ* measurements of pH, temperature, and dissolved oxygen, conductivity (µScm-1) were conducted using a hand held probe a multi-parameter device (HACH Multi-meter HQ40d Model). For the rest physicochemical parameters, water samples were collected in acid-washed plastic bottles (except for phosphate, which requires glass bottle containers to avoid the effect of adsorption onto plastic bottles). The collected samples were transported in ice-cooled boxes from sampling sites to the laboratory of Addis Ababa University for the analysis of physicochemical parameters. Water sample was analyzed using Spector photometer method. Nitrite was determined by the reaction between Sulfanilamide and N–naphthyl–(1)–ethylendiamin–dihydrochloride.Nitrate ($NO_3$-N)was analyzed with sodium salicylate method.Soluble Reactive Phosphorus (SRP as $PO_4^{3-}$P) and Total Phosphorus (TP) were analyzed with ascorbic method (APHA, 1998).

## 3.4. Soil Sample Analysis

For analysis of soil particle size, forty-grams of the sediment were dispersed overnight in a 50-g sodium hexametaphosphate solution. Thereafter, the sand size particles were separated from the suspensions by wet sieving through a 53-m sieve and sand fraction was determined by drying and weighing the material remaining on the sieve. The clay fraction was determined using the hydrometer method as described by Janitzky, (1986). Organic matter content of the sediment was analyzed by loss-on-ignition techniques. limnology laboratory, Addis Ababa university Organic matter was oxidized by heating at 375$^{o}$c over night (16 hours) and estimated by weight loss. (loss of ignition equal to approximate organic matter) .Loss of ignition (%) = Weight of oven dried sample (g)–weight of sample dried after ignition (Kalra and Maynard,1991).

## 3.5. Data Analysis

### 3.5.1. Macro Invertebrate Data Analysis

From the collected data, different macro-invertebrate metrics were calculated. These metrics include Family–Level Richness (RICH), Shannon Diversity Index (SDI) (Rosenberg and Resh, 1993) and proportion of sediment sensitive Invertebrates (PSI) (Extence*et al.,* 1999; Chadd and Extence, 2004).

### 3.5.2. Statistical Analysis

RDA was used to relate macro‒ invertebrate (response variables) and physical and chemical parameters (explanatory variables). Redundancy analyses (RDA) was used to estimate how much of the variance of the spatial distribution of macro‒ invertebrate species was explained by the environmental variables using CANOCO for windows 4.5 version. RDA was chosen after confirming through a preliminary deterred analysis of correspondence (DCA) that the length of ordination axes in DCA was less than 3 (Jan and Petrš, 2003). The statistical significance in RDA was assessed by Monte-Carlo permutation tests (499 permutations) and conclusions were made based on 5% level of significance ($P < 0.05$). Physicochemical parameter which showed significant correlation (inflation factor greater than 10) were excluded from analysis. The results of RDA were visualized in the form of ordination diagrams in CANOCO draw for Windows. The variation between physicochemical parameters on each site was examined using One-way ANOVA.

# CHAPTER FOUR

# 4. Results and Discussion

## 4.1. Results

### 4.1.1. Physicochemical Parameters

The result of these two parameters pH and Temperature varied significantly among sampling sites (F=10.2 P=<0.012, $R^2$=0.65 and F=102.3, p=000 $R^2$=70.5, respectively. Dissolved oxygen at the upstream (site one) was significantly higher than mid-stream (site two) and downstream (site three). Where temperature at the upstream (site one) lower than mid-stream (site two) and downstream (site three). The profile of dissolved oxygen and conductivity significantly varied among sampling sites(F=232.584, p=<000, $R^2$=22.672 and F=6.9, P=<0.27 $R^2$=30244.1, respectively. The profile of pH and dissolved oxygen at the upstream (site one) were significantly higher than mid-stream (site two) and downstream (site three).

The levels of Nitrate in the water samples varied significantly among sampling sites (F=8890.5, P<0.00, R2 =2.022 Nitrate and at the upstream (site one) were significantly lower than mid-stream (site two) and downstream (site three) where the level of Nitrite did not show significant difference among sampling sites F=1768, P<0.24, R2 =0.002. The level of TP and SRP water samples value did not show significant difference among sampling sites (F=0.437, P=0.6, $R^2$ =0.66) and (F=0.99, P=0.4, $R^2$ =86.4), respectively.

