MACROPHYTES COMMUNITY STRUCTURE, RELATION TO SEDIMENTATION, IMPACT ON MACRO-INVERTEBRATES AND LEVEL OF HEAVY METAL CONTAMINATION IN LAKE KOKA, ETHIOPIA

SCHOOL OF GRADUATE STUDIES

A THESIS PRESENTED TO THE SCHOOL OF GRADUATE STUDIES OF THE ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN BIOLOGY (FISHERIES AND AQUATIC SCIENCES)

BY: ASSEFA WOSNIE YSHEBER

Addis Ababa University

Addis Ababa, Ethiopia

January 2020

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Macrophytes Community Structure, Relation to Sedimentation, Impact on Macro-Invertebrates and Level of Heavy Metal Contamination in Lake Koka, Ethiopia

By

Assefa Wosnie Ysheber

A Thesis Presented to the School of Graduate Studies of the Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Biology (Fisheries and Aquatic Sciences)

Approved by Examining Board:

Name		Signature
1. Prof. Seyoum Mengistou	(Advisor)	
2. Prof. Charles M' Erimba	(External Examiner)	
3. Dr. Girum Tamire	(Internal Examiner)	
4. Dr. Bezawork Afework	(Chairperson)	

DECLARATION

I hereby declare that this thesis, entitled: *Macrophyte of Lake Koka, Ethiopia: Community Structure, Relation to Sedimentation, Impact on Macro-invertebrates and Level of Heavy Metal Contamination* has been composed entirely by myself and has not been submitted for any other degree or qualification. The work complies with the regulations of the University and meets the accepted standards with respect to originality and quality and all sources of information have been specifically acknowledged.

Assefa Wosnie: Signature ___________________ Date______________________

ABSTRACT

Macrophytes community structure, relation to sedimentation, impact on macro-invertebrates and level of heavy metal contamination in Lake Koka, Ethiopia

Assefa Wosnie

Addis Ababa University, 2020

Lake Koka is a multipurpose artificial lake in the Ethiopian Rift Valley and it is among the first to be invaded by *Eichhornia crassipes* (water hyacinth). The lake is under pressure from intensive anthropogenic activities and sedimentation problem. Like most Ethiopian water bodies, previous studies on the lake focused on plankton, fish and pollution neglecting the importance of macrophytes in the lake ecology. Thus, this study aimed at assessing the macrophyte abundance and diversity, efficiency of the dominant macrophytes in trapping sediment, impact of *Eichhornia crassipes* on water quality and macro-invertebrates and heavy metal contamination level in Lake Koka, Ethiopia. Data for macrophyte community was collected during the dry and wet seasons of 2017 using a line transect method and sediment trap experiment was conducted from July to September, 2017 to assess the efficiency of macrophytes in reducing sedimentation problem. The impact of *E. crassipes* on macro-invertebrates of the lake was investigated by collecting macro-invertebrates from *E. crassipes* mats and *Echinochloa stagnina* stand using a D-frame net (500µm). Heavy metal contamination of the lake was investigated by collecting water, sediment and *E. crassipes* organs (leaves and roots) samples from the lake and inflowing rivers and analyzing using ICP-OES. Data for physicochemical parameters were collected by *in situ* measurement and laboratory analysis according to standard methods.

A total of 28 macrophyte species belonging to 15 families were identified. The most dominant families were Asteraceae and Cyperaceae each represented by 6 species. *E. crassipes* was the dominant macrophyte followed by *Leptochloa caerulescens*, *E. stagnina*, *Cyperus dives* and *Typha angustifolia*. The dry season had significantly higher species richness (28) and diversity (H=1.00) ($p<0.05$) than the wet season and most families were absent during the wet period. RDA analysis indicated that conductivity, pH, and nitrate were the main factors that governed the distribution of macrophytes in the lake. The result from the sedimentation study indicated that all macrophytes significantly facilitated sedimentation and reduced re-suspension than the non-vegetated area ($P < 0.05$) with the order *E. stagnina* = *T. angustifolia* > *E. crassipes* = *L. caerulescens* for sedimentation and *E. crassipes* = *L. caerulescens* > *E. stagnina* = *T. angustifolia* for re-suspension. So development and maintenance of wetlands from *E. stagnina and T. angustifolia* after conducting further studies on the effect of wind velocity and direction on their efficiency might be used as a biological management option for sedimentation problem. Except its significant reduction of macro-invertebrate evenness, *E. crassipes* did not affect water quality of the lake and macro-invertebrate diversity. But to have a full picture of its impact on the lake ecosystem, its effect on macrophytes, fishes and other aquatic lives should be investigated.

Heavy metal levels in water samples from Modjo downstream (MODD) site were significantly higher than the other sites while there was a uniform distribution of all the metals in the lake sites. Levels of As, Pb, Cr, Mn and Ni at most sites were beyond the WHO guideline limit for drinking water while As, Cd, Cr, Cu, Pb and Zn at all sites were beyond the threshold values for the protection of aquatic life. Similarly the concentration of heavy metals in sediment samples from MODD had significantly higher concentration of Cr and Mn than most sites on the lake and there was uniform distribution of As, Co, Cr, Mn, Pb and Zn on the lake sites. Levels of As, Cd, Cr, Cu, Mn, Pb and Zn from sediments samples of Lake Koka and its inflowing rivers were beyond the sediment quality guideline suggesting the possibility to pose a significant effect to aquatic organisms. Hence profound measures against a further pollution and continuous monitoring of the heavy metal concentrations of the lake are recommended. Heavy metal analysis of leaf and root material proved *E. crassipes* to be a high accumulator of most measured metals with the concentrations in the roots being significantly higher than those in the leaves. Therefore, while considering its appropriate disposal, *E. crassipes* can be recommended for utilization as phytoremediation agent and bio-indicator of heavy metal pollution in the lake. Further investigation on the efficiency of the dominant macrophytes in the lake as a phytoremediation agents is necessary.

Keywords: *Eichhornia crassipes*; Heavy metals; Macro-invertebrates; Macrophytes; Phytoremediation; Sedimentation

ACKNOWLEDGEMENTS

Completion of this study was possible with the support of several people and organizations. I would like to express my sincere gratitude to all of them.

First and foremost, I am grateful to my Advisor Professor Seyoum Mengistou, for his valuable guidance, scholarly inputs and consistent encouragement I received throughout my study. He is a person with an amicable and positive disposition, availing himself to clarify my doubts despite his busy schedules. This makes my stay at the university smoother and easier. Thank you Prof. for all your help and support.

My sincere appreciation also goes to Dr. Miguel Alvarez for his advice and unreserved support on data analysis, identification of macrophytes, reviewing the chapters and arranging the fellowship from ARBINETH Project for heavy metal analysis.

I would like to thank Professor Abebe Getahun, for his positive responses and coordination during my study and all staff members of the department for their encouragement, insightful comments and suggestions starting from the proposal development.

I am also highly grateful for macrophyte identification support form Kai Bein. I would like to thank Dr. Katharina Prost for her support during heavy metal laboratory analysis and reviewing the chapter. Heavy metal analysis was done in University of Bonn, Plant Nutrition and Soil Sciences Department Laboratories and I would like to thank Angelika Glogau and Addi Kiener for their help during the analysis. My thank also goes to Prof.

Dr. Mathias Becker, Prof. Dr. Nicolas Brüggemann and Dr. Gerhard Welp for their cooperation, feedback and positive responses for the analysis.

I gratefully acknowledge the funding sources that made this study possible. The study was funded by Addis Ababa University, Zoological Sciences Department, Water Thematic Research of Addis Ababa University and Dilla University. The study was also supported by the Ethiopian Ministry of Water, Irrigation, and Electricity (MoWIE). Part of this work was also funded by ARBONETH Project sponsored by German Academic Exchange Service (DAAD).

My colleagues have also contributed immensely to my study. Dr. Abinet W/senbet, Dr. Alamirew Eyayu, Ato Solomon Wagaw, Dr. Tarekegn Wondimagegn, Ato Yadessa Chibsa and Dr. Yirga Enawugaw have contributed a lot in both the tedious field and laboratory works. Particularly, the group work in the field has been a source of fun, friendships, good advice and collaboration making the tedious work easier. I would also like to acknowledge Ato Kassahun Tessema and W/o Meseret Teferi for their help and cooperation in the laboratory. Their help made the laboratory work easier for me.

Last but not least, special thanks to my family and friend for their support and encouragement throughout the study period.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
CSQG	Canadian Sediment Quality Guideline
DCA	Detrended Correspondence Analysis
DW	Dry Weight
EDTA	Ethylenediaminetetraacetic acid
ENMA	Ethiopian National Meteorological Agency
FAO	Food and Agriculture Organization of the United Nations
GERD	Great Ethiopian Renaissance Dam
LFDP	Lake Fisheries Development Project
m.a.s.l	Meter above sea level
Mm^3	Million metric cube
MoWIE	Ministry of Water, Irrigation and Electricity
MW	Mega Wat
PVC	Polyvinyl chloride
RDA	Redundant Analysis
SD	Standard Deviation
SE	Standard Error
USEPA	United States Environmental Protection Agency
VDLUFA	Association of German Agricultural Analytic and Research Institutes
WHO	World Health Organization

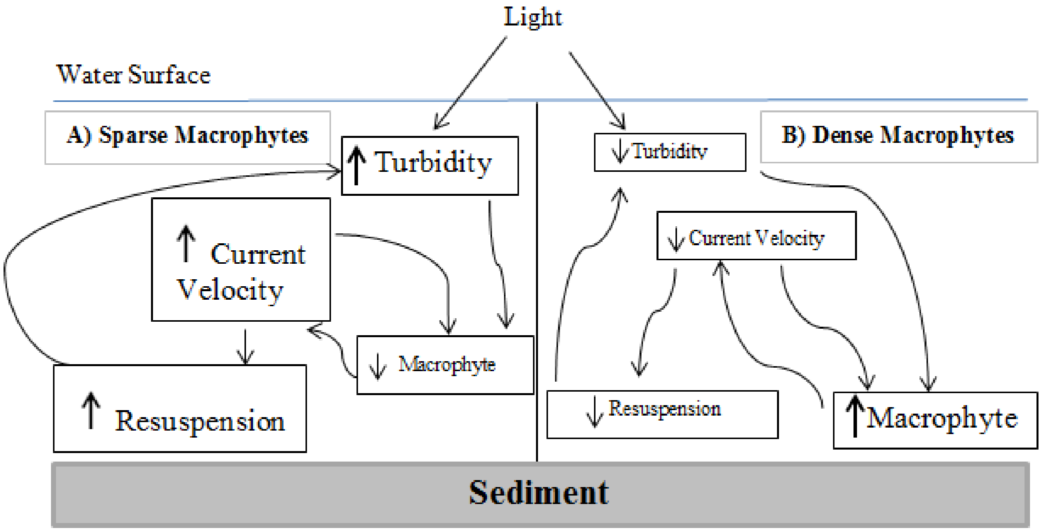
CHAPTER 1: GENERAL INTRODUCTION

1.1 Macrophytes and their Ecological Roles

The littoral zone is structurally and functionally an important part of most lakes for several reasons. These include: (1) in smaller lakes, the zone comprises a large proportion of total lake area, (2) it influences the movement and processing of material flowing into the lake; in so doing, it affects the physical and biological processes in the lake ecosystem, (3) it is the most productive area of the lake and (4) human uses of aquatic ecosystems often focus on the littoral zone (Peters and Lodge, 2009). Macrophytes constitute one of the major components in the littoral zone (Lewis, 2009; Dar *et al.*, 2014) playing variety of roles in the ecosystem (Wetzel, 2001; Cazzanelli *et al.*, 2008; Peters and Lodge, 2009; Pirini *et al.*, 2011). Therefore, knowledge of the their community structure and habitat preference provides information about the ecological status of aquatic ecosystems and makes it possible to predict possible changes in ecosystem quality (Topuzović *et al.*, 2009). In the next section, a short recap on two of the ecological roles of macrophytes on which this thesis focused (reducing sedimentation and phytoremediation) will be presented.

1.1.1 Role in Reducing Sediment Loading

The process of sediment deposition in aquatic ecosystems is influenced by vegetation presence and patterns and physical (e.g., water depth, wetland area, and flow velocity) characteristics (Brueske and Barrett, 1994). Aquatic macrophytes play an important role in promoting sediment deposition (Li *et al.*, 2016) by reducing turbulence (Barko *et al.*, 1991; Chao *et al.*, 2010) and water velocity (Elliott, 2000; Schulz *et al.*, 2003; Nolte *et al.*, 2013). Studies conducted on constructed wetlands (Knight *et al.*, 1987; Mitsch and Reeder, 1992) and macrophytes (Rooney *et al.*, 2003) reported high sediment trapping efficiency which is associated with the presence of macrophytes. Therefore, development and maintenance of macrophyte stands may be an effective management tool for sedimentation problem and for limiting wind-driven sediment resuspension (Dieter, 1990; James and Barko, 1994; Madsen *et al.*, 2001). A brief illustration of the interaction between sediment and macrophytes is given in **Figure 1.1**.



1

Figure 1. 1 A conceptual model of the interactions among water movement, sediment, and aquatic macrophytes

(A), current velocity is affected only slightly, sediment resuspension is relatively high and turbidity and light attenuation are also high. In contrast, (B), currents are strongly attenuated, leading to reduced sediment resuspension, turbidity, and light attenuation (Modified from Madsen *et al.* (2001))

1.1.2 Phytoremediation

The discharge of toxic effluents from various industries is common environmental problem all over the world (Lu *et al.*, 2004). The contamination of the aquatic ecosystems with these toxic pollutants adversely affects aquatic ecosystems , agriculture, and human health (Solomon, 2008; Shah, 2017) and therefore appropriate treatment technology is imperative (Mishra and Tripathi, 2009). From the remediation technologies available for reducing the harmful effects of pollutants, phytoremediation is relatively cost effective emerging technology that could remediate different contaminants and applies in different site conditions (Lasat, 2002; Borker *et al.*, 2013).

Because of their general fast growth and high biomass production, wetland plants have high remediation potential for macronutrients and heavy metals from the environment (Stoltz and Greger, 2002; Bragato *et al.*, 2006). Studies had been conducted in different parts of the world and reported the efficiency of different macrophytes; *Typha sp.* (Chandra and Yadav, 2010; Yen and Saibeh, 2013), common reed (*Phragmites australis*) (Ye *et al.*, 2003; Bragato *et al.*, 2006), *Cyperus alternifolius* and *Villarsia exaltata* (Cheng *et al.*, 2002), different macrophytes including *Leersia hexandra*, *Juncus effuses*, *Carex rostrate,* and *Equisetum ramosisti* (Stoltz and Greger, 2002; Deng *et al.*, 2004) in remediation of heavy metal pollution. In Ethiopia too, studies indicated the potential of macrophytes as phytoremediation agent for different pollutants (Yezbie Kassa, 2016; Zekaryas Fanta, 2016).

Even though *Eichhornia crassipes* approaches being a scourge in many parts of the world, choking waterways and hindering transport upon them, its phytoremediation ability has also attracted considerable attention (Smolyakov, 2012). Recently, *E. crassipes* have been utilized as an efficient heavy metal phytoremediation agent in different parts of the world (Ashok *et al.*, 2014; Bais *et al.*, 2015; Mishra and Maiti, 2017). In Ethiopia, the weed was first officially reported in 1956 on Lake Koka and Awash River (Rezene Fessehaie, 2005) and is now distributed in different water bodies of the country (Firehun Yirefu *et al.*, 2014; Dereje Tewabe *et al.*, 2017). There is a start to study its phytoremediation efficiency for treatment of tannery wastewater and was found to be efficient in absorbing chromium (Feleke Zewge *et al.*, 2011). Therefore, instead of considering it as a curse, it is important to exploit its positive sides while trying to control its burden on waterbodies.

1.2 Factors Governing Macrophytes Diversity and Abundance

The role macrophytes play is closely linked with their distribution and biomass, which in turn is dependent on a various environmental factors (Nurminen, 2003a; Mikulyuk *et al.*, 2011; Madsen and Wersal, 2017) including light, water temperature, nutrient enrichment and sediment composition (Dar *et al.*, 2014). In reservoirs for hydroelectricity generation, the rapid water level fluctuations and sudden modifications in seasonal discharge trends can affect species richness (Silva *et al.*, 2014) by depressing the establishment and development of anchored aquatic and helophyte plant species favoring opportunistic ones (Bolpagni and Piotti, 2015).

The excessive addition of pollutants to aquatic ecosystems is also responsible for habitat destruction and diversity changes causing a temporary or permanent shift in species composition (Ansari *et al.*, 2015). The event favor the establishment of exotic species, at the expense of native species (Chambers *et al.*, 2008). Other factors include herbivory, human activities in the water body and riparian land, and competition between and within species (Altınsaçlı *et al.*, 2014). For instance, Alvarez *et al.* (2012) reported that small wetlands in East Africa are increasingly converted into sites for agricultural production which will affect the wetlands' vegetation.

Because of the significant role played by macrophytes and the introduction and spread of nonnative species, understanding macrophyte community structure and their relation to environmental factors is crucial for integrated management practices (Dar *et al.*, 2014). Therefore, this study was conducted on Lake Koka to test the following hypotheses: (1) Lake Koka has diverse and abundant macrophyte distributions than its Rift Valley counterparts; (2) the dominant macrophytes in the lake are efficient in trapping sediment and restraining resuspension (3) the dominant *E. crassipes* affects the lake's water quality and macro-invertebrate community; and (4) Lake Koka and its inflowing rivers are highly contaminated with heavy metal.

1.3 Statement of the Problem

Ethiopian water bodies are under pressure from pollution (Tigist Ashagre *et al.*, 2014; Kebede Nigussie *et al.*, 2015; Berhan Teklu *et al.*, 2018), sedimentation (Girma Taddese *et al.*, 2003; Fasikaw Atanaw *et al.*, 2016; Teklu Gebretsadik and Kassahun Mereke, 2017), and occurrence of invasive species (Firehun Yirefu *et al.*, 2014; Yezbie Kassa, 2016). Several studies have been conducted on the freshwater bodies mainly focusing on water quality, plankton, benthic fauna and fish. However, the importance of macrophytes in the ecology of lakes has long been neglected and only few studies have been conducted (Girum Tamire and Seyoum Mengistou, 2012; Dikaso Unbushe, 2013; Pattnaik, 2014; Yezbie Kassa, 2016; Getu Dida, 2017; Lalisa Gemechu, 2018).

Koka is one of the lakes which is heavily affected by sediment load that come from the inflowing rivers (Julien and Shah, 2005; Kebede Wolka, 2012). The lake is also affected by pollutants from anthropogenic activities around the lake and along the catchment of the inflowing rivers (Zinabu GebreMariam and Pearce, 2003; Dsikowitzky *et al.*, 2013). Over the past years, several researchers have investigated on Lake Koka primarily focusing on different aspects (See **Table 1.1**).

Table 1. 1 Previous studies on Lake Koka

Focus area	**Reference/s**
Limnological observations including physicochemical parameters, plankton and benthic invertebrates	Melaku Mesfin *et al.* (1988); Lakew Wondimu (2014)
Heavy metal contamination of the lake and its inflowing rivers; water, sediment, fish and macrophyte tissue	Zinabu GebreMariam and Pearce (2003); Dsikowitzky *et al.* (2013); Yetneberk Ayalew *et al.* (2016); Kassahun Tessema (2017)
Population and ecosystem based fisheries assessment, food and feeding habit	Elias Dadebo *et al.* (2015); Gashaw Tesfaye and Wolff (2015)
Lake management issues	Seyoum Tegegne (2011)
Water Hyacinth (*E. crassipes*) coverage and its socio-economic importance	Firehun Yirefu *et al.* (2014)

No previous attempt was made to study the macrophyte community structure and their importance in trapping sediment and preventing re-suspension. Even though the invasive *E. crassipes* which may affect the abundance and diversity of other organisms (Villamagna and Murphy, 2010; Wang and Yan, 2017) appeared in the lake long time ago (Rezene Fessehaie, 2005). But there is no data about its impact on the lake ecosystem except the work of Habtamu Getnet (2019) who studied about its impact on water quality and plankton community. In addition, studies conducted on heavy metal contamination of the lake and its inflowing rivers focused only on a few sites and contained only fragmented information. Therefore, this study has tried to fill the above listed research gaps by addressing the following research questions and objectives.

1.4 Research Questions

The overall goal of this dissertation was to assess the macrophyte community structure of Lake Koka and their roles in the ecosystem. Therefore, the analyses address:

1. What does the macrophyte structure in the lake looks like and which environmental factors are determinants of the structure (chapter 2)?
2. Can macrophytes be a biological management options for preventing sedimentation and re-suspension problem (chapter 3)?
3. Does *E. crassipes* affect the water quality and macro-invertebrate diversity of Lake Koka, Ethiopia (chapter 4)?
4. What is the level of heavy metals contamination in the different sections of Lake Koka and the inflowing rivers (chapter 5)?
5. Are heavy metal concentrations in water and sediments samples of Lake Koka and its inflowing rivers below internationally accepted threshold values and the water therefore safe to use (chapter 5)?

1.5 Objectives of the Study

1.5.1 General Objective

- To assess the community structure of macrophytes in relation to factors that affect their dynamics, and examine the impact of the dominant macrophytes on sedimentation, biota, and pollutants of Lake Koka, Ethiopia

1.5.2 Specific Objectives

1. To quantify the diversity and abundance of macrophyte species in Lake Koka
2. To determine the most important abiotic and seasonal factors influencing macrophyte species diversity and abundance in Lake Koka
3. To determine the efficiency of the dominant macrophytes in trapping sediment and preventing sediment resuspension
4. To investigate the impact of *E. crassipes* on water quality and benthic invertebrates abundance and diversity
5. To determine the concentration of heavy metals in water, sediment and *E. crassipes* (root and leaf) samples taken from different localities on the lake and the inflowing rivers

1.6 Description of the Study Area

Lake Koka is an artificial lake in south-central Ethiopia in the East Shewa Zone of the Oromia Region, approximately 100 km southeast of Addis Ababa (Lakew Wondimu, 2014). It was formed in 1959 and the inflow to the reservoir is supplied by the Awash and the Mojo rivers (Melaku Mesfin *et al.*, 1988). The lake was primarily constructed for hydropower generation with an installed capacity of 43.2 MW from three turbines. It is also used for large (Wonji sugarcane irrigation 6,000 ha) and small irrigation schemes (LFDP, 1997; McCartney, 2007; Fasil Degefu *et al.*, 2011). The lake is also used for flood control (Solomon Kibret *et al.*, 2009). Some features of the Lake are given in **table 1.2** below.

Table 1. 2 Location and morphometric characteristics of Lake Koka

No.	Parameter	Value	Reference
1	Location	8°28'N 39°9' E	Fasil Degefu *et al.* (2011); Seyoum Tegegne (2011)
2	Altitude	1590 m a s l	Fasil Degefu *et al.* (2011); Seyoum Tegegne (2011)
3	Surface area	250 km^2	LFDP (1997); Fasil Degefu *et al.* (2011); Seyoum Tegegne (2011)
4	Maximum depth	14 m	Melaku Mesfin *et al.* (1988); LFDP (1997)
5	Mean depth	9 m	Melaku Mesfin *et al.* (1988); LFDP (1997)
6	Trophic state	Eutrophic-hypereutrophic	Fasil Degefu *et al.* (2011)

1.6.1 Climatic and Hydrological Features

The main rainy season starts in June and extends to the end of August/September, while the short rainy season occurs from March to May. A data from 2000 to 2016 indicated that the mean annual temperature of the area is 22.4 ºC. The mean annual maximum and minimum temperatures are 33.8 ºC and 11.5 ºC, respectively while the mean annual rainfall is 922 mm. Summary of these climatic futures is displayed in **Fig. 1.2**.

The mean monthly inflow to Lake Koka from Awash and Modjo Rivers was 117.32 million m^3 and 11.96 million m^3, respectively. The minimum and maximum outflow through Awash River was 23.53 and 67.07 m^3/s, respectively (data source MoWIE, 2017). Using the area of the lake as 250 km^2 (LFDP, 1997; Fasil Degefu *et al.*, 2011; Seyoum Tegegne, 2011) and mean depth of 9 m (Melaku Mesfin *et al.*, 1988; LFDP, 1997), the residence time was calculated and found to be 0.118 to 0.337 years which is very short in comparison with Lake Ziway having about 1.5-2 years residence time (Spliethoff *et al.*, 2009).

