Africa Center of Excellence for Water Management

Addis Ababa University

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Macrophyte species diversity, composition and distribution in relation to some environmental factors in Upper Awash River, Ethiopia

By

Temesgen Tigab Derso

October, 2020

Addis Ababa, Ethiopia

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Macrophyte species diversity, composition and distribution in relation to some environmental factors in Upper Awash River, Ethiopia

MSc Thesis

By

Temesgen Tigab Derso

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Management Specialization of Aquatic Ecosystem Management

Advisor:

Prof. Seyoum Mengistou

October, 2020

Addis Ababa, Ethiopia

Declaration

This is to certify that this research entitled Macrophyte species composition, distribution and Diversity in relation to some environmental factors in the upper Awash River, Ethiopia, submitted to the African Center of Excellence for Water Management, Addis Ababa University, in Partial Fulfillment of the Requirement for the Degree of Master of Science in Aquatic Ecosystem Management by Temesgen Tigab (ID.No. GSR/3590/11) is an authentic work carried out by him under my guidance.

Temesgen Tigab: ____________ ____________
Date Signature

Prof. Seyoum Mengistou ______________ ____________
Date Signature

ADDIS ABABA UNIVERSITY AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT SCHOOL OF GRADUATE STUDIES

Thesis Approval Form

The undersigned have examined the thesis entitled, "**Macrophyte species composition, distribution and diversity in relation to some environmental factors in Upper Awash River, Ethiopia**' by **Temesgen Tigab,** a candidate for the degree of Master of Science in Water Management, specialization in Aquatic Ecosystem Management and here by certify that it is worthy of acceptance.

Advisor:

Name: Prof. Seyoum Mengistu Signature ____________ Date____________

Internal Examiner:

Name: Signature_____________ Date___________

External Examiner

Name: Signature ____________ Date_____________

Chair person

Name: Signature ____________ Date_____________

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LIST OF ABBREVIATIONS AND ACRONYMS

AAEPGDC	Addis Ababa Environmental Protection and Green Development Commission
APHA	American Public Health Association
CAM	Crassulacean Acid Metabolism
CCA	Canonical Correspondence Analysis
DO	Dissolved Oxygen
EC	Electrical Conductivity
FV	Flow Velocity
H’	Shannon Weber index
NTU	Nephelometer Turbidity Units
UNEP	United Nations Environmental Protection
SRP	Soluble Reactive Phosphate
Tm	Temperature
TN	Total nitrogen

Abstract

Macrophytes play an important role in providing a stable habitat structure to the aquatic ecosystems. Recently Awash River has experienced some undesirable ecological changes due to invasion by exotic weed, Eichhornia crassipes (water hyacinth).With a view come up with scientific information usable in the protection of aquatic resources, this study was carried out between October2019 to April 2020 to assess macrophyte species composition and diversity in upper Awash River in relation to selected environmental factors. Macrophytes were collected manually and physicochemical parameters were measured in situ using YSI 556 multi probe system. Selected nutrients (SRP, TP, TN and Nitrate) were analyzed using standard methods of water and sediment.

In Awash River, a total of Twenty six macrophyte species belonging to fifteen families were identified with relatively low species diversity (H' = 2.56, Margalef index = 2.91). The emergent macrophytes had the highest percentage composition (92 %) and attained the highest relative frequency and density, followed by free floating (4%) and rooted floating (4%). Results of CCA indicated that Nitrate, SRP, TP and flow velocity were among the factors that had significant impact on the diversity, composition and distribution of the macrophytes in the river. Environmental factors of Awash River were recorded to relate to macrophyte distribution, with emphasis on Eichhornia crassipes density along the river bank. The coverage of Cyperus articulatus L., Echinochloa colona L., Solanum incanum L., Eichhornia crassipes, Persicaria senegalensis, Rorripa nasturtium aquaticum, Ipomoea aquatica and Phragmites mauritianus were almost restricted to sites where there was higher Nitrate, SRP and TP and Ludwigia spp., Sida schimperiana, Alternanthera sessilis, Lagarosiphon cordofanus Casp, Brachiaria mutica, Juncus effuses, Ludwigia abyssinica, Cyperus latifolius, and Cyperus papyrus to sites where there was higher DO,TN and Silt.

In conclusion, the in situ and experimental data obtained indicate that 50% of the macrophytes diversity was determined by the environmental factors like total nitrogen and phosphorus, flow velocity, nitrate (water) and sediment texture and half of the unexplained environmental factors that regulate the macrophyte diversity and distribution in the Awash basin have to be investigated in future studies.

Key words: Awash River; Canonical Correspondence Analysis; flow velocity; Macrophyte; Principal Component Analysis; Water hyacinth

1. Introduction

1.1. Background of the study

Rivers are the most dynamic and complex among the aquatic ecosystems playing a major role in the landscape's biodiversity and are highly sensitive to the inputs of nutrients, which influence the primary producers at most. Despite being characterized as dynamic systems, running waters often have geographically unique macrophyte assemblages. The characteristics of the river, or rivers, within the total basin system are related to a number of features. These features include the size, form and geological characteristics of the basin and the climatic conditions which determine the quantities of water to be drained by the river network (Lacoul and Freedman, 2014).

A study of macrophyte species composition, diversity and distribution is an essential component of understanding river ecosystems. This is due to the important ecological role of macrophyte vegetation and the ability of the vegetation to characterize the water quality (Lacoul and Freedman, 2014). Species composition and distribution of macrophytes in river ecosystems depend on various environmental factors such as light, water temperature, sediment nutrient, flow velocity, substrate composition, disturbance and quality of the river water (Birk and Willby, 2010).

Both hydrologic dynamics and human impact expressed as land-use types are found to be responsible for the variability of aquatic macrophyte assemblages in aquatic ecosystem (Otahelova *et al.*, 2007).

Macrophytes play an important role in providing a stable habitat structure to the aquatic ecosystems (Danielle and Barmuta, 2004). They also serve as a base of aquatic food-chains and actively contribute to the promotion and maintenance of food webs and services in freshwater ecosystems (Smith, 2011).

In terrestrial systems the distribution of plants along environmental gradients such as altitude, temperature, topography and nutrient have been well studied and quantified (Barbour *et al*,. 1987). In contrast, very little research has investigated the relationship between macrophytes particularly riverine macrophytes and environmental factors (Haslam, 1987). This may be due to the fact that terrestrial plants are more directly linked to societal requirements (food) and the economy (forestry and agriculture) than macrophytes. Detailed work may also be lacking in rivers because of the practical difficulties associated with working in lotic water by comparison with lentic water (Bilby, 1977).

Rivers are hierarchically structured, from source to mouth, meaning that spatio-temporal variation in the species richness and composition of the macrophyte communities which they support is influenced by a combination of local in-stream variables, regional environmental factors, and catchment characteristics (Chambers, 2008). This research examined the aquatic macrophyte composition, distribution and diversity in relation to abiotic habitat factors (flow velocity, substrate type, Nutrient), and relative abundance of species in the bank of the northern segment of the Awash River, Ethiopia.

1.2 Statement of the problem

Awash River Basin is one of the most important river basins in the country. It serves as home to 10.5 million inhabitants. Irrigation, electric power generation, fish production, serving as a water source for domestic consumption to the inhabitants dwelling nearby the river course, as well as for domestic and wild animals of the area are some of the most important services provided by the Awash River water (Fasil Degefu *et al.,* 2013). However, the Awash River ecosystem is being affected by catchment degradation, unregulated abstraction, pollution, flood hazard/ siltation, and uncontrolled fishing practices. Some of the peculiar features of the river are its large variation in Seasonal hydrology and over flooding to floodplains, high sediment loading in the wet season, large river bank height variation between seasons and exposed and wetted plants on middle beds of the river channel.

Previous studies on the Awash River focused on flood hazard assessment (Yitea Sineshaw Getahun and Sintayehu Legesse Gebre, 2015), plant community distribution along the river corridor (Mitiku Tikssa *et al.,* 2009), water quality degradation (Fasil Degefu *et al*., 2013) and composition and diversity of phytoplankton (Lakew Wondimu, 2014). Lakew Wondimu (2014) noted the massive growth of macrophytes such as *Eichhornia crassipes*, *Lemna* sp and *Azolla* in Awash River but did not make further study. In general, the diversity, composition and distribution of macrophytes in relation to some environmental factors in the Awash River have not been investigated. It is understood that aquatic macrophytes are reliable indicators of habitat conditions in running waters, because various species respond sensitively to alteration in water chemistry and/or current velocity (Schaumburg *et al.*, 2004) and have frequently been used in Limnology and vegetation ecology studies.

Also, assessing the taxonomic composition, diversity, distribution and abundance of macrophytes in aquatic ecosystem is important in the determination of the ecological status of the river. It is imperative to identify the driving force for macrophyte dynamics in a system, both for growth enhancement and control interventions.

Therefore, this study was undertaken to assess the diversity, composition and distribution of the aquatic macrophytes in relation to environmental factors in the Awash River and to investigate the coverage and distribution of the invasive weed *Eichhornia crassipes* (water hyacinth).

1.3 Research Questions

This study tested the hypothesis that the major driving forces for macrophyte dynamics of the Awash River are the physico-chemical factors, through answers to the following research questions.

- What are the most abundant/frequent aquatic macrophyte species in the study area?
- What is the extent of water hyacinth coverage in the river?
- How do environmental factors influence the diversity, composition and distribution of macrophyte species in the study area?
- Is there variation in composition of aquatic macrophyte species among seasons in the study area?

1.4 Objectives

1.4.1 General objective

- The general objective of the study was to provide comprehensive assessment of the environmental factors regulating macrophyte species diversity, composition and distribution in Awash River and to use this basic information as a framework to predict and manipulate changes in macrophyte community structure.

1.4.2 Specific objectives

The specific objectives of the thesis are to:

- Determine macrophyte species diversity, composition and distribution in the study area.
- Determine the coverage and distribution of the invasive water hyacinth along several reaches of the Awash River.
- Investigate the environmental factors that influence the diversity, composition and distribution of macrophyte species in the study area.
- Identify the impact of seasonal changes in macrophyte species diversity and abundance in the study area.

2. Review of related literature

2.1 Brief history of running water macrophytes

The interest in aquatic macrophytes generally began in the tropics in the beginning of the second half of the 20th century. This interest arose from the possible advantages and threats of macrophyte may pose to man and water body utilization (Adigun, 2005). Aquatic macrophytes, are large photosynthetic organisms, that can be seen with the naked eye and actively grow permanently or periodically sub- merged below, floating on, or growing up through the water surface (Chambers *et al.*, 2008). Therefore, this will include flowering plants, conifers, mosses, ferns and fern allies, charophytes, macro-algae of all descriptions, and any other plant found in standing or moving water. Plants that are completely submersed rooted in the sediment with leaves floating on the surface, Plants rooted in standing water with leaves emerging from the water, and plants that are free-floating in the water with leaves either submersed, or partly or fully emergent. Together with microalgae, aquatic plants are responsible for the primary production of lakes and rivers (Sand-Jensen, 1991).They play important roles in the structure and functioning of freshwater ecosystems (Girum Tamire and Seyoum Mengistou, 2012).

Macrophytes serve as a link between sediment, water, and (sometimes) atmosphere in rivers, lakes, and wetlands. Macrophytes are involved in ecosystem processes such as bio mineralization, transpiration, sedimentation, elemental cycling, materials transformation, and release of biogenic trace gases into the atmosphere (Carpenter and Lodge, 1986).Recent studies also suggest that macrophytes play a central role in shallow lakes which can have two possible stable equilibria: a clear-water state that is dominated by aquatic macrophytes and a turbid-water state that is dominated by phytoplankton (Scheffer *et al.*, 1993).

Aquatic macrophytes can be classified based on species structural and environmental adaptation (traits) to environment (growth forms) or attachment (life forms). Growth forms are divided in to halophytes, nymphaeids, isoetids, elodeids, ceratophyllids, lemnids, bryids and charids (Mäkirinta, 1978), whereas rhizophytes (incl. halophytes, isoetids, eloideids, charids) are macrophytes attached to a substrate and pleustophytes (incl. ceratophyllids, lemnids and bryophytes) are free floating species (Sculthorpe, 1967). In general, rhizophytes often indicate long term environmental changes, because they mainly take up nutrients and other minerals through their root system, whereas pleustophytes are directly dependent on water quality and respond more rapidly to anthropogenic impacts. However, macrophytes are mainly species-specific in preferring different kinds of nutrient conditions, ranging from oligotrophic to (hyper-) eutrophic (Toivonen and Huttunen 1995). Species also respond differently to other environmental conditions, such as anoxia, water level fluctuations, freezing, and flooding and ice erosion (Lacoul and Freedman 2016).

Many aquatic macrophytes are widely distributed due to their efficient reproduction strategies and good dispersal capabilities (Santamaria, 2002). Vegetative and clonal reproduction is a major mechanism for population growth and dispersal of macrophytes, whereas sexual reproduction and genetic recombination are often subordinate strategies (Wetzel, 2001). All growth forms of populations expand mainly by plant fragments, rhizomes and winter buds that are dispersed even long distances via wind, water, animals and humans. Some species, often halophytes, combine intensive vegetative growth with wind dispersed seed production resulting to high colonization capability (Wetzel, 2001).