**Table 1: Variation in physicochemical characteristics Mean ±SE along gradient of Awash River**

| | DO(mg/L) | Temp($^0$) | PH | COND(µs/cm) | $NO_2$(mg/L) | $NO_3$(mg/L) | TP(mg/L) | SRP(mg/L) |
|---|---|---|---|---|---|---|---|---|
| S I | 6.49±05 | 19.3±1.1 | 6.4±0.44 | 116.5±0.13 | 0.075±0.03 | 1.07±0.01 | 3.7±0.176 | 3.0±.002 |
| S II | 5.6±0.1 | 26.5±0.7 | 6.7±0.015 | 247.8±113.9 | 0.24±0.07 | 2.5±0.02 | 3.77±0.11 | 3.03±0.03 |
| S III | 1.3±0.6 | 28.5±0.4 | 7.9±0.01 | 226.0±103.9 | 0.19±0.176 | 2.5±0.005 | 3.6±0.22 | 3.02±0.04 |

### 4.1.2 Soil Texture and Soil Organic matter

High percent of clay soil are found on S-III (80%) than S-I and S-II. In S-II (44%) sand was found higher than S-I and S-III. High percentage of organic matter was found on S-II than S-I and S-III (Table 2).

**Table 2: Summary statistics of Soil particle size (%) and Soil organic matter (%) in Awash River during sampling period**

| **Soil (%)** | **Sampling Sites** | | |
|---|---|---|---|
| | S-I | S-II | S-III |
| Clay | 65 | 35 | 80 |
| Silt | 20 | 21 | 15 |
| Sand | 15 | 44 | 5 |
| organic matter | 23 | 48 | 49 |

### 4.2. Biological Parameters

A total of 19 taxa comprising 7,094 individuals were collected from the three sites during the study period. As shown in Table 1.4, the total number of taxa present at each site ranged from 10 (S3) to 16 (S1), while the total number of individuals present at each site ranged from 1,722 (S3) to 3,164 (S1). The major components of the community were Oligochata (2,187), Lymnaeidae (774), Hydrophilidae(561) and Corixidae (531). The families least encountered were Gerridae (2), Hydracarina (3) and culicudae (4). The result also showed that the number of individuals and taxa shows decreasing trend with increasing sedimentation level.

**Table 3: Abundance and PSI scores of macro-invertebrates collected from the study sites.**

| **Taxa family /Genus** | **Index** | **Sampling Sites** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **S1** | | **S2** | | **S3** | | |
| | | **Collacted** | **Score** | **Collectd** | **Score** | **collacted** | **Score** | **Total** |
| **Ephemeroptera (may flay)** | | | | | | | | |
| Baetidae | A | 172 | 4 | 13 | 3 | 0 | 0 | **185** |
| Caenidae | D | 107 | 4 | 7 | 2 | 135 | 4 | **249** |
| **Trichoptera (cadds flay)** | | | | | | | | |
| Lepidostomatidae | B | 19 | 2 | 4 | 1 | 0 | 0 | **23** |
| **Odonata (dames flayand dragonfly)** | | | | | | | | |
| Libellulidae | D | 147 | 4 | 102 | 4 | 295 | 4 | **504** |
| Coenagrionidae | D | 193 | 4 | 132 | 4 | 0 | 0 | **329** |
| **Coleoptera (beetles)** | | | | | | | | |
| Dytiscidae | D | 119 | 4 | 0 | 0 | 0 | 0 | **119** |
| Hydrophilidae | D | 246 | 4 | 108 | 4 | 7 | 2 | **561** |
| **Diptera (two winged/true flay)** | | | | | | | | |
| Chironomidae | * | 43 | * | 585 | * | 69 | * | **697** |
| Culicudae | * | 4 | | 0 | 0 | 0 | 0 | **4** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | * | | | | | |
| **Hemiptera (water/True bugs)** | | | | | | | | |
| Gerridae | * | 2 | * | 0 | 0 | 0 | 0 | **2** |
| Corixidae | D | 210 | 4 | 124 | 4 | 197 | 4 | **531** |
| Belostomatidae | D | 302 | 4 | 0 | 0 | 0 | 0 | **302** |
| Veliidae | * | 0 | 0 | 0 | 0 | 47 | * | **47** |
| Nepidae | D | 122 | 4 | 2 | 2 | 0 | 0 | **124** |
| Pleidae | * | 0 | 0 | 189 | * | 96 | * | 285 |
| **Arachnida** | | | | | | | | |
| Pisauridae | * | 0 | 0 | 104 | * | 64 | * | **168** |
| Hydracarina (water mite) | * | 3 | * | 0 | 0 | 0 | 0 | **3** |
| **Mollsuks (snails)** | | | | | | | | |
| Lymnaeidae | D | 154 | 4 | 612 | 4 | 8 | 2 | **774** |
| **Oligochata (aquatic earth worm)** | D | 1,321 | 5 | 62 | 3 | 804 | 4 | **2,187** |
| **Total individual(abundance)** | | **3,164** | | **2,044** | | **1,722** | | **7,094** |
| **Total taxon(diversity)** | | **16** | | **13** | | **10** | | **19** |
| **Total score(index)** | | | **47** | | **31** | | **20** | |