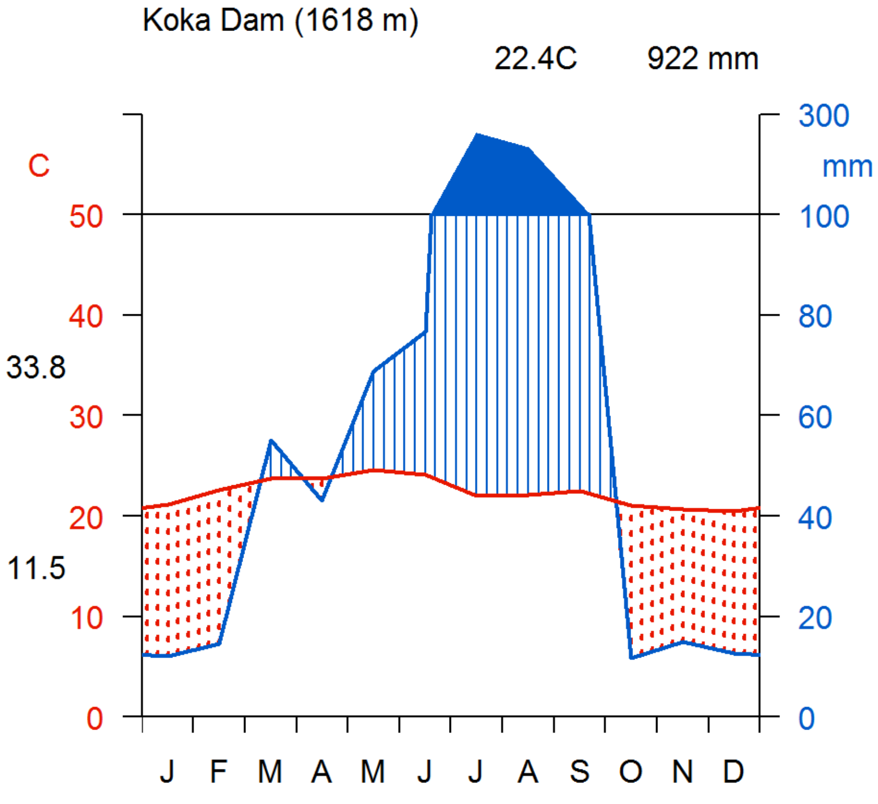


Figure 1. 2 Mean monthly rainfall (mm) and temperature (ºC) around Lake Koka of the years 2000 to 2016 (Data source ENMA, 2017)

1.6.2 Biological Features

In Lake Koka different flora and fauna have been reported including phytoplankton dominated by *Microcystis*, zooplankton with low diversity but abundant and include major groups such as rotifers, copepods and cladocerans (Melaku Mesfin *et al.*, 1988; Fasil Degefu *et al.*, 2011), benthic invertebrates (Melaku Mesfin *et al.*, 1988), and macrophytes (Hadgembes Tesfay, 2007; Yetneberk Ayalew *et al.*, 2016). The reservoir also supports fish species including *Oreochromis niloticus*, *Cyprinus carpio* and *Clarias gariepinus* (Gashaw Tesfaye and Wolff, 2015).

1.6.3 Major Stressors to the Lake

Lake Koka is under pressure from different stressors and some of which are listed below.

1.6.3.1 High Rate of Sedimentation

The inflow to the Lake comes from the Awash and Mojo rivers (Melaku Mesfin *et al.*, 1988). During the rainy season, both rivers are heavily laden with suspended matter (concentration up to 30 000 ppm) (**Plate 1.1**). Reports indicated that the reservoir part of the lake is continuously losing its storage capacity due to sedimentation (Muluneh Imru, 1992; Shahin, 1993).

Plate 1. 1 Sediment load on Lake Koka

1.6.3.2 Recession Agriculture

During the dry season, there is intensive recession agriculture in and around the lake by clearing and burning the water hyacinth. During the practice of this recession agriculture, the farmers and/or the investors use different pesticides and fertilizers to increase the productivity of their crops and vegetables (**Plate 1.2**). Finally, the remnants from these activities will pollute the lake.

Plate 1. 2 Intensive use of fertilizers and pesticides for recession agriculture

1.6.3.3 Floriculture

Flower farms around the lake use water from the inflowing rivers or from the lake and they directly discharge their waste into the lake (**Plate 1.3**). The flower farms are Syngenta flowers, Florensis and Sher flower: Blen farm. The flower farms intensively use different fertilizers and pesticides to produce the best flowers for export purpose (Degytnu Tilahun, 2012; Mulugeta Getu, 2013; Mesay Adugna, 2017).

Plate 1. 3 Floriculture waste and its direct disposal into Lake Koka

1.6.3.4 Tannery and other Industrial Wastes

There are different industries constructed around Modjo River: one of the inflows to Lake Koka including tanneries, food complexes, and textile industry (Amde Eshete *et al.*, 2016). The industries directly discharge their waste into the river that finally enters the lake. Around the lake, Ethiopian Tannery also abstracts water from the lake and directly discharges its waste into the lake (**Plate 1.4**).

Plate 1. 4 Ethio-Tannery abstracting water from Lake Koka

1.6.3.5 Invasive (Alien) Species

In Lake Koka and the Awash River, Water hyacinth (*E. crassipes*) was first officially reported in 1956 (Rezene Fessehaie, 2005). Nowadays most part of the lake is covered by water hyacinth particularly during the rainy season (Personal observation) (**Plate 1.5**). The weed in the lake causes serious problems including hindrance of fishing activity by entangling the fishing nets and boats' propeller (Aloo *et al.*, 2013; Waithaka, 2013; Erkie Asmare, 2017), and blockage of hydroelectric installations and hinders the accessibility of the lake water for various purposes. On the other hand, the weed may also provide habitat for fish and increase their abundance by reducing their catchability and overfishing (Kateregga and Sterner, 2009; Villamagna and Murphy, 2010).

Plate 1. 5 Water hyacinth *(E. crassipes*) coverage in Lake Koka

a) Meto Aleka, b) Ayage c) Near the Floriculture d) Hydro Electric Power Plant (HEPP)

1.7 Thesis Outline

This thesis comprises of six chapters (**Fig. 1.3)**. Chapter 1 is general introduction to the study while chapter 2 deals with macrophyte community structure and its governing factors. Chapters 3 and 4 provide a complementary analysis to chapter 2 by examining the effect of four dominant macrophytes on sediment deposition and resuspension and the effect of water hyacinth on macro-invertebrate diversity of the lake. Chapter 5 describes heavy metal contamination level of the lake and its inflowing rivers and the potential of water hyacinth as a phytoremediation agent. The final chapter concludes the major findings of the study with specific recommendations or research gaps for further investigation in the study area.

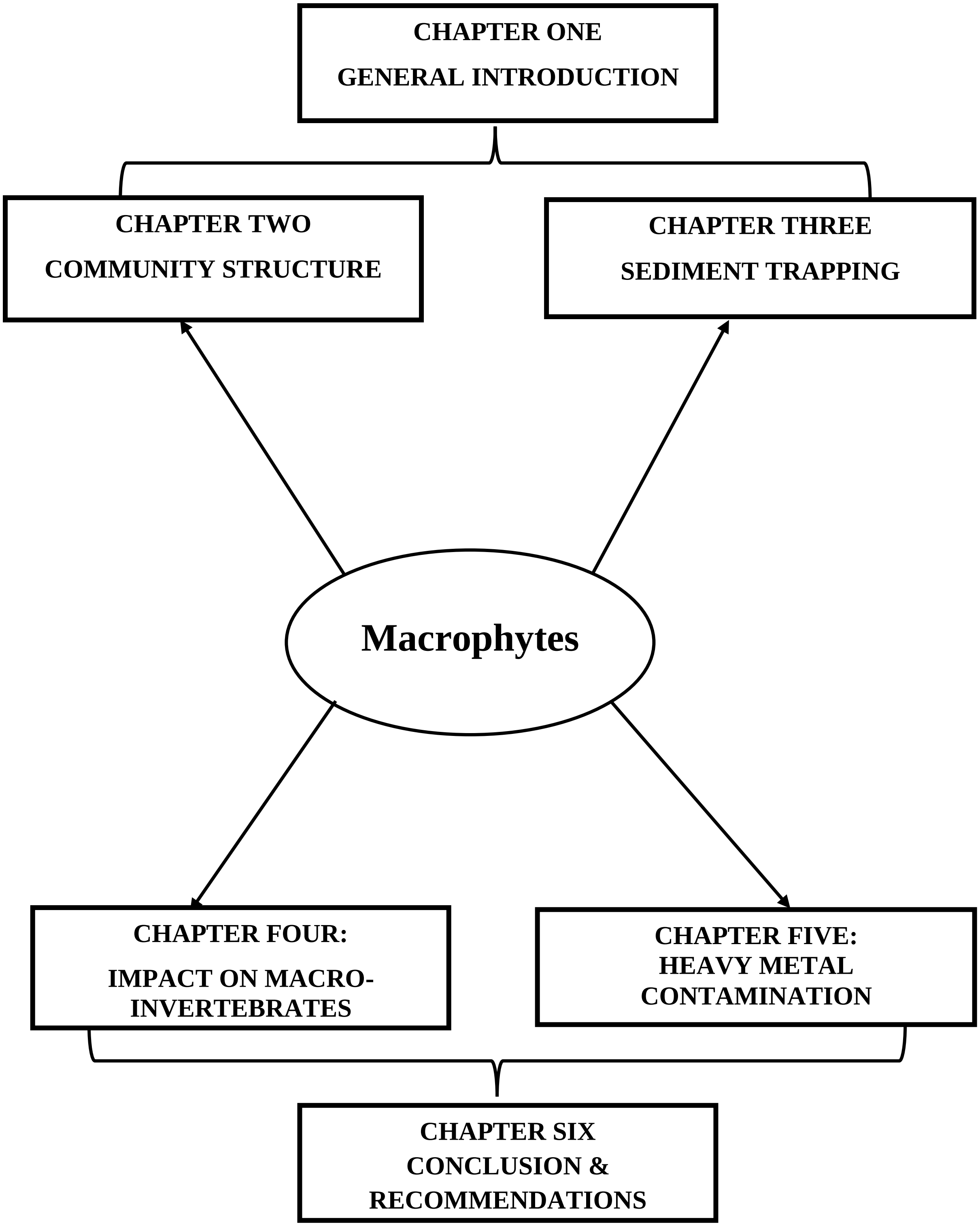


Figure 1. 3 Thesis structure

CHAPTER 2: AQUATIC MACROPHYTE COMMUNITY STRUCTURE IN RELATION TO PHYSICOCHEMICAL PARAMETERS IN LAKE KOKA, ETHIOPIA

2.1 Introduction

As an important component of the littoral zone of many freshwater ecosystems, macrophytes play different roles (Lewis, 2009; Dar *et al.*, 2014). These include being primary producers (Wetzel, 2001), providing refuge for macro-invertebrates (Hudon *et al.*, 2000; Pirini *et al.*, 2011), zooplankton (Cazzanelli *et al.*, 2008) and habitat for the feeding, breeding, and refuge of littoral fish (Pirini *et al.*, 2011). Moreover, macrophytes affect the cycling of nutrients and contaminants (Wetzel, 2001; Peters and Lodge, 2009), reducing shoreline erosion and sediment re-suspension. They can also be used as indicators of water quality (Dhote and Dixit, 2007; Topuzović *et al.*, 2009; Altınsaçlı *et al.*, 2014) .

Distribution and biomass of macrophytes depend on different environmental factors (Nurminen, 2003a; Mikulyuk *et al.*, 2011; Pirini *et al.*, 2011; Madsen and Wersal, 2017) including light, water temperature, water quality changes and sediment composition (Dar *et al.*, 2014). Moreover, in reservoirs for hydroelectricity generation, the highly variable hydrological regime caused by frequent fluctuations may strongly affect species composition and vegetation structure (Silva *et al.*, 2014). Herbivory, human activities in the water body and riparian land as well as competition between and within species are further important factors (Altınsaçlı *et al.*, 2014).

Many threats to fresh waters (e.g., eutrophication) will also result in reduced macrophyte diversity and favor the establishment of exotic species, at the expense of native species (Chambers *et al.*, 2008). In Ethiopia, the invasive *E. crassipes* is now distributed in different water bodies of the country (Firehun Yirefu *et al.*, 2014; Dereje Tewabe *et al.*, 2017) creating serious problems for the use of the water as a resource and may affect the abundance and diversity of other macrophytes (Villamagna and Murphy, 2010; Wang and Yan, 2017). Therefore, because of the significant role played by macrophytes in freshwater ecosystems and the introduction and spread of numerous nonnative species, understanding and quantifying their abundance, diversity and their relation to environmental factors is crucial for integrated management practices (Dar *et al.*, 2014).

The ecological importance of macrophytes in Ethiopian lakes has been neglected and only few studies have been conducted on this regard. These include: Dikaso Unbushe (2013) on ecology of the wetland vegetation around Abaya and Chamo in Southern and Fincha'a-Chomen and Dabus in Western Ethiopia, Girum Tamire and Seyoum Mengistou (2012) on macrophytes of Lake Ziway, Pattnaik (2014) and Lalisa Gemechu (2018) on macrophytes composition of Lake Hawassa, Yezbie Kassa (2016) on wetlands of Lake Tana and their macrophyte composition and Getu Dida (2017) on floristic composition of wetland in Wonchi District, South Western Shewa.

Moreover, in Lake Koka, although the ecology of the plankton (Melaku Mesfin *et al.*, 1988; Hadgembes Tesfay, 2007; Lakew Wondimu, 2014), macro-invertebrates (Melaku Mesfin *et al.*, 1988) and fish (Elias Dadebo *et al.*, 2015; Gashaw Tesfaye and Wolff, 2015; Gashaw Tesfaye, 2016) has been studied, the ecology of the macrophytes was largely neglected. Therefore, this study was conducted to understand the structure of the macrophyte communities in the lake and assess the relative importance of environmental factors and seasons as predictors of macrophyte distribution which will provide vital information that can be used for management purposes.

2.2 Materials and Methods

2.2.1 Sites Selection

For this study, 9 sites were selected based on their distance from anthropogenic effect and presence of macrophyte coverage. The aim of such site selection was to encompass varying environmental conditions in the assessment of distribution and abundance of macrophytes and to note the variation in macrophyte distribution and abundance along different environmental gradients (Girum Tamire and Seyoum Mengistou, 2012). Since the western shore of the lake had no macrophyte coverage, there were no sampling sites on this shore. The sampling sites are described and displayed in **Table 2.1** and **Fig. 2.1**, respectively.

Table 2. 1 Description of sampling sites

Site	Description	Altitude (m.a.s.l)
Meto Aleka	On the main road to Hawassa; high anthropogenic activity (fish and vegetable market and disturbances like agriculture, livestock grazing, and sediment excavation)	1597
Ayage I	Near an island and only livestock grazing	1593
Ayage II	Near an island where there is livestock grazing, and little agricultural practices during the dry season	1594
Tulu Bofa	Near another island (livestock grazing and agricultural practices during the dry season)	1594
Ashewa	On the main road to Hawassa (livestock grazing and agricultural practice during the dry season)	1593
Awash I	Around the inlet of awash river (floriculture, agriculture, and livestock grazing)	1583
Awash II	Away from Awash I (floriculture and livestock grazing)	1588
Awash III	Away from Awash II (little agricultural practice)	1592
HEPP	Hydro Electric Power Plan (no human disturbance, deepest part of the Lake and is the only outlet)	1587

* HEPP- Hydro Electric Power Plant

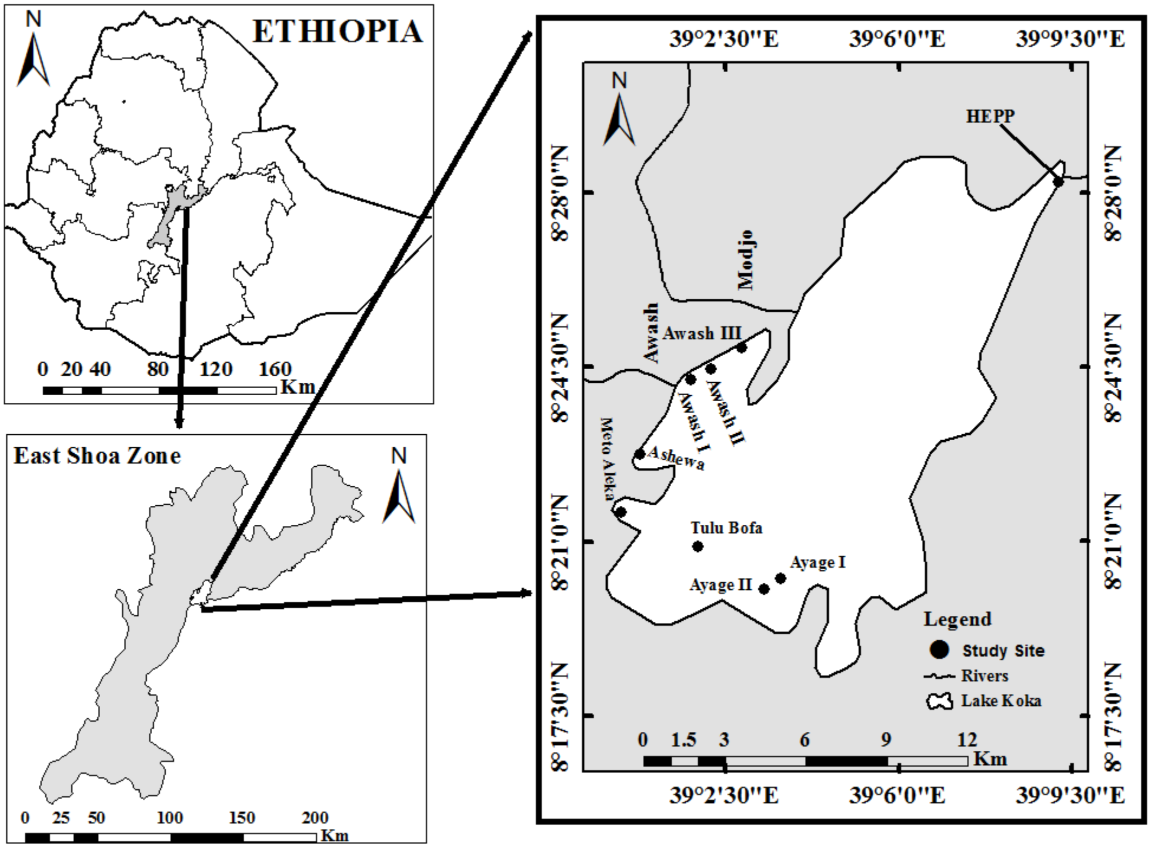


Figure 2. 1 Location of sampling sites (Dam is indicated as HEPP- Hydro Electric Power Plant)

2.2.2 Data Collection

2.2.2.1 Environmental Data

In situ measurement of temperature (T), pH, electrical conductivity (EC) and dissolved oxygen (DO) was conducted with portable HQ40D Multimeter. For nutrient analysis, composite water samples (by compositing samples from varying depths) at each site were taken in duplicates and transported to laboratory in an icebox. In the Limnological

Laboratory of Addis Ababa University, the samples were filtered using GF/F and the nutrients were analyzed spectrophotometrically using a JENWAY 6405UV/Vis spectrophotometer. NO_3-N was analyzed with sodium salicylate method (Robarge *et al.*, 1983), NH_3-N with indo-phenol blue (APHA, 1995), and soluble reactive phosphate (PO_4-P) with ascorbic acid method (APHA, 1999). NO_2-N concentration was determined by the reaction between sulfanilamide and N-naphthyl-(1)-ethylenediamine dihydrochloride (APHA, 1995). Total phosphorus (TP) from unfiltered samples and silica (SiO_2-Si) were determined using persulfate digestion and Molybdosilicate method, respectively (APHA, 1999)

2.2.2.2 Macrophyte Sampling, Identification and Analysis

Macrophyte samples were taken from 9 sites in the year 2017. To consider the effect of increased water level on the macrophytes, samples were collected on monthly basis, three times at the end of the dry season (April, May and June) and three times at the end of the wet season (October, November and December). At each site, macrophytes were collected manually, rinsed *in situ*, coded, pressed and dried for subsequent identification and verification at the National Herbarium, Addis Ababa University, Ethiopia (ETH). Identification was made using Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Edwards *et al.*, 1995), herbarium collections at Addis Ababa University and with the help of standard literatures (Haines and Lye, 1983; Cook, 2004; Agnew, 2013) and finally authenticated by staff of the Herbarium.

For quantitative study of the macrophytes community, a systematic sampling method along line transects which is better to effectively monitor and assess emergent and floating aquatic plant communities (Madsen and Wersal, 2017) was applied. The length of transects was adjusted according to the depth of the littoral zone (Burlakoti and Karmacharya, 2004) and each transect was taken from the shoreline perpendicularly towards the center of the lake to the maximum range of macrophyte occurrence (Sender, 2012). The number of transects at each site varied from 1 – 2 depending on vegetation cover and environmental heterogeneity (Rolon and Maltchik, 2006). Sampling was carried out using a 1 by 1 m quadrat following Fernández-Aláez *et al.* (1999) and Ghosh and Biswas (2015). Depending on the area coverage of the vegetation, variable number of quadrates (2 - 5) were laid along each transect at 15 m intervals. Macrophytes in each quadrat were counted and an independent morphological unit arising from rhizome was considered as an individual macrophyte (Pompeo and Moschini-Carlos, 1996). To capture all macrophytes present and get the best picture of total richness and composition, sampling effort was proportional to the vegetation cover of the site (Rolon and Maltchik, 2006). Moreover, to generate the most comprehensive species list possible, new species observed along transects, outside of the quadrats, were also noted (Dikaso Unbushe, 2013).

2.2.3 Data Analysis

The macrophyte data were quantitatively analyzed for abundance, relative frequency and relative density as in the study by Singh *et al.* (2013) and Ghosh and Biswas (2015). Macrophyte species diversity in the lake was computed using species richness, diversity index following Shannon and Weiner (1963) and Evenness index (Pielou, 1975). Spatial and temporal variations in abundance and diversity of macrophytes and physicochemical parameters were tested using one-way ANOVA followed by Tukey-HSD and paired sample independent t-test, respectively. After determining the gradient length (<2) using DCA (Detrended Correspondence Analysis), RDA (Redundant Analysis) was employed to determine the relationship between macrophyte species composition and abundance and environmental parameters using CANOCO for windows 4.5 version Software (Ter Braak and Smilauer, 2002). To reduce the effect of rarity on RDA analysis, families that comprised <1% of the organisms at sampling sites were excluded (Kuchapski and Rasmussen, 2015). All statistical analyses were conducted using R-programming language version 3.4.2.

2.3 Results

2.3.1 Physicochemical Variables

All the physicochemical parameters significantly varied among the sampling sites ($p<0.05$) (**Table 2.2**). The pH value ranged from 7.85 (Awash I) to 8.8 (Ashewa) and showed significant variation among the sampling sites ($P < 0.05$); the value at Awash I being significantly lower than Ashewa, HEPP, Meto Aleka and Tulu Bofa. Similarly, the values of temperature (ºC) and conductivity (µScm^{-1}) varied significantly among the sampling sites and ranged from 21.80 (HEPP) – 27.20 (Ashewa), and 78.83 (HEPP) – 496.18 (Awash I), respectively. Temperature value at Ashewa was significantly higher than most sites except Awash I, Awash III, and Tulu Bofa while conductivity values at Awash sites were significantly higher than the rest sites except Awash II. All the nutrients also displayed significant variation among the sampling sites ($P < 0.05$). Nitrate at Awash I (3.68 mgL^{-1}) and Awash II (3.27 mgL^{-1}) sites where the floriculture effluent directly discharged was significantly higher than the other sites ($P < 0.05$). Awash I site had significantly higher values of total phosphorous (1.64 µgL^{-1}) and soluble reactive phosphorous (0.28 µgL^{-1}) than the other sites.

Table 2. 2 Spatial variation in environmental variables (mean ± SD)

Sites	pH	Temperature	Conductivity	DO	NO_2-N
Ashewa	8.80±0.38c	27.2±4.55c	117±33.9ab	6.02±2.72bc	0.29±0.18b
Awash I	7.85±0.07a	24.6±5.27abc	496±665c	3.23±2.11a	0.28±0.12ab
Awash II	8.20±0.70ab	23.6±3.06ab	295±129bc	4.88±3.50ab	0.32±0.21b
Awash III	8.22±0.61ab	25.4±3.68bc	189±94.7ab	4.95±2.57ab	0.24±0.09ab
Ayage I	8.21±0.41ab	23.5±3.18ab	97.6±27ab	5.93±2.05bc	0.15±0.09a
Ayage II	8.21±0.37ab	23.9±2.33ab	88.1±28.0a	5.13±2.35abc	0.34±0.22b
HEPP	8.48±0.33bc	21.8±1.81a	78.8±12.4a	6.99±0.62bc	0.25±0.19ab
Meto Aleka	8.43±0.30bc	23.5±2.52ab	128±42.7ab	5.09±2.71abc	0.26±0.14ab
Tulu Bofa	8.53±0.53bc	26.6±3.24bc	90.3±32.9a	7.17±1.45c	0.28±0.15ab
Sites	**NO_3-N**	**NH_3-N**	**TP**	**PO_4-P**	**Silica**
Ashewa	1.21±1.05a	0.12±0.10d	0.61±0.47a	0.06±0.02a	0.25±0.04a
Awash I	3.68±3.42b	0.10±0.05bcd	1.64±1.38b	0.28±0.37b	0.32±0.07b
Awash II	3.27±3.62b	0.10±0.07cd	0.19±0.18a	0.06±0.08a	0.40±0.11c
Awash III	0.86±0.64a	0.07±0.02abc	0.25±0.41a	0.05±0.06a	0.33±0.05b
Ayage I	0.31±0.17a	0.05±0.01a	0.60±0.67a	0.04±0.04a	0.25±0.05a
Ayage II	1.52±1.80a	0.08±0.05abcd	0.21±0.14a	0.05±0.06a	0.26±0.04a
HEPP	0.25±0.08a	0.06±0.01ab	0.17±0.13a	0.05±0.03a	0.26±0.04a
Meto Aleka	0.36±0.28a	0.06±0.01ab	0.27±0.19a	0.06±0.07a	0.25±0.05a
Tulu Bofa	1.16±1.50a	0.06±0.03abc	0.35±0.31a	0.07±0.10a	0.25±0.05a

* Means within a column followed by the same letter are not significantly different

* HEPP – Hydro Electric Power Plant, DO = Dissolved Oxygen and TP = Total Phosphorous, Temperature (ºC), NO_2-N, NO_3-N, NH_3-N, Silica (mgL^{-1}), TP and PO_4-P (μgL^{-1}) and Conductivity (μScm^{-1})

2.3.2 Macrophyte Community

The present study attempted to determine the abundance and diversity of macrophyte in Lake Koka and 199 quadrates were laid along transects that were set up at the different study sites.