2.1.1 Evolution and physiological characteristics of aquatic macrophytes

The terrestrial higher plants evolved in the Ordovician period (450 million years ago) from the Characeae being a family of complex structured Chlorophyta (green algae) with a stem and lateral branches (Bresinsky *et al.* 2008). The evolution of aquatic angiosperms probably emanated from terrestrial angiosperms involving processes of reduction and loss with regard to more complex ancestors (Les *et al.,* 1997).

Submerged plants show a variety of adaptations in the water: leaves, shoots and rhizomes are typically rich in gas-filled lacunae causing buoyancy and facilitating oxygen and carbon dioxide transport within the plants (Sand-Jensen and Prahl, 1982). Submerged leaves have only a thin cuticle with a water permeability about three times higher than that of surfaces from emergent leaves (Schönherr, 1976), allowing effective nutrient uptake (Sand-Jensen *et al.,* 1992). Early studies attributed anchoring in the sediment as the main function to the roots of hydrophytes (Sutcliffe, 1962), but their roots also play a significant role in nutrient uptake (Denny, 1972). Defense strategies of macrophytes include the translocation of nutrients and shortening of the growth period as observed for *Potamogeton perfoliatus* under grazing pressure (Miler & Straile 2010). For *Stratiotes aloides* the allelopathic inhibition of algal growth has been observed (Mooij *et al.,* 2005) and Elodea nuttallii is capable of performing chemical defense against herbivorous insects (Erhard *et al.,* 2007).

Aquatic plants except for bryophytes have the ability to use carbon not only from carbon dioxide, of which the uptake is a diffusive process, but also from bicarbonate being actively transported through the cell membrane (Madsen, 1993). Depending on the pH of the water, inorganic carbon is predominantly present in the form of carbon dioxide (at 0 °C: pH <6.5), bicarbonate (pH 6.5–10) or carbonate (pH >10) (Gessner, 1959). Another specific feature, though only of a few macrophyte species, is the capability to perform Crassulacean acid metabolism (CAM) being a photosynthesis mechanism involving night time fixation of carbon in the form of malate acid for decarboxylation at day time. The Crassulacean acid metabolism occurs in terrestrial plants adapted to aridity and in aquatic plants, like *Isoëtes lacustris* or *Littorella uniflora,* adapted to carbon limitation (Keeley, 2020).

2.1.2 Ecology and Ecological functions of river macrophytes

Aquatic plants grow partially or completely in water. As with other plants, they require light and carbon dioxide (or other inorganic carbon source) for photosynthesis, oxygen for respiration, water, and nutrients such as nitrogen, phosphorus and others. Plants that grow with emergent or floating leaves form some of the most productive communities in the world, because they are rarely limited by water availability. With leaves exposed to the air, they have a ready source of light, carbon dioxide and oxygen. Submersed plants, however, are much less productive. Light energy is rapidly attenuated as it penetrates the water, so light becomes a limiting resource for submersed plant growth. Carbon dioxide and oxygen must be acquired from the water, or stored in the plant stem, with the consequence that it is much more limiting to submersed plants than to emergent species. Diffusion is slow through water, further reducing plant growth rates. Plants rooted in the bottom typically have a ready source of nutrients such as nitrogen and phosphorus. Algae and free-floating plants, however, must acquire nutrients from the water column, which can likewise limit their growth.

Several studies show that macrophytes are essential for the ecological functioning of aquatic systems and essential in promoting the diversity of aquatic environment (Carpenter and Lodge, 1986). Among the others they offer increase the diversity of ecological niches by providing hiding place, feeding habitat and spawning ground or serving as food for fish (Valley *et al.*, 2004), invertebrates (Newman, 1991), habitat for zooplankton which feed on phytoplankton (Adigun, 2005) and waterfowl (Søndergaard *et al.*, 1998) and their stems, roots and leaves serve as a substrate for periphyton, and a shelter for numerous invertebrates and different stages of fish, amphibians and reptiles (Dvořák, 1996). Moreover, they can play a role in water purification (Seidal, 1976). An example for an indirect positive effect of aquatic rhizophytes in running waters for animals depending on the hyporheic interstitial - like the brown trout being the host fish of the freshwater pearl mussel - is the reduction of the load of fine particles in the water column. Due to erosion, caused for example by hydraulic engineering or coming from agricultural land, high amounts of suspended matter can regularly be found in lowland rivers, silting the interstitial (Dettmer, 1996). As macrophytes reduce the current velocity within the vegetation patches, they cause sedimentation and act as “sand filters” (Sand-Jensen, 1998). They also prevent erosion from the banks by fixing the sediment with their roots. Macrophytes contribute to the “self-purification” of water bodies directly by uptake of nutrients and oxygenation of the water and sediment, but also indirectly by building the substrate for epiphytic algae that multiply the same effects (Engelhardt, 2001).

2.1.3 Practical applications of aquatic macrophytes

An application of aquatic macrophytes is the use as bio indicators. Although the knowledge about the synecological tolerance ranges of macrophyte species or communities against specific factors is still insufficient (Lansdown and Bosanquet, 2010), the sensitivity of macrophytes to changes in environmental conditions as for example eutrophication and pollution has been verified by means of field (Hare *et al.,* 2010) and experimental studies (Geurts *et al.,* 2009). In the European Water Framework Directive (European Union, 2000) macrophytes are used as one of five biological components for the assessment of the ecological quality of water bodies.

Other applications of macrophytes include the use of fast growing macrophytes like *Lemna minor, Spirodela polyrhiza* or *Salvinia minima* for phytoremediation purposes like organic wastewater treatment (Körner *et al.,* 2003). The gained protein-rich phytomass can be harvested and used as animal food or for the production of fuel ethanol (Cheng and Stomp, 2009). *Lemna minor* is also frequently used to test chemicals for environmental toxicity in standard tests (European Union, 2000).

2.2 The factors that affect the distribution of macrophytes

Many studies have investigated environmental factors determining plant establishment in river systems, such as those related to physical habitat (Riis, 2001), and its perturbation (Henry *et al.,* 1994). Macrophytes have also shown sensitivity to chemical pollution (Whitton, 1979). Frequently, abiotic factors related to the physical habitat and the hierarchical position of each site along the river system, are found to prevail over factors associated with the chemical environment (Chambers and Kalff, 1987; Riiset *et al.,* 2000). Flow regime is a key component of the physical environment (Poffet *et al.,* 1997) and altered flow regime can cause severe modifications of the river ecosystems (Norris and Thoms, 1999).

2.2.1 Flow velocity

Water flow velocity is a dominant environmental variable determining the occurrence of macrophytes (Chambers *et al.,* 1991). As early as the 1920s, Butcher (1933) recognized that changes in water flow or velocity could alter the biomass and species composition of submersed aquatic macrophytes in streams and rivers. In the upstream, where rivers are small and often close to their natural ecological status, two main parameters (speed of water flows and the substrates) control the growth of macrophytes. In the middle and lower reaches, rivers create a system of secondary channels, meanders and oxbows. In situations where water flow is slow and the width of the water body prevents heavy shading, macrophytes will become abundant (Janauer and Dokulil, 2006). In the center of the main stem of large rivers, high flow velocities and moving sediment material prevent macrophyte growth. Near to the banks, the flow is lower, but plants rarely grow in water deeper than 1.5 m. This phenomenon is caused by shading due to either inorganic suspended material or phytoplankton growth (Westlake, 1975). Physiological studies have shown that photosynthetic rates of freshwater macrophytes are positively correlated with current velocity at low levels (0–0.10 m s−1), the range likely to occur within dense macrophyte beds (Madsen and Søndergaard, 1983). However, biomass is often negatively correlated with stream current speeds above this range (French and Chambers, 1996).

Current velocity can benefit aquatic macrophyte growth by enhancing CO_2 and nutrient supply, or be detrimental to growth due to mechanical stress. In addition to the physical stresses imparted by moving water, macrophyte metabolic and uptake processes, including photosynthesis, are affected by water movement. Gases diffuse 10000 times more slowly in water than air, so diffusive processes are limiting steps to macrophyte metabolism. In addition, the boundary layers through which gases and nutrients must diffuse are typically substantially larger in water than in air, so this distance is a key factor to metabolic activity. Laboratory experiments have generally shown positive relationships between photosynthesis or nutrient uptake and flow rates for very slow current velocities (≤0.01 m s−1 for freshwater species and ≤0.02 to 0.06 m s−1 for marine species), presumably due to a greater flux of solutes resulting from reduced thickness of the diffusion boundary layer (Koch, 1994). Thus, slow currents appear to enhance the growth of freshwater macrophytes by increasing the flux of CO_2 or nutrients across the diffusive boundary layer, whereas only slightly faster currents constrain growth due to mechanical stress. Current speed also can affect the growth of macrophytes indirectly by determining the particle size of sediments. The particle size that can be eroded and transported is a function of current velocity. Thus, sand particles are most easily eroded (critical erosion velocity of about 0.20 m s−1), whereas larger particles require faster current speeds to initiate movement (about 1.0 m s−1 for coarse gravel). Although having a smaller grain size than sand, silts and clays require greater critical erosion velocities because of their cohesiveness. Organic particles, due to their low density, tend to erode easily. Therefore, coarse substrates, which are characteristic of strong flow areas, generally lack organic matter and are nutrient-poor (Chambers *et al.*, 1991). Because rooted macrophytes obtain most of their needed phosphorus and nitrogen from the sediments, current velocity, through its effect on sediment particle size and organic content, have the potential to constrain macrophyte growth (Barko and Smart, 1986). In addition, it may be difficult for macrophytes to root firmly into coarse sediments. Conversely, the settling of particles has a significant impact on macrophyte growth. Initially, low rates of settling will stimulate growth through the influx of more nutrients in the sediments. However, at some point, the flux of settling particles will become too great, resulting in shading of photosynthetic surfaces and burial of the plant. The growth of some aquatic macrophytes may be aided by the influx of nutrients in groundwater (Lodge *et al.*, 1989). Mineral nutrition in rivers may be aided by hyporheic flow, or the flow of stream water through the interstices of bottom sediment particles, specifically in coarse sand and gravel sediments. In addition to the increased mineral nutrients, the flow of groundwater around roots increases the uptake rate by reducing boundary layer around root surfaces. Hyporheic flow moves the nutrients into the water column and, therefore, the increased availability of nutrients in the water column and decreased diffusion boundary layers of leaves in flowing waters may enable a shift in nutrient source from the sediment to the water column (Carignan, 1982).

2.2.2 Nutrient enrichment

Depending on their growth strategy, macrophytes may obtain dissolved nutrients from either or both of the sediment and water columns (Xie *et al.,* 2005). Rooted species can typically obtain nitrogen, phosphorus, calcium, and other key nutrients from sediment, even while absorbing inorganic carbon from the water column. In contrast, non-rooted submerged hydrophytes absorb all of their nutrients from water, while emergent and floating species also have access to atmospheric sources of some nutrients, particularly carbon dioxide. Various factors related to nutrients and acidity and alkalinity have important influences on aquatic plants and their communities (Bini *et al.*, 1999). In general, productivity is limited by the supplies of phosphate and nitrogen (as nitrate and (or) ammonium), but other nutrients may also be important (e.g., inorganic carbon, calcium, and potassium) (Barko *et al.,* 1986).

In marshes the productivity of macrophyte is generally nitrogen limited when the N: P ratio is <14, and phosphorus limited when N: P is >16 (Verhoeven *et al.,* 1996). However, generalizations based on N: P ratios cannot yet be made for aquatic plants and their productivity in wetlands or in lotic ecosystems (Mores *et al.,* 2004). In less fertile lotic and lentic habitats, the productivity of aquatic plants is most likely to be limited by the availability of phosphate and (or) inorganic nitrogen (as nitrate or ammonium, depending mostly on acidity). This is also generally the case in more productive situations, although for submerged hydrophytes the supply of inorganic carbon may also be limited to photosynthesis (Barko *et al.*, 1986).

In general, dissolved CO_2 is the preferred source of inorganic carbon, but its concentration is generally low in the water, particularly in situations with pH > 5.4 (Hough and Fornwall, 1988). Most species of non-acidic habitats can utilize bicarbonate-C, but this is inefficient under low-light conditions because of the energy requirement for active transport of bicarbonate (Hough and Fornwall, 1988).

A few macrophytes are indicators of the availability of particular nutrients. For instance, *Callitriche stagnalis, Ceratophyllum demersum, Ceratophyllum submersum, Potamogeton polygonifolius, Potamogeton praelongus,* and *Urtricularia* spp are useful indicators of high nitrogen conditions (Heegaard *et al.,* 2001; Tracy *et al.,* 2003). In general, submerged macrophytes such as *Potamogeton coloratus* and *Chara hispidata* do not tolerate high ammonium conditions (Boedeltje *et al.,* 2001).