* taxa have been excluded from FSSR allocation, because they are considered inappropriate for fine sediment assessment for a variety of reasons(Extence*et al*.,2013).

## 4.3. Macro-invertebrate Metrics Characterization along Awash River

### 4.3.1. Taxa Richness

Taxa richness shows significant difference among sampling sites (F=9.58, P=0.014, R2=381.7) with site one showing higher value (16) than site two (13) and three (10).

### 4.3.2. Shannon Diversity Index

The value of this metrics ranged from 0.88($S_3$) to 0.99 ($S_1$) and it showed significant difference among sampling sites (F=0.01, P=0.01, $R^2$=0.57). The value from total taxa at each site showed a decreasing trend from the S1 to S3 depending on the sedimentation impact (Fig 5).

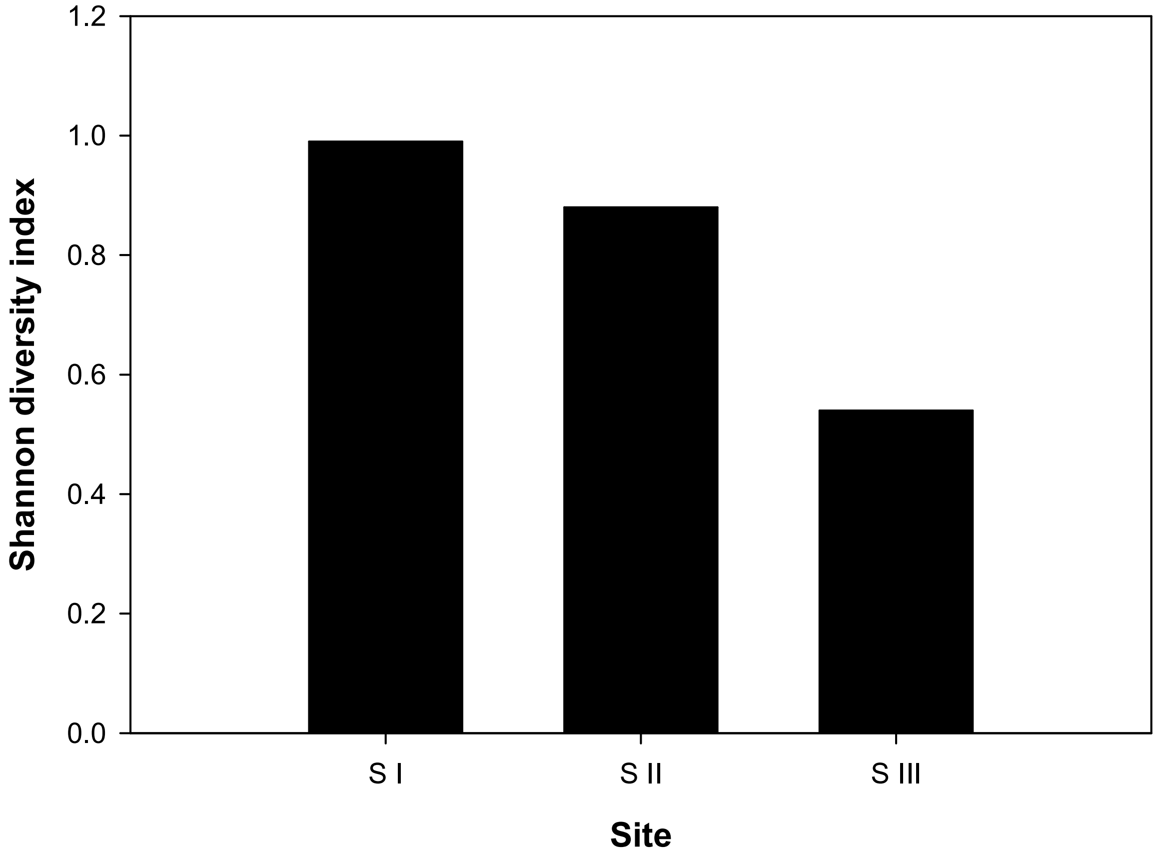


Figure 2: Shannon Diversity Index along the sampling sites

### 4.3.3. Proportion of sediment sensitive index (PSI)

The PSI developed from the collected macro- invertebrate data from three sites showed significant difference among sites (F=72.8, P=0.00, $R^2$=307.4). S-I had higher value than S-II and S-III.

### 4.3.4. Categorization of Sites Based on PSI Values

Based on PSI value the sites are categorized in to difference sedimentation levels. Site one S-I was moderately sedimented, site two (S-II) Sedimented and site three (S-III) heavily sedimented Table 5.

**Table 4: Categorization of sites in to different impairment levels based on PSI results (Extence*et al*., 2013)**

| PSI | River bed condition | Sites at each Impairment Level |
|---|---|---|
| 81–100 | Minimally sedimented unsedimented | |
| 61–80 | Slightly sedimented | |
| 41–60 | Moderately sedimented | S-I |
| 21–40 | Sedimented | S-II |
| 0–20 | Heavily sedimented | S-III |

### 4.3.5. Relationships between Species Composition and Physicochemical Parameters

To show the relationship between environmental variables and macro -invertebrate species RDAwas employed and the result is summarized in Table 6 and Fig 6.

**Table 5: Summary of RDA of the relationship between environmental parameter and macro invertebrate species at different sites**

| Parameter | Axis 1 | Axia 2 |
|---|---|---|
| Eigenvalues | 0.642 | 0.208 |
| Species-environment correlations : | 1.000 | 1.000 |
| of species-environment relation: | 64.2 | 20.8 |
| DO | -0.8298 | -0.5580 |
| clay | -0.7458 | 0.6661 |
| sand | 0.5470 | -0.8372 |
| orga | 0.9299 | -0.3677 |