2.3.2.1 Species Composition and Abundance

A total of 28 macrophyte species belonging to 15 families were identified. No submerged macrophyte was recorded during the study. The complete catalogue of the macrophytes found in the lake is displayed in **Table 2.3**. The most dominant families were Asteraceae, Cyperaceae and Poaceae. Both Cyperaceae and Poaceae were represented by 6 (21.4%) species each while Asteraceae was represented by 3 (10.7%) species. The rest families, except Polygonaceae with 2 (7.14%) species, were represented by a single species. *E. crassipes* occurred at all the sites and was the dominant macrophyte with relative frequency of 17.4%, density of 70.7% and importance value index of (140). *Leptochloa caerulescens*, *Echinochloa stagnina*, and *Cyperus dives* followed in their dominancy with relative frequency of 11.8%, 11.6% and 9.74%, relative density of 9.60%, 9.43% and 4.43% and importance value index of 30.4, 30.0 and 19.3, respectively. Even though *Typha angustifolia* dominantly occurred only at two sites, it had also higher relative frequency (5.31%) and density (1.51%).

Table 2. 3 Macrophyte abundance and diversity in Lake Koka

Macrophyte			**Abu. (m^2)**	**%RF**	**%RD**
Family	**Species**	**Common Name**			
Amaranthaceae	*Alternanthera sessilis* (L.) R. Br. ex DC.	Sessile joy weed	7	3.05	0.34
Asteraceae	*Eclipta prostrata* (L.) L.	False daisy	3	0.79	0.04
	Grangea maderaspatana (L.) Desf.	Madras carpet	1	0.59	0.01
	Sphaeranthus sp.	-	14	1.67	0.40
Boraginaceae	*Heliotropium sp.*	-	3	0.59	0.02
Brassicaceae	*Rorippa sinuate* (Nutt.) A.S. Hitchc.	Yellow cress	7	2.85	0.31
Chenopodiaceae	*Chenopodium ambrosioides* (L.)	Wormseed	3	0.49	0.02
Cyperaceae	*Cyperus articulates* (L.)	Jointed flat sedge	12	2.95	0.59
	Cyperus dives Delile	-	27	9.74	4.43
	Cyperus rotundus (L.)	Nut Sedge	14	3.54	0.85
	Schoenoplectiella juncea (Willd.) Lye	-	4	0.59	0.04
	Cyperus sp.	-	5	0.39	0.03
	Courtoisina assimilis (Steud.) Maquet	-	3	0.29	0.02
Lythraceae	*Ammannia baccifera* (L.)	Blistering ammannia	4	1.38	0.08
Malvaceae	*Hibiscus sp.*	-	2	0.49	0.01
Molluginaceae	*Glinus lotoides* (L.)	Lotus sweet juice	5	1.18	0.09
Onagraceae	*Ludwigia adscendens* (L.) H. Hara	Water primrose	4	12.1	0.78
Poaceae	*Digitaria abyssinica* (Hochst. ex A. Rich.) Stapf	Couch grass	3	0.69	0.03
	Echinochloa colona (L.) Link	Jungle rice	6	2.66	0.27
	Echinochloa stagnina (Retz.) P. Beauv.	Hippo. grass	48	11.6	9.43
	Eleusine indica (L.) Gaertn.	Indian goose grass	3	0.49	0.03
	Leptochloa caerulescens Steud.	-	49	11.8	9.60
	Phragmites australis (Cav.) Trin. ex Steud.	Common reed	3	0.20	0.01
Polygonaceae	*Persicaria decipiens* (R. Br.) K. L. Wilson	Knot weed	3	2.07	0.11
	Persicaria senegalensis (Meisn.) Soják	-	3	4.72	0.20
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.	Water hyacinth	260	17.4	70.7
Solanaceae	*Physalis sp.*	-	2	0.30	0.01
Thyphaceae	*Typha angustifolia* (L.)	Narrowleaf-cattail	17	5.31	1.51

Abbreviations: Abu. = Abundance, RF = Relative Frequency, RD = Relative Density

Note: *E. crassipes* is the only floating macrophyte, the rest are either emergent, helophytes or semi-aquatic

2.3.2.2 Site Specific Diversity Measures

In macrophyte assemblage terms, *E. crassipes*, *L. caerulescens* and *L. adscendens* were shared by all the sites, *E. crassipes* being dominant throughout the year followed by *L. caerulescens*. *E. stagnina*, *C. articulatues*, *C. dives*, *C. rotundus,* and *P. senegalensis* were shared by all the sites except HEPP. On the contrary, *Cyperus sp* and *C. assimilis* were recorded only at Meto Aleka site. Species richness at the sampling sites ranged from 5 (HEPP) to 24 (Ayage II) (**Appendix 1**).

Key community parameters (Shannon Diversity Index and evenness) were generated for each site. The overall macrophyte diversity index of Lake Koka was H′ = 1.10 and showed significant site-specific variation (ANOVA, $P < 0.05$); HEPP site having value significantly lower than Awash I and II, Ayage I and II, and Tulu Bofa sites. Evenness also varied significantly among the sampling sites ($P < 0.05$); Ashewa (0.40) and Meto Aleka (0.41) having value significantly lower than Awash I and II (**Fig. 2.2)**. Generally, HEPP had the least species richness and Shannon diversity value while Ashewa and Meto Aleka sites exhibited low evenness value. *E. crassipes* was highly dominant throughout the year (Personal observation) while most species identified were rare.

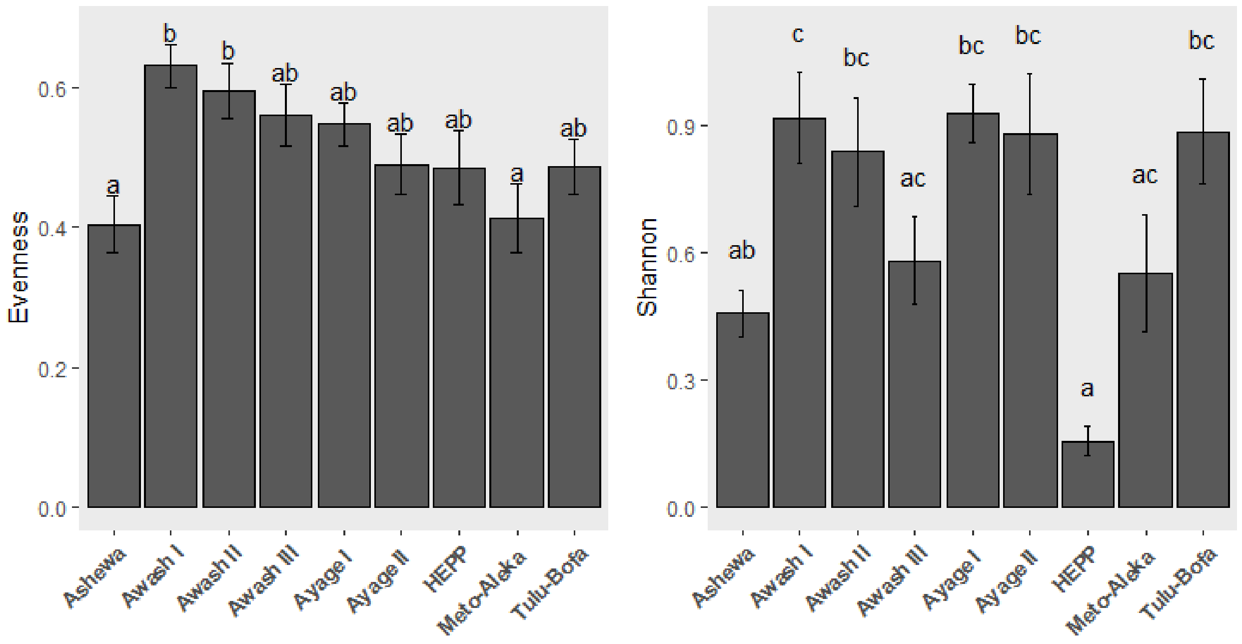


Figure 2. 2 Spatial variation in macrophyte diversity indices (mean ± SD)
(Bars labeled by the same letter are not significantly different

2.3.2.3 Seasonal Variation in Physicochemical Variables and Macrophyte Distribution

Physicochemical Variables

Except for NH_3-N, NO_2-N, and dissolved oxygen (DO), all the physicochemical parameters significantly vary between the seasons: the dry season having significantly higher value (Two-sample t-test, $P < 0.05$) (**Table 2.4**).

Table 2. 4 Seasonal variation in physicochemical variables (mean ± SD)

Seasons	Physicochemical Parameters				
	pH	**Temperature**	**Conductivity**	**DO**	**NO_2-N**
Dry	8.40±0.53b	25.8±4.09b	223±353b	5.73±2.81a	0.29±0.18a
Wet	8.25±0.47a	22.9±2.71a	128±84.2a	5.25±2.32a	0.25±0.15a
Seasons	**NO_3-N**	**NH_3-N**	**TP** (µgL^{-1})	**PO_4-P**(µgL^{-1})	**Silica**
Dry	1.72±2.72b	0.08±0.07a	0.63±0.72b	0.13±0.20b	0.27±0.05a
Wet	1.09±1.44a	0.07±0.03a	0.32±0.67a	0.03±0.03a	0.30±0.10b

* Means within a column followed by the same letter are not significantly different
* Temperature (ºC), NO_2-N, NO_3-N, NH_3-N, Silica and DO (mgL^{-1}), and Conductivity (µScm^{-1}); DO= Dissolved Oxygen, TP = Total Phosphorous

Macrophyte Distribution

Significant seasonal variation was observed in species richness and Shannon diversity index (Two-sample t-test, $P < 0.05$). The dry period had significantly higher species richness (28) and diversity (H=1.00) **(Table 2.5)**. Families Asteraceae, Boraginaceae, Brassicaceae, Chenopodiaceae, Lythraceae, Malvaceae, and Molluginaceae were absent during the wet period (**Appendix 2**).

Table 2. 5 Seasonal variation in macrophyte assemblages

Seasons	Species Richness	Shannon Diversity (H’)	Evenness (J)
Dry	28a	1.00±0.60a	0.52±0.18a
Wet	13b	0.46±0.37b	0.53±0.22a

* Means within a column followed by the same letter are not significantly different

2.3.2.4 Correlations of Macrophytes with Environmental Variables

Results of RDA showed that five of the environmental factors (pH, conductivity, nitrate, total phosphorous and soluble reactive phosphorous) were the main determining factors that governed the distribution of macrophytes in Lake Koka. The first two axes explained

92.6% of the species-environment relation while axis 1 only explained 81.2%. pH had significant positive correlation with axis 1 and determined the distribution of *P. decipiens* and *E. crassipes*. On the other hand, conductivity and nitrate were strongly and negatively correlated with axis 1 and determined the distribution of most of the macrophytes. Soluble reactive phosphorous was also strongly and negatively correlated with axis II and predicted the distribution of most macrophytes. RDA supports the result obtained with ANOVA and the physicochemical parameters conductivity, nitrate, total phosphorous and soluble reactive phosphorous characterize Awash I site (**Table 2.6 and Fig. 2.3**).

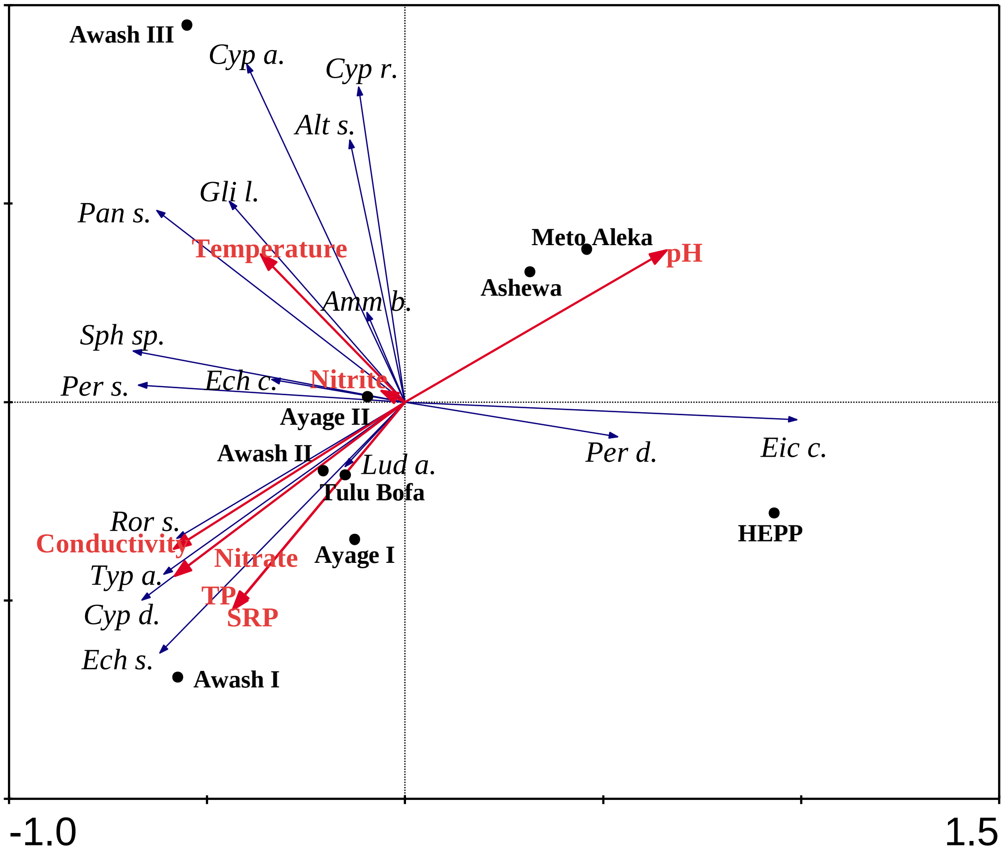


Figure 2. 3 Redundancy analysis (RDA) diagram of macrophytes in relation to water physicochemical properties and sites (sites not abbreviated, except HEPP)

(Abbreviations: *Alt s. - Alternanthera sessilis, Amm b. - Ammannia baccifera, Cyp a. - Cyperus articulatus, Cyp d. - Cyperus dives, Cyp r. - Cyperus rotundus, Ech c. - Echinochloa colona, Ech s. Echinochloa stagnina, Eic c. - Eichhornia crassipes, Gli l. - Glinus lotoides, Lud a. - Ludwigia adscendens, Pan s. - L. caerulescens, Per d. - Persicaria decipiens, Per s. - Persicaria senegalensis, Ror s. - Rorippa sinuata, Sph sp. - Sphaeranthus sp., Typ a. - Typha angustifolia,* TP – total phosphorous, SRP – PO_4-P, Nitrite NO_2-N, Nitrate – NO_3-N and HEPP – Hydro Electric Power Plant)

Table 2. 6 Correlation table of physicochemical parameters with the first two axis (strong correlations are marked bold at $p < 0.05$)

Environmental Variables	**Axis 1**	**Axis 2**
Eigenvalues	0.78	0.1
Cumulative percentage variance of species-environment relation	81.2	92.6
pH	**0.66**	0.36
Temperature	-0.36	0.36
Conductivity	**-0.58**	-0.35
Nitrite (NO_2-N)	-0.06	-0.02
Nitrate (NO_3-N)	**-0.58**	-0.42
Total Phosphorous (TP)	-0.43	**-0.50**
Soluble Reactive Phosphate (PO_4-P)	-0.43	**-0.50**

2.4. Discussion

2.4.1 Environmental Variables

Comparison of the result from this study with results from other lakes indicated that the pH of Lake Koka water was comparable with the two Ethiopian Rift Valley Lakes (Hawassa and Ziway). However, concentration of NO_2-N in Lake Koka was 17-75 times higher than Lake Ziway. Similarly, NO_3-N in Lake Koka (0.25-3.68 mgL^{-1}) was 41-83 times higher than Lakes Ziway and Hawassa. But the levels of total phosphorous and soluble reactive phosphorous in Lake Koka were lower than Lakes Ziway and Hawassa (**Table 2.7**). This might be attributed to the presence of water hyacinth that absorb high levels of nutrients (Petrucio and Esteves, 2000) and variation in using nitrogen and phosphorous fertilizers for agricultural activities. The analysis of ANOVA indicated that higher values of conductivity, nitrate and soluble reactive phosphorous were recorded at Awash sites (I, and II) and this might be associated with the presence of floriculture farm that directly discharge its waste into the lake (**Plate 2.1**). Several authors have reported that floriculture farms are responsible for the discharge of wastes with high concentration of nutrients (Mulugeta Getu, 2009; Degytnu Tilahun, 2012; Sisay Misganaw and Seyoum Leta, 2017). Similarly, the high values of nutrients at Ashewa, Meto Aleka and Tulu Bofa sites might be attributed to the associated agricultural activities and livestock grazing (Zia *et al.*, 2013) in these localities. However, HEPP which is relatively protected from human interference had lower value of conductivity, nitrate and soluble reactive phosphorous.

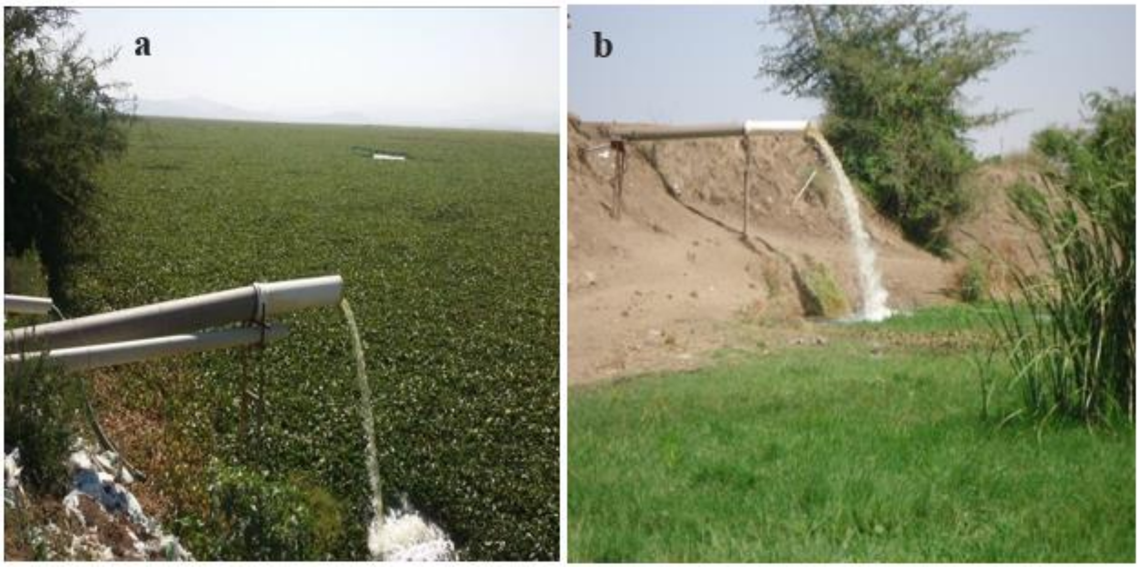


Plate 2. 1 Discharge of floriculture waste into Lake Koka a) wet season, b) dry season

Table 2. 7 Comparison of physicochemical parameters of Lake Koka with other Ethiopian Rift Valley Lakes

Lakes	**pH**	**Temperature** (ºC)	**Conductivity** (µS/cm)	**Secchi** (cm)
Koka[1]	7.85 - 8.80	21.8-27.2	78.3-496	9-28
Ziway[2,3]	7.85 – 8.72	22.4– 27.9	399 - 478	11.3 - 35.0
Hawassa[2]	8.66	23.5	844	85
Lakes	**NO_2-N**(mgL^{-1})	**NO_3-N**(mgL^{-1})	**TP**(μgL^{-1})	**PO_4-P**(μgL^{-1})
Koka[1]	0.15-0.34	0.25-3.68	0.17-1.64	0.04-0.28
Ziway[2,3]	0.002-0.02	0.00-0.09	68.5	10.1-64.5
Hawassa[2]	-	0.003	34.1	15.4

[1]This study; [2]Girma Tilahun and Ahlgren (2010); [3]Girum Tamire and Seyoum Mengistou (2012) (TP = Total Phosphorous)

2.4.2 Macrophyte Diversity

In this study, 28 macrophyte species belonging to 15 families were identified. This was higher than the other Rift Valley Lakes, Ziway (14 spp.) (Girum Tamire and Seyoum Mengistou, 2012) and Hawassa (5 spp.) (Pattnaik, 2014; Lalisa Gemechu, 2018) but fewer than the highland Lake Tana (30 spp.) (Yezbie Kassa, 2016). This variation might be due to the difference in nutrient deposition (**Table 2.7**), sampling effort and frequency and nature of the lakes. Unlike the findings of the above authors, no submerged macrophytes were recorded in Lake Koka and the most likely cause for this might be the turbid nature of the lake (Melaku Mesfin *et al.*, 1988; Fasil Degefu *et al.*, 2011) as compared to Lake Hawassa, Ziway (**Table 2.7**) and Tana (Ayalew Wondie, 2006; Adane Melaku, 2017). Different authors have stated water transparency or turbidity as one factor which limit the diversity and abundance of submerged macrophytes (Lougheed *et al.*, 2001; Nurminen, 2003a).

The most dominant families were Cyperaceae and Poaceae each represented by 6 (21.4%) species. The dominance of these families might be related with advantage of the recession of the water during the dry period, in which the species in these families grew and flourished (**Plate 2.2**). Most families were represented by single species indicating the uneven distribution of macrophytes in the lake. *E. crassipes* occurred at all sites and was the dominant macrophyte with relative frequency of 17.4% and density of 70.7% followed by *L. caerulescens*, *E. stagnina*, and *C. dives*. The density of *E. crassipes* was 260 m^{-2} (258 m^{-2} in the lake and 289 m^{-2} in the dam) which is lower than the report from Firehun Yirefu *et al.* (2014) who reported 298 m^{-2} in the lake part and 308 m^{-2} in the dam part. The variation might be due to the difference in the sampling time where difference in the extent of wind, waves, rainfall and water level may displace the plants (Ngari *et al.*, 2009) affecting its abundance. In support of this, Albright *et al.* (2004) reported that heavy winds and waves associated with heavy rain significantly contribute to the variation in extent of *E. crassipes* (Water hyacinth) infestation and mat-size in Lake

Victoria basin. However, variation in sampling effort and frequency might be also one reason for the difference in the two results. In comparison with infestation level in other Ethiopian Lakes and Dams, the density of *E. crassipes* in Lake Koka was higher than Aba-Samuel dam, Melka Hida, Lake Taree, Lake Elltoke and Lake Abaya but lower than Lake Ellen (Firehun Yirefu *et al.*, 2014). Even though *T. angustifolia* mostly occurred only at two sites (Awash I and Ayage I), it had also higher relative frequency (5.31%) and density (1.51%) **(Table 2.3)** and was dominant at these sites.

In comparison with other Ethiopian Rift Valley Lakes, Hawassa dominated by *Paspalidum germinatum* (Lalisa Gemechu, 2018) and Ziway dominated by *Arundo donax* (Girum Tamire and Seyoum Mengistou, 2012), *E. crassipes* was the dominant macrophyte in Lake Koka followed by *L. caerulescens*, *E. stagnina* and *C. dives*. The high nutrient concentration in Lake Koka (**Table 2.7**) may create favorable condition for *E. crassipes* to flourish and outcompete the other species. The dominance of *E. crassipes* in the lake was revealed by the low evenness value at each site. Even though Lake Ziway had lower taxa richness than Lake Koka, the Shannon diversity index (H=1.805) (Girum Tamire and Seyoum Mengistou, 2012) was higher than Lake Koka (H=1.10) which might be attributed to the low evenness value in Lake Koka. Generally, the lower light transparency and higher nutrient concentration in Lake Koka may be the reason for the variation in the macrophytes assemblages between these lakes. In addition, variation in the sampling effort and frequency might also play role for the variation. For instance, 199 quadrate samples were considered for this study while the corresponding value for the study on Lake Ziway was only 123 (Girum Tamire and Seyoum Mengistou, 2012).