Some species of macrophytes are adapted to ecosystems that have low phosphorus availability. For instance, *Littorella uniflora* is restricted to low phosphorus habitats, while *Lemna minor*, *Spirodela polyrhiza* and *Zanichellia palustris* require medium to high phosphorus concentrations (Heegaard *et al*. 2001, Paal and Trei 2004). However, the distributions of *Isoetes lacustris*, *Lemna minor*, *Lobelia dortmanna*, *Myriophyllum alterniflorum*, *Sparganium angustifolium*, and *Sparganium erectum* are influenced by integrating gradients of nitrogen, phosphorus, and sometimes other nutrients (Heegaard *et al.,* 2001; Paal and Trei, 2004).

It has been well emphasized that the distribution and growth of aquatic macrophytes are associated with nutrient rich environments, particularly nitrate and phosphate, which have been noted to favor macrophytes growth (Frankouich *et al.,* 2006). Several studies have established that the nutrient enrichment can cause significant changes in the density, species composition and richness of aquatic vegetation in aquatic ecosystems (Toivonen and Huttunen, 1995; Bini *et al.,* 1999; Lougheed *et al.,* 2001). There is a possibility that the elevated nutrient concentrations might hamper climate-driven distribution patterns of macrophytes (Rosset *et al.,* 2010).

2.2.3 Hydrological variations

Hydrology has a great influence on the environmental characteristics of lentic and lotic ecosystems. The associated stressor regime (particularly disturbance and drought) affects the species composition, relative abundance, distribution, and successional dynamics of communities of aquatic macrophytes (Paal and Trei, 2004). The hydrologic regime is related to temporal and spatial variations of water depth, sediment characteristics, water clarity and chemistry, and (in lotic systems) currents and scouring (Gafny and Gasith, 1999). Aquatic habitats may be affected by water inputs associated with streams or rivers, as well as groundwater springs inflowing below the surface. If hydrological conditions and water level are relatively stable, communities of aquatic plants in the river bank (i.e., in shallow water and the adjacent banks) tend to stabilize at a low level of species richness (Shay *et al.,* 1999). Habitats with water levels that naturally fluctuate during the growing season may support rich bank vegetation. This occurs because large seasonal variations of water level render the bank habitat unsuitable for species that are highly competitive under more stable conditions, while providing opportunities for others tolerant of hydrologically stressful environments (Anderson, 2001). River-edge species tolerant of these conditions is typically amphibious, ruderal (i.e., short-lived and r-strategist) helophytes, whose seeds require drawn-down water levels and oxygenated conditions to germinate and grow in low-competition habitats (Andersson, 2001). Other longer lived species, with broader environmental tolerances, may have phenotypically plastic responses to variations of water level and associated environmental conditions (Sand-Jensen and Frost-Christensen, 1999). In lotic systems, large seasonal variations of hydrology are equivalent to scouring disturbances associated with intense flow, erosion, and turbidity, often followed by siltation (Mackay *et al.,* 2003). Fluctuating water levels are a common occurrence in rivers and wetlands. Water levels can fluctuate on different time scales, from the seasonal to the daily, and by varying amplitudes. Fluctuating water levels are a component of the water regime which is described by the water depth and the rate, amplitude and timing of flooding or drawdown events. Water regime, as distinct from instantaneously measured water depth, has been implicated in affecting the composition, diversity (Casanova and Brock, 2000) and distribution (Boar, 2006) of macrophyte communities. Water depth can constrain plant growth by limiting the availability of resources, particularly atmospheric carbon (Blanch *et al.,* 1999a) and oxygen (Crawford, 1992).

Ordinarily, emergent macrophytes adjust to a static water depth and the ensuing limitations in atmospheric carbon and oxygen through morphological plasticity; in particular, an elongation of the shoot to maintain an emergent canopy (Rea and Ganf, 1994b) and an increase in the dimensions of the lacunae to increase aeration potential (Sorrell and Tanner, 2000). However, where water level fluctuations occur quickly, plants may not have the opportunity to morphologically adjust to rising water levels before water levels change once again requiring a different set of responses to optimize resource capture (Vretare *et al.,* 2001). Rapid cyclic fluctuations in the water level may therefore result in intermittent periods of resource limitation, where the degree of limitation should be commensurate with the amplitude of water level fluctuations, and, when water levels drop, periods when atmospheric resources are in relative abundance.

Several studies have found that the variations in water depth lead to variations in species zonation, distribution, biomass and richness (Fernandez-Alaez, 1999). Lacoul and Freedman, 2006). The turbidity of water also seems to determine the extent of colonization of submerged aquatic plants (Scheffer *et al.*, 1992). Nurminen (2003) noted that higher turbidity, fluctuations in water level and other factors seem to limit the macrophyte distribution to mainly turbidity tolerant species (e.g., *Nymphaea*, *Nelumbo* and emergent).

Low water levels may have a greater impact on submerged vegetation in comparison to the lower rivers, due to the steeper banks (Pankhurst, 2005). It is believed that the reduction in water level and change in Limnology of lake waters could change considerably the composition of macrophytes over decades (Getachew Beneberu and Seyoum Mengistou, 2010). Water depth, the effects of spring flooding in removing litter and the fertility gradient produced by flowing water are the three main factors affecting vegetation composition (Day *et al.*, 1988).

2.2.4 Shading

Macrophytes require light for photosynthesis; the position of the photosynthetic parts of the plant relative to the water surface is a key control. Strong shadowing of river channels due to either inorganic suspended material or phytoplankton growth limits the development of aquatic plants, their abundance, and biodiversity (Ali *et al.*, 2011). Any increase in the turbidity of the water column caused by suspended fine sediment will reduce light availability, and hence photosynthesis, and have an impact on the growth of submerged macrophytes (Parkhill & Gulliver, 2002). At its most extreme, constant high turbidity from fine sediment and other particulates suspended in the water column can attenuate light to such an extent that submerged macrophytes are excluded from all but the shallowest (usually marginal) areas (Vermaat & De Bruyne, 1993). Although the impact of fine sediment turbidity on light attenuation has a less pronounced effect on emergent and floating leaved macrophytes, where the majority of the photosynthetic parts are above the water column, the submerged parts can contribute substantially to the photosynthetic capability of such species, particularly early in the growing season (Delbecque, 1983).

Nevertheless, high concentrations of inorganic fine sediments in the water column do not tend to occur for prolonged periods, being strongly associated with high flow events; sustained high densities of fine particulates tend to be of biological origin (phytoplankton) rather than eroded inorganic sediment. Where mining activity has resulted in sustained high levels of turbidity, such as streams influenced by placer gold mines in Alaska (Koenings & LaPerriere, 1987), there is a negative correlation between turbidity (as Nephelometer Turbidity Units: NTU) and primary production (g O_2 m^{-2} day^{-1}). A similar reduction in primary production, benthic chlorophyll and diatom density was reported downstream of gravel extraction in a French river (Rivier & Seguier, 1985). Lloyd *et al.*, (1987) developed a model that related turbidity to gross primary production, where an increase from 1 to 5 NTU resulted in a decrease of 3-13 % of gross primary production, and an increase from 1 to 25 NTU a decrease of 13-50 %. However, isolating the effect of turbidity on light availability from the other effects of sediment on macrophytes is difficult, and requires modeling of light attenuation and determination of the relationship between light and photosynthesis/growth (Sand-Jensen & Madsen, 1991). Using this approach Vermaat and De Bruyne (1993) established that low light availability due to turbidity (from suspended sediment and phytoplankton) resulted in almost total exclusion of macrophytes in the River Vecht. In the River Spree turbidity (primarily phytoplankton) was responsible for a 45% reduction in light availability at a depth of 0.5 m, although this only had a significant effect on macrophyte growth when combined with shading attributable to bankside vegetation and periphyton (Köhler *et al.*, 2010). In the river Mitchell Macrophyte cover showed an inverse relationship to turbidity

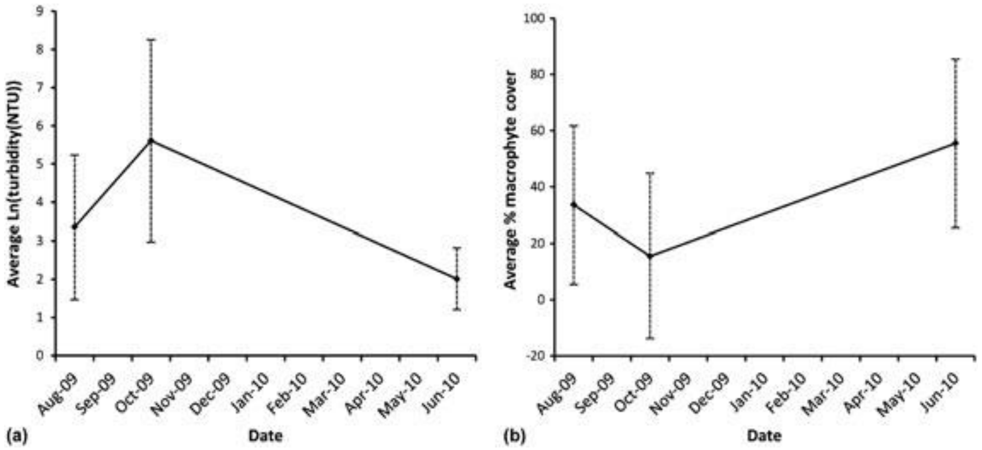

Figure: 2.1 (a) Average turbidity and (b) Average% macrophyte cover in Mitchell river (dashed bars represent standard deviation) Source (Ward *et al.*, 2012).

Increased sunlight penetration generally enhances the vegetation biomass, plant cover, and biological diversity (Sender, 2016). In the case of photophobic species, excessive sunlight can lead to limiting shoot elongation and slowing down biomass development (Szoskiewicz *et al.*, 2009). On the other hand, a decrease of sunlight caused by emergent macrophytes can lead to a reduction in the number of phytoplankton organisms in lowland rivers (Wersal & Madsen, 2013). Wersal & Madsen, (2013) noted changes in aquatic plant cover caused by limitation of light penetration can affect spatial variability and characteristics of river channel sediments, which are modified by the presence of vascular plants.

2.2.5 Temperature

Ambient temperature (of water and sediment) influences the distribution of aquatic plants by affecting their physiology, including the germination of seeds, initiation and rate of seasonal growth, and onset of dormancy (Barko *et al.*, 1982, Spencer *et al.*, 2000). The influence of water temperature on aquatic plants and their communities is well known (Scheffer *et al.*, 1992, Lacoul and Freedman, 2006*a*). Only a few species of macrophytes can survive unless ambient temperature during the growing season reaches at least 10 ◦C, and most species are killed or rendered dormant by temperatures cooler than 3 ◦C and warmer than 45 ◦C (Sculthorpe, 1967; Best and Boyd, 2003).

The sprouting of propagules is regulated in part by temperature (Madsen and Adams 1988; Spencer and Ksander, 1992). Many submerged hydrophytes have a wide temperature tolerance for the germination of propagules, e.g., *Vallisneria americana* 7–20 ◦C (Korschgen and Green, 1988), *Potamogeton pectinatus* 3–15 ◦C (Spencer and Ksander, 1992), and P. nodusus 10–20 ◦C (Flint and Madsen, 1995). In nature, this is more closely related to sediment temperature than to that of water (Spencer *et al.,* 2000). Community structure is also affected by variations of ambient temperature. Callaway and King (1996) found that *Typha latifolia* and *Myosotis laxa* could co-exist at relatively cool temperatures (11–12 ◦C) but not at warmer ones (24–25 ◦C) in which Typha was competitively dominant.

2.2.6 Altitude

In general, species richness decreases with increasing elevation, a change that can be attributed to climatic deterioration. An altitudinal decline in richness occurs in both temperate and tropical latitudes (Heegaard *et al.,* 2001; Jones *et al.,* 2003). A study of macrophytes in 316 lakes and ponds varying from 2 to 837 m in Cumbria, United Kingdom, suggested that altitude was the strongest predictor of species richness among the environmental factors examined (Jones et al. 2003). Similarly, a study of 28 lakes ranging over 77 to 4980 m in the Himalayas found that water temperature (which is strongly and linearly correlated with altitude) was the strongest predictor of macrophyte richness, followed by transparency, pH, alkalinity, and conductivity (Lacoul and Freedman, 2006*a*).

Aquatic ecosystems at high altitude are extreme environments in which physical stressors associated with ice and snow (winter cover, scouring, and avalanche) and severe climate are limiting factors for the distribution of aquatic plants (Lacoul and Freedman, 2006*b*). The phenology of high-altitude plants is tightly coupled to that of the melting of snow or surface ice and other key seasonal events that initiate or end the brief growing season (Lacoul and Freedman 2006*b*). The dispersal of macrophytes among high-altitude lakes is limited by their isolation and infrequent visitation by animal vectors (Lacoul, 2004).