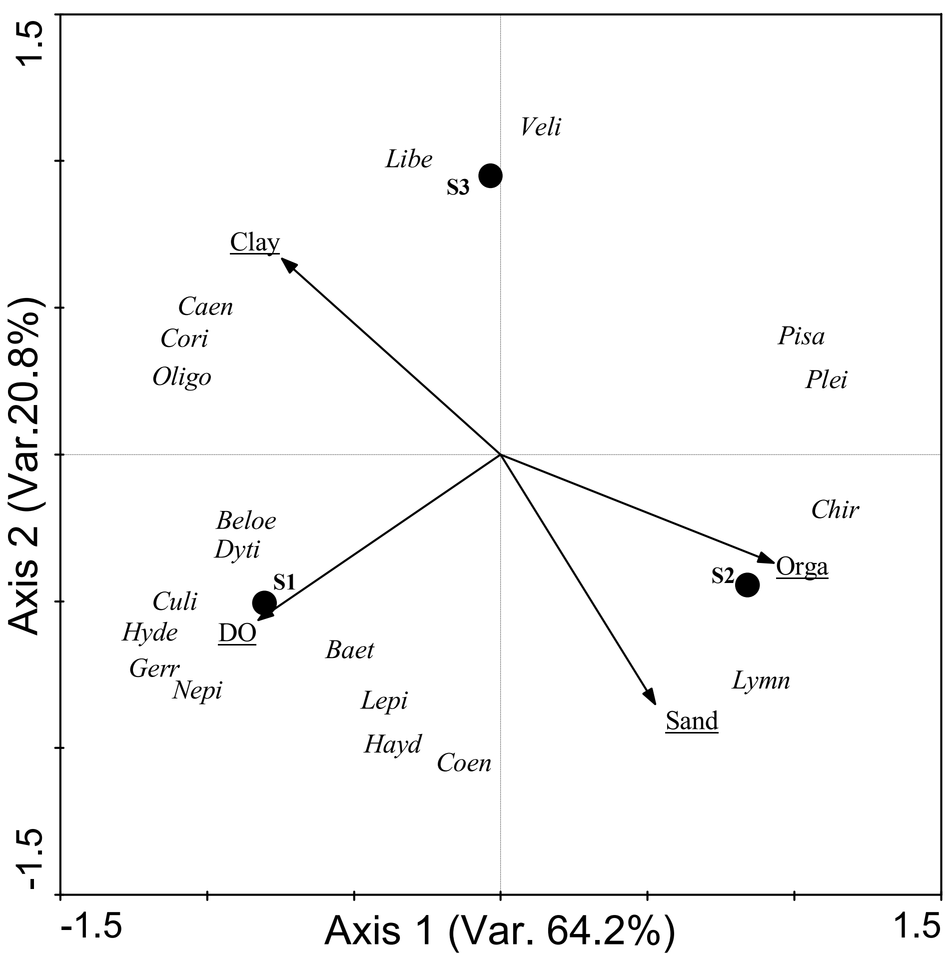

Figure 3: RDA of the association of macro invertebrate species, water chemistry, soil particle size and organic matter among sampling sites.

Full descriptions of codes for names of macro – invertebrate taxa and environmental variables are given in Annex 1.The arrows show the direction and proportional influence of the environmental variables. Axis-1 described more of the variance in species assemblage of macro– invertebrate (64.2%) than axis-1 (28.8%).In the above RDA biplot axis-1 clearly separated SI, from SII and SIII in terms of macro– invertebrate diversity.

.S1was dominated by sediment sensitive macro invertebrate species (e.g.*Ephemeroptera, Trichoptera*) but not all *Ephemeroptera, Trichoptera* were sediment sensitive, there were also sediment tolerant species, while SII and SIII were dominated by sediment tolerant macroinvertebrate speciesFig.6High level of organic matter occured in S-II than S-I and S-III.high level of clay soil found at SIII and the most dominant macro–invertaverate were*Oligochata* ( aquatic earth worm ) while at site two there was high percent of sand and the most dominant macro–invertebrate were mollusks (*Lymnidae* ) .

Even though macro– invertebrate and environmental parameters did not show significant ($P > 0.05$) correlation, the RDA result indicated variations in macro– invertebrate assemblage in relation to environmental parameters.

# CHAPTER FIVE

# 5. Discussion

## 5.1. Physical and chemical Parameters

Water temperature and pH are important parameters that can influence chemical and biological processes in the stream water (Rosenberg and Resh, 1993). Temperature affects the speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize the metabolic rate of other organisms. pH also affects the ability of other aquatic organisms to regulate basic life-sustaining processes, primarily the exchanges of respiratory gasses