Even though HEEP site is protected from human interference, it had significantly lower values of species richness (5) and Shannon Diversity Index (0.15) than most sites and this might be attributed to the high depth at this site which favored only the floating *E. crassipes* and some other species that can grow high and attached to the *E. crassipes* mat. This is supported by findings from different authors (Khedr, 1996; Fernández-Aláez *et al.*, 1999; Capers *et al.*, 2010) who reported water depth as one factor governing changes in species composition. More specifically, Topuzović *et al.* (2009), in their study on distribution of macrophytes in the Gruža Reservoir (Serbia) indicated that the greatest diversity and abundance of species can be found in shallowest parts of the reservoir. Despite the higher taxa richness at Meto Aleka (20), the site exhibited significantly lower evenness value than Awash I and II sites. This might be due to the high anthropogenic activity at Meto Aleka site (**Table 2.1**) that reduce the abundance of the other species and favor total dominance of *E. crassipes*. *E. crassipes* dominance also affected the abundance of other macrophytes (Villamagna and Murphy, 2010; Wang and Yan, 2017) and in turn even distribution of macrophytes at these localities.

Significant seasonal variations in taxa richness and Shannon diversity were observed ($p<0.05$); the dry season having significantly higher value [(28) and (1.00±0.61)], respectively. The possible reason for this might be the great variation in the water level between the two periods **(Plate 2.2)** which was responsible for the total absence of families Asteraceae, Boraginaceae, Brassicaceae, Chenopodiaceae, Lythraceae, Malvaceae, and Molluginaceae during the wet period due to being totally submersed in the water. However, during the dry period, as the water recedes, these families got a chance to flourish again. But the other species survive during the wet period as they can grow taller and taller together with the increasing water level. This result concur with the findings of Thomaz *et al.* (1999) who reported that highly variable hydrological regime caused by frequent fluctuations in reservoirs for hydroelectricity generation affected species richness. Moreover, Dar *et al.* (2014) indicated that reduction in water levels could bring drastic changes in the species composition and distribution of macrophytes. Contrary to the result of this work, Lake Ziway did not display seasonal variation in macrophyte diversity and abundance (Girum Tamire and Seyoum Mengistou, 2012) and this might be attributed to the low water level fluctuation between the two seasons as compared to the significant variation in the artificial Lake Koka.

Plate 2. 2 Water level fluctuation and associated change in macrophyte coverage

a) Awash I wet season, b) Awash I dry season, c) Meto Aleka wet season, d) Meto Aleka dry season

2.4.3 Environmental Variables as Determinants of Macrophyte Abundance

The RDA species-environment analysis (**Fig. 2.3**) showed that pH and conductivity and nitrate ere the most important predictors of macrophyte species distribution in Lake Koka. This result concur with the findings of several authors (Mäkelä *et al.*, 2004; Capers *et al.*, 2010; Sousa *et al.*, 2011; Kõrs *et al.*, 2012). The RDA result also showed nitrate and soluble reactive phosphorous as predictors of macrophyte distribution in Lake Koka. This is also supported by the findings of different authors (Bini *et al.*, 1999; Lougheed *et al.*, 2001; Nurminen, 2003a; Sousa *et al.*, 2011; Dar *et al.*, 2014) who reported that nutrient enrichment (particularly nitrate and phosphate) as a possible cause of significant changes in the species richness, and density of aquatic vegetation. In this study, macrophytes including *A. baccifera, C. dives, E. colona, E. stagnina, L. adscendens, P. senegalensis, R. sinuata, T. angustifolia,* were strongly associated with high conductivity and nutrient conditions (soluble reactive phosphorus and nitrate). However, the emergent *P. decipiens* and free-floating *E. crassipes* were associated with high pH.

CHAPTER 3: EFFECTS OF FLOATING AND EMERGENT MACROPHYTES ON SEDIMENT DEPOSITION AND RE-SUSPENSION IN LAKE KOKA, ETHIOPIA

3.1 Introduction

Aquatic macrophytes and sediment dynamics are strongly interrelated (Li *et al.*, 2016). In water bodies with erosion and sedimentation problems, macrophytes play role in reducing shoreline erosion, trapping sediments and associated nutrients (Horppila and Nurminen, 2003; Li *et al.*, 2008; Chao *et al.*, 2010) by reducing turbulence (Barko *et al.*, 1991; Chao *et al.*, 2010) and water velocity (Madsen *et al.*, 2001; Nolte *et al.*, 2013). In doing so, they also prevent sediment re-suspension and enhance water quality (Dieter, 1990; Horppila and Nurminen, 2003). Several authors reported that aquatic ecosystems with vegetated littoral regions generally had higher sediment deposition and lower re-suspension rate than non-vegetated regions (Madsen *et al.*, 2001; Schulz *et al.*, 2003; Li *et al.*, 2016).

Studies on efficiency of wetlands to retain suspended solids entering into a water body reported a trapping efficiency of 55-80% (Knight *et al.*, 1987; Mitsch and Reeder, 1992). Moreover, Rooney *et al.* (2003) indicated that in lakes in which half of the sediment surface is colonized by submerged macrophytes, the littoral zone accounts for roughly two thirds of whole-lake bulk sediment accumulated annually. Re-suspension related study in Lake Taihu, China, indicated that macrophytes provided strong abatement of sediment re-suspension reducing its rate by up to 29-fold (Zhu *et al.*, 2015). Chao *et al.*

(2010) also reported that with vegetation, bed shear stress is reduced by about 20% - 80%, which, in turn, reduces sediment suspension.

However, efficiency of macrophytes in restraining re-suspension vary among species and growth forms (Li *et al.*, 2008). This might be due to the variation in the architecture and distribution of plant tissue over the water column (Vermaat *et al.*, 2000). For instance, Horppila and Nurminen (2005b) studied the efficiency of three different life forms and reported re-suspension rate for both submerged and emergents was on average 43% of that in the adjacent open water, while the corresponding value within floating-leaved was 87%. Moreover, Li *et al.* (2008) studied two submerged macrophytes (*Potamogeton maackianus* and *Vallisneria spinulosa*) and found *P. maackianus* to be more effective in restraining sediment re-suspension. But compared to submerged macrophytes, the influence of emergent and floating macrophytes on sediment dynamics have been studied less (Nurminen, 2003b; Li *et al.*, 2016) and in lakes with low or no submerged macrophytes, the emergent and floating macrophytes should not be overlooked.

Nowadays, many parts of Ethiopia are experiencing deforestation, poor soil and improper farming techniques resulting in excess sediment and nutrient loads (Julien and Shah, 2005). Due to this, reservoir and lake sedimentation is a serious problem in the country (Mesfin Mergia *et al.*, 2015). Most modeling studies and also reviews on reservoirs (Nigussie Haregeweyn *et al.*, 2006; Devi *et al.*, 2008; Takele Zeleke *et al.*, 2013), on lakes (Fasikaw Atanaw *et al.*, 2016; Teklu Gebretsadik and Kassahun Mereke, 2017) and on different basins (Seleshi Bekele *et al.*, 2009; Agizew Nigussie, 2010) indicated the severity of sedimentation problem in Ethiopia. Despite the serious sedimentation problem, only few management studies have been conducted: Mesfin Mergia *et al.* (2015) on constructing dams and Mulatie Mekonnen (2016) on indigenous grass species and sediment storage dams as a management option. Hence, sedimentation studies in freshwater ecosystems are still in their infancy and there is a need for biological management options.

Lake Koka is one of the water bodies in Ethiopia, which is heavily affected by sediment load that comes from the inflowing rivers (Julien and Shah, 2005; Kebede Wolka, 2012). The total sediment deposited in the reservoir part of the lake in the period 1961-1981 has been estimated at 0.34 km^3, yielding an average of 17 Mm^3 yr^{-1} (Muluneh Imru, 1992). This volume corresponds to a trap efficiency of 95% and to a general rise of the reservoir's initial bed by 3 m. The capacity of the reservoir has declined from 1650 Mm^3 in 1959 to 1186 Mm^3 due to sedimentation over the years. The loss of total storage capacity is estimated to be 464 Mm^3, which is 28.1% of the total storage volume of the reservoir (Shahin, 1993). The same author stated in 1993 that under the current rules of operation, the reservoir would not be able to function effectively after the next 16 years or so (which corresponds to ca. 2010). Yet, presently in 2019, the reservoir is still operating. It was therefore hypothesized that sediment trapping by macrophytes in the upper catchment of the lake could be partly responsible for sediment reduction and elongation of the decommissioning date of the reservoir.

In this study, a sediment trap field experiment was performed in Lake Koka. For the study, four dominant macrophytes communities were selected and their relationship with sedimentation and re-suspension was investigated to test the hypothesis: all the macrophytes promote sediment deposition and prevent re-suspension. The results from this study can be applied to the other lakes and dams of Ethiopia including the Great Ethiopian Renaissance Dam.

3.2 Materials and Methods

3.2.1 Environmental Variables

Simultaneously with deployment and retrieval of sediment traps, measurement of turbidity was conducted with an OAKTON: T-100 Turbidimeter and depth with an ECHOTEST II DEPTH SOUNDER.

3.2.2 Sediment Data

The sediment trapping experiment was conducted at Ayage site (an Island) where there is little human disturbance and the experimental macrophytes are found. At this site, *E. crassipes* was also the dominant macrophytes with a relative abundance of 58.7% followed by *E. stagnina*, *L. caerulescens*, and *T. angustifolia* with a relative abundance of 17.6%, 13.0% and 4.71, respectively (**Appendix 1**). So this four macrophytes were used as an experimental subjects.

3.2.2.1 Trap Anchor or Frame

Traps were attached to a rigid supporting frame work (Flower, 1991), to avoid problems of trap tilt (Gardner, 1985) and to make the collecting area beyond 1 m above the natural sediment surface (Flower, 1991). The metal framework was a modification from Blomqvist (1981) where a surface buoy is attached to it for marking purpose during retrieval (Håkanson, 1984). A brick was tied to the frame to increase the weight and avoid the drift of the frame and the trap by the current and the floating water hyacinth, (Håkanson, 1984). Each frame can hold four PVC sediment trap tubes as replication. The structure of the frame is displayed in **plate 3.1** below.

Plate 3. 1 Modified sediment trap anchor design used in this study

3.2.2.2 Sediment Trap Design

Sediment traps are simple instruments constructed from tubes of varying shapes (i.e cylindrical, funnel or bottleshaped) with a removable vessel attached at the base and have been used in limnological research for different purposes (Schillereff, 2015). Static sediment traps have been successfully used to examine the processes of particle flux and resuspension in aquatic ecosystems. But the quantity and frequency of samples by using sedimet traps is restricted because of deployment and retrieval cost (Muzzi and Eadie, 2002). When used correctly, a sediment trap of good design will measure the downward flux of particles in the water surrounding the trap. Unfortunately there is little agreement as to the proper design of sediment traps (Hargrave and Burns, 1979) and a proper trap protocol is missing (Bloesch, 1996). Sediment traps can be constructed from tubes of varying shapes: cylindrical, funnel or bottleshaped (Schillereff, 2015). But simple cylinder is the most favourable form of sedimet trap in all types of water (Bloesch and Burns, 1980; Gardner, 1980; Blomqvist, 1981; Håkanson, 1984) and is used by different researchers (Horppila and NiemistÖ, 2008; Li *et al.*, 2008; Fortino *et al.*, 2009; Kaitaranta *et al.*, 2013).

In addition to the shape, the dimension: the cylinder height to diameter ratio (aspect ratio) is also critical in trap design (Hargrave and Burns, 1979; Bloesch and Burns, 1980; Håkanson, 1994). Researchers recommend that the appropriate dimension for cylinder is a minimum diameter of 5 cm and aspect ratio of 5:1 in calm conditions and 10:1 in turbulent waters (Hargrave and Burns, 1979; Bloesch and Burns, 1980; Bloesch, 1996). Moreover, Håkanson (1984) indicated that cylinders should have a diameter larger than 4 cm and an aspect ratio larger than 3, but this value should be increased in turbulent waters. So for this study, a PVC tube with an internal diameter of 7 cm and aspect ratio of 10:1 was used. The tops of the traps were 115 cm above the sediment to avoid over estimation due to re-suspension, and upper part of each trap had an external buoyant with a rope of different lengths depending on the depth of the water (**Plate 3.2**).

Plate 3. 2 Sediment trap anchor with PVC tube

3.2.2.3 *In situ* Sediment Trap and Installation

Sediment and seston sampling, and emptying of sediment traps, was conducted 3 times from July to September 2017 at monthly intervals to avoid artificial mineralization and no preservative for preventing decomposition inside the traps were used to avoid problems of chemical reaction (Bloesch and Burns, 1980). Using a wooden boat, the traps were deployed at five sites making eight (8) replication for each site (eight in open water area, eight in *E. stagnina* stand, eight in *Pancium sp*. stand, eight in *T. angustifolia* stand and eight in *E. crassipes* stand). The open water station was used as a reference. The distance between the sites where traps deployed was in the range of 50-100 m. Every month, the traps were retrieved and scrubbed with a brush to remove any attached growth and rinsed with the Lake water. During retrieval, the traps were pulled to the surface at constant rate to avoid problem of re-suspension of the entrapped sediment (Dillon *et al.*, 1990). The abundance of the emergent and floating macrophytes was determined by measuring the changes in their stem density as in Horppila and Nurminen (2005b).

Trap Deployment Trap Retrieval

Emptying Supernatant Emptying Entrapped Sediment

Plate 3. 3 Entrapped sediment sampling

3.2.2.4 Sample Collection and Handling

Upon retrieval of the sediment traps anchors, the PVC tubes were tied off from the anchor, the supernatant water was removed and the bottom sediment was emptied into a polyethylene bag and brought to the laboratory for analysis (**Plate 3.3**). In the laboratory, the contents of the traps were oven dried at 105ºC and weighed. Organic fraction of the entrapped material (f_S) was determined by the loss on ignition at 550ºC (**Plate 3.4**). From each station, four seston samples were taken with a tube sampler, filtered through a GF/C filter and, following filtration, analyzed for loss on ignition (f_T). In addition, four surface sediment samples (topmost 1 cm of the bed sediment) were collected from each stand with a corer (3.5 cm internal diameter) and analyzed for loss on ignition (f_R) (**Plate 3.5**). From the supernatant of each PVC tube, subsamples were taken, filtered through a GF/F to determine the dry weight of the suspended matter in the supernatant.

Plate 3. 4 Entrapped sediment sample analysis

Plate 3. 5 Surface sediment sampling and laboratory analysis

3.2.2.5 Determining Sedimentation and Re-suspension Rates

The values of gross sedimentation rate (S) was calculated by subtracting the dry weight of suspended matter, contained by the water volume in each trap, from the gross dry weight per trap following Gasith (1975) cited in Horppila and Nurminen (2005b). The re-suspension rate at each location was calculated using the method by Gasith (1975) cited in Horppila and Nurminen (2005b). This method is preferable in lakes where there are cyanobacterial blooms (Horppila and Nurminen, 2005a) and is based on the assumption that the content of organic matter in the bottom sediment differs from that of suspended seston. The method uses the following equation:

$$R = S\,\frac{(f_S - f_T)}{(f_R - f_T)}$$

Where

R is the sediment re-suspension rate (g DW m^{-2} d^{-1})

S is the entrapped settling flux (g DW m^{-2} d^{-1})

f_S is the organic fraction of gross sedimentation (S)

f_R is organic fraction of R (surface sediment) and

f_T is the organic fraction of seston (T) suspended in the water (James and Barko, 1991; Nurminen, 2003b; Horppila and Nurminen, 2005b).

3.2.3 Data Analysis

The variation in the environmental variables, rate of sedimentation and re-suspension among the macrophyte stands (sampling stations) was tested using one-way analysis of variance (one-way ANOVA). The validity of the applied method was tested by comparing the values of f_R and f_T at the macrophytes stand using paired-sample t-test and hence the method of Gasith (1975) cited in Horppila and Nurminen (2005b) was found to be applicable for this study. All the statistical analysis and graphing were made using R programming language version 3.4.2.

3.3 Results

The efficiency of four macrophyte species in trapping sediments and magnitudes and patterns of sediment re-suspension along these species were assessed in Lake Koka, Ethiopia. The assessment was based on analyses of sediment trap collections for three months over the rainy season of 2017.

3.3.1 Environmental Variables

The role macrophytes play depends on different environmental factors (Maltchik *et al.*, 2007; Ngari *et al.*, 2009; Dar *et al.*, 2014) like depth and turbidity. In this study, the depth at the macrophyte stands ranged from 2.13±0.21 m (*L. caerulescens*) to 2.93±0.30 m (*T. angustifolia*). Turbidity was also in the range of 402.29±71 NTU (*E. stagnina*) and 455.33±75 NTU (open water). But the results of analysis of variance indicated that these parameters did not vary significantly among the sampling stations ($p > 0.05$).

3.3.2 Role of Macrophytes in Trapping Sediment and Preventing Re-suspension

In this study, an attempt was made to determine the efficiency of the four dominant macrophytes in trapping sediment and reducing re-suspension. The density of the macrophytes (number of stems m^{-2}) was 23, 74, 116 and 179 for *T. angustifolia*, *E. crassipes*, *E. stagnina* and *L. caerulescens*, respectively.

3.3.2.1 Concentration of Suspended Solids at the Macrophyte Stands

The mean concentration of SS was 0.13 g DW L^{-1} in July increased to 0.15 g DW L^{-1} in August and had fallen to 0.08 g DW L^{-1} in September **(Table 3.1**). Concentration of SS among the sampling months showed significant variation ($P < 0.0001$; $F = 10.411$; df =

2): the concentration in September being significantly lower than the other two months. However, the difference among the sampling stations and the interaction between sampling station and months was not significant (P = 0.074; F = 2.198; df = 4 and P = 0.583; F = 0.824; df = 8, respectively).

Table 3. 1 Concentration of suspended solids (g DW L^{-1}) in each macrophyte stand (N=24) and month (N=40) in Lake Koka, Ethiopia

Macrophyte species	**Period of incubation**		
	Jul.	**Aug.**	**Sept.**
T. angustifolia	0.12±0.03	0.14±0.00	0.07±0.03
E. stagnina	0.10±0.01	0.14±0.02	0.06±0.03
L. caerulescens	0.10±0.01	0.14±0.01	0.09±0.04
E. crassipes	0.20±0.24	0.15±0.01	0.10±0.01
Open water	0.11±0.03	0.16±0.01	0.08±0.04

3.3.2.2 Organic Fraction

The organic fraction of the entrapped material (f_S) fluctuated between 10.1% and 11.5% in the macrophyte stands and was 13.5% in the open water station. The f_S was influenced by sampling stations (P = 0.001; F = 4.924, and df = 4); the open water station having value significantly higher than the other stations except at the *E. crassipes*. The organic fraction of surface sediment (f_R) significantly varied among the sampling stations ($P < 0.0001$; F = 104.6, and df = 4). It fluctuated between 7.66% and 21.9% in the macrophyte stands and was significantly higher compared with the open water station (4.44%). The order of f_R within the stations was *T. angustifolia* = *E. stagnina* > *E. crassipes* = *L. caerulescens* > open water station. But the organic fraction of suspended seston (f_T) was not influenced by vegetation type and absence (P = 0.067; F = 2.26; df = 4) (**Table 3.2**).

Table 3. 2 Organic fraction (%, ± SD) of surface sediment (f_R), entrapped material (f_S) and suspended solids (f_T) in the different macrophytes stands (N=24) in Lake Koka, Ethiopia

Sampling stations	Surface sediment (f_R)	Entrapped material (f_S)	Suspended solids (f_T)
T. angustifolia	21.9±0.07c	10.2±0.03a	1.92±0.01a
E. stagnina	20.5±0.04c	10.1±0.02a	1.79±0.01a
L. caerulescens	7.66±0.01b	10.8±0.02a	2.04±0.01a
E. crassipes	8.25±0.02b	11.5±0.02ab	2.48±0.01a
Open water	4.44±0.01a	13.5±0.05b	2.03±0.01a

* Means within a column followed by different letters are significantly different ($P < 0.05$)

3.3.2.3 Sedimentation and Re-suspension Rates at the Macrophyte Stands

The sedimentation rate at the sampling stations ranged from 3.74±0.34 (open water station) to 17.96±1.5 g DW m^{-2} d^{-1} (*E. stagnina*) (**Fig. 3.1**). Macrophyte type and presence/absence had a significant influence on sedimentation rate ($P < 0.0001$; $F = 27.171$; df = 4; Fig. 2). All the macrophytes significantly increased sedimentation compared with the non-vegetated area. But among the macrophytes, sedimentation within the *E. stagnina* and *T. angustifolia* plants was higher than that of *L. caerulescens* and *E. crassipes* indicating the former two species had greater sediment trapping efficiency. Moreover, the sedimentation rate at the open water station was on average 22.6% of the *T. angustifolia* and *E. stagnina* while the corresponding value for *L. caerulescens* and *E. crassipes* was 43%.

Similarly, both macrophyte type and presence/absence significantly influenced sediment re-suspension ($P < 0.0001$; $F = 13.642$; df = 4; **Fig. 3.1**). All the macrophytes significantly reduced sediment re-suspension compared with non-vegetated area. Re-suspension among the four macrophyte communities also differed significantly and the order of re-suspension among the macrophyte communities was *E. crassipes* = *L. caerulescens* > *E. stagnina* = *T. angustifolia*. The relative re-suspension rate indicated that re-suspension within *T. angustifolia* and *E. stagnina* was on average 36.4% of the open water station while the corresponding value for *L. caerulescens* and *E. crassipes* was 70.9% **(Fig 3.1**). Hence, *T. angustifolia* and *E. stagnina* had a higher ability to restrain sediment re-suspension than the other two species.

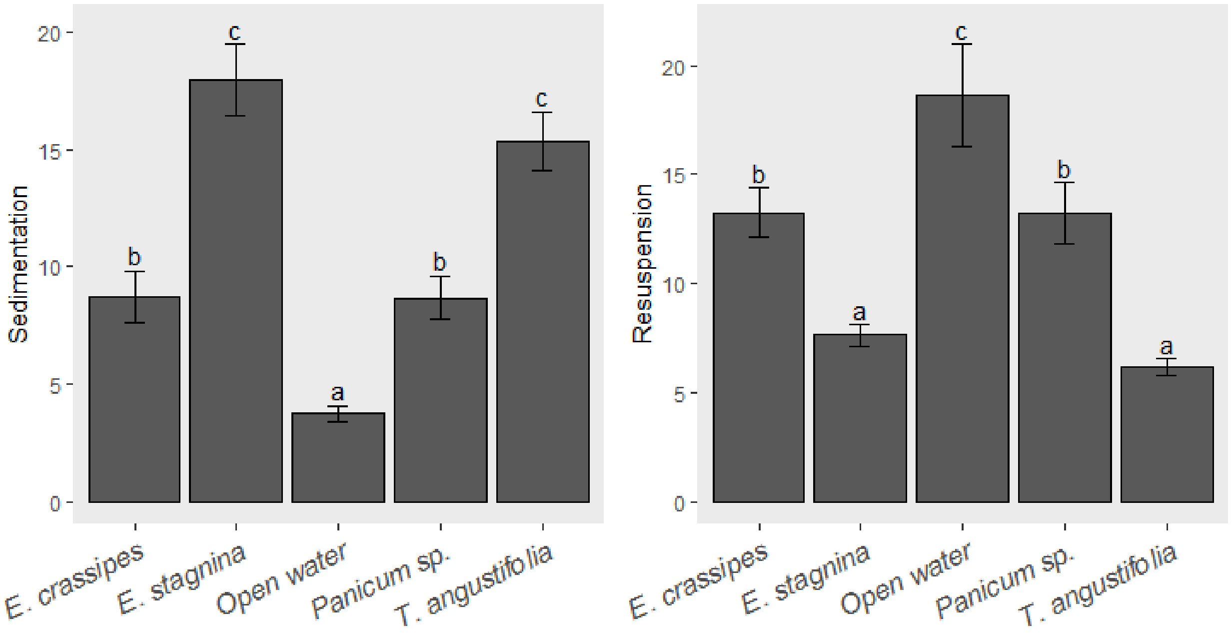


Figure 3. 1 Variation in daily sedimentation and re-suspension rates (g DW m-2 day-1) among the macrophyte stands (mean ± SE, n=24) in Lake Koka, Ethiopia (groups followed by different letters are significantly different at the 0.05 significance level)

3.4 Discussion

3.4.1 Environmental Variables

Bloesch (1982) and Brueske and Barrett (1994) indicated that depth is one factor that determined sediment deposition and re-suspension. But in this study, depth had no significant variation among the sampling stations and hence its effects on sedimentation could not be detected. Results of reduced turbidity in the presence of macrophyte have been reported by different authors (Dieter, 1990; Madsen *et al.*, 2001; Horppila and Nurminen, 2003) which can be attributed to the macrophytes. Their filtration effect (Brix, 1994) and ability to change the turbulence intensity leading to reduced water turbidity and increased water transparency (Chao *et al.*, 2010). Contrary to this, in this study, turbidity was not influenced by the presence or absence of macrophytes and this can be explained by the insignificant variation in the concentration of suspended solids among the sampling stations.