2.2.7 Herb ivory

Aquatic plants may be grazed by invertebrates, fish, turtles, waterfowl, and mammals, and this affects their abundance and the composition of communities (Lodge, 1991). In some cases, herbivores have been used as a management tool to reduce the abundance of aquatic plants (Hanlon *et al.,* 2000). For example, grass carp (*Ctenopharyngodon idella*) feeds on more than 170 species of aquatic plants and has been widely used to reduce their biomass (Redding and Midlen, 1992). This fish has been shown to reduce the abundances of *Ceratophyllum, Egeria, Hydrilla, Lemna, Limnophila, Myriophyllum, Najas, Nechamandra, Ottelia, Potamogeton,* *Spirodela, Trapa, Utricularia, Vallisneria*, and *Wolffia*, but it is ineffective in controlling the floating plants *Eichhornia, Pistia, Salvinia*, and *Nymphaea*. Other herbivorous fish used to reduce the abundance of hydrophytes include common carp (*Cyprinus carpio* (Sidorkewicj *et al.*, 1998), species of tilapia (e.g., *Tilapia zillii* (Saeed and Ziebell, 1986) and rudd and roach (*Scardinius erythrophthalmus* and *Rutilus* respectively; Lammens and Hoogenboezen 1991). In some cases, however, selective feeding by fishes may lead to an eruption of resistant aquatic plants, such as *Ranunculus* released by grass carp herb ivory in a canal system in Turkmenistan (Charyev 1984). Moreover, there are many examples of introduced herbivorous fishes becoming seriously invasive in novel ranges, as has occurred with various species in North America (e.g., common carp, grass carp, bighead carp (*Hypophthalmichthys nobilis*), silver carp (*Hypophthalmichthys molitrix*), black carp (*Mylopharyngodon piceus*), and northern snakehead (*Channa argus).*

Intensive grazing by birds may have a large effect on communities of aquatic and wetland plants (Van Donk 1998). For example, large populations of snow goose (*Chen caerulescens*) have greatly reduced the abundance of rhizomatous grasses and sedges in subarctic and arctic salt-marshes, and have even created expanses of devegetated mud (Williams et al. 1993). In Delta Marsh, Manitoba, waterfowl may consume as much as 40% of the standing crop of *Potamogeton pectinatus* (Anderson and Low, 1976).

The abundance of herbivorous birds may itself be affected by changes of aquatic plants. In Currituck Sound, North Carolina, an eruption of invasive *Myriophyllum spicatum* supported increased populations of various dabbling ducks (*Anas acuta, A. americana, A. crecca, A. platyrhynchos, A. rubripes*), ring-necked duck (*Athya collaris*), and coot (*Fulica americana*) (Wicker and Endres, 1995).

Herbivorous mammals may also affect aquatic plants and their communities. In Florida and Guyana, the manatee (*Trichechus manatus*) consumes at least 36 genera of aquatic plants, and in some cases can keep water bodies relatively clear of invasive *Eichhornia crassipes*, *Hydrilla verticillata*, and other hydrophytes (Hauxwell *et al.*, 2004).

Insects are also important herbivores of aquatic plants, although their effect is not yet well studied. The purple loosestrife (*Lythrum salicaria*), an invasive plant of wetlands in North America, is being controlled in some regions by two herbivorous beetles (*Galerucella calmariensis* and *G. pusilla*) introduced from its native range (Stamm *et al.*, 1999).

2.2.8 Invasive species

Because of the severe ecological damage they cause, alien invasive species are one of the most rapidly increasing and pressing environmental problems of recent times (Palumbi, 2001). The grave concern about invasive species has led to the development of national and international programs, such as the Global Invasive Species Program of the World Conservation Union, which is mandated to combat these ecological pathogens and reduce the damage they cause to native species, natural ecosystems, and economic resources.

Invasive plants of aquatic and wetland ecosystems are alien species that produce large numbers of disseminules (seeds and (or) vegetative propagule), distribute them over long distances, and become rapidly abundant in novel habitats, where they may exclude native plants, degrade the habitat of animals, and cause economic damage to recreation, irrigation, and other human interests (Kercher and Zedler, 2004). However, not all alien aquatic plants become abundant enough in wild habitats to be considered seriously invasive — in many cases, they have little influence on native species (Houlahan and Findlay, 2004). Globally, about 6–10% of alien aquatic plants are considered seriously invasive (Houlahan and Findlay, 2004).

In general, the success of invasive aquatic plants depends on there being a relatively empty niche for them to exploit, or on their competitive superiority in appropriating resources and tolerating anthropogenic stressors, especially those associated with cultural eutrophication (Corbin and D’Antonio 2004). In addition, alien invaders typically have few or no natural herbivores or diseases to limit their productivity and abundance (Mack *et al.,* 2000). For example, *Lythrum salicaria* is a highly invasive competitor in wetlands in North America, although its success may be diminished if controlling herbivores are introduced from its native habitat (Houlahan and Findlay, 2004).

Severe damage caused to aquatic and wetland habitats by invasive plants has been reported worldwide, and the problem is increasing in both extent and severity (Houlahan and Findlay, 2002).

Invasive aquatic plants can spread quickly when introduced to suitable habitats beyond their native range. For instance, Free-floating *Eichhornia crassipes* has spread remarkable quickly in tropical and subtropical regions (Talling and Lemoalle, 1998).

2.2.8.1 Distribution of water hyacinth

Water hyacinth was discovered by German naturalist C. von Maritus in Amazon basin in 1823 (Gopal, 1987). Then it spread throughout the world. The ability to reproduce both sexually and asexually and its rapid proliferation rate are some of its biological adaptations to spread easily. Its attractiveness with purple color flowers and shiny smooth leaves made people to use it as an ornamental plant. As communication and transportation improved early in 19th and 20th century people carried the plant from place to place across the continent. The Trans-Atlantic triangular trade could have some contribution to the spread of this and other plants from Latin America to Europe and then to Africa. At the end of the 20th century the weed already spread throughout tropical and sub-tropical countries from Brazil to Southeast Asia.

In Africa the first invasion of water hyacinth was reported in Egypt in 1879 (Gopal, 1987).Then it spread to Kenya in 1940. In 1998 it was observed in Lake Victoria and reached its maximum (Gichugi *et al.,* 2012). The weed also observed in other African countries like: Zimbabwe in 1937, Mozambique in 1946, Tanzania and Zambia in the 1960s and in several other sub Saharan African countries

In Ethiopia the existence of water hyacinth was reported for the first time in 1956 around Koka reservoir and Awash River (Stroud, 1991). Currently it is reported in Gambella area, Aba Samuel reservoir, Wonji- Shewa and Metehara Sugar Estate and in Lake Tana (Wondie Zelalem, 2013).

2.2.8.2 Impact of water hyacinth on macrophytes abundance and composition

In the presence of invasive species only few macrophytes will survive i.e. invasive plants could affect the vegetation composition and abundance of macrophytes (UNEP 2013; Gichugi *et al.,* 2012) .Water hyacinth has thick mat growth that could affect seedling recruitment by blocking seed dispersal (Shibu *et al.,* 2013). Those plants whose seed dispersal is aided by water can be affected by this plant and remain kidnapped in a certain area. The shading effect of this plant also can affect other plants especially the submerged macrophytes. This fact is also supported by Gichugi *et al.,* (2012). According to their result, water hyacinth affect the occurrence of floating leaved plants i.e. submerged plants like *Nymphaea lotus, Ceratophyllum demersum* and *Najas horrida* through shading and competition for nutrients. Water hyacinth is relatively taller than these plants and it has broader leaves that can reduce the amount of light beneath its canopy. The fibrous root system of the plant used to with draw nutrients effectively compared to the submerged ones. The allelopathic effect of water hyacinth is also reported by many authors (Chai *et al.*, 2013).

3. Materials and Methods

3.1 Study Area

This study was conducted in upper Awash River (head water to Koka reservoir), a total course of 500 km and downstream of Koka reservoir up to Siri robi kebele. Awash River basin is the most important river basin in the country. It covers a catchment area of 110,000 km^2 and serves as home to 10.5 million inhabitants. The river originates from a high plateau near Ginchi town, about 80 km to the west of Addis Ababa and flows along the rift valley into the Afar triangle and ends in saline Lake Abbe. Irrigation, electric power generation, fish production, serving as water source for domestic consumption to the inhabitants dwelling near by the river course as well as for domestic and wild animals of the area are some of the most important services provided by the Awash River water.

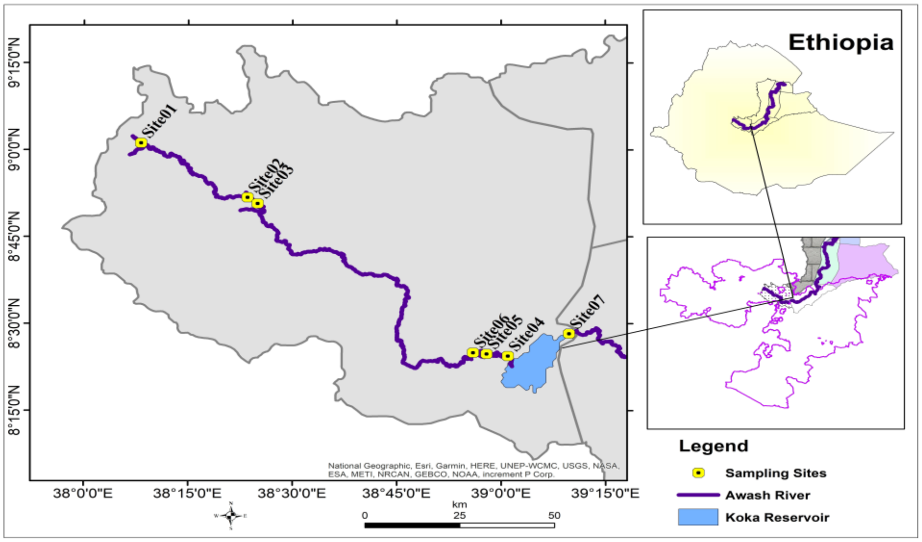

Figure: 3.1 Map of the study area and sampling sites

3.1.1 Description of sampling sites

A total of seven different sites which includes: Yejera Bole (Head water), Yejera Ebu, Awash Bello, Koka Nagawo, Awash Tutie, Guro Ruta, and Sire Robi were established. The sampling sites were characterized as reference or impaired based on physical, chemical, and biological and land-use information. The first sampling site (S1) was located about 80 km west of Addis Ababa, near Ginchi Town. In this sampling site, there was natural vegetation' in the instream and bank of the river. Anthropogenic activities such as farming and grazing, washing clothes and bathing were common during the sampling period. Hence, it was considered as intermediate impacted site for this study. The second and Third sampling sites (S2 and S3) were located about 50 km south-west of Addis Ababa, near Awash Bello town above and below the Awash Bridge, respectively. In the second sampling site the macrophyte community is relatively diverse. Hence it was considered as slightly impacted site in this study. In the third sampling site agricultural activities are intense including river water abstraction for irrigation using motor pumps. The macrophyte diversity is very poor and usually dominated by invasive species in the riparian zone. This sampling site was considered to be highly impacted. The fourth sampling site (S4) was located at 100 km southeast of Addis Ababa, above the bridge of Awash River near Koka town. There are many factories like Ethio tanneries, Mojo oil mill factory which discharge their raw effluent directly into the river. Furthermore abattoir houses and poultry farms were observed in the sub-catchment of the river in this sampling site.

The fifth sampling site (5) was located near to the fourth sampling site in south west direction and the factories that were listed the fourth sampling site traversed through those sampling site. In this sampling site high diversity of macrophytes was noted. The six sampling site (6) *was located at* Awash Tuti Kebele. In this sampling site intense agricultural activities including river water abstraction for irrigation using motor pumps and sand mining activities were taking place. The seventh sampling site (7) was located below Koka dam in Sirie Robi Kebele. The catchment area of this sampling site were highly invaded by invasive species called *Lantana camara* which could be an impact in the diversity of macrophytes in the bank of the river by competing for nutrients which came from the surrounding environment. In this sampling site less diversity of macrophytes was noted due to high flow velocity and sandy sediment texture (personal observation).

Table: 3. 1 Locations of the sampling sites in upper Awash River

No	East	North	Elevation(m)	Sites	Sampling site
1	38^{0}08’13’’	9^{0}09’50”	2337	Yejera Bole	Site01
2	38^{0}23’33’’	8^{0}51’48”	2063	Yejera Ebu	Site02
3	38^{0}24’59’’	8^{0}50’45”	2058	Awash Bello	Site03
4	38^{0}57’33’’	8^{0}27’57”	1589	Koka Nagawo Kebele(Lumie Woreda)	Site04
5	39^{0}00’58’’	8^{0}24’25’	1590	Goro Ruta (Lumie Woreda)	Site05
6	38^{0}56’30’’	8^{0}25’16”	1595	Awash Tuti (Liben Ziquala)	Site06
7	39^{0}09’46’’	8^{0}28’16”	1574	Sirie Robi Kebele	Site07

3.2 Sampling methods and analysis

3.2.1Sampling design

A reconnaissance survey of the Awash River was conducted in October 2019 to identify sampling sites. Sampling sites were selected subjectively following the Braun-Blanquet approach (Westhoff & Van Der Maarel, 1978). Sample surveys were undertaken, during October-December 2019 to February-April 2020 for collection of macrophytes and environmental data. Macrophytes were collected manually from seven sampling sites selected as representative of the Upper Awash River ecosystem (Figure 3.1).