and salts with the water in which they live .The water temperature during the sampling period across the sampling sites was significantly different (ANOVA, $p < 0.05$). pH variation was significant (ANOVA, $p < 0.05$) between minimally sediment (S-I) and heavily sediment site three (S-III).

Dissolved oxygen is essential to all forms of aquatic life. Its solubility and concentration varies with temperature and turbulence; the photosynthetic activity of algae and aquatic plants; bacterial decomposition and respiration processes(Wetzel, 2001). DO variation was significant (ANOVA, $P < 0.00$)among sampling sites. In this study, DO decrease within increasing of sedimentation level due tothe solubility of oxygen decreases as temperature increases. Conductivity can be influenced largely by geology of the catchments as the later highly influences mineral salts (Talling and Lemoalle, 1998). In this study, conductivity increased along the river course (downstream) coupled withincreasing sedimentation level.

Increasing human population, intensive agriculture and rapid industrial growth have led to an increasing release of domestic waste, agricultural residues, industrial wastes and land run-off into various water bodies. These wastes contained large quantities of nutrients. This elevates the concentration of nutrients in the water body. Elevated concentrations of nutrients cause accelerated growth of algae and higher forms of plant life resulting in eutrophication which produce undesirable disturbance to the balance of organisms present in the water (Quinn *et* *al*., 1994).Profile of Nitrate has significant difference among sampling sites (ANOVA, P<0.000).In sampling site the level Nitrate is high because of anthropogenic source, animal farming urban and agricultural source run off, industrial west and sewage effluent. The profile of TP and SRP did not show significant difference among sampling sites.