3.4.2 Role of Macrophytes in Trapping Sediment and Preventing Re-suspension

Sediment dynamics in aquatic ecosystems have been widely studied and one factor that affect its dynamics is presence of macrophytes (Brix, 1994; Brueske and Barrett, 1994). In a trial to determine the efficiency of different macrophytes in facilitating sedimentation and restraining re-suspension, the organic fraction of surface sediment, entrapped material and suspended seston was determined. As in the results from different authors (Sand-Jensen, 1998; Madsen *et al.*, 2001), results from this study demonstrated that the organic fraction of surface sediment (f_R) was influenced by the presence or absence of macrophytes in that f_R at the open water station was lower than that of at the macrophyte stands. This can be attributed to the macrophytes capacity to provide a low-energetic environment where organic seston can easily settle. But it is also possible for the macrophytes to directly contribute to the formation of organic sediments (Schulz *et al.*, 2003).

In this study, sedimentation rate in all four macrophyte stands was higher compared to the open water station which is in agreement with our hypothesis. Studies on the importance of aquatic macrophytes on sediment dynamics reported that sediment deposition rate was highest in vegetated areas (Braskerud, 2001; Schulz *et al.*, 2003; Mudd *et al.*, 2010) where macrophytes reduce current velocities and attenuate wave energy resulting in increased sedimentation (Madsen *et al.*, 2001; Wetzel, 2001). The result from this study also showed that the emergent *E. stagnina* and *T. angustifolia* were more efficient in trapping sediment than the other emergent *L. caerulescens* and the floating *E. crassipes*. This accords with the results from several authors who reported macrophytes efficiency in promoting sedimentation vary based on species and growth forms (Vermaat *et al.*, 2000; El-lil, 2006; Li *et al.*, 2016). This could be due to the substantial variation in the architecture and distribution of plant tissues over the water column among growth forms and species (Vermaat *et al.*, 2000; Horppila and Nurminen, 2005b).

The higher efficiency of *E. stagnina* might be due to its morphology which form dense mats with its creeping rhizomes and extensively decumbent stem that is branched at the base and rooted at the nodes (Cook, 2004). Similarly, the high sediment retention capacity of *T. angustifolia* might be due to thick corm like stem (Cook, 2004) which cannot easily be compressed by the current reducing its interaction area with the water column. In a similar study in Lake Hiidenvesi, Finland (Horppila and Nurminen, 2001) high sedimentation rate was reported in the emergent *T. angustifolia* stands. On the contrary, the lower sediment retention capacity of the *L. caerulescens* might be due to its soft, erect and thin culm rooting at some lower nodes (Cook, 2004). Thus it can easily be compressed by the water current reducing its interaction area with the water column leading to low sediment trapping ability. In this study, *E. crassipes* had also low sediment retention capacity and this can be attributed to its floating nature (Masifwa *et al.*, 2001) which cannot protect the water current from eroding or re-suspending the sediment bed.

A study to determine the roles of three emergent macrophytes in promoting sedimentation in Dongting Lake, China, Li *et al.* (2016) reported that plant density is significantly correlated with rate of sedimentation. In addition, Madsen *et al.* (2001) indicated that areas with dense beds of macrophytes have high sedimentation. Contrary to this, in this study, low sedimentation rate (8.67 g DW m^{-2}) was recorded at the *L. caerulescens* which had higher stem density (179 stems m^{-2}) than the others. This might be due to the influence of the high density on the water flow resistance as water flow prefers sparsely vegetated areas (Brueske and Barrett, 1994).

Sediment re-suspension occurs in lakes of different sizes due to water turbulence and bed shear stress (Chao *et al.*, 2010) and is an important internal process with regard to nutrient cycling, turbidity and water column production (Fortino *et al.*, 2009). Previous studies have shown that the intensity of sediment re-suspension is influenced by macrophyte coverage (Dieter, 1990; Madsen *et al.*, 2001; Huang *et al.*, 2007; Zhu *et al.*,

2015) because of their effect in moderating the effect of wind waves (Chao *et al.*, 2010; Horppila *et al.*, 2013). For instance, Dieter (1990) reported that in shallow lakes (South Dakota), re-suspension in areas protected by emergent vegetation was only one-third of the rate in the open water. Zhu *et al.* (2015), in their study on the effect of macrophytes on sediment re-suspension in shallow large lake (Lake Taihu, China) also reported that the occurrence of macrophytes may reduce sediment re-suspension up to 29-fold. In this study, the effectiveness of four macrophyte species was tested and the findings accord with such results. On average 10.07 g DW d^{-1} sediment was re-suspended in the vegetated area and 18.67 g DW d^{-1} in the open area indicating that all the macrophytes substantially decreased re-suspension rate as compared to the open water station. This is also in agreement with our hypothesis.

Similar to sedimentation, the effect of macrophytes on sediment re-suspension vary among growth forms (Horppila and Nurminen, 2005b) and species (Horppila and Nurminen, 2003) due to the variation in the architecture and distribution of plant tissues over the water column (Horppila and Nurminen, 2003). The findings of this study agree with such results in that *E. stagnina* and *T. angustifolia* being highly efficient in restraining reuspension than the other two species. This might be due to the structrural complexity of these two macrophytes (Cook, 2004) which is described above. Similar species-specific and growth form variation in restraining sediemtation have been reported by several authors (Horppila and Nurminen, 2003; Horppila and Nurminen, 2005b; Li *et al.*, 2008). For instance, Li *et al.* (2008), in their research to study the effect of different submerged macrophyte species on sediment re-suspension, reoprted that *Potamogeton maackianus* was more efficient than *Vallisneria spinulosa*. Moreover, Horppila and

Nurminen (2005b) studied the effects of different macrophyte growth forms on sediment re-suspension and found the effects of floating-leaved species to be weaker than emergent and submergent macrophytes. In this study, the re-suspension rate at *E. stagnina* and *T. angustifolia* stands was on average 36.4% of the open water station while the corresponding value at the floating-leaved *E. crassipes* was 70.9%. The emergent *L. caerulescens* had comparable efficiency with *E. crassipes* and this might be due to its architecture (Cook, 2004).

Horppila and Nurminen (2005b) reported that with submergents and emergents, stem density had influence on sediment re-suspension and in the stand of emergents, re-suspension was reduced, when stem density reached 22 stems m^{-2}. Horppila and Nurminen (2001) also reported that *T. angustifolia* (with 10 - 22 stems m^{-2}) reduced re-suspension by 9.7 - 16.4 g DW m^{-2}. Finding is in accordance with the results of the above authors and *T. angustifolia* (with 23 stems m^{-2}) reduced re-suspension by 12.51 g DW m^{-2}. Among the floating-leaved macrophytes, increasing stem density had no strong effects on re-suspension (Horppila and Nurminen, 2005b). In this study too, even though the floating *E. crassipes* had higher stem density (74 stems m^{-2}) than *T. angustifolia* (23 stems m^{-2}), the re-suspension rate was significantly higher for the floating species. This might be because the efficiency of the floating *E. crassipes* depends on the underwater structure rather than the stem above the water column. In conclusion, all the four macrophytes had a considerable effect on retaining sediment and restraining re-suspension, the effect of *E. stagnina* and *T. angustifolia* being stronger than the other two species.

CHAPTER 4: IMPACT OF WATER HYACINTH (*Eichhornia crassipes*) ON WATER QUALITY AND MACRO-INVERTEBRATE COMMUNITY OF LAKE KOKA, ETHIOPIA

4.1 Introduction

The invasion of rivers, dams and lakes throughout Africa by introduced aquatic weeds represents one of the largest threats to the socioeconomic development of the continent. *E. crassipes* is one of the weeds and has been present in Africa since the late 1800s, and its importance has increased since then (Cilliers *et al.*, 2003). In the East African region, the weed was first noticed almost simultaneously in Uganda, Tanzania and Kenya in 1987 (Ogwang and Molo, 1998). In Ethiopia, it was first officially reported in 1956 on Koka Lake and Awash River (Rezene Fessehaie, 2005). Nowadays most part of the lake is covered by the weed particularly during the rainy season (Personal observation) and it is common in various water bodies located at low, mid and high altitudes (Firehun Yirefu *et al.*, 2014). Reports indicated the presence of the weed in Baro, Gillo, and Akobo Rivers (Rezene Fessehaie, 2005) and Lake Tana (Wondie Zelalem, 2013; Dereje Tewabe *et al.*, 2017; Erkie Asmare, 2017).

The presence of *E. crassipes* in a water body may cause serious problems including blockage of water pumps (Aloo *et al.*, 2013), hindrance of fishing activity (Waithaka, 2013; Erkie Asmare, 2017), increase in water borne diseases, increased evapotranspiration, blockage of hydroelectric installations and livestock watering (Yigrem Mengist and Yohannes Moges, 2019). Moreover, several studies elsewhere have documented the impact of *E. crassipes* on different aquatic biodiversity components

(Masifwa *et al.*, 2001; Brendonck *et al.*, 2003; Toft *et al.*, 2003; Villamagna, 2009) and water quality (Gichuki *et al.*, 2012; Mironga *et al.*, 2012; Yongo *et al.*, 2017). Macro-invertebrates are biodiversity components, which are important trophic connections in lake ecosystems by consuming primary producers and other secondary producers, and serving as a food resource for higher trophic level consumers (Merritt and Cummins, 1996). However, invasive macrophytes like *E. crassipes* often have effects on macro-invertebrate communities (Kovalenko *et al.*, 2010).

In Ethiopia, even though *E. crassipes* is expanding in its distribution, only few studies have been conducted about its impact on water quality, biodiversity and socio-economic activity (Firehun Yirefu *et al.*, 2007; Firehun Yirefu *et al.*, 2014; Dereje Tewabe *et al.*, 2017; Wondie Zelalem *et al.*, 2017). In addition, even though Lake Koka is among the first water bodies to be infested by *E. crassipes* (Rezene Fessehaie, 2005), there is no data regarding the impact of the weed on macro-invertebrate and water quality of the lake. the Even though the study was restricted to only one locality, Habtamu Getnet (2019) tried to investigate the impact of the weed on water quality and plankton community of Lake Koka. But to make management decisions, a well-developed understanding of the relationships between macro-invertebrates, other biota and *E. crassipes* is necessary. Therefore, this study tried to investigate the impact of the dominant *E. crassipes* on water quality and macro-invertebrate diversity in comparison with the other dominant emergent macrophyte in the lake (*E. stagnina*). It was hypothesized that *E. crassipes* has negative impact on water quality and macro-invertebrate diversity of Lake Koka and the result may give picture of long-term effects of the weed on the lake.

4.2 Materials and Methods

4.2.1 Site Selection

Sites for this study were selected based on the presence and absence of *E. crassipes* and *E. stagnina* to compare the impact of the invasive species. These two macrophytes were selected since they are the dominant species in the lake and *E. stagnina* was found in many localities than the other dominant *L. caerulescens* (**Table 2.3 and Appendix 1**). Open water stations were selected at each locality to be used as a reference for the water quality study. Based on this criterion, ten sites were selected as described **Table 4.1** and displayed in **Fig. 4.1**.

Table 4. 1 Description of sampling sites (No macro-invertebrate samples from open sites)

Site Name	Abbreviation	Habitat type	Depth
Meto Aleka Shore	MAS	*E. crassipes* mats	70 cm
Meto Aleka Open	MAO	Open water site (without macrophyte)	2.0 m
Awash Shore 1	AWS1	*E. stagnina* stand	70 cm
Awash Shore 2	AWS2	*E. crassipes* mats	70 cm
Awash Open	AWO	Open water site (without macrophyte)	1.5 m
HEPP Shore	HEPPS	*E. crassipes* mats	1.0 m
HEPP Open	HEPPO	Open water site (without macrophyte)	3 m
Ayage Shore 1	AYS1	Island shore covered by *E. crassipes*	70 cm
Ayage Shore 2	AYS2	Island shore covered by *E. stagnina*	70 cm
Ayage Open	AYO	Open water site (without macrophyte)	2.0 m

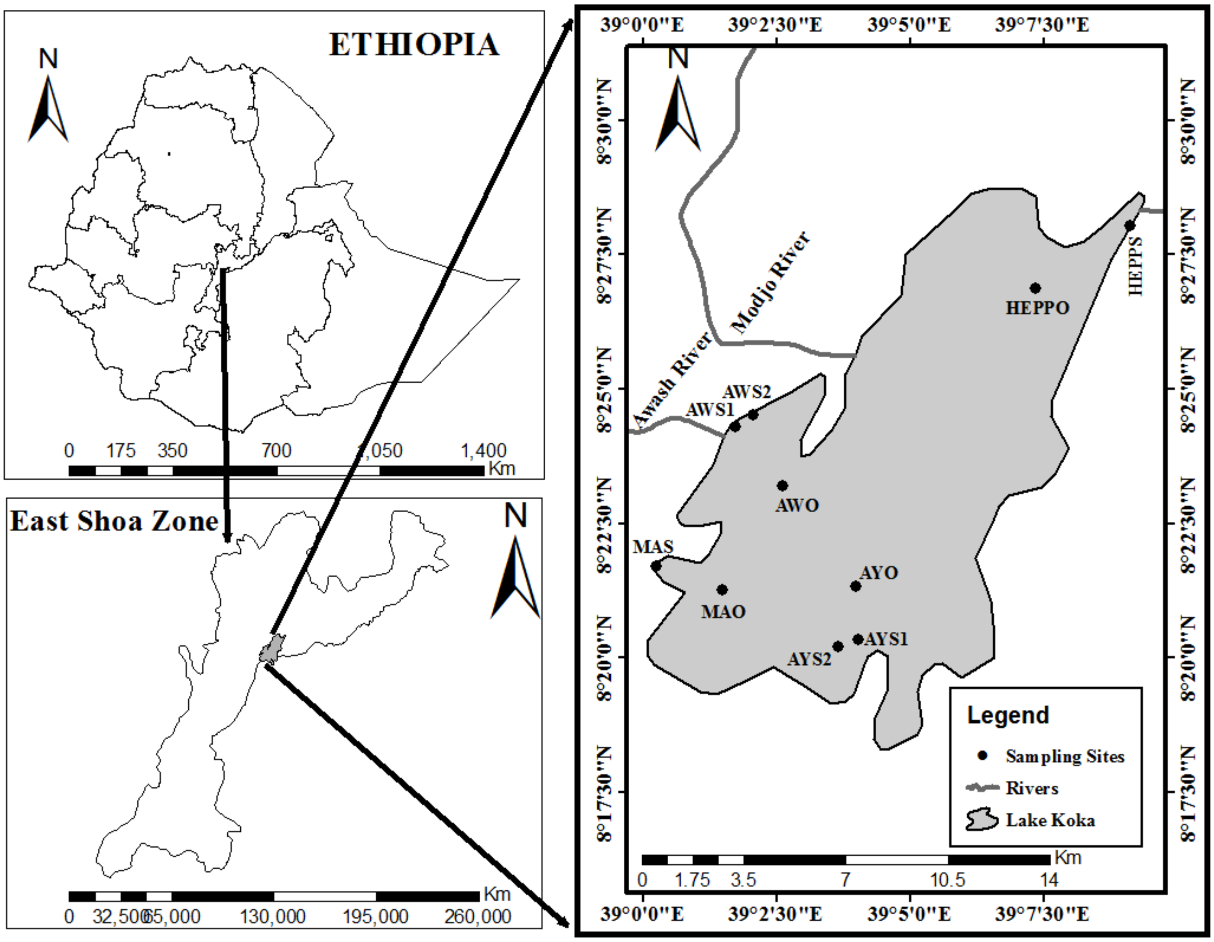


Figure 4. 1 Location of sampling sites on Lake Koka (dam is indicated as HEPP)

(Abbreviations: MAS= Moto Aleka Shore, MAO= Moto Aleka Open, AWS1= Awash Shore 1, AWS2= Awash Shore 2, AWO= Awash Open, HEPPS=Hydro Electric Power Plant Shore, HEPPO=Hydro Electric Power Plant Open, AYS1= Ayage Shore 1, AYS2= Ayage Shore 2, AYO= Ayage Open)

4.2.2 Sampling

Data for physicochemical parameters were collected simultaneously with macro-invertebrates samples monthly from March to June 2017, when the water current was low and *E. crassipes* was stable.

4.2.2.1 Physicochemical Parameters

In situ measurement of temperature (T), pH, electrical conductivity (EC) and dissolved oxygen (DO) was conducted with portable HQ40D Multimeter. For nutrient analysis, composite water samples (by compositing samples from varying depths) at each site were taken in duplicates and transported to laboratory in an icebox. In the Limnological Laboratory of Addis Ababa University, the samples were filtered using GF/F and the nutrients were analyzed spectrophotometrically using a JENWAY 6405UV/Vis spectrophotometer. NO_3-N was analyzed with sodium salicylate method (Robarge *et al.*, 1983), NH_3-N with indo-phenol blue (APHA, 1995), and soluble reactive phosphorous (PO_4-P) with ascorbic acid method (APHA, 1999). NO_2-N concentration was determined by the reaction between sulfanilamide and N-naphthyl-(1)-ethylenediamine dihydrochloride (APHA, 1995). Total phosphorus (TP) from unfiltered samples and silica (SiO_2-Si) were determined using persulfate digestion and Molybdosilicate method, respectively (APHA, 1999).

4.2.2.2 Macro-invertebrate Sampling

To sample macro-invertebrates from the *E. crassipes* and *E. stagnina*, a 25 cm by 25 cm metal frame kick-net with a 500µm mesh size and long wooden handle was used. Macro-invertebrates were collected from *E. crassipes* by submerging the sampling net and sweeping a demarcated quadrat; this quadrat was set up using the surface area of the net (catching area: 625 cm^2). Then, the kick-net was carefully lifted out of the water to prevent the escape of agile animals (Poi de Neiff and Carignan, 1997; De Marco *et al.*, 2001; Kouamé *et al.*, 2011). In addition, care was taken to avoid contact with the lake bottom to prevent collecting benthic organisms, although some mud was inevitably stirred up in the littoral samples (Brendonck *et al.*, 2003). Similarly, care was taken not to sample open water habitats above or surrounding *E. crassipes* to avoid sampling invertebrates in that region (Walker *et al.*, 2013). After pulling the net near the shore, the vegetation projecting outward from the marginal area of the net frame, were cut off (Masifwa *et al.*, 2001). Then, root masses of *E. crassipes* were manually separated from the other parts of the plant (Kouamé *et al.*, 2010), and the macroinvertebrates in the samples were shaken and dislodged from the root masses by vigorously shaking each root sample in a bucket containing 95% alcohol (Gichuki *et al.*, 2012).

In a similar way, macro-invertebrates samples were obtained from *E. stagnina* stand using 60 cm sweep with the net being covered at the end of the sweep to prevent escape or contamination of the sample as the net was removed from the sampling point. Similar care was taken during sampling to avoid sampling of benthic organisms and not to sample open water habitats. Samples were sorted in a white plastic tray with clear water, visible organisms were picked and the remaining material was washed with water through sieves of 500µm to remove the debris and the organisms were finally preserved in 10% formalin in vials (Masifwa *et al.*, 2001; Kouamé *et al.*, 2011).

In the laboratory, all the macro-invertebrates were identified and enumerated to family level using a dissecting microscope and important keys (Clifford, 1991; Jessup *et al.*, 1999; Gooderham and Tsyrlin, 2002; Bouchard, 2004). After identification, each taxon was allocated to a functional feeding group according to their trophic category to know which feeding groups prefer it as a habitat as assigned by Cummins (1973), Merritt and

Cummins (1996), Ramírez and Gutiérrez-Fonseca (2014) for insects, and by Pointier *et al.* (1989) for molluscs.

4.2.3 Data Analysis

Descriptive statistics was used to analyze physicochemical data. The macro-invertebrate composition and structure were evaluated by taxonomic richness (R), abundance and diversity indices. Variation in physicochemical parameters and macro-invertebrate indices among sites was analyzed using one-way ANOVA and then means were separated using Tukey-HSD test. The relationship of macroinvertebrates relative abundance with physicochemical variables was evaluated by redundancy analysis (RDA) using CANOCO for windows 4.5 version Software (Ter Braak and Smilauer, 2002). RDA was used because the species data showed a linear response to the environmental variables and the longest gradient length was less than 3. To reduce the effect of rarity on RDA analysis, families that comprised <1% of the organisms at sampling sites were excluded (Kuchapski and Rasmussen, 2015). The statistical analysis was conducted using R programming language 3.4.2.

4.3. Results

In this section, results of both physicochemical parameters and macro-invertebrate assemblages are presented.

4.3.1 Physicochemical Parameters

Analysis of variance (ANOVA) indicated that the mean values of electrical conductivity ranged from 92.6±4.21 µS/cm (HEPPO) to 322±206 µS/cm (AWS1). Electrical conductivity significantly differ among the sampling sites ($P < 0.05$); Awash sites (1 and 2) having value significantly higher than the other sites. The pH fluctuated between 8.35±0.16 (AWS1) to 8.88±0.02 (HEPPO) and value at AWS1 was significantly lower than HEPPO, AYS1 and AYS2 but not from the other sites ($p<0.05$). Similarly temperature ranged from 24.03±0.36 ºC (HEPPS) to 27.06±0.46 ºC (AYS1) and significantly differ among the sampling sites ($P < 0.05$). The values at HEPPS and AYO were significantly lower than the other sites (**Table 4.2**).

NO_3-N concentration ranged from 0.08±0.01 mgL^{-1} (AYO) to 7.71±1.72 mgL^{-1} (AWS1) and showed significant variation among the sampling sites; AWS1 AWS2 and AWO having value significantly higher than the rest sites ($P < 0.05$). But NH_3-N and dissolved oxygen (DO) did not show significant variation (**Table 4.2**). NO_2-N concentration among the sampling sites ranged from 0.15±0.00 mgL^{-1} (HEPP and Ayage sites) to 0.24±0.03 mgL^{-1} (AWS1) and significantly differ among the sampling sites; AWS1 and AWS2 having significantly higher value than the rest sites except AWO ($P < 0.05$). PO_4-P fluctuated between 0.01±0.00 μgL^{-1} (HEPPO) and 0.25±0.05 μgL^{-1} (AWS1), and showed significant difference among the sites; Awash sites having significantly higher values than all the other sites ($P < 0.05$) (**Table 4.2**).

Table 4. 2 Physicochemical variables measured at each site (Mean ± SD) from March to June 2017 **(**Conductivity in µScm^{-1})

Sites	**pH**	**Temperature** (ºC)	**DO** (mgL^{-1})	**Conductivity**	**NH$_3$-N** (mgL^{-1})
MAS	8.83 ± 0.13^{ab}	27.0 ± 2.50^{b}	7.32 ± 2.27^{a}	150 ± 23.7^{ab}	0.08 ± 0.03^{a}
MAO	8.73 ± 0.26^{ab}	24.7 ± 1.34^{ab}	6.86 ± 1.63^{a}	144 ± 17.9^{ab}	0.10 ± 0.05^{a}
AWS1	8.35 ± 0.55^{a}	27.7 ± 3.52^{ab}	5.59 ± 0.84^{a}	322 ± 206^{c}	0.10 ± 0.08^{a}
AWS2	8.48 ± 0.52^{ab}	25.1 ± 2.94^{ab}	5.60 ± 0.42^{a}	292 ± 178^{c}	0.10 ± 0.08^{a}
AWO	8.67 ± 0.24^{ab}	24.4 ± 2.08^{ab}	6.92 ± 1.05^{a}	220 ± 94.8^{bc}	0.08 ± 0.05^{a}
HEPPS	8.76 ± 0.19^{ab}	24.0 ± 1.24^{a}	6.71 ± 1.05^{a}	92.9 ± 5.31^{a}	0.06 ± 0.01^{a}
HEPPO	8.88 ± 0.05^{b}	24.4 ± 0.95^{ab}	6.83 ± 0.41^{a}	92.6 ± 4.21^{a}	0.05 ± 0.01^{a}
AYS1	8.85 ± 0.54^{b}	27.06 ± 1.61^{b}	6.85 ± 4.81^{a}	130 ± 15.8^{ab}	0.05 ± 0.02^{a}
AYS2	8.84 ± 0.42^{b}	26.4 ± 1.18^{ab}	6.41 ± 3.89^{a}	130 ± 15.4^{ab}	0.05 ± 0.01^{a}
AYO	8.72 ± 0.33^{ab}	24.1 ± 1.12^{a}	8.15 ± 1.14^{a}	130 ± 14.1^{ab}	0.05 ± 0.01^{a}

Sites	**NO$_2$-N**(mgL^{-1})	**NO$_3$-N**(mgL^{-1})	**TP** (µgL^{-1})	**PO$_4$-P**(µgL^{-1})	**SiO$_2$-Si** (mgL^{-1})
MAS	0.16 ± 0.01^{a}	0.29 ± 0.07^{a}	0.37 ± 0.16^{b}	0.03 ± 0.01^{a}	0.15 ± 0.01^{c}
MAO	0.16 ± 0.01^{a}	0.50 ± 0.08^{a}	0.41 ± 0.20^{b}	0.04 ± 0.00^{a}	0.13 ± 0.03^{abc}
AWS1	0.24 ± 0.10^{b}	7.71 ± 5.97^{b}	0.38 ± 0.16^{b}	0.25 ± 0.18^{b}	$0..13\pm0.02^{abc}$
AWS2	0.23 ± 0.08^{b}	7.31 ± 5.59^{b}	0.35 ± 0.15^{b}	0.18 ± 0.14^{b}	0.10 ± 0.06^{ab}
AWO	0.20 ± 0.06^{ab}	4.91 ± 3.75^{b}	0.24 ± 0.15^{ab}	0.17 ± 0.12^{b}	0.11 ± 0.04^{abc}
HEPPS	0.15 ± 0.02^{a}	0.20 ± 0.15^{a}	0.14 ± 0.10^{a}	0.02 ± 0.00^{a}	0.12 ± 0.04^{abc}
HEPPO	0.15 ± 0.01^{a}	0.13 ± 0.05^{a}	0.12 ± 0.07^{a}	0.01 ± 0.00^{a}	0.10 ± 0.00^{ab}
AYS1	0.15 ± 0.01^{a}	0.34 ± 0.23^{a}	0.29 ± 0.06^{ab}	0.02 ± 0.01^{a}	0.14 ± 0.01^{bc}
AYS2	0.15 ± 0.01^{a}	0.36 ± 0.22^{a}	0.30 ± 0.05^{ab}	0.02 ± 0.01^{a}	0.11 ± 0.06^{abc}
AYO	0.15 ± 0.01^{a}	0.08 ± 0.04^{a}	0.28 ± 0.18^{ab}	0.02 ± 0.01^{a}	0.13 ± 0.01^{abc}

* Means within a column followed by the same letter are not significantly different (Tukey test; $p < 0.05$)

(Abbreviations: MAS= Moto Aleka Shore, MAO= Moto Aleka Open, AWS1= Awash Shore 1, AWS2= Awash Shore 2, AWO= Awash Open, HEPPS=Hydro Electric Power Plant Shore, HEPPO=Hydro Electric Power Plant Open, AYS1= Ayage Shore 1, AYS2= Ayage Shore 2, AYO= Ayage Open, TP=Total phosphorous, SD =Standard Deviation)

4.3.2 Abundance and Diversity of Macro-invertebrates

A total 36 820 individuals belonging to 32 taxa were collected from all sites (picture for some displayed in **Appendix 3**). All the 32 taxa were found at the *E. crassipes* mats while only 22 were found at the *E. stagnina* stand. The lowest taxa richness (17) was recorded at the *E. stagnina* stand (AYS2) while the highest (25) was recorded at the *E. crassipes* mats (MAS) and the two macrophytes shared more taxa. Taxa richness did not show significant variation among the macrophyte stands (ANOVA, p>0.05). The mean density of macro-invertebrates at the two macrophyte beds varied greatly from 3328 ind. m^{-2} (*E. stagnina*) to 11472 ind. m^{-2} (*E. crassipes*). In terms of functional feeding groups, there were 20 and 14 predator groups at *E. crassipes* mats and *E. stagnina* stand, respectively. Similarly, there were proportionally more collector-gatherer taxa at the *E. crassipes* sites (**Table 4.3)**.