Vegetation stands were analyzed along a 100 m river reach. At least one sampling site is established for each physically homogeneous river reach: the reaches were identified according to a combination of geological background and slope. 10 quadrats (1*1 m^{2}) at every 10 m distance (Gaudet and Muthuri, 1981) were systematically laid at each river reach as a function of the area covered by vegetation. The quadrate size (1*1 m^{2}) was determined by the species curve area method as mentioned in Wheater *et al., (*2011). A total of 70 quadrats 10 for each site were laid during the study period.

Percentage cover values for all macrophytes were estimated and later converted into the modified Braun-Blanquet scale following Van Der Maarel, (1978). Plant specimens were identified in the field using the guide of Gunter *et al.,* (2014), and otherwise specimens were collected and later identified at the National Herbarium (ETH), Department of Biology, Addis Ababa University, using the published volumes of Flora of Ethiopia and Eritrea, (Hedberg & Edwards 1989, Mesfin & Hedberg 1995).

The macrophyte species abundance was surveyed using a five level scale; "Plant Mass Estimate"; 1 – rare, 2 – occasional, 3 – frequent, 4 – abundant, 5 – very abundant (Kohler, 1995). Macrophyte species in each quadrat were counted by hand picking. The relative frequency and relative density of each species were calculated as in the study by Singh *et al.,* (2013) by the following formula:

$$\text{Frequency (\%)} = \frac{\text{No of quadrats in which the species occurs}}{\text{Total number of quadrats studied}} * 100$$

$$\text{Density/Quadrat} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Abundance/quadrat} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occurs.}}$$

$$\text{Relative frequency} = \frac{\text{Frequency of species A}}{\text{Total frequency of all species}} * 100$$

$$\text{Relative density} = \frac{\text{Density of species A}}{\text{Total density of all species}} * 100$$

3.2.2 Surface Water Collection for Physico Chemical Parameters

At each of the sampling site a set of water samples were collected in a pre-cleaned 500ml polyethylene container and transported to the laboratory for further analysis. The physico-chemical parameters that were analyzed are: nitrate, SRP, TP, pH, Temperature measured in °C, Dissolved Oxygen measured in mg/l. Flow velocity measured in m/s using a floating body and a stopwatch (Weber-Oldecop 1969) and Conductivity measured in (µs cm^{-1}). DO, pH, EC and temperature were measured *in situ* using YSI 556 multi-probe system.

The analysis of SRP and nitrate were based on Palintest Phosphate LR method and Palintest Nitratest method ,respectively, whereas TP analysis was done for unfiltered water sample using standard procedures as indicated in APHA *et al.,* (1999), using a spectrophotometer (Jenway 6405 UV) at Addis Ababa Environmental Protection and Green Development Commission

(AAEPGDC). Nitrate and SRP analyses were made immediately after sample collection using water samples filtered through Whatman GF/F.

3.2.3 Sediment analysis

Sediment samples were taken from each study site, for analysis of TP, TN concentration and substrate type (Soil texture) using Ekman grab from approximately 10 cm of the sediment surface. The collected sediment samples were air dried and sieved through a 2 mm sieve. In the process 5 g dry sediment was added to 50 mL 0.002N H_2SO_4 solution in 500 mL Erlenmeyer flask and shaken for 30 minutes with mechanical shaker and filtered through a Whatman No 42 filter paper. Finally, this solution was analyzed according to the methods mentioned in water sample analysis for total phosphorus, (persulfate digestion followed by ascorbic acid method) while for total nitrogen using Kjeldahl method which involves a two-step process. First, the sample was digested with a sulfuric acid to convert organic nitrogen compounds to ammonium ion. Secondly the converted ammonium ion was converted to ammonia in an alkali distillation process. The liberated ammonia in this process was finally quantified for determination of the total nitrogen in the original digest as stated in APHA *et al.* (1999).

3.2.3.1 Particle size analysis (Soil texture)

The substratum types were determined according to Schaumburg *et al.,* (2006) in a semi quantitative way using class scales, to enable a fast and easy field application.

50g of soil is dispensed in a mechanical shaker with 100ml sodium metaphosphate for three hours and the solution is transferred to a mixer cup by washing the bottle very well and brought up to 500ml in the cup and is stirred for 5-minute.The dispersed soil suspension was transferred to a hydrometer jar and adjusted to 1 litter with distilled water. After mixing the suspension shaken by hand for 30 sec, by lowering the hydrometer into the solution the first hydrometer reading is taken at 40 sec. The reading measures the percent of silt and clay (Particles < 50 Microns) in suspension, and when subtracted this percent from all sum percent (100%) the sand percent is obtained.

3.2.5 Determination of water hyacinth coverage

During field survey on both side banks of Awash River, the sites starting from the Koka reservoir water inlet to upper part of Awash basin, which were infested by Water Hyacinth were recorded by using hand held GPS to identify the infestation coverage level by Water Hyacinth.

From field two independent datasets were collected, that is first data set was training points to be used in supervised classification, and the other dataset was ground-truthing points to be employed in evaluating the accuracy of classification during post-classifications. The training dataset was 20 points, whereas the ground truthing locations were 51 points. To perform supervised classification, clustering pixels in the image into classes corresponding to user-defined training classes based on the training dataset collected during field survey.

To map the Water hyacinth coverage on the river, based on GPS points the width of the river was digitized from Imagery, and area of the Water Hyacinth was determined from the Landsat8 of OIL imagery of date 07/03/2020 path 168 and row 054, which was downloaded from http:// earthexplorer.usgs.gov/. The image was classified using supervised classification approach in the ERDASIMAGINE 2015 software, and the same software used for accuracy assessment.

3.3 Data analysis

The collected data were analyzed by using R-software version 3.6.2 (2019-12-12). A descriptive statistical method was employed to analyze and summarize the data and to calculate percentages, frequency and mean.

The inferential statistical method was also employed to perform canonical correspondence analysis.

The relationship between macrophyte species abundance and environmental variables was evaluated by CCA using R- software version 3.6.2 (2019-12-12). It was used as the species data showed a unimodal response to the environmental variables, the segments were more than four in the data set and clear and strong hypothesis on constraints or involving deductive reasoning from a general principle to a necessary effect according to (Kent and Coker, (1992).

Macrophyte species diversity in the River was computed using Shannon- Weiner Diversity Index following Shannon and Weiner (1963) using the following formula:

$H' = - \Sigma \text{ pi ln pi}$

$E = \frac{H'}{Hmax} = \frac{H'}{\ln S}$ Where: H` = the value of Shannon diversity index, Pi = the proportion abundance of the ith species (n/N),

ni is the number of individuals in the ith species

N = total Number of organisms in each species

ln = natural logarithm of pi, E = evenness, Hmax = the maximum diversity of a sample, S = the number of species in the community.

The dominance of macrophyte species in the river was computed using Simpson index following Magurran, (2004) using the following formula:

$$D = \frac{\Sigma\, n(n-1)}{N(N-1)}$$

Where:

D = Simpson index

n = the total number of organisms of a particular species

N = the total number of organisms of all species

The coverage and distribution of the invasive water hyacinth was done by ERDAS Imagine (Earth Resource Data Analysis System) software, version 16.5 and ARCGIS (Aeronautical Reconnaissance Coverage Geographic Information System) software, version 10.7.

4. Results

4.1 Macrophyte species composition and structure

Data on species composition revealed that there were a total of twenty six macrophytes species which belonged to fifteen families and nine invasive plant species in the riparian zone which belonged to five families. The relative frequency, density, occurrence and percentage of coverage of the macrophyte species identified are shown in Tables 4.1 &4.2, respectively, below.

One of the macrophyte is free floating (water hyacinth), one is floating rooted (*Ipomoae aquatica*) and the rest are emergent. Emergent macrophytes have the highest percentage composition (92 %) and the lowest percentages (8 %) were contributed by floating rooted (4%) and (4%) free floating species. All the sites were dominated by emergent macrophytes that attained the highest relative density and frequency followed by floating rooted and free floating species. The relative density of macrophytes in the sampling sites of the Awash River shown in Table 4.2 indicated that *Cyperus latifolius* had the highest relative density recorded in site 1 34.79% and *Cyperus papyrus* had the second highest relative density in site 1 alone. *Persicaria senegalensis* recorded the highest relative density value of 54.75% in site 2 and the least 8.43 on site 3. *Eichhornia crassipes* is found only in two sites, *which* had the highest relative density value 31.36% in site 4 and 19.61% in site 5.The highest relative density of *Cynodon dactylon* 57.83% was recorded on site 3 and the least 1.14% in site 4. *Ipoma aquatica* which is found in sites 2, 4 and 5. The highest relative density value recorded 20.5% in site 2 whereas *Panicum maximum Jacq* which is found on similar sites in *Ipoma aquatica* and the highest relative density value recorded 17.52% in site 4 and the least recorded 4.58% in site 2.

Table 4.1 Macrophyte species identified and their relative frequency and relative density in the Upper Awash River

Species	**Family**	**Life form**	**Relative frequency (%)**	**Relative density (%)**
Acorus calamus	*Acoraceae*	Emergent	3.6	1.95
Alternanthera sessilis L.	*Amaranthaceae*	Emergent	3.6	0.68
Brachiaria mutica	*Poaceae*	Emergent	1.8	0.5
Brachiaria sp.	*Poaceae*	Emergent	7.1	5.36
Cynodon dactylon	*Poaceae*	Emergent	8.9	4.15
Cyperus articulatus L.	*Cyperaceae*	Emergent	3.6	5.96
Cyperus latifolius Poir	*Ceratophyllaceae*	Emergent	1.8	9.29
Cyperus papyrus L.	*Cyperaceae*	Emergent	1.8	6.76
Echinochloa colona L.	*Poaceae*	Emergent	7.1	0.92
Echinochloa stagnina	*Poaceae*	Emergent	3.6	2.05
Eichhornia crassipes	*Pontederiaceae*	Floating	3.6	13.20
Ipomoea aquatica	*Convolvulaceae*	Floating	5.4	6.81
Juncus effuses	*Juncaceae*	Emergent	1.8	0.27
Lagarosiphon cordofanus	*Hydrocharitaceae*	Emergent	1.8	0.36
Leersia hexandra	*Poaceae*	Emergent	5.4	2.39
Ludwigia abyssinica A. R	*Onagraceae*	Emergent	1.8	0.05
Ludwigia erecta L.	*Onagraceae*	Emergent	1.8	0.75
Ludwigia spp.	*Onagraceae*	Emergent	3.6	0.27
Panicum maximum Jacq	*Poaceae*	Emergent	5.4	7.84
Persicaria senegalensis	*Polygonaceae*	Emergent	7.1	22.44

Phragmites mauritianus	*Poaceae*	Emergent	5.4	4.18
Rorripa nastrutium aquatic	*Brassicaceae*	Emergent	1.8	0.84
Scripus articulatus L.	*Cyperaceae*	Emergent	1.8	0.22
Sida schimperiana Hochst.	*Malvaaceae*	Emergent	3.6	0.5
Solanum incanum L.	*Solanaceae*	Emergent	1.8	0.56
Sphaeranthus bullatus Mat	*Asteraceae*	Emergent	5.4	1.69

Table: 4.2 Occurrence and percentage coverage of macrophyte species in the Upper Awash River Basin, Ethiopia

No	Species	Sites						
		Yb	Ye	Ab	Ko	Gr	At	Sr
1	*Acorus calamus*	-	-	-	-	-	14.42	24.34
2	*Alternanthera sessilis L.*	1.15	3.05	-	-		-	-
3	*Brachiaria mutica*	2.30	-	-	-		-	-
4	*Brachiaria sp.*	5.75	4.75	-	-	1.38	-	46.82
5	*Cynodon dactylon*	5.3	1.86	57.83	1.16	-	-	20.22
6	*Cyperus articulatus L.*	-	-	-	10.35	11.83	-	-
7	*Cyperus latifolius Poir*	43.79	-	-	-	-	-	-
8	*Cyperus papyrus L.*	31.84	-	-	-	-	-	-
9	*Echinochloa colona L.*	-	1.69	-	-	0.49	8.65	4.87
10	*Echinochloa stagnina*	2.88	-	-	6.23	-	-	-
11	*Eichhornia crassipes*	-	-	-	31.36	19.61	-	-
12	*Ipomoea aquatica*	-	20.51	-	6.86	7.54	-	-
13	*Juncus effuses*	1.27	-	-	-	-	-	-
14	*Lagarosiphon cordofanus*	1.72	-	-	-	-	-	-
15	*Leersia hexandra*	-	-	33.73	-	1.70	47.12	-
16	*Ludwigia abyssinica A.*	0.23	-	-	-	-	-	-
17	*Ludwigia erecta L.*	-	-	-	-	-	29.81	-
18	*Ludwigia spp.*	0.34	1.36	-	-	-	-	-
19	*Panicum maximum Jacq*	-	4.58	-	17.52	10.37	-	-
20	*Persicaria senegalensis*	-	54.75	8.43	24.92	28.69	-	-
21	*Phragmites mauritianus Ku*	-	-	-	1.59	11.83	-	3.75
22	*Rorripa nastrutium aquatic*	-	5.76	-	-	-	-	-
23	*Scripus articulatus L.*	1.03	-	-	-	-	-	-
24	*Sida schimperiana Hochst.*	1.38	1.36	-	-	-	-	-
25	*Solanum incanum L.*	-	-	-	-	1.86	-	-

26	*Sphaeranthus bullatus Mat*	1.02	0.34	-	-	-	-	-

Note: Abbreviations for sites: Ab: Yegera Bole; Ye: Yegera Ebu; Ab: Awash Bello; KO: koka; Gr: Guro Ruta; At: Awash Tuti; Sr: Sira Robi.