## 5.2. Biological Parameters

Freshwater environments may also be at increasing risk of sedimentation because of climate change, involving both increased sediment delivery to the channel associated with the greater frequency and intensity of rainfall/runoff events (Lane *et al*., 2007).

Hydraulics varies spatially in rivers with riffles having faster velocities and pools having slower velocities. Flow rate will affect the rate and amount of fine sediment on the riverbed. Slower flowing pool areas may be more sensitive and faster to respond to finesediment addition than riffle areas because they are depositional sites.The effect of sediment runoff from land clearing and urban development on the macro‑ invertebrate pool fauna of the Murrumbidgee River was investigated by Hogg and Norris (1991). They concluded that fine sediment deposition following storm events and the resulting change in substrate composition was the major cause of low macro‑invertebrate numbers and species richness in pools. Therefore, it is important to consider the response of macro‑ invertebrates to fine sediment accumulation from a range of habitats.In this study the Samples were taken from three sites in the same kinds of microhabitats (pools and vegetated areas) were found.

For some taxa, environmental preferences are somewhat uncertain. For example, *Hemiptera* of the families *Gerridae and Hydrometridae*are excluded from FSSR allocation becausethey are quite indifferent to the character of the river bed (Huxley, 2003).

In this study PSI showed significant difference (ANOVA, P < 0.00) among sampling sites with PSI having lower ratioindicating higher sedimentation stress. This approach allows direct comparisons to be made spatially between sites on the same river and from different catchments/regions and also enables comparison between different types of fine sediment impacts (e.g., construction activities and bank erosion) or recovery (e.g., following natural spates or river restoration activities) **(**Extence*et al*.,2013). Hence, the higher sedimentation rate in S3 could be due to cumulative effects of sediment transport from the headwater and increased stress from agricultural and urban activities in the middle and lower courses of the Awash River.

In this study taxa richness showed significant difference among sampling sites. Site one (minimally sedimented site) has higher taxa richness than site two (sedimented site) and site three (heavily sedimented site).And the diversity also showed significant difference. Species of macro- invertebrate richness and diversity showed decreasing trend from minimally sedimented site to heavily sedimented site.Abundance of macro-invertebrate alsodecreased with increase in sedimentation level.In a similar way, Sheyla (2010) reported that anthropogenicsedimentation has had a significant negative impact on aquatic macro-invertebrate diversity and density in streams in the Urucu Petroleum Province, Brazilia Amazon.

Wilson (2007) also indicated that fine sediment accumulation leads to changes in macro-invertebrate community composition, by favoring some macro-invertebrates at the expense of others Many macro-invertebrate taxa belonging to the *Ephemeroptera, Plecoptera and Trichoptera*(EPT) orders, which provide the most productive and available food for stream fishes, are particularly affected by sedimentation. This is because sedimentation inhibits *periphyton* as food. Density of prey items, available oxygen for respiration and interstitial space for refuge, which are necessary for the existence for many of these taxa, are inhibited by increased sedimentation.

High percent of clay soil was found at the site three and site one than site two means the silt-clay proportion in S1 and S3 is more or less same.  Butin the above RDA biplot axis-1 clearly separated S1, from S2 and S3 in terms of macro- invertebrate diversity and richness due to increasing sedimentation level leads to decreasing of dissolved oxygen. On those sites the most dominant macro- invertebrate are *Oligochata* (aquatic earthworms) whereas in site two, there was high percent of sand and dominant macro- invertebrate are mollusks (*Lymnaeidae*). Similar finding by Harding (1999) reported that, headwater species composition (*Ephemeroptera, Plecoptera and Trichoptera* (EPT)) taxa were replaced at silted downstream sites by *molluscs, oligochaetes*and *chironomids.* In another study, Wood *et al*., (2005) found that filter feeding macroinvertebrates such as *Trichoptera* larvae from the *Hydropsychidae* family were also likely to be more susceptible to increased sediment accumulation in contrast to taxa such as *Chironomidae*, *Oligochaeta* and *Sphaeridae*which are frequently associated with fine sediment, because they are able to burrow into the sediment. The results of these studies emphasize that macro- invertebrate taxa display individual responses to fine sediment accumulation.