Table 4. 3 Distribution of macro-invertebrate families at each study site (1=Meto Aleka Shore, 2=Awash Shore 1, 3=Awash Shore 2, 4=Ayage Shore 1, 5=Ayage Shore 2, 6=HEPP Shore, + = Present and - =Absent)

		Sites					
Taxon Order/Family	***Feeding Group**	**1**	**2**	**3**	**4**	**5**	6
Ephemeroptera (Mayflies)							
Amelotopsidae	Pr	-	-	-	+	+	-
Baetidae	Cg	+	+	+	+	+	+
Canidae	Cg	+	+	+	+	+	+
Odonata (Damselflies & Dragonflies)							
Coenagrionidae	Pr	+	+	+	+	+	+
Gomphidae	Pr	+	-	-	-	-	-
Libellulidae	Pr	+	+	+	+	+	+
Hemiptera (Water or true bugs)							
Belostomatidae	Pr	+	+	+	+	+	+
Corixidae	Pr	+	+	+	+	+	+
Gerridae	Pr	-	-	-	+	+	-

Taxon Order/Family	***Feeding Group**	**Sites** **1**	**2**	**3**	**4**	**5**	6
Mesoveliidae	Pr	-	-	+	-	-	+
Naucoridae	Pr	+	+	+	+	+	+
Nepidae	Pr	+	-	-	-	-	-
Notonectidae	Pr	+	+	+	+	+	+
Pleidae	Pr	+	+	+	+	-	+
Diptera (Two winged / True flies)							
Ceratopogonidae	Pr, Cg, Sc	+	-	+	+	-	+
Chironomidae	Pr, Cf, G	+	+	-	+	+	+
Culicidae	Ft and Cg	+	-	-	-	+	-
Phoridae	-	+	-	-	-	-	-
Tipulidae	Sh-Dt, Cg	-	-	-	-	-	+
Coleoptera (Aquatic Beetles)							
Dubriphia		-	-	+	+	-	-
Dytiscidae	Pr	+	+	+	+	+	+
Haliplidae	Sh, Pr	-	-	-	+	-	-
Hydrophilidae	Pr	+	+	+	+	+	+
Noteridae	Pr	+	+	+	-	-	+
Gastropods							
Glacidorbidae	-	-	+	+	+	-	+
Lymnaeidae	Sc	+	+	+	+	-	+
Planorbidae	Sc	+	+	+	-	-	-
Physidae	Sc	+	+	+	+	+	+
Hirudinae							
Glossiphoniidae	Pr	+	+	+	+	+	+
Arachnida (Class)							
Hydracarina	Pr	+	-	+	+	-	-
Aquatic spider	-	+	+	+	+	+	+
Aquatic worm	Cg	+	-	+	+	-	+
Total taxon per site		25	19	23	24	17	22

* Abbreviations: Cg = collector-gatherers Cf= collector-filterers Pr = predators Sc = scrapers Sh = shredders G = gatherers, Ft= Filters, Sh-Dt is a shredder on plant detritus, not of live tissue, HEPP=Hydro Electric Power Plant

* Some taxa were not assigned to feeding groups due to absence of data

The Shannon diversity index varied between 1.39 (HEPPS site with the *E. crassipes* mats) and 1.86 (AYS2 site with *E. stagnina* stand) and was not significantly different among the macrophyte stands (F=0.72, p=0.62). Pielou's evenness index ranged from 0.28 (MAS and HEPP) represented by *E. crassipes* mats to 0.59 (AYS2) represented by *E. stagnina* stand. The values showed significant variation among the sampling sites (F=3.56, p=0.03); AYS2 (*E. stagnina*) having value significantly higher than MAS and HEPP sites (*E. crassipes*). But there was no significant variation among the other sites (**Fig. 4.2**).

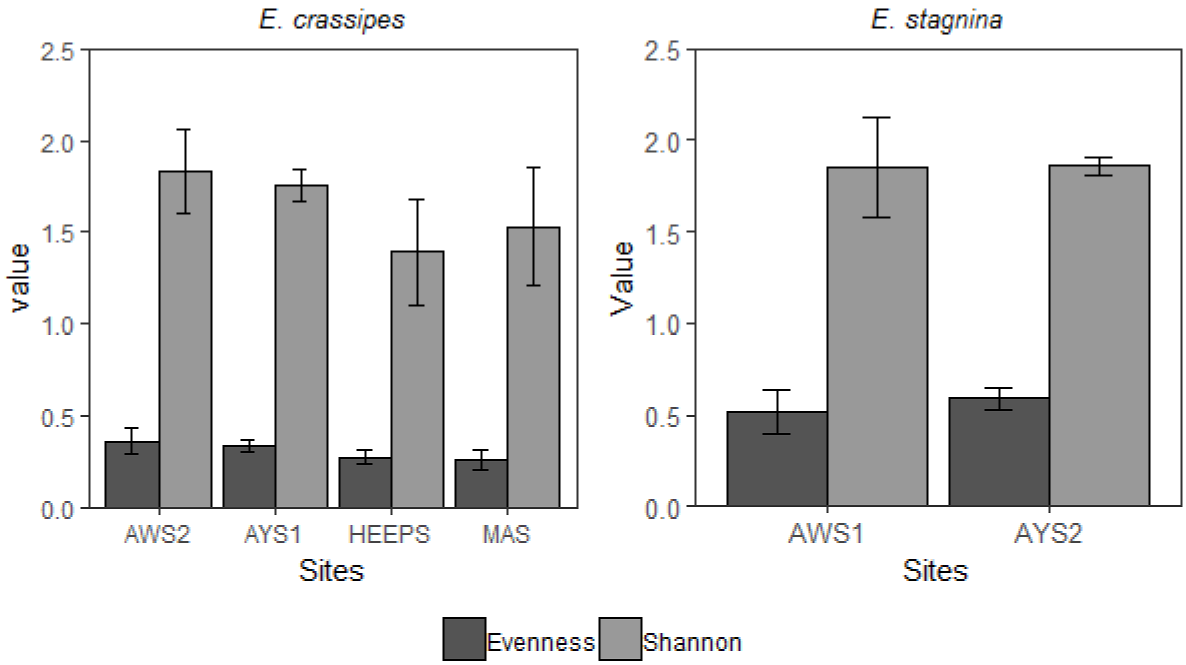


Figure 4. 2 Diversity indices of macro-invertebrates among the sampling sites (Abbreviations: MAS= Moto Aleka Shore, AWS1= Awash Shore 1, AWS2= Awash Shore 2, HEPPS=Hydro Electric Power Plant Shore, AYS1= Ayage Shore 1, AYS2= Ayage Shore 2)

4.3.3 Sites Similarity Based on Macro-invertebrates Abundance

To reduce the effect of rare taxa in clustering and RDA analysis, families that comprised an average of <1% of the organisms at sampling sites were excluded (Kuchapski and Rasmussen, 2015). Hierarchical cluster analysis (**Fig. 4.3**), classified the sampling sites into three groups. Cluster I consisted sites MAS and AYS1, both represented by *E. crassipes* mats. Cluster II comprised sites AWS1 and AYS2 dominated by *E. stagnina* stand. The last, cluster III, comprised sites AWS2 and HEPP covered by *E. crassipes* as the first cluster. Based on this cluster, AWS1 and AYS2 (both represented by *E. stagnina* stand) were clustered together while those represented by *E. crassipes* mat were clustered into different groups. This might be due to the taxa included in the clustering analysis.

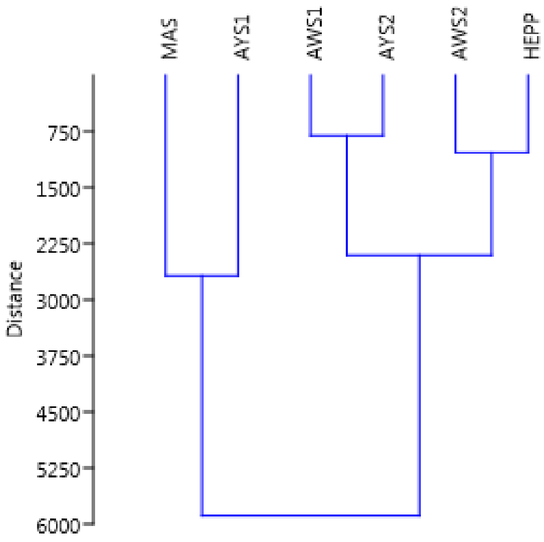


Figure 4. 3 Hierarchical clustering, based on similarities in aquatic macroinvertebrate assemblages, of the sampling sites with a Ward linkage method and a Euclidian distance

MAS= Meto Aleka,Shore, AWS1=Awash Shore 1, AWS2=Awash Shore 2, AYS1=Ayage Shore 1, AYS2=Ayage Shore 2, HEPP=Hydro Electric Power Plant

4.3.4 Response of Macroinvertebrate to Physicochemical Parameters

In the RDA result, the first two axes explained 92.8% of the species-environment relation while axis 1 only explained 68.2% (**Table 4.4**). The remaining 7.3% may be explained by some other unobserved physical and biological variables. The parameters pH, temperature, and dissolved oxygen were most strongly and positively correlated with axis 1. They were the most influential factors that determine the distribution of Ephemeroptera (Amelotopsidae, Baetidae, and Caenidae), Coleoptera (Dytiscidae), Hemiptera (Belestomatidae, Corixidae, Notonectidae and Pleidae), Diptera (Chironomidae), Gastropoda (Physidae and Planorbidae). PO_4-P, NO_2-N and NO_3-N were most strongly and negatively correlated with axis 1. They influence the distribution of Odonata (Coanogrionidae and Libellulidae), Gastropoda (Lyminidae), and the Hirudinae (Glossiphoniidae) (**Fig. 4.4** and **Table 4.4**).

Moreover, AYS2 and AWS1 sites (covered with *E. stagnina*), AWS2 and HEEPS (covered with *E. crassipes*) were closely associated with the physicochemical parameters NO_2-N, NO_3-N, NH_3-N, PO_4-P and conductivity and 4 families of macro-invertebrates (Coanogrionidae, Libellulidae, Lymnaeidae and Glossiphoniidae). But AYS1 and MAS (covered by *E. crassipes*) were more closely associated with Temperature, SiO_2, pH and DO and 12 families of macro-invertebrates including Amelotopsidae, Baetidae, Caenidae, Dytiscidae, Belestomatidae, Corixidae, Physidae and Planorbidae (**Fig. 4.4** and **Table 4.4**).

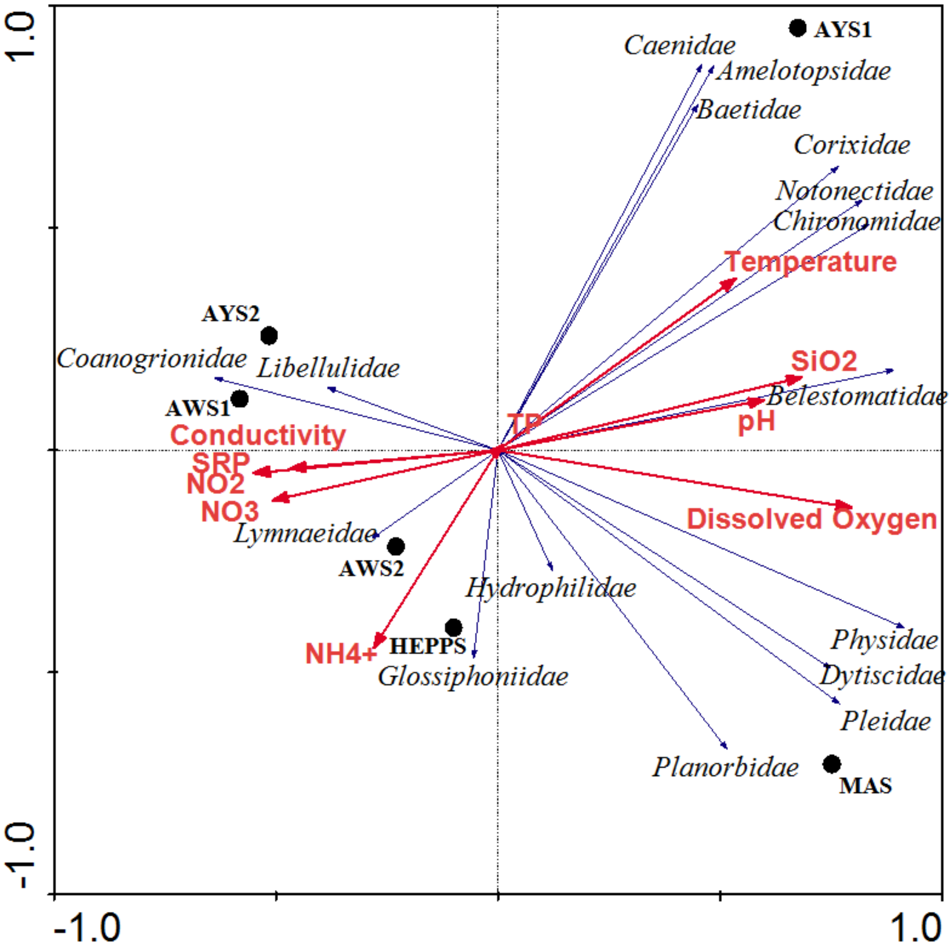


Figure 4. 4 Redundancy analysis (RDA) diagram of macro-invertebrates in relation to water physicochemical properties

(Abbreviations: MAS= Moto Aleka Shore, AWS1= Awash Shore 1, AWS2= Awash Shore 2, HEPPS=Hydro Electric Power Plant Shore, AYS1= Ayage Shore 1, AYS2= Ayage Shore 2, SRP= PO_4-P, TP=Total Phosphorous, NO2=NO_2-N=, NO3=NO_3-N, NH4+=NH_3-N)

Table 4. 4 Correlation table of physicochemical parameters with the first two axis (strong correlations are marked bold at $p < 0.05$)

Environmental Variables	**Axis 1**	**Axis 2**
Eigenvalues	0.682	0.245
Cumulative percentage variance of species-environment relation	68.2	92.8
pH	**0.60**	0.11
Temperature	**0.54**	0.39
Conductivity	-0.47	-0.04
Dissolved Oxygen	**0.80**	-0.13
Nitrite (NO_2-N)	**-0.55**	-0.05
Nitrate (NO_3-N)	**-0.51**	-0.11
Ammonium (NH_3-N)	-0.28	-0.45
Total Phosphorous (TP)	0.01	0.01
Soluble Reactive Phosphate (PO_4-P)	**-0.55**	-0.05

4.4 Discussion

Except dissolved oxygen and NH_3-N, the physicochemical parameters showed significant variation among the sampling sites (ANOVA, $p < 0.05$) (**Table 4.2**). However, in most of the cases, there was no significant variation among the sites with and without *E. crassipes*. The results of RDA also supported this and indicated variability in physicochemical parameters was not associated with the presence or absence of *E. crassipes* (**Fig. 4.4**). Therefore, it can be said that *E. crassipes* did not affect the water quality of the lake and the observed variation in the stated parameters among the sampling sites might be due site-specific anthropogenic activities. For instance, the significantly higher values of NO_2-N, NO_3-N and PO_4-P at the Awash sites might be due to the presence of flower farm that discharge its waste into the lake. Contrary to this, Mironga *et al.* (2012) and Yongo *et al.* (2017) reported a significant effect of *E. crassipes* on the water quality on Lake Naivasha and Lake Victoria, respectively. The variation may come from the turbulent nature of Lake Koka with continuous mixing (Fasil Degefu *et al.*, 2011) which tends to uniformly distribute nutrients and supply dissolved oxygen.

All the 32 taxa collected were found at the *E. crassipes* mats while the corresponding value at *E. stagnina* stand was only 22. The lowest taxa (17) was recorded at the *E. stagnina* stand (AYS2) while the highest taxa richness (25) was recorded at the *E. crassipes* mats (MAS). Moreover, most of the taxa were shared between the sites with and without *E. crassipes* (**Table 2.3**) and taxa richness did not show significant variation among the macrophyte stands ($p>0.05$). The RDA analysis also supported this indicating higher number of taxa associated with sites covered by *E. crassipes*. Similar result of high taxa richness but insignificant variation between sites with *E. crassipes* mats and other littoral macrophytes were reported by different authors (Kouamé *et al.*, 2010; Kouamé *et al.*, 2011).

In comparison with other similar studies (Poi de Neiff and Carignan, 1997; De Marco *et al.*, 2001; Viljoen *et al.*, 2001; Rocha-Ramírez *et al.*, 2007), the taxa richness associated with *E. crassipes* in this study was lower and this might be due to the differences in study locations and duration of the studies. *E. crassipes* support greater predator and collector-gatherer taxa than *E. stagnina* and in line with this Barker *et al.* (2014) suggested that the suspended roots of *E. crassipes* provide more than structure for colonization and support a broad range of functional feeding groups. Poi de Neiff and Carignan (1997) reported collector-gatherers and predators as the most abundant functional feeding groups found attached to *E. crassipes* roots. De Marco *et al.* (2001) also reported detritivores (most frequently oligochaetes) as dominant invertebrates on *E. crassipes* roots. This indicated that most of the functional feeding groups prefer the *E. crassipes* as a habitat than *E. stagnina*.

Density of macro-invertebrates varied greatly from 3328 ind. m^{-2} (*E. stagnina* stand) to 11472 ind. m^{-2} (*E. crassipes* mat). Studies comparing macroinvertebrate density on *E. crassipes* roots and other littoral macrophytes reported similar higher density associated with *E. crassipes* roots (Masifwa *et al.*, 2001; Villamagna, 2009; Kouamé *et al.*, 2011). Studies focusing only on *E. crassipes* roots also indicated the presence of high macro-invertebrate density associated with the roots (Kouamé *et al.*, 2010; Barker *et al.*, 2014; Wondie Zelalem *et al.*, 2017). The general preference of *E. crassipes* by macro-invertebrates might be due to its complex fibrous roots structure hanging downward through the water column (AL-Hadeethi *et al.*, 2017) while *E. stagnina* is known only by its stout floating rhizomes rooting and branching at the lower nodes. Villamagna and Murphy (2010) indicated that morphologically complex macrophytes support greater richness of invertebrates. Different authors (Cheruvelil *et al.*, 2002; Villamagna, 2009; Barker *et al.*, 2014) stated that the greater diversity and abundance of macro-invertebrates associated with *E. crassipes* roots might be primarily due to the architecture types where the complexity of its roots compared to the other macrophytes play a role for supporting a greater density of invertebrates. However, the slight difference in physicochemical parameters among the sites with and without *E. crassipes* might also have an impact (Rommens *et al.*, 2003).

The indices Shannon diversity, did not show significant variation among the sampling sites. Despite the higher taxa richness at *E. crassipes* mats (**Table 4.3)**, the Shannon diversity was lower than that of at the *E. stagnina* stand. This might be attributed to the significantly lower Pielou's evenness value (0.28) at the *E. crassipes* mats (MAS and HEPPS). In conclusion, results from this study indicated that *E. crassipes* did not significantly affect the water quality of Lake Koka and the observed variation might be due to the anthropogenic activities specific to the sites. Moreover, *E. crassipes* mats support relatively greater abundance and high taxa richness than *E. stagnina* stand and significantly affect evenness favoring gastropods and families like *Chironomidae* and *Hirudinae*. This is supported by Barker *et al.* (2014) who reported that more scrapers especially gastropods were abundant on water hyacinth roots. However, to have a full picture of its effect on the lake ecosystem, the effect of *E. crassipes* on macrophytes, fishes and other aquatic life forms should be investigated based on other research designs.

CHAPTER 5: HEAVY METAL CONTAMINATION IN LAKE KOKA, ETHIOPIA

5.1 Introduction

The pollution of water bodies with heavy metals, chlorinated hydrocarbons, and petroleum products is a serious problem because of their high toxicity, tendency to be incorporated into the food chain and persistence in the environment (Mohammed *et al.*, 2012). Heavy metal discharge into the aquatic environment is of great concern all over the world (Altun *et al.*, 2009). In aquatic ecosystems, heavy metals can be mainly found in the water, the sediment, and in the biota (Cheng *et al.*, 2002; Zhang *et al.*, 2009), with their concentration usually being low in water samples but attaining considerable magnification in its sediments and the aquatic biota (Namminga and Wilhm, 1976).

Because aquatic ecosystems are important sources of food and water for humans, heavy metals in these systems can ultimately jeopardize human health. This may happen directly through daily use of water for human life, in industry and in agriculture, as well as indirectly by a long-term effect through their gradual accumulation in the food chain (Zhang *et al.*, 2009). For humans, heavy metal intake can e.g lower energy levels and damage the functioning of brain, lungs, kidney, liver and blood composition. Long term exposure may also lead to gradual and progressive physical, muscular and neurological degenerative processes that initiate disease like multiple sclerosis, Parkinson’s, Alzheimer’s and muscular dystrophy as well as cancer (Shah, 2017). For the lake environment, heavy metals have shown to adversely affect aquatic organisms in a variety of ways including reduction of growth, increase of developmental anomalies, reduction of fish survival - especially at the beginning of exogenous feeding or even extinction of entire fish population thereby affecting finally biological cycles (Khayatzadeh and Abbasi, 2010).

To maintain ecological balance of aquatic ecosystems and improve public health, there is thus an urgent need to evaluate and monitor the extent of heavy metal pollution by accepted and updated methods. Cleanup (remediation) technologies available for reducing the harmful effects of heavy metal-contaminated sites include (i) physical removal, (ii) stabilization of the metals *in situ*, and (iii) phytoremediation (the use of plants to extract the metals from the polluted site) (Odjegba and Fasidi, 2007). Phytoremediation is an emerging technology, which is relatively cost effective and can be used to remediate different contaminants and is applicable in different site conditions (Lasat, 2002). Recently, *E. crassipes* has been utilized as an efficient heavy metal phytoremediation agent in different parts of the world (Ashok *et al.*, 2014; Bais *et al.*, 2015; Mishra and Maiti, 2017). The weed has been present in Africa since the late 1800s, and its importance has increased since the late 1980s (Cilliers *et al.*, 2003). Nowadays, the weed is invading many waterbodies of Ethiopia (Firehun Yirefu *et al.*, 2014; Dereje Tewabe *et al.*, 2017).