Table: 4.3 Aquatic macrophyte species scientific names and their rating in each study site in Upper Awash River, Ethiopia.

Species name	Sites						
	1	2	3	4	5	6	7
Acorus calamus						A	VA
Alternanthera sessilis L.		A					
Brachiaria mutica	R						
Brachiaria sp.	A	O					
Cynodon dactylon	O	R	A	R			O
Cyperus articulatus L.				VA	VA		
Cyperus latifolius Poir	VA						
Cyperus papyrus L.	VA						
Echinochloa colona L.		R			R	F	R
Echinochloa stagnina	R			R			
Eichhornia crassipes				VA	A		
Ipomoea aquatica		O		A	A		
Juncus effuses	O						
Lagarosiphon cordofanus	R						
Leersia hexandra			F		R	VA	
Ludwigia abyssinica A. R	R						
Ludwigia erecta L.						F	
Ludwigia spp.	R	R					
Panicum maximum Jacq		R		A	F		
Persicaria senegalensis		F	R	VA	VA		
Phragmites mauritianus				F	A		
Rorripa nastrutium aquatic		R					
Scripus articulatus L.	R						
Sida schimperiana Hochst.	R	R					
Solanum incanum L.					R		
Sphaeranthus bullatus Mat	R	R					

Note: **A = Abundant; O = Occasional; R = Rare and VA = very Abundant and F = frequent**

Table: 4.4 List of invasive species in the riparian zone of Awash River

No	Species	Family	Local name	Habitat
1	*Xanthium strumarium* L.	*Asteraceae*		Herb
2	*Argemone ochroleuca*	*Papaveraceae*	Nech lebashe	Herb
3	*Cirsium dender*	*Asteraceae*	Dander	Herb
4	*Cirsium vulgare*	*Asteraceae*	Yahya esho	Herb
5	*Datura stramonium L.*	*Solanaceae*	Ate faris	Herb
6	*Lantana camara*	*Verbenaceae*	Yewof kolo	Shrub
7	*Parthenium hystrophorus*	*Asteraceae*	Qenchee	Herb
8	*Xanthium spinosum*	*Asteraceae*	Yesat mlas	Herb
9	*Amaranthus graecizans*	*Amaranthaceae*	Aluma	Herb

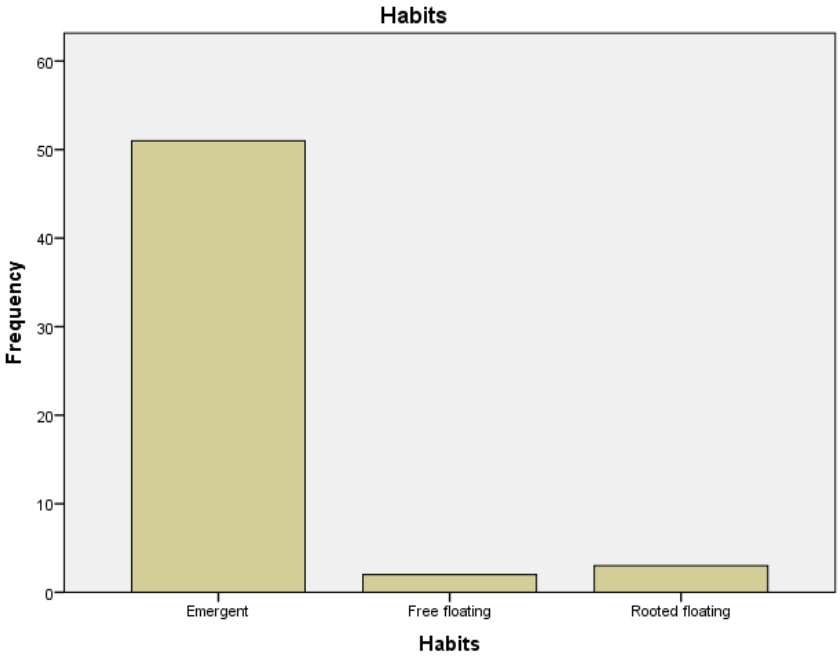

Figure: 4.1 Frequency of macrophyte life form classes to the total macrophyte counts in the bank of Awash River

All the sites were dominated by emergent macrophytes that attained the highest relative frequency and density, followed by rooted floating and free floating species. Comparatively; the most frequent species recorded in the river were *Cynodon dactylon (8.9%), Brachiaria sp, Echinochloa colona L.* and *Persicaria senegalensis* each accounting (7.1%) and *Ipomoea aquatica, Leersia hexandra, Sphaeranthus bullatus, Panicum maximum Jacq* and *Phragmites mauritianus* each accounting (5.4%). The remaining species account less than 5% frequency of occurrence. The highest density was recorded by *Persicaria senegalensis* (22.44%), *Eichhornia crassipes* (13.20%), *Cyperus latifolius Poir* (9.29%), *Panicum maximum Jacq* (7.84%), *Ipoma aquatica (6.81%), Cyperus papyrus* (6.76%), *Cyperus articulates* (5.96%), *and Brachiaria sp.* (5.36%) *followed by Cynodon dactylon (*4.15%) and Phragmites *mauritianus* (4.18%). The remaining species account for less than 4% of coverage. Macrophytes were characterized by the dominance of taxa belonging to the families. The *Poaceae* family had the highest number of species (30.7%).Two families (*Onagraceae* and *Cyperaceae*) had three species (11.54%) each followed by *Amaranthaceae, Asteraceae, Polygonaceae, Pontederiaceae, Convolvulaceae, Solanaceae, Acoraceae, Juncaceae, Ceratophyllaceae, Brassicaceae, Hydrocharitaceae* and *Malvaaceae*) had only one species (3.85 %) each. However, there were no significant differences in the abundance of macrophytes between the two sampling seasons (t-test p-value= 0.33675 which is > 0.05).

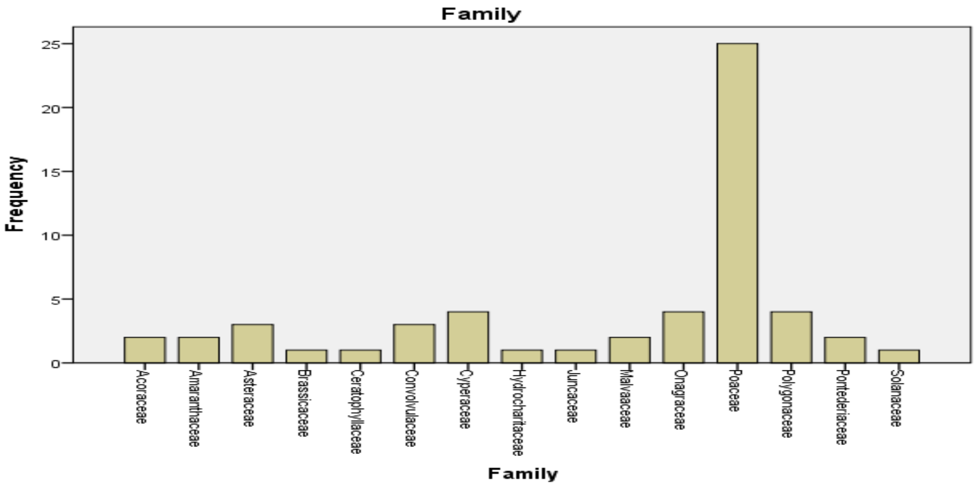

Figure: 4.2 Frequency of macrophyte family classes in the Awash River

The mean macrophyte species diversity of Awash River had H′ value of 2.56 (Table 4.5). In Yejera Bole (head water) there were high diversity of macrophytes and low evenness value compared with other sites in the study area (Table: 4.4). The decrease of evenness in site 1 is due to the increase in dominant species of *Cyperus papyrus* and *Cyperus latifolius*. Species diversity is clearly related to species richness and evenness. Species richness, diversity and evenness can therefore be used as indicators of restoration. The seasonal macrophyte species diversity also showed certain variations. It follows the order: post rainy with H′ value of 2.59 > dry with H′ value of 2.52 (Table 4.6).

Table: 4.5 Spatial variations of diversity indices of macrophytes in the Upper Awash River.

Sampling site	**No. of Species**	**H' valve**	**Margalef's index value**	**Simpson index value**	**Evenness value**
Yb	14	1.59	1.86	0.7	0.36
Ye	11	1.45	1.5	0.65	0.40
Ab	3	0.89	0.45	0.54	0.81
Ko	8	1.62	0.96	0.76	0.68
Gr	11	1.93	1.36	0.82	0.655
At	4	1.21	0.65	0.66	0.84
Sr	5	1.27	0.725	0.67	0.71

Table: 4.6 Temporal changes in diversity indices of macrophytes in the Upper Awash River.

Parameter	**Post rainy**	**Dry**
H' valve	**2.59**	2.52
Margalef's index value	**3.01**	2.81
Simpson index value	**0.89**	0.89
Evenness value	**0.51**	0.52

Margalef's index values were disproportionate along the sampling sites fluctuating between 0.45(Site 3) and 1.86 (Site 1). Site 4 had a maximum value of Shannon's index (1.93) and a minimum at Site 3 (0.89). Simpson's value was highest at Site 5 (0.82) followed by Site 4 (0.76) and least at Site 3 (0.54). The species evenness ranged from 0.84 (Site 6) to 0.36 (Site 1) in the study area.

4.2 Physicochemical parameters in the study sites

Spatial variation of environmental factors investigated was listed in Tables 4.6 and 4.7. High variations of environmental factors among sites were observed for all parameters. The mean values ranged between 4.38 – 7.84mg/l for dissolved oxygen, 340.3 – 488.10 µs/cm for electrical conductivity, 0.0 - 29.73 mg/l for nitrate, 7.20 – 8.08 for PH, 376.45 – 2540.30 mg/l total nitrogen, 0.0 – 8.72 for mg/l for soluble reactive phosphate, 2.520 – 120.2 mg/l for total phosphorus, 0.0 -7.63 mg/l for total phosphorus in water, 0.0 – 0.36 m/s for flow velocity, 2.25 – 46.1m for width, 23.21 – 25.5 ^{0}C for temperature, 1.4 – 41.3% for clay, 3.6 – 56.1% for silt, 10.3 – 83.1% for sand, respectively.

The study showed certain temporal variation in environmental factors. The mean concentration of dissolved oxygen, total phosphorus, total nitrogen, Flow velocity, nitrate and soluble reactive phosphate were higher during post rainy season than dry season. Whereas the mean pH value and water surface temperature were lower in the post rainy season than dry season, but the variations were not significant (Two sample t test p-value = 0.9874 which is > 0.05%).