In this study, high percent of organic matter and sandwas found at S2 than S1 and S3 because sampling site S2 was surrounded by agricultural land and the most dominant macro-invertebratewere mollusks. Similarto the finding to this study,Lenat*et al*., (1981) reported that mollusks dominated at the high percent of sand sites, which mightbe due to behavioral adaption (to hide themselves from predators).

According to Hynes (1970), the presence of large number of aquatic worms at the sediment site might be due to their body structure which is well designed for burrowing, for example,dragonfly larvae. In other instances, a number of traits may prevent/ exclude the colonization of fine sediment habitat.

# CHAPTER SIX

# 6. Conclusion and Recommendations

## 6.1. Conclusion

Awash River is an economically important river that serves as critical source of water for hydropower. in addition, nearly half of the urban and all the rural population of the catchment areas are at one time or other, dependent on it as a source of water for domestic use, irrigation of vegetables and other crops. However, unsustainable land management practices haveled to soil erosion which ends up in rivers with possible ecological impacts on aquatic organisms.

Fine sediment accumulation can cause a loss of abundance and diversity of sensitive macro- invertebrate communities. Increases sedimentation level leads to replacing sediment sensitive macro- invertebrate (e.g. taxa from the EPT orders) by sediment tolerant macro- invertebrate (*Oligochata* and *Mollusca*). The proportion of sediment sensitive index can be used to assess and monitor the impacts of sedimentation level along sediment gradient, and to set goals for the restoration of watersheds and rivers impacted by human land use. Generally the result of this study concluded that S1 near the head water was moderately sedimented with high diversity of macro- invertebrate while site two and site three were sedimented and heavily sedimented, respectively, with lower diversity of macro - invertebrate. Macro invertebrate which indicated moderately sedimented sites are *Baetidae and Lepidostomatidae* whereas for heavily sedimated site *Hydrophilidae and Lymnaeidae* were dominant. S3 near the Koka dam was heavily sedimented and had lowest diversity of macro-invertebrates that were tolerant of fine sediment; so this study also supports previous observations that macro invertebrate taxa can be used as indicators of sedimentation level in large rivers, such as Awash River.

## 6.2. Recommendations

1. This study was limited by the small number of sampling sites taken due to budget constraint. More intensive sampling along small sediment gradients should be done to fine tune and identify specific macro-invertebrate indicators of fine sediment stress. Future research should be conducted to determine the processes causing fine sediment accumulation, and how macro- invertebrate communities are affected by fine sediment at broad watershed scales and local reach scales.

2. Awash River represents a serious threat to aquatic and terrestrial life. The concerned government bodies including EEPA should do their utmost to put an end to the ever-increasing degradation of the water quality of this ecologically and economically important river.

3. *Hydrophilidae* and *Lymnaeidae* species of macro-invertebrate can be used as indicators of heavy sedimentation in the other River.