As in many developing countries, Ethiopia is experiencing rapid population growth at high urbanization rate (Niguse Bekele *et al.*, 2018). Hence due to associated improper waste management practices, the progressive pollution of aquatic ecosystems with heavy metals is becoming one of the most widespread environmental problems (Yetneberk Ayalew *et al.*, 2012; Yared Beyene *et al.*, 2013; Minbale Aschale *et al.*, 2016; Alemnew

Berhanu *et al.*, 2018). Studies indicate that, among the water bodies in Ethiopia, Lake Koka is highly affected by heavy metal pollution caused by intensive anthropogenic activities along the side of the two inflowing rivers (Awash and Modjo) and around the lake shores (Zinabu GebreMariam and Pearce, 2003; Masresha Alemayehu *et al.*, 2011; Dsikowitzky *et al.*, 2013; Yetneberk Ayalew *et al.*, 2016). However, most of these studies focused only on a limited amount of sites and contained only fragmented information on the lake and its inflowing rivers. This was the motivation for this study to fill the gap by (i) considering multiple sites on the lake and (ii) upstream and downstream sites on the inflowing rivers, which have been selected based on proximity to expected anthropogenic emission sources. Moreover, the study tries to determine the efficiency of *E. crassipes* as a phytoremediation agent in Lake Koka.

5.2. Materials and Methods

5.2.1 Sampling Strategy

For this study, 10 sites were selected to cover a gradient from potentially low to high heavy metal input by human activities. Six sites were on the lake itself and 4 sites on the inflowing rivers (**Table 5.1 and Fig. 5.1**). From each site, duplicate samples were collected two times in the year 2018, i.e April, and June. But for the upstream sites, samples were collected in August.

Table 5. 1 Description of sampling sites and samples taken from each site

Site Name	Abbreviation	Site Description/Characteristics	Site category	Sample taken	Altitude
Sites with potentially low heavy metal input					
Awash Upstream	AWUP	Upstream of Awash River, less anthropogenic influence	Reference	Water and Sediment	1994 m.a.s.l
Modjo Upstream	MOUP	Upstream of Modjo River with less anthropogenic influence than the downstream	Reference	Water and Sediment	1760 m.a.s.l
Sites with potentially high heavy metal input					
Awash Downstream	AWDD	Close to Awash River bridge and the road to Hawassa, just before the river joins the Lake	Downstream	Water and Sediment	1587 m.a.s.l
Modjo Downstream	MODD	Before the river joins the Lake, affected by industrial and municipal wastes	Downstream	Water and Sediment	1586 m.a.s.l
Ayage	AYAG	Close to an island, used for livestock grazing; little agricultural practices during the dry season	Lake	Water, Sediment, Macrophyte	1594 m.a.s.l
Hydroelectric Power Plant	HEPP	At power generation site, no anthropogenic disturbance, deepest part of the Lake and the only outlet	Lake	Water and Sediment	1587 m.a.s.l
Meto Aleka	MALE	Close to the main road to Hawassa, Fish and vegetable market, agriculture, livestock grazing, and sediment excavation	Lake	Water, Sediment, Macrophyte	1588 m.a.s.l
Ashewa	ASHE	Close to the main road to Hawassa, livestock grazing and agriculture during the dry season	Lake	Water, Sediment, Macrophyte	1593 m.a.s.l
Floriculture	FLOR	Close to Awash River bridge, livestock grazing and effluent from floriculture farm	Lake	Water and Sediment	1583 m.a.s.l
Tannery Lake Site	TALK	Affected by tannery effluent, agriculture, livestock grazing and water abstraction for the tannery	Lake	Water and Sediment	1583 m.a.s.l

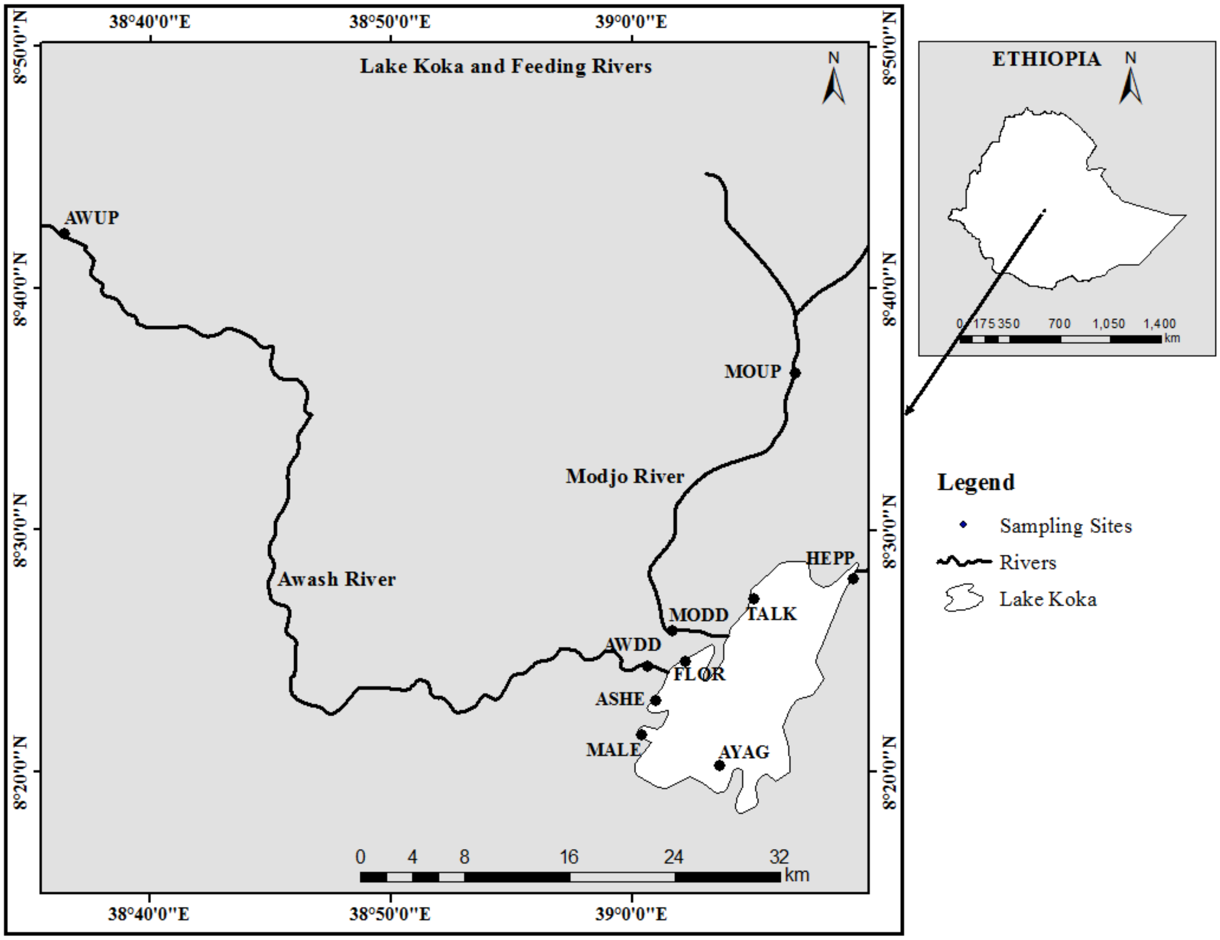


Figure 5. 1 Location of sampling sites on Lake Koka and feeder rivers

(Abbreviations: AWUP = Awash Upstream, MOUP = Modjo Upstream, AWDD = Awash Downstream, MODD = Modjo Downstream, AYAG = Ayage, HEPP = Hydroelectric Power Plant, MALE = Meto Aleka, ASHE = Ashewa, FLOR = Floriculture, TALK = Tannery Lake site)

5.2.1.1 Sample Collection and Pretreatment

Water samples were collected based on the method on USEPA 3010A (1992) with polyethylene bottles (washed with detergent, then with deionized water, 2M nitric acid, then with deionized water again). Before collection of the sample, each bottle was rinsed three times with the surface water of the sampling site. Duplicate samples were then collected from each site by direct immersion of the polyethylene bottle into the water. Immediately after sample collection, 2 mL nitric acid (AR grade) was added to the water samples decreasing the pH to < 2 to reduce adsorption of metals onto the walls of the plastic bottles. Sample bottles were then transported to the laboratory in an ice-box and stored at 4 ºC until analysis.

Duplicate sediment samples were also collected from each site from approximately 15 cm depth under the water surface (Demirak *et al.*, 2006) using a 3.5 cm internal diameter sediment corer. The sediment samples were placed in clean zip-lock polyethylene bags, stored in an ice-box and transported to the laboratory. In the laboratory, twigs, leaves and stones were discarded and the sediment oven dried to a constant weight (Štrbac *et al.*, 2014). After drying, the samples were homogenized, crushed with mortar and pestle, and then sieved through a 2-mm sieve. The prepared samples were then stored in polyethylene bags for analysis.

After collecting duplicate samples from each site, *E. crassipes* were thoroughly washed with the lake water to loosen detritus and separated into root and leaf (Xu *et al.*, 2015). Root parts were cleaned carefully by repeated washing to avoid erroneous result (Chatterjee *et al.*, 2012). After collection, the plant samples were put in zipper polyethylene plastic bags to avoid extraneous contamination. In the laboratory each sample was rinsed with distilled water and oven dried to constant weight. The dried samples were then blended to fineness for easy digestion with an electrical blender and stored in sealed plastic bags until analysis. Pretreatment of all the samples was conducted at Limnology Laboratory of Addis Ababa, University.

5.2.1.2 Sample Digestion and Analysis

The prepared samples were transported to University of Bonn, Germany, for further process and analysis of heavy metal at the Laboratories of Plant Nutrition and Soil Science, Institute for Crop Sciences and Resource Protection.

Water

Digestion of water samples was conducted based on USEPA 3010A (1992) method. In brief, 25 mL of the water sample was transferred to a 50 mL Griffin beaker with a Mohr Pipette (**Plate 5.1a**), 0.75 mL conc. HNO_3 (65% nitric acid for analysis, MERCK) was added and evaporated to a low volume (5 mL) on a heating plate (90-95 ºC) (**Plate 5.1b**). Then the beaker was cooled in a container slightly filled with cool water. After cooling, another 75 mL of conc. HNO_3 was added to the sample and the beaker heated again but now covered with a watch glass to enable a gentle reflux. Additional acid was added as necessary, until the digestion process was completed (until the digestate reached a light color or did not change in appearance with continued refluxing). The watch glass was removed from the beaker, and the solution evaporated to 3 mL. Then the beaker was removed from the hot plate allowed to cool, and another 2.5 mL 1:1 HCl (50% H_2O dest. + 50% HCl; HCl of 37% p.a. grade) added to the sample covered with a watch glass and put on the hot plate to reflux for 15 minutes to dissolve any precipitate or residue resulting from evaporation. After refluxing, the watch glass was removed from the plate, the watch glass and the beaker walls rinsed with distilled water and the sample transferred to a 25 mL conical flask and the volume of the sample adjusted up to the mark. Thereafter, the sample was filtered (MACHEREY-NAGEL, MN 640 m), stored in 100 mL polyethylene bottles and kept at 4 ^{o}C until analysis.

Plate 5. 1 Digestion of water samples

Available Heavy Metal Concentrations

For analysis of available heavy metal concentrations in sediments, EDTA extraction was performed in accordance with Fischer and Fechter (1982). Based on the method, 10 g of sediment sample was weighed into a 200 mL PE-bottle. 100 mL of EDTA III extracting solution (AR grade) was added and the mixture shaken for 2 hours (Gerhardt Laboshake heavy-load shaker, 180 strokes min^{-1}, **Plate 5.2a**). After shaking, the samples were filtered (MACHEREY-NAGEL folded filter paper, MN 640 m, **Plate 5.2b**). The first 5 mL aliquot of the filtrate was removed and the rest stored in 100 mL PE-bottles at 4 ^{o}C until analysis.

Plate 5. 2 EDTA extraction of sediment samples

Total Heavy Metal Concentrations

For determination of total concentrations of heavy metals in sediments, aqua regia extraction was performed after the method of VDLUFA (1991). In brief, 1.00 g of sediment sample was weighed into a reaction vessel and aqua regia solution (7 mL of hydrochloric acid (ρ = 1,19 g mL^{-1}) and 21 mL of nitric acid (ρ = 1,40 g mL^{-1}) added. The reaction vessel was then closed with loosely fitted ground glass stoppers and allowed to stand at room temperature for at least 12 hours (overnight). The next day, the solution extracted with a Kjeldhal therm block digestion unit (Gerhardt GmbH, Königswinter, Germany) with the following temperature program: 70 °C (held 45 min), 110 °C (held 30 min), 120 °C (held 180 min). After cooling, the solution was rinsed into a reaction vessel with 25 mL nitric acid, the reaction vessel loosely closed with a ground glass stopper until it cooled completely and the content transferred to a volumetric flask with nitric acid. Finally, the mixture was filtered into a filter vessel (MACHEREY-NAGEL filter paper, MN 640 m), the first 10 mL aliquot of the mixture removed and the rest filtrate stored in 100 ml polyethylene bottles at 4 ˚C until analysis.

E. crassipes (Water hyacinth) Organs

Digestion of plant samples was conducted by pressure digestion according to Heinrichs *et al.* (1986). In brief, 0.5 g of plant material was weighed into TEFLON crucible, 4 mL of 65% HNO_3 added (**Plate 5.3a**) the crucibles closed (**Plate 5.3b**) and placed in a Lotfield Pressure Digestion system, which had been preheated at 180°C. The crucibles were heated in line with the following heating scheme: 1 h heating; 1 h resting phase; 6 h heating and 5 h cooling phase until ambient temperature had been reached. After cooling, the digestate was transferred with deionized water into a 25 mL volumetric flask over a funnel. The volume was made up to the mark using deionized water, the solution shaken, filtered with a MACHEREY-NAGEL filter paper (MN 640 m) into 50 mL PE-bottles, and stored at 4 ºC until analysis.

Plate 5. 3 Digestion of E. crassipes samples

Water, sediment and macrophyte samples were analyzed for As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn at Soil Sciences Department Laboratory, University of Bonn, Germany using A Perkin Elmer Optima 4300 DV Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES, Jobin Yvon Ultima 2, Horiba, Frankfurt, Germany).

5.2.2 Data Analysis

The concentration of heavy metal in the *E. crassipes* and in the water samples was used for the calculation of bioaccumulation factor (BAF) which provides an index for the ability of the plant to accumulate the metal with respect to the metal concentration in the substrate (Gonzaga *et al.*, 2006). The BAF was calculated as the ratio of $[\text{Element}]_{\text{root}}$: $[\text{Element}]_{\text{water}}$ (Salem *et al.*, 2014). Variation in water heavy metal concentrations among sampling sites was analyzed using Kruskal–Wallis test followed by Dunn test because of lack of homogeneity of variances even after transformation. Variation in the concentrations of sediments heavy metals among sampling sites was analyzed using one-way ANOVA followed by Tukey-HSD. The statistical analysis was conducted using R programming language 3.4.2.

5.3 Results

5.3.1 Heavy Metals in Water

As indicated in **Table 5.2**, the mean concentration of heavy metals in water samples from the lake sites was in the order of Fe > Mn > Zn > Ni > Cr > Pb > As > Cu > Co > Cd. The results varied significantly among the sampling sites (Kruskal–Wallis, $p < 0.05$) with Modjo downstream site (MODD) showing significantly higher concentrations of Co, Cr, Cu, Mn, Ni and Zn than the upstream sites. For all the metals, there was no significant difference between the two upstream sites and the same is true for the two downstream sites except for Cu and Mn. From all sites, Modjo downstream (MODD) showed the highest concentrations for all heavy metals. However, heavy metal concentrations varied widely among the different sampling times at MODD, which explains the large standard deviation.

The values of Cu and Mn for Awash downstream were 18 times and 6.7 times lower than those of Modjo downstream, respectively. Comparison of upstream and downstream sites with sites on the lake indicated that the upstream sites had similar concentrations of all metals to the lake sites. But there was considerable difference between the downstream and lake sites especially for MODD. Sites on the lake had significantly lower concentration of Cr and Cu than MODD. With the other metals also, even though there is no a clear pattern, concentrations at MODD were significantly higher than most lake sites. The result also showed a uniform distribution (similar concentration) of all the metals on the lake sites.

Table 5. 2 Concentrations of heavy metals (µg L^{-1}) in water from Lake Koka, Ethiopia and its inflowing Rivers (mean ± SD)

Sites	**Site category**	**As**	**Cd**	**Co**	**Cr**	**Cu**
AWUP	Reference	25.6±0.19^{ab}	0.51±0.09^{ab}	1.07±0.31^{a}	76.9±43.5^{ab}	18.9±3.80^{a}
MOUP	Reference	16.6±6.43^{ab}	0.32±0.15^{ab}	0.22±0.28^{a}	88.3±31.8^{ab}	21.6±11.5^{a}
AWDD	Downstream	24.4±2.28^{ab}	0.54±0.19^{ab}	8.49±1.29^{ab}	179±62.2^{bc}	31.7±3.04^{a}
MODD	Downstream	69.4±64.6^{b}	1.27±1.19^{b}	44.3±40.8^{b}	247±117^{c}	586±1420^{b}
AYAG	Lake	12.1±5.53^{ab}	0.01±0.01^{a}	9.78±10.7^{ab}	25.7±16.2^{a}	10.4±4.80^{a}
HEPP	Lake	29.5±3.82^{ab}	0.54±0.17^{ab}	19.1±3.96^{ab}	51.5±8.47^{ab}	17.7±7.50^{a}
MALE	Lake	3.42±2.66^{a}	0.15±0.16^{a}	1.52±0.81^{a}	9.78±6.54^{a}	8.14±12.5^{a}
ASHE	Lake	6.68±5.67^{a}	0.17±0.23^{ab}	1.84±2.01^{a}	13.4±9.57^{a}	5.64±5.66^{a}
FLOR	Lake	11.5±12.3^{ab}	0.10±0.13^{a}	5.52±7.41^{a}	18.1±17.8^{a}	5.52±11.0^{a}
TALK	Lake	5.92±2.90^{a}	0.26±0.34^{ab}	3.42±4.44^{a}	31.2±32.9^{a}	7.87±9.07^{a}
Overall mean	Lake	10.6±10.2	0.20±0.24	6.27±7.87	23.3±20.5	9.09±9.40
Sites	**Site category**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
AWUP	Reference	10,812±677^{ab}	105±6.37^{a}	0±0^{a}	27.4±0.40^{ab}	32.7±9.10^{a}
MOUP	Reference	5,604±2151^{a}	58.8±23.7^{a}	2.60±3.39^{a}	16.7±6.13b^{a}	43.8±48.3^{a}
AWDD	Downstream	42,409±3,233^{ab}	398±4.50^{a}	58.9±34.5^{ab}	26.8±3.64^{ab}	105±24.0^{ab}
MODD	Downstream	164,395±164,921^{b}	2664±2087^{b}	139±127^{b}	70.9±65.6^{b}	377±280^{b}
AYAG	Lake	17,015±10,614^{ab}	318±194^{a}	22.0±14.0^{ab}	14.4±3.79^{ab}	117±32.3^{ab}
HEPP	Lake	55,686±17,573^{ab}	1628±120^{ab}	82.9±35.2^{ab}	34.6±7.59^{ab}	273±98.9^{ab}
MALE	Lake	2,671±2,310^{a}	115±63.4^{a}	14.8±13.2^{a}	3.96±3.24^{a}	118±67.8^{ab}
ASHE	Lake	9,509±7,451^{a}	196±142^{a}	9.79±8.61^{a}	4.99±5.71^{a}	46.7±46.4^{a}
FLOR	Lake	13,1862±19,990^{ab}	1294±1533^{ab}	30.2±15.5^{ab}	8.28±13.8^{a}	117±96.2^{ab}
TALK	Lake	3,821±1,737^{a}	114±65.6^{a}	28.4±39.6^{ab}	14.0±4.99^{ab}	51.7±51.0^{a}
Overall mean	Lake	15391±20595	556±808	29.5±31.4	12.3±12.1	120±95.3

* Means within a column followed by the different letter are significantly different, $p < 0.05$; (Abbreviations: AWUP = Awash Upstream, MOUP = Modjo Upstream, AWDD = Awash Downstream, MODD = Modjo Downstream, AYAG = Ayage, HEPP = Hydroelectric Power Plant, MALE = Meto Aleka, ASHE = Ashewa, FLOR = Floriculture, TALK = Tannery Lake site, and SD = Standard Deviation)

5.3.2 Heavy Metals in Sediment

In this study, sediment samples were analyzed for both total and available heavy metal concentrations and the results are displayed below.

Total Heavy Metal Concentrations

The concentration of Fe in lake sediment samples was 61-132,260 times higher than those of other analyzed metals, while Cd showed lowest concentrations. The order of heavy metal concentrations in lake sediment samples was thus as follows: Fe > Mn > Zn > Cr > Ni > Cu > Pb > As > Co > Cd (**Table 5.3**). The result indicated that concentrations of heavy metals in sediments were considerably higher than those obtained in water samples. Except for As, the concentration of all metals in sediment samples varied significantly (ANOVA, $P < 0.05$) among sampling sites. Interestingly, highest concentration of Cd, Ni, Pb and As (with significant difference for Cd and Ni) were found at Modjo River upstream (MOUP), a sampling site which was expected to show lowest concentrations due to lower anthropogenic influence. Modjo downstream (MODD) had significantly higher concentration of Cr and Mn than HEPP, FLOR and AWUP. Generally, even though there was no a clear pattern among the sites, there was uniform distribution of As, Co, Cr, Mn, Pb and Zn on the lake sites.

Table 5. 3 Total concentrations of heavy metals (µg g^{-1} DW) in aqua regia extracts of sediment samples from Lake Koka, Ethiopia and its inflowing rivers (mean ± SD)

Sites	Category	As	Cd	Co	Cr	Cu
AWUP	Reference	23.1±2.79^{a}	0.53±0.03^{a}	50.9±6.21^{cd}	67.1±12^{a}	44.2±5.41^{abc}
MOUP	Reference	77.3±103^{a}	29.5±57.8^{b}	47.4±31.3^{bcd}	87.7±2.15^{ab}	48.4±1.51^{bc}
AWDD	Downstream	22.9±2.28^{a}	0.58±0.03^{a}	61.2±12.9^{d}	77.9±6.37^{ab}	43.3±5.04^{abc}
MODD	Downstream	33.4±5.16^{a}	0.79±0.09^{a}	32.6±4.00^{abc}	161±86^{b}	42.0±8.53^{ab}
AYAG	Lake	45.5±2.96^{a}	0.94±0.08^{a}	32.2±2.55^{abc}	97±8.38^{ab}	56.0±4.48^{bc}
HEPP	Lake	28.4±1.71^{a}	0.60±0.03^{a}	22.5±1.29^{a}	44.6±1.32^{a}	27.6±0.72^{a}
MALE	Lake	43.9±3.54^{a}	0.89±0.08^{a}	31.9±2.65^{abc}	106±7.76^{ab}	56.5±5.58^{bc}
ASHE	Lake	47.9±4.38^{a}	0.97±0.09^{a}	31.5±1.45^{abc}	138±51.7^{ab}	60.6±4.51^{c}
FLOR	Lake	35.6±1.69^{a}	0.84±0.04^{a}	23.7±1.38^{a}	73.5±6.35^{a}	53.6±14.0^{bc}
TALK	Lake	41.3±2.92^{a}	0.86±0.04^{a}	25.7±4.50^{ab}	110±29.1^{ab}	49.2±8.38^{bc}
Overall mean	Lake	39.8±6.84	0.86±0.12	27.3±4.63	92.4±35.2	50.9±13.0
Sites	**Category**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
AWUP	Reference	101469±15772^{abc}	2936±260^{bc}	75.2±8.48^{a}	52.5±5.29^{cd}	246±28.9^{bc}
MOUP	Reference	99337±7655^{abc}	2778±1840^{abc}	1015±1804^{b}	58.3±5.51^{d}	162±84.4^{a}
AWDD	Downstream	124007±18066^{cd}	3443±645^{c}	80.7±6.26^{a}	53.4±2.99^{cd}	257±14.8^{c}
MODD	Downstream	91559±13011^{ab}	2106±370^{abc}	70.0±10.1^{a}	44.2±4.46^{ab}	190±39.2^{ab}
AYAG	Lake	131709±13453^{d}	1954±183^{ab}	81.0±6.85^{a}	57.4±3.52^{d}	273±21.6^{c}
HEPP	Lake	86705±11259^{a}	1585±132^{ab}	39.5±2.68^{a}	39.8±2.44^{a}	200±6.79^{abc}
MALE	Lake	122470±7475^{cd}	2059±282^{abc}	84.6±5.61^{a}	53.8±3.96^{cd}	250±13.8^{bc}
ASHE	Lake	132480±12125^{d}	1943±109^{ab}	90.3±7.12^{a}	57.3±5.41^{d}	268±21.9^{c}
FLOR	Lake	105165±5802^{abc}	2029±190^{ab}	62.3±4.18^{a}	46.63±1.68^{abc}	262±15.9^{c}
TALK	Lake	112762±8920^{bcd}	1504±128^{a}	76.6±13.0^{a}	49.9±1.88^{bcd}	236±5.37^{bc}
Overall mean	Lake	113744±17529	1859±276	71.1±17.5	50.2±6.60	250±27.5

* Means within a column followed by the same letter are not significantly different, $p < 0.05$ (Abbreviations: AWUP = Awash Upstream, MOUP = Modjo Upstream, AWDD = Awash Downstream, MODD = Modjo Downstream, AYAG = Ayage, HEPP = Hydroelectric Power Plant, MALE = Meto Aleka, ASHE = Ashewa, FLOR = Floriculture, and TALK = Tannery Lake

Available Heavy Metal Concentrations

Available concentrations of metal in EDTA extracts of sediment samples were analyzed. The result indicated that available heavy metal concentrations in lake sediments samples were found to decrease in the sequence of Fe > Mn > Cu > Zn > Pb > Ni > Co >As > Cr > Cd > (**Table 5.4**). One-way analysis of variance showed that there were significant differences in the available concentration of all metals among sampling sites (ANOVA; $P < 0.05$). The concentration of Cd at MOUP, Cr at MODD and Zn at FLOR were significantly higher than that of at HEPP, at all other sites and all other sites, respectively. Concentrations of As at ASHE and FLOR, Co at all river sites and Cr at MODD were significantly higher than the rest sites. The upstream and downstream sites on the rivers had uniform distribution of As, Cd, Cu, Fe, and Zn while Co, Ni and Pb concentrations at MOUP were significantly higher than that of the other sites on the river. Moreover, the concentration of available heavy metals was uniform among most of the lake sites, except their lower concentration at HEPP.