Table: 4.7 Mean and standard error values of environmental factors of the seven study sites (N= 70)

Sites	DO	EC	NO3	SRP	pH	TN	TP	TPW	FV	W	Tm	Clay	Silt	Sand
Yb	7.84 ± 0.003	340.3 ± 0.13	3.80 ± 0.08	0.00 ± 0.00	7.66 ± 0.14	2540.30 ± 0.46	120.2 ± 0.19	0.04 ± 0.27	0.00 ± 0.00	2.25 ± 0.8	23.21± 0.52	8.40 ± 022	54.40 ± 0.34	37.20 ± 0.36
Ye	6.83 ± 0.4	316.62 ± 29.97	3.65 ± 0.16	0.00 ± 0.00	7.89 ± 0.28	1420.60 ± 2.83	105.1 ± 3.34	0.00 ± 0.00	0.22 ± 0.08	5.20 ± 0.66	23.45 ± 0.23	9.1 ± 0.38	29.90 ± 0.46	61.00 ± 0.71
Ab	5.9 ± 0.8	338.30 ± 0.34	0.00 ± 0.00	0.00 ± 0.00	8.08 ± 0.04	1219.20 ± 4.20	2.520 ± 0.16	0.00 ± 0.00	0.33 ± 0.01	6.20 ± 0.39	24.13 ± 0.17	1.40 ± 0.16	27.30 ± 0.26	71.30 ± 0.40
Ko	4.38 ± 0.12	488.10 ± 1.74	18.20 ± 0.17	8.72 ± 0.23	8.06 ± 0.06	1556.15 ± 11.0	1250.6 ± 2.35	7.63 ± 0.32	0.17 ± 0.01	39.30 ± 0.34	24.87 ± 0.36	1.80 ± 0.25	56.10 ± 0.35	42.10 ± 0.31
Gr	4.72 ± 0.25	338.40 ± 2.27	29.73 ± 0.48	8.56 ± 0.23	7.71 ± 0.19	1899.29 ± 35.27	1273.6 ± 8.49	6.14 ± 0.23	0.15 ± 0.008	33.20 ± 0.90	24.55 ± 0.28	41.3 ± 0.42	48.40 ± 0.64	10.30 ± 0.65
At	5.65 ± 0.9	425.72 ± 0.48	5.21 ± 0.07	0.00 ± 0.00	8.08 ± 0.03	1135.25 ± 7.36	61.29 ± 1.08	6.06 ± 0.22	0.30 ± 0.00	8.35 ± 0.25	24.76 ± 0.10	29.7 ± 0.3	19.40 ± 0.52	50.90 ± 0.78
Sr	5.79 ± 1.04	310.95 ± 2.15	8.24 ± 0.16	0.82 ± 0.16	7.20 ± 0.17	376.45 ± 180.51	319.51 ± 3.61	3.89 ± 0.19	0.36 ± 0.01	41.6 ± 0.62	25.50 ± 0.24	13.3 ± 0.54	3.60 ± 0.45	83.10 ± 0.96

Table: 4.8 Mean and standard deviation values of environmental factors of the seven study sites (N = 70)

sites	DO	EC	NO3	SRP	pH	TN	TP	TPW	FV	W	Tm	Clay	Silt	Sand
Yb	7.84 ± 0.01	340.3 ± 0.41	3.80 ± 0.26	0.00 ± 0.00	7.66 ± 0.43	2540.30 ± 1.47	120.20 ± 0.58	0.04 ± 0.86	0.00 ± 0.00	2.25 ± 0.25	23.21 ± 0.17	8.40 ± 0.7	54.4 ± 1.07	37.2 ± 1.14
Ye	6.83 ± 0.13	316.62 ± 94.77	3.65 ± 0.05	0.00 ± 0.00	7.89 ± 0.09	1420.60 ± 8.93	105.1 ± 10.58	0.00 ± 0.00	0.22 ± 0.03	5.20 ± 2.09	23.45 ± 0.74	9.10 ± 1.2	29.9 ± 1.45	61.0 ± 2.26
Ab	5.90 ± 0.27	338.30 ± 1.06	0.00 ± 0.00	0.00 ± 0.00	8.08 ± 0.13	1219.20 ± 13.28	2.520 ± 0.49	0.00 ± 0.00	0.33 ± 0.04	6.20 ± 1.23	24.13 ± 0.53	1.40 ± 0.52	27.3 ± 0.82	71.3 ± 1.25
Ko	4.38 ± 0.33	488.10 ± 5.49	18.2 ± 0.17	8.72 ± 0.73	8.06 ± 0.19	1556.15 ± 34.77	1250.6 ± 7.44	7.63 ± 1.01	0.17 ± 0.03	39.3± 1.09	24.87 ± 1.12	1.80 ± 0.79	56.1± 1.10	42.1± 0.99
Gr	4.72 ± 0.79	338.40 ± 7.17	29.7 ± 1.50	8.56 ± 0.74	7.71 ± 0.60	1899.29 ± 111.55	1273.6 ± 26.86	6.14 ± 0.72	0.15 ± 0.03	33.2 ± 2.86	24.55 ± 0.87	41.3 ± 1.34	48.4 ± 2.01	10.3 ± 2.06
At	5.65 ± 0.28	425.72 ± 1.53	5.21 ± 0.22	0.00 ± 0.00	8.08 ± 0.10	1135.25 ± 23.28	61.29 ± 3.42	6.06 ± 0.69	0.30 ± 0.01	8.35 ± 0.78	24.76 ± 0.32	29.7 ± 1.06	19.4 ± 1.65	50.9 ± 2.47
Sr	5.79 ±	310.95 ± 6.80	8.24 ± 0.49	0.82 ± 1.83	7.20 ± 0.55	376.45 ± 570.85	319.51 ± 11.42	3.89 ± 0.59	0.36 ± 0.04	41.6 ± 1.96	25.50 ± 0.74	13.3± 170	3.60 ± 1.43	83.1 ± 3.03

4.3 Relationship between environmental factors and density of macrophyte species

The results of Canonical Correspondence Analysis (CCA) between environmental factors and macrophyte data showed the first two axis have made up 50.39% of the cumulative percentage of variance in species–environmental factor relationship (Table: 4.8). The first axis, which contributed 27.39% of the variance, were positively correlated with TPW, W, NO$_3$ and SRP and the second axis with DO and TN.

The coverage of *Cyperus articulatus L., Echinochloa colona L., Solanum incanum L., Eichhornia crassipes, Persicaria senegalensis, Rorripa nasturtium aquaticum, Ipomoea aquatica* and *Phragmites mauritianus* was positively correlated with TPW,W,NO$_3$, SRP and TP of the first axis, whereas the coverage of other species had negative association with those physicochemical parameters (Fig: 4.3). Especially, the coverage of those plants had a strong positive correlation with TPW, NO$_3$, SRP and W. In contrast the coverage of those plants had a weak positive association with Clay, EC, TO and pH. On the other hand the coverage of *Sphaeranthus bullatus, Ludwigia spp., Sida schimperiana, Alternanthera sessilis, Lagarosiphon cordofanus Casp, Brachiaria mutica, Juncus effuses, Ludwigia abyssinica, Cyperus latifolius,* and *Cyperus papyrus* L., was positively correlated with DO,TN and Silt. Moreover, the coverage of *Cynodon* *dactylon, Leersia hexandra, Acorus calamus* and *Brachiaria* sp, had non- linear association with almost all physicochemical parameters (Fig: 4.3).

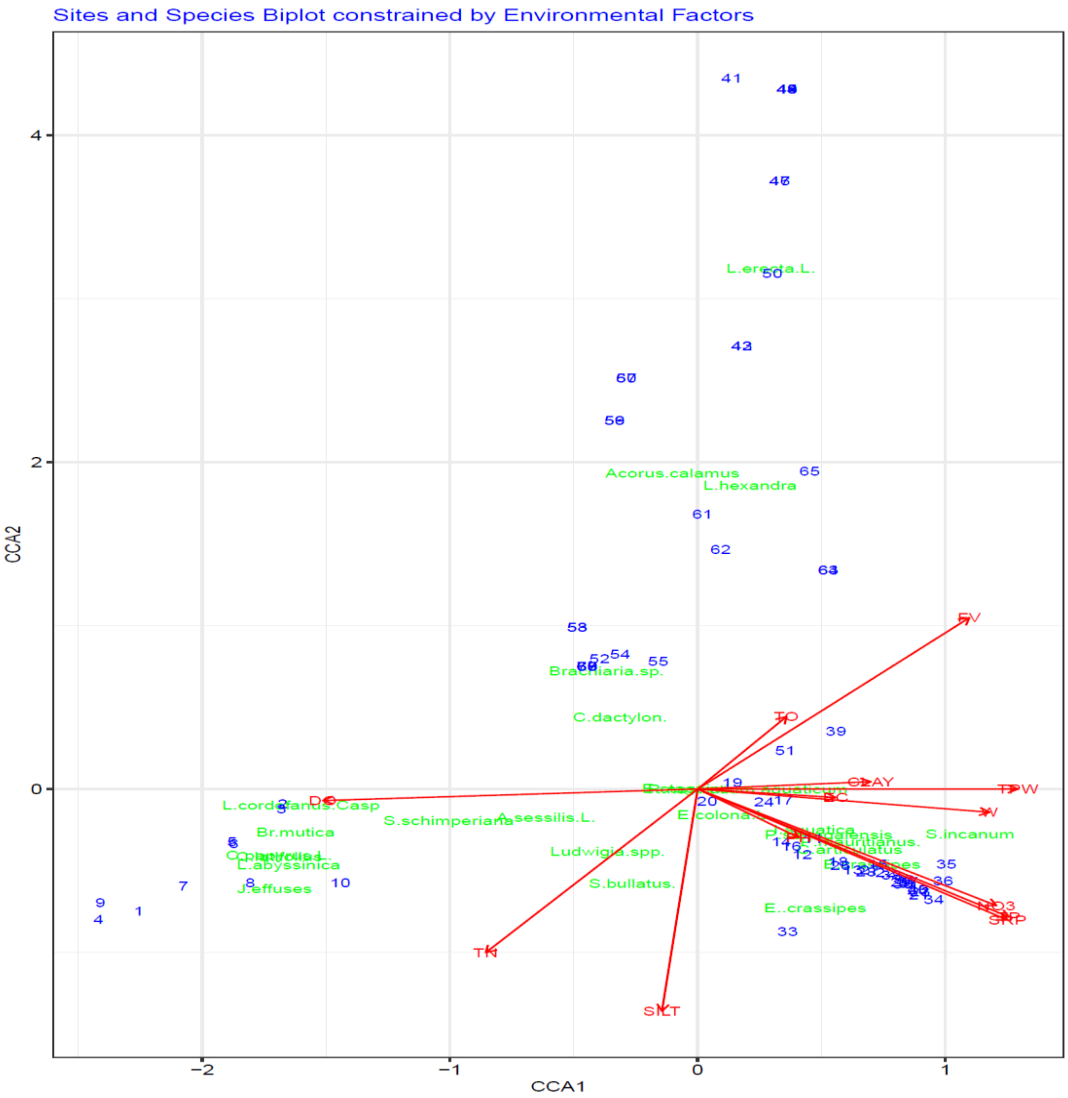

Figure: 4.3 Plot of the first two axis of the Canonical Correspondence Analysis (CCA) for macrophyte species and environmental variables. (Abbreviations: *E.crassipes: Eichhornia crassipes; C. dactylon: Cynodon dactylon; S.bullatus: Sphaeranthus bullatus; S.incanum: Solanum incanum L; J. effuses: Juncus effuses; L. abyssinica: Ludwigia abyssinica; L. cordofanus Casp: Lagarosiphon cordofanus Casp; B. mutica: Brachiaria mutica; S.schimperiana: Sida schimperiana; C. latifolius: Cyperus latifolius; C.papyrus L: Cyperus papyrus L.; A. sessilis: Alternanthera sessilis, P.mauritianus: Phragmites mauritianus; E. colona*

L: Echinochloa colona L; C. articulatus L: Cyperus articulatus L; C. articulatus L: Cyperus articulatus L.

Table: 4.9 Eigenvalues, cumulative percentage variance of species-environment relation, and correlation coefficient/ Biplot scores of physico-chemical variables with the first two axes in Awash River (strong correlations are marked bold at $p< 0.05$)

Parameters	Axis 1	Axis 2
Eigenvalues:	0.7593	0.6374
Cumulative percentage of variance of species data	27.39	23.00
DO	-0.822	$-3.8e^{-02}$
EC	0.303	$-2.8e^{-02}$
NO3	**0.655**	$-3.9e^{-01}$
SRP	**0.680**	$-4.4e^{-01}$
TN	0.465	$5.4e^{-01}$
TP	**0.683**	$-4.3e^{-01}$
TPW	**0.703**	$8.2e^{-05}$
FV	-0.596	$-5.7e^{-01}$
W	0.641	$-7.8e^{-02}$
SILT	-0.078	$-7.4e^{-01}$

Note Temperature and Clay are **not** significant P values>0.005

4.4 Percentage coverage of water hyacinth in Awash River

The result categorized 3 groups, mainly as water body/ water of the river, Water hyacinth that was covered 100% by Water hyacinth only, and Mixed which contains few water hyacinth but dominated by other plant species. Water hyacinth infested area of Awash River was mapped and reported as indicated in Table 4.9 and Figure 4.5. The total area of the river covered with water hyacinth was 10.19ha and mixed 16.54 ha for the infested area only.

Table: 4.10 Area coverage of water hyacinth in hectare

No	Classes	Area(ha)
1	Water Body	13.96
2	Mixed(Water Hyacinth and other species)	16.54
3	Water Hyacinth	10.19

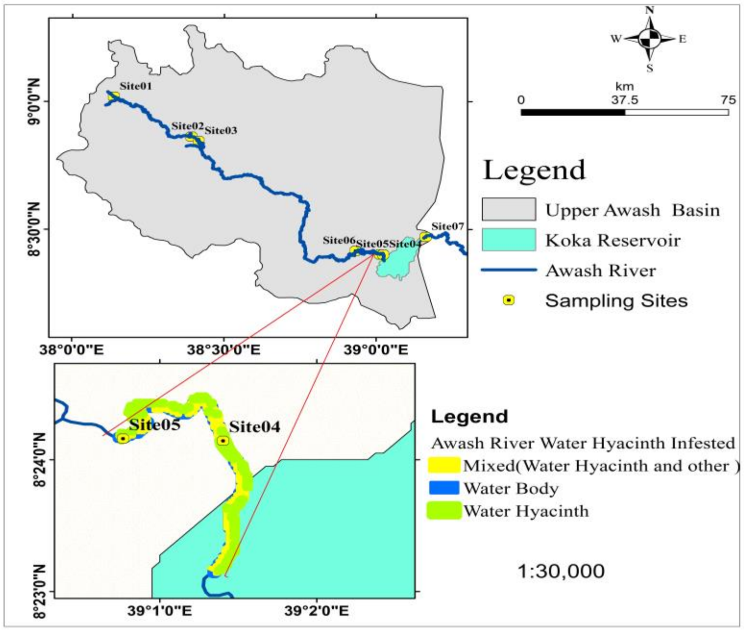

Figure: 4.4 Map of water hyacinth coverage in Awash River

The overall classification accuracy of the infested area was 90.20% and the overall Kappa statistics were 0.85. Both met the recommended value suggested by Janssen *et al.* (1994).