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## Appendices

## Appendix I:

Number of macro-invertebrate collected from the study sites andfamily codes

| Macro-invertebrate taxa | Site one (1) | | | Site two (2) | | | Site three (3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sampling times | | | Sampling times | | | Sampling times | | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| **Ephemeroptera (may flay** | | | | | | | | | |
| Baetidae (Baet) | 42 | 101 | 29 | 0 | 12 | 1 | 0 | 0 | 0 |
| Caenidae(Caen) | 17 | 81 | 9 | 1 | 6 | 0 | 21 | 13 | 101 |
| **Trichoptera (cadds flay)** | | | | | | | | | |
| Lepidostomatidae(Lepi) | 2 | 13 | 4 | 0 | 1 | 3 | 0 | 0 | 0 |
| **Odonata (dames flayand dragonfly)** | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Libellulidae(Libe) | 21 | 27 | 99 | 25 | 41 | 36 | 60 | 120 | 115 |
| Coenagrionidae(Coen) | 27 | 64 | 102 | 62 | 39 | 31 | 0 | 0 | 0 |
| Coleoptera (beetles) | | | | | | | | | |
| Dytisidae(Dyti) | 17 | 73 | 29 | 0 | 0 | 0 | 0 | 0 | 0 |
| Haydrophilidae(Hayd) | 33 | 101 | 112 | 61 | 47 | 0 | 3 | 4 | 0 |
| **Diptera (two winged/true flay)** | | | | | | | | | |
| Chironomidae(Chir) | 14 | 19 | 10 | 124 | 285 | 176 | 29 | 18 | 22 |
| Culicudae(Culi) | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Hemiptera(water/True bugs** | | | | | | | | | |
| Gerridae(Gerr) | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Corixidae(Cori) | 105 | 62 | 43 | 42 | 27 | 55 | 0 | 127 | 70 |
| Belostomatidae(Belo) | 103 | 79 | 120 | 0 | 0 | 0 | 0 | 0 | 0 |
| Veliidae(Veli) | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 16 | 14 |
| Nepidae(Nepi) | 19 | 82 | 21 | 0 | 2 | 0 | 0 | 0 | 0 |
| Pleidae(Plei) | 0 | 0 | 0 | 109 | 72 | 8 | 36 | 27 | 33 |
| **Arachnida** | | | | | | | | | |
| Pisauridae(Pisa) | 0 | 0 | 0 | 0 | 63 | 41 | 39 | 21 | 4 |
| Hyderacarina (Hyde) | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Mollsuks (snails)** | | | | | | | | | |
| Lymnaeidae(Lymn) | 54 | 68 | 32 | 212 | 271 | 129 | 3 | 2 | 3 |
| **Oligochata (aquatic earth worm)** | 435 | 394 | 492 | 32 | 19 | 11 | 367 | 298 | 139 |
| Total individual | 892 | 1168 | 1104 | 668 | 885 | 491 | 575 | 646 | 501 |
| Total taxa | 14 | 14 | 14 | 9 | 13 | 10 | 10 | 10 | 10 |

| | | | |
|---|---|---|---|
| Total Individual | 31642044 | | 1722 |
| Total taxa from site | 16 | 13 | 10 |

## Appendix II:

Sediment Sensitivity Rating definitions and abundance weighted scores for PSI calculation (Extence,.*et al*,2013)

| Group | Sediment Sensitivity Rating (FSSR) | Log Abundance |
|---|---|---|

| | | 1–9 | 10–99 | 100–999 | 1000+ |
|---|---|---|---|---|---|
| A | Highly sensitive | 2 | 3 | 4 | 5 |
| B | Moderately sensitive | 1 | 2 | 3 | 4 |
| C | Moderately insensitive | 1 | 2 | 3 | 4 |
| D | Highly insensitive | 2 | 3 | 4 | 5 |

## Appendix III:

Physicochemical data form upper Awash River

| Macro-invertebrate taxa | Site one (1) | | | Site two (2) | | | Site three (3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sampling times | | | Sampling times | | | Sampling times | | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 13 |
| To | 19.1 | 18.2 | 20.5 | 26.1 | 26.1 | 27.4 | 28.1 | 28.4 | 28.9 |
| DO | 6.3 | 6.97 | 5.9 | 5.61 | 5.6 | 5.62 | 1.28 | 1.29 | 1.29 |
| PH | 7.1 | 7.8 | 6.99 | 7.91 | 7.9 | 7.93 | 8.21 | 8.21 | 8.23 |
| Cond. | 116.7 | 116.4 | 116.5 | 313.7 | 313.71 | 116.5 | 313.7 | 313.7 | 313.8 |
| $NO_3^{-2}$-N | 62.4 | 41.2 | 18.6 | 68.17 | 70.18 | 83.19 | 50.8 | 51.8 | 50.5 |
| $NO_2^{-}$-N | 19.3 | 17.7 | 11.3 | 49.7 | 52.8 | 46.9 | 32.1 | 32.8 | 45.5 |
| TP | 59.1 | 59 | 59.2 | 56.9 | 69.9 | 71.8 | 63.3 | 69.6 | 71.1 |
| $PO_4$-P | 53 | 53.1 | 53.2 | 61.1 | 47 | 42 | 59.3 | 64.5 | 56.6 |

TP

19.10

18.20

20.50

26.10

26.10

27.40

28.10

28.40

28.90

TP

6.30

6.97

5.90

5.61

5.60

5.62

1.28

1.29

1.29