5. Discussion

5.1 Macrophyte abundance and distribution

Ethiopian rivers, like other tropical rivers, are endowed with diverse populations of riparian vegetation which vary in nature, density, types and functions according to locations. Those encountered in this study were similar or vary from those reported elsewhere in both lotic and lentic systems globally. Aquatic macrophyte species composition assessment in the Awash River revealed that there were 26 species which belonged to 15 families. Similar or less numbers of macrophyte species were documented from other studies. Daddy *et al*., (1993) reported 13 families and 31 species in the herbarium of Kainji and Jebba Lakes in Nigeria, Roger *et al*., (2010) recorded 37 species and 34 families in Brazil; Ekpo *et al*., (2014) identified 33 families and 98 species of macrophyte in Odot river, Nigeria while Dienye (2015) noted that there were 10 families of macrophytes representing 12 species in the New Calabar River, among others. The family *Poaceae* had the highest number of species, while *Onagraceae* and *Cyperaceae* had the second in this study. This result is in consonance with the report of Dienye (2005). Seasonal variations of aquatic macrophyte species diversity followed the order: post rainy season greater than dry season (Table 4.5), although the variation was not significant (t-test, p-value = 0.2406 which is > 0.05). One species in *Poaceae* family was completely absent during the dry season. This result is comparable with the work of Ekpo et al., (2016) who found 15 families of macrophytes representing 19 species in Odot River Nigeria. Also, Ali and Kushi (2001) reported that Poaceae and Cyperaceae were most represented with 19 and 13 species in the post rainy season and 9 and 6 in the dry season respectively. Some terrestrial plant species also occur in the aquatic environment. This may probably be due to dispersal by wind and other agents or the fact that both ecosystems have similar factors required by such plants. Depending on the season, some of these plants had flowers and seeds of diverse types (Ekpo *et al.,* 2011). Terrestrial alien invasive plant species also exist in the bank of Awash River, especially *Lantana camara*, *Argemone ochroleuca* and *Xanthium spinosum* have highly invaded/infested the study area. Among the sampling sites Yejera Bole site is the only site that is not infested/invaded by alien invasive plant species (Personal observation).

High number of individual macrophyte species were recorded during post rainy season than the dry season, which might be due to different factors such as lack of precipitation and human utilization in dry season. The work of Ayalew Wondie (2006) also described that macrophytes are more common in the post rainy season because of the absence of human interference due to the high volume of water and flood condition. The absence of significant differences in density and species composition of macrophytes in Awash River could be due to the absence of significant variation between post rainy and dry seasons in environmental factors that determine the abundance of macrophytes, and this result is contrary to the work of Pompeo and Moschini-

Carlos, (1996). In their study, there were significant difference in density of macrophytes in Mogi Guacu River due to seasonal variations of temperature and rainfall.

5.2 Macrophyte species diversity in Awash River

The highest macrophyte species diversity index (H′) and evenness index values among the seven sampling sites in the Guro Ruta site was with H′ value of 1.96 and Awash Tuti site had highest evenness index value of 0.84 and Koka site with H′ value of 1.72 and with evenness index value of 0.70. Yejera Bole and Yejera Ebu sites were with medium anthropogenic impacts not threatened by industrial and urban expansions and expected to have high diversity of species and low evenness value compared with other sites in the study area (Table: 4.4). The decreases of evenness are due to the increase in dominant species of *Cyprus papyrus*, *Cyprus latifolius and persicaria senegalensis,* respectively. These lower evenness values indicate the sites need restoration. Lower diversity index (H ′) value of 0.89, 1.21, 1.29, were observed in Awash Bello, Awash Tuti and Sirie Robi sampling sites, respectively. Higher anthropogenic impacts are expected to cause a decrease in species diversity and composition and the mean value of sediment texture 71.3%, 50.9% and 83.1% were sandy, respectively. The findings of this study conform to the intermediate disturbance hypothesis (Ward and Stanford 1983) which postulates that biodiversity is greatest in habitats with intermediate level of disturbance as compared with habitats with low levels and high levels of disturbance; In view of the bank of the upper Awash River, the head water and Yejera Ebu reaches might be with intermediate disturbance reaches, whereas other site reaches could be with high level of disturbance (Personal observation).

Among the sampling sites Koka Nagawo and Guro Ruta sites are highly invaded by water hyacinth. This has an impact on the diversity of macrophytes and other aquatic organisms. However, some macrophytes species from Cyperaceae and Poaceae family were observed to share the same niche with Water hyacinth.

The macrophyte species diversity of Awash River is low compared with some published data of similar works on tropical and temperate Rivers (e.g. Biswas *et al.,* 2015; Ekpo *et al.,* 2016). In their work of bio monitoring Macrophytes Diversity and Abundance in Ganga River, India and abundance, distribution and biotic indices of aquatic macrophyte community in Odot River, Niger obtained Shannon diversity index (H’) value of 2.74 and 2.64, respectively. But the value obtained in Awash River was higher than that of Wel river, Poland with Shannon diversity index (H’) value of 0.74 (Szoskiewicz *et al.,* 2014). Mechore *et al.,* (2010) reported that homogeneity of habitats favored lower diversity of macrophytes in water courses of Bloscica and Cerkniscica (Slovenia).

5.3 Influence of environmental variables on macrophyte abundance

Environmental drivers that influence macrophyte distribution in rivers and streams are similar across the world (Johnson and Hering, 2009). Several studies have shown that distribution and composition of macrophytes in river is a result of the interactions of several environmental variables, including abiotic, biotic and anthropogenic factors (Rolon and Maltchik, 2006). In this study 50% of the explained variations in macrophyte diversity were due to concentration of nutrients (N &P),SRP, soil texture and flow velocity (Fig 4.4) and half of the unexplained variation in macrophyte diversity could be due to the influence of human and livestock activities on the river bank and riparian agricultural activities. Crosbie and Chow-Fraser (1999) found that wetlands in agro-dominant catchments contain more fine grain soil particles (silt and clay) which tend to bind to the nutrients.

Among the study sites Koka site and Guro Ruta site were characterized by having higher nitrate, soluble reactive phosphate, and sediment and water total phosphorus. However *Cyperus articulatus, Persicaria senegalensis, Ipomoea aquatica, Panicum maximum Jacq, Phragmites mauritianus* were found in nutrient rich sites whereas *Echinochloa colona was* found on both nutrient rich and poor sites (Table 4.2). The occurrence of this macrophyte in the river seems not to be affected by differences in the nutrient condition among sites, and ability to colonize these varied sites indicates its potential to adapt to diverse trophic conditions (Girum Tamire and Seyoum Mengistou, 2012). On the other hand, *Cyperus articulatus* was restricted to sites where there was higher nutrient concentration, which suggests that this species needs high nutrient levels. Similarly, the abundance of *Eichhornia crassipes* was positively correlated with total phosphorus, soluble reactive phosphate and nitrate.

During the study period *Eichhornia crassipes* was observed starting from Lake Koka up to Guro Ruta site near to the new highway of Hawassa Bridge, the site closest to many factories like Ethio tanneries, Mojo oil mill factory which discharge their raw effluent directly into the river. Furthermore abattoir houses and poultry farms were observed in the sub-catchment of the river in this sampling site. *Cyperus papyrus* and *Cyperus latifolius* were observed in relatively low nitrate, sediment phosphorus and very low soluble reactive phosphate sites. Similar observations of the negative effects of increase pH, SRP and TP on *Cyperus papyrus*, *Echinochloa stagnina* was noted in some studies in the Ethiopian rift valley lakes (e.g. Girum Tamire and Seyoum Mengistu, 2012).

The result indicated that the increase in pH, soluble reactive phosphate and TP could significantly and negatively affect the density of *Brachiaria* species, *Ludwigia abyssinica* and *Leersia hexandra* (fig 4.10). Similar observations of negative effects of increase pH, soluble reactive phosphate and TP on the density of *Leersia hexandra*, *Nymphaea lotus*, *Phragmites karka* and *Ipomoea aquatica* and *Ludwigia abysinica* were found in both nutrient-rich and nutrient-poor sites, as noted in some studies in Lake Tana (Yezbie Kassa, 2016 unpublished data). *Ipomoea aquatica* was found in Koka and Gro Ruta sampling sites which had high concentration of TP, SRP and Nitrate. Yezbie Kassa, (2016) noted that *Ipomoea aquatica* have the ability to colonize varied sites which indicates their potential to adapt diverse trophic conditions.

Total composition and abundance of macrophyte communities in Awash River was positively correlated with sediment nutrient (total nitrogen ($r = 0.5$) and total phosphorus ($r = 0.58$) and inversely (negatively) correlated to flow velocity ($r = - 0.59$) and sandy sediment ($r = - 0.4$) may relate to the observation that finer sediments tend to have higher nutrient (e.g. nitrogen and phosphorus content) than coarser sediments. The observation that the flow velocity is one of environmental factors affecting composition and abundance of macrophytes is consistent with Chambers *et al.,* (1991) who found that the abundance of macrophytes was significantly ($P < 0.0005$) and inversely correlated ($r > - 0.68$) with flow velocity over the range 0.01- 1m/s in the Bow River, Alberta.

Flow velocity is an important environmental factor determining controlling the species composition and abundance of macrophyte communities. Thus *Cyperus latifolius* and *Cyperus papyrus* were the dominant species on Yejera Bole sites of Awash River with stagnant water (no flow) whereas *Persicaria senegalensis* dominated in Yejera Ebu, Guro Ruta and Koka Nagawo sites of moderate flow velocity within the range of (0.15 - 0.22 m/s).

5.4 Physico-chemical conditions in comparison with past data

The range value of DO in this study was 4.38 - 7.84 mg/L. This was similar to the same range of previous studies 4 – 8.6 mg/L by Lakew Wondimu, **(**2014*)* and 4.67- 7.84 by Fasil Degefu *et al.*, (2013) in Awash River. The possible entry of organic matter during runoff from the surrounding agricultural fields and their decomposition contributed to the low levels of dissolved oxygen in the bank sites.

The Awash, as the major river in the economy of Ethiopia, is an important center for dry- land biodiversity conservation with relatively low water temperatures, varying only within small limits Mitiku Tikssa *et al.*, (2009). The range value of the surface water temperature showed almost no change during the last decade as the mean value found in this study 23.21 -25.50 °C. This fell within the range value 23.53 -25.65 reported by Fasil Degefu *et al.*, (2013). The range was within the range of variation observed in most tropical water bodies (John 1986). The observed pH value 7.20- 8.08 also fell within the range of 7.79-8.24 reported by Mitiku Tikssa *et al.*, (2009). The pH value could mainly be controlled by freshwater swamp exudates that regulate the acidity of the water body. Conductivity showed almost no change during previous studies as the mean values found in this study ranged 340.3 - 488.1 µs/cm. This was comparable with the values 327.67 - 492.87µs/cm reported by Fasil Degefu *et al.*, 2013. The long term similarity of physico chemical conditions might be good for macrophyte dynamics because the climate and other factors may not change the physico chemical properties of the river. This implies that the composition and diversity of macrophyte species might be similar. The electrical conductivity of most freshwaters ranges from 10 to 1,000 µs/ cm but may exceed 1000 µs/ cm, especially in polluted waters, or those receiving large quantities of land run-off (APHA *et al*., 1999).

6 Conclusions and Recommendation

This is the first study to determine the influence of environmental factors on macrophyte species composition and abundance in the upper Awash River. The results show that 50% of the macrophytes diversity were determined by the environmental factors like total nitrogen and phosphorus, flow velocity, nitrate (water) and sediment texture. The dependence of macrophyte abundance on some environmental factors show that slight increase in nutrient levels may drive significant changes in the abundance of observed macrophytes, particularly the invasive species, *Eichhornia crassipes*. This study may be used as a baseline for future work, particularly in the context of the ecosystem services, sustainable monitoring of aquatic ecosystems and conservation programs. Half of the unexplained environmental factors that regulate the macrophyte distribution in the Awash basin could be due to the influence of human and livestock activities on the river bank and riparian agricultural activities. There should be regulations to prevent or reduce these impacts in and around Awash River.

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1. List of Appendices

1.1 Some macrophyte species from the study area

Persicaria sengalesis

Cyperus erectus

Pancimum maxima

Phragmatius maurianus

Eichhornia crassipes

Cyperus latifolius