Table 5. 4 Available concentrations of metals (µg g^{-1} DW) in EDTA extracts of sediment samples from Lake Koka, Ethiopia and its inflowing rivers (mean ± SD)

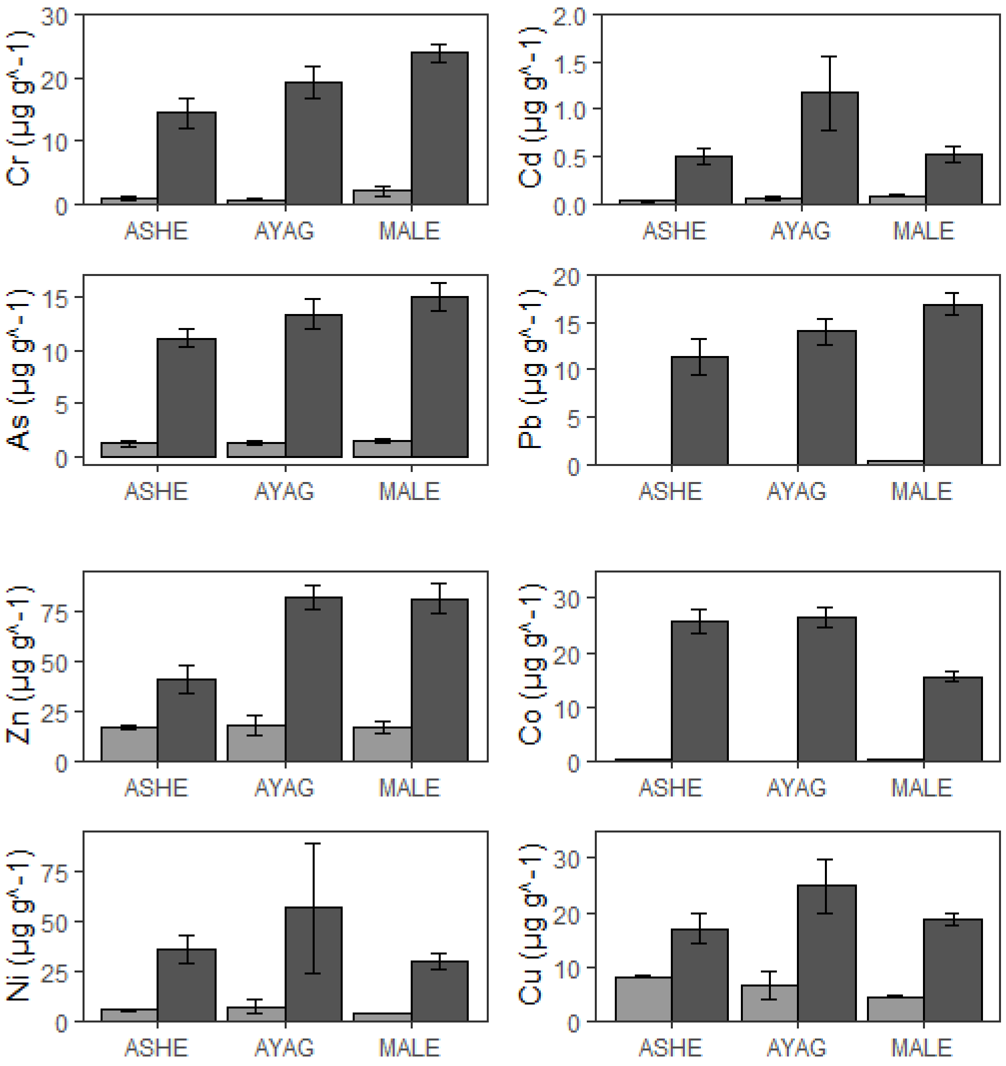
Sites	**Category**	**As**	**Cd**	**Co**	**Cr**	**Cu**
AWUP	Reference	1.20±0.05^{ab}	0.09±0.01^{ab}	10.6±1.90^{e}	0.13±0.01^{a}	6.61±0.13^{abc}
MOUP	Reference	1.30±0.04^{b}	0.11±0.00^{b}	19.9±0.20^{g}	0.14±0.01^{a}	7.15±0.18^{abc}
AWDD	Downstream	1.10±0.04^{ab}	0.10±0.01^{ab}	14.3±0.80^{f}	0.10±0.00^{a}	5.43±0.53^{ab}
MODD	Downstream	1.15±0.08^{ab}	0.10±0.01^{ab}	7.07±0.65^{d}	1.67±0.88^{b}	6.22±0.83^{ab}
AYAG	Lake	1.55±0.12^{c}	0.09±0.00^{ab}	4.80±0.64^{c}	0.29±0.12^{a}	12.1±2.44^{cd}
HEPP	Lake	1.01±0.08^{a}	0.08±0.01^{a}	2.31±0.09^{a}	0.03±0.02^{a}	3.22±0.45^{a}
MALE	Lake	1.54±0.06^{c}	0.09±0.01^{ab}	4.29±0.26^{bc}	0.29±0.05^{a}	12.2±0.82^{cd}
ASHE	Lake	1.87±0.11^{d}	0.10±0.00^{ab}	4.19±0.21^{abc}	0.44±0.22^{a}	14.9±1.25^{d}
FLOR	Lake	1.86±0.09^{d}	0.10±0.01^{ab}	2.70±0.27^{ab}	0.16±0.06^{a}	15.2±5.20^{d}
TALK	Lake	1.65±0.11^{c}	0.10±0.01^{ab}	3.29±1.36^{abc}	0.23±0.05^{a}	10.6±1.89^{bcd}
Overall mean	Lake	1.62±0.30	0.09±0.01	3.46±1.06	0.23±0.15	11.9±4.85

Sites	**Category**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
AWUP	Reference	1359±160^{abc}	1673±166^{c}	9.62±1.74^{d}	5.43±0.49^{bcd}	3.72±0.12^{a}
MOUP	Reference	817±40.3^{a}	2076±30.9^{c}	23.6±0.58^{f}	6.86±0.12^{e}	2.75±0.08^{a}
AWDD	Downstream	816±24.5^{a}	1752±82.5^{c}	12.5±0.67^{e}	4.95±0.30^{abc}	3.31±0.39^{a}
MODD	Downstream	542±209^{a}	1180±271^{b}	7.68±0.96^{c}	4.85±0.54^{ab}	3.00±0.16^{a}
AYAG	Lake	2301±955^{cd}	1101±52.4^{b}	5.82±0.81^{bc}	6.43±0.66^{de}	5.36±1.25^{a}
HEPP	Lake	399±37.1^{a}	457±40.7^{a}	2.19±0.21^{a}	4.03±0.26^{a}	3.06±0.24^{a}
MALE	Lake	2149±659^{cd}	1205±219^{b}	5.04±0.21^{b}	5.89±0.44^{cde}	4.36±0.54^{a}
ASHE	Lake	2973±712^{d}	1151±146^{b}	6.03±0.33^{bc}	6.57±0.58^{e}	6.61±0.47^{a}
FLOR	Lake	1818±241^{bc}	1197±156^{b}	4.30±0.30^{b}	6.51±0.49^{e}	12.6±5.19^{b}
TALK	Lake	1112±181^{ab}	672±268^{a}	4.66±1.69^{b}	5.14±0.58^{bc}	3.66±0.50^{a}
Overall mean	Lake	1772±912	986±327	4.62±1.38	5.84±1.01	6.77±4.63

* Means within a column followed by different letter are significantly different, $p < 0.05$ (Abbreviations: AWUP = Awash Upstream, MOUP = Modjo Upstream, AWDD = Awash Downstream, MODD = Modjo Downstream, AYAG = Ayage, HEPP = Hydroelectric Power Plant, MALE = Meto Aleka, ASHE = Ashewa, FLOR = Floriculture and TALK = Tannery Lake)

5.3.3 Heavy Metals in *E. crassipes* Organs

The concentration of heavy metals in the leaf of *E. crassipes* was in the order of Fe > Mn > Zn > Cu > Ni > As > Cr > Co > Pb > Cd while the corresponding value in the root was Fe > Mn > Zn > Ni > Co > Cu > Cr > Pb > As > Cd. In all the cases, the concentration of heavy metals in the root was higher than in the leaf. Concentrations of As, Cr, Pb, Fe and Zn at MALE were higher than the others while Cd, Cu and Ni exhibited higher concentration at AYAG (**Fig. 5.2**).



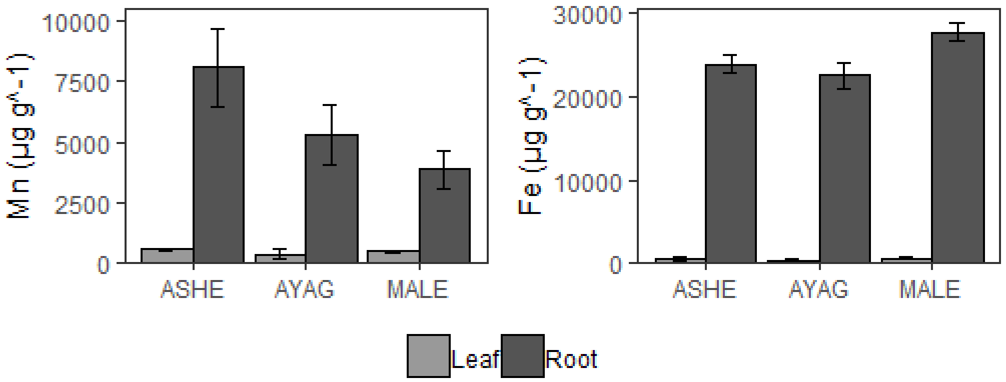


Figure 5. 2 Concentrations of heavy metals in *E. crassipes* (µg g^{-1}) on a dry weight basis (mean ± SD) (ASHE = Ashewa, AYAG = Ayage, MALE = Meto Aleka)

The accumulation factors for all the examined metals were considerably higher for roots than for leaves. The *E. crassipes* roots accumulated Cd (18.37) and Co (20.59) at the highest level while Zn (0.59) at the lowest level (**Table 5.5**).

Table 5. 5 Phytoremediation efficiency of *E. crassipes* using bioaccumulation factor for root

Parameter	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Bioaccumulation factor	2.20	18.37	20.59	1.27	5.94	4.21	42.91	2.45	11.75	0.59

5.4 Discussion

5.4.1 Concentration of Heavy Metals in Water

Most heavy metal concentrations of water sampled at the downstream site of Modjo River (MODD) were higher than those sampled at upstream sites and at sites on the lake. This might be attributed to the discharge of untreated or insufficiently treated waste close to the downstream sampling sites of Modjo River. Several authors have reported that Modjo River receives effluent discharges from several industries, including car battery refilling, textile factory, meat processing plants, and tanneries (Zinabu GebreMariam and Pearce, 2003; Tamene Fite and Seyoum Leta, 2013; Amde Eshete *et al.*, 2016). The black color of Modjo River downstream water (**Plate 5.4**) is also an indicator and suggests the situation is getting worse. So from this result, it can be concluded that, the major source of pollution for Lake Koka is the Modjo River.

The concentration of most heavy metals in the water samples was significantly higher at the downstream sites (especially at MODD) than those from sites on the lake. These results suggest that a sedimentary process is taking place in the lake as part of self-cleaning net effect. Avila-Pérez *et al.* (1999) stated that sedimentation and adsorption perform as a natural cleaning processes, decreasing the dissolved concentrations and increasing the metallic content of the sediments. Similarly, also Rai (2009) suggested that lentic ecosystems with self-purification capacity accumulate heavy metals in their bottom sediments. This might be attributed to the strong affinity of heavy metals for particles leading to a stronger accumulation in bottom sediments compared to water (Bazrafshan *et al.*, 2016). In the present study, this was confirmed by the high concentration of heavy metals in most lake sediment samples. On the lake sites, heavy metals were uniformly distributed probably due to the continuous mixing caused by strong currents in the lake (Fasil Degefu *et al.*, 2011).

Average concentrations of metals in water samples was also compared with data published for the lake, its feeder rivers and other Rift Valley Lakes (**Table 5.6**). There was a significant increase in the concentrations of all metals in Lake Koka and its inflowing rivers. Moreover, mean concentrations of all metals in Lake Koka were also higher than those in other Ethiopian Rift Valley Lakes, except As (Lake Abijata), Cd (Lakes Abaya, Chamo and Abijata) and Cr (Abijata) (Zinabu GebreMariam and Pearce, 2003). The results of Cr, Cu and Mn at river downstream sites are also higher than those measured in Kenyan Rift Valley Lakes (Nakuru, Elementaita, Naivasha, Bogoria and Baringo) (Ochieng *et al.*, 2007; Ogendi *et al.*, 2014; Yang *et al.*, 2017). This might be attributed to intensive industrial activities in Lake Koka catchment area (Zinabu GebreMariam and Pearce, 2003; Tamene Fite and Seyoum Leta, 2013; Amde Eshete *et al.*, 2016). In addition, intensive agricultural development (including four floriculture farms) around the lake with intensive utilization of agrochemicals and fertilizers may contribute to the large increase in heavy metal concentrations in the water as stated by (Bazrafshan *et al.*, 2016). This makes Lake Koka and its feeder (Modjo) river the most affected water bodies in the Rift Valley area. But, the effect of the difference in the sampling time and specific location of sampling sites as well as the methods used in each study cannot be ruled out.

Table 5. 6 Comparison of Lake Koka water heavy metal concentration (µg L^{-1}) with previous data and other Ethiopian Rift Valley Lakes (year of study bold in parenthesis in the legend)

Location	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Lake Koka[1]	10.6	0.20	6.27	23.3	9.09	15391	556	29.5	12.3	120
Lake Koka[2]	2.8	0.04	-	27.8	15.5	-	303	22.4	4.9	48
Lake Koka[3]	0.57-3.0	<0.1	-	1.7-2.5	-	-	-		0.24-0.59	-
Lake Koka[4]	2.4-3.9	ND-2.2	ND-0.7	4.6-6.7	0.1-2.5	99.2-1520	3.2-56.3	2.7-5.1	ND	5-8.4
AWDD[1]	24.4	0.54	8.49	179	31.7	42481	398	58.9	26.8	105
AWDD[3]	1.6	<0.1	-	1.8	-	-	-	-	0.25	-
AWDD[4]	3.2	ND	ND	3.0	1.0	110.0	2.9	ND	ND	16.3
MODD[1]	69.4	1.27	44.3	247	586	164395	2664	139	70.9	377
MODD[3]	2.8	<0.1	-	1.6	-	-	-	-	0.96	-
MODD[4]	4.4	ND	ND	5.7	2.7	155.8	5.6	3.4	ND	13.7
Lake Abaya[4]	6.6-12.0	ND-8.8	ND-1.4	5.9-15.4	4.0-5.3	62.2-4699	2.2-128	ND-8.5	ND-6.4	11.8-50.9
Lake Chamo[4]	5.6-10.3	ND-1.4		12.6-15.4	1.2-1.7	46.9-49.3	3.3-14.0	ND-1.3	ND-2.4	7.8-16.1
Lake Abijata[4]	302-702	ND-13.1	-	34.4-121	0.7-17.5	ND-3.2	ND-4.0	2.5-4.0	3.7-11.6	12.8-18.0
Lake Langano[4]	17.0	ND	-	20.0	1.5	567.9	29.9	0.6	0.2	3.2
Lake Hawassa[2,4]	2.4-3.4	ND-0.01	0.05	1.2-5.7	ND-3.0	ND	2.6-18.1	ND-0.71	ND-0.20	1.6-2.5
Lake Ziway[2,4,5]	2.5-2.7	ND-0.02	1.3	1.4-8.6	ND-4.7	ND-2600	4.0-117	ND-7.8	ND-2.2	<0.01-51.0

[1]This study (**2018**); [2]Yetneberk Ayalew *et al.* (2016) (**Feb, 2008**); [3]Dsikowitzky *et al.* (2013) (**Dec, 2008**); [4]Zinabu GebreMariam and Pearce (2003) (**1995-1996**); [5]Berhan Teklu *et al.* (2018) (**2013-2015**); Lake Koka[1] - Average of 6 sampling sites on the lake during the sampling period was taken

The mean concentration of heavy metals was also compared with threshold values for heavy metal contamination in water (**Table 5.7**). Based on these mean concentrations, As and Pb (lake and downstream river sites), Cr (upstream and downstream river sites), and Mn and Ni (Modjo downstream site) levels were beyond the WHO guideline limit for drinking water. The striking values were those recorded at Modjo downstream (MODD) site. The concentrations of As, Cd, Cr, Cu, Pb and Zn (all sites) were beyond the threshold values for the protection aquatic life while Cr (downstream river sites), and Cu and Mn (MODD) were beyond international threshold limits for irrigation. For instance, Temesgen Eliku and Seyoum Leta (2017) studied heavy metal concentrations in vegetables grown around Lake Koka and found that Cd (in Cabbage, Onion, Green pepper and Tomato), Pb (in Cabbage, Onion, and Green pepper), and Cr (in Green pepper) surpassed the FAO/WHO permissible limit. But only Mn at all sites was beyond the international threshold limit for livestock watering (**Table 5.7**). Since Lake Koka supports people's subsistence through domestic water provision, irrigation, and fishing and due to its habitat provision for aquatic organisms, significantly raised levels on heavy metals in the lake and its inflowing rivers above international threshold values are source of big concern.

Table 5. 7 Comparison of heavy metal concentration ($\mu g\ L^{-1}$) in Lake Koka and its inflowing rivers with acceptable levels in natural waters for various purposes

Limit	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
AWUP	25.6	0.51	1.07	76.9	18.9	105	0	27.4	32.7
MOUP	16.6	0.32	0.22	88.3	21.6	58.8	2.60	16.7	43.8
AWDD	24.4	0.54	8.49	179	31.7	398	58.9	26.8	105
MODD	69.4	1.27	44.3	247	586	2664	139	70.9	377
Lake Koka	10.6	0.20	6.27	23.3	9.09	556	29.5	12.3	120
Drinking[a]	10	3	-	50	2000	400	70	10	-
Aquatic life[b]	5	0.017	-	1-8.9	2-4	-	25-150	1-7	30
Irrigation[c]	100	10	50	100	200	200	200	5000	2000
Livestock watering[c]	200	50	1000	1000	500	50	-	100	24,000

[a]WHO (2008); [b]Solomon (2008); [c]FAO (1985), Lake Koka - Average of 6 sampling sites on the lake during the sampling period was taken

In their study in 2008, Dsikowitzky *et al*. (2013) assessed heavy metals in water from Lakes Awassa and Koka and found that the lakes were not significantly impacted from the industrial discharges. Moreover, Zinabu GebreMariam and Pearce (2003) studied heavy metal concentrations in Lake Koka and other Ethiopian Rift Valley Lakes and found relatively unimpaired water quality for the lakes and their inflows (except for the soda lakes). But they hypothesized that in lakes in the neighborhood of fast growing cities, it is very likely that more domestic and industrial wastes will find ways directly into the lakes, and elevate their levels of heavy metals. This study shows now that it is true that levels of heavy metals in water of Lake Koka are elevated. Therefore, immediate potential health hazard cannot be disregarded as many people use water from the lake and the inflowing rivers for domestic purposes, including consumption by humans and livestock and irrigation. Alarmingly, the locals and investors even use the most polluted Modjo River water for irrigation of vegetables (**Plate 5.4).**

Plate 5. 4 Use of polluted Modjo River water for irrigation and bathing

5.4.2 Concentration of Heavy Metals in Sediment Samples

Since heavy metals have the affinity to accumulate rather in particulate matter than in water (Bazrafshan *et al.*, 2016), heavy metal pollution in aquatic ecosystems is often reflected in high metal levels in sediments (Rai, 2009). The present study also revealed higher concentrations of heavy metals in sediment samples compared to water samples. Here, Fe was the predominant heavy metal in the sediment samples and had high concentration in the upstream, downstream and most lake sites. This situation suggests the presence of non-point source in the area. High concentrations of Co and Zn were recorded at Awash downstream site (AWDD). As suggested by Sires (2017), the possible source might be the intensive agricultural usage of fertilizers and pesticides along the shore of Awash River. These metals might be also contributed by the tributaries big and little Akaki Rivers, which are used as a discharging canal for municipal and wide range of industrial wastes in the capital Addis Ababa (Tamiru Alemayehu 2001; Girma Taddese *et al.*, 2003) .

High concentration of Cr and Mn at Modjo downstream site (MODD) might be attributed to the discharge of untreated or insufficiently treated waste by the textile, tanneries and other anthropogenic activities along the gradient of Modjo River (Zinabu GebreMariam and Pearce, 2003; Tamene Fite and Seyoum Leta, 2013; Amde Eshete *et al.*, 2016). But among the sites on the lake, there was a uniform distribution of most heavy metals in sediment which agrees with the result from the water. The effects of heavy metals in the environment depend to a large extent on whether they occur in forms that can be taken up by plants or animals (Ebrahimpour and Mushrifah, 2008) and similar results were found for available metals (from EDTA extracts). In the EDTA extract, Co, Mn and Ni values at MOUP were higher than those for sediment samples from downstream sites. This might be due to the variation in the sampling time. The sampling session for the upstream sites was during the rainy season (August), where metals from other non-point sources may be added to the upstream sites through surface runoff.

The mean concentrations of heavy metals in the sediment samples were also compared with previous data (**Table 5.8**) published for Lake Koka by Yetneberk Ayalew *et al.* (2016) and there was a considerable increase in the concentrations of all metals except for Cr. The increase in heavy metals concentration can be attributed to the discharges of waste by growing industrial activities along the inflowing rivers and around the lake (Tamene Fite and Seyoum Leta, 2013; Amde Eshete *et al.*, 2016). Heavy metal concentrations in Lake Koka sediment are also generally higher compared to metal levels of sediments in Lake Hawassa (Yared Beyene *et al.*, 2013; Kebede Nigussie *et al.*, 2015; Yetneberk Ayalew *et al.*, 2016), Lake Ziway (Kebede Nigussie *et al.*, 2015; Yetneberk Ayalew *et al.*, 2016) and Aba-Samuel Reservoir (except for Pb) (Alemnew Berhanu *et al.*, 2018). This is in accordance with the water results and indicated the serious pollution load on Lake Koka. Moreover, concentrations of sediment metals in this study are higher than those of five Kenyan Rift Valley Lakes (**Table 5.8**).

The concentrations of the metals in the sediments were compared to Canadian Sediment Quality Guideline (CSQG, 1995) which is based on the potential negative effects of metal contents on flora and fauna of the affected water bodies. Levels of As, Cd, Cr, Cu, Mn, Pb and Zn from Lake Koka and its inflowing rivers were beyond the CSQG limit, which suggests that the sediment metals are likely to pose a significant effect to aquatic organisms, including fishery (Altun *et al.*, 2009). The concentrations of As, Cd, Cr and Zn were 4-13, 1-49, 1-4 and 1-2 times higher than their respective sediment quality guideline (**Tables 5.3 and 5.8**).

Table 5. 8 Comparison of Lake Koka sediment heavy metal concentration (µg g^{-1} dry weight) with previous data and other Rift Valley Lakes

Location	**As**	**Cd**	**Co**	**Cr**	**Cu**
Lake Koka[1]	39.79	0.85	27.3	92.4	50.9
Lake Koka[3]	4.8	0.13	18.0	95.0	37.0
Lake Hawassa[5,6]	4.02	0.21	5.49	8.27	8.69
Lake Hawassa[4]	ND	0.28–1.2	-	5.99–74.3	1.71–86.7
Lake Hawassa[3]	3.9	0.23	6.0	13.0	5.0
Lake Ziway[4]	ND	0.28–8.9	-	23.8–63.4	47.6–127
Lake Ziway[3]	2.8	0.27	5.5	21.0	12.8
Aba Samuel Reservoir[2]	-	2.6	-	25	4.5
Lake Baringo[7]	-	0.57-0.76	0.69-1.38	2.17-4.87	15.1-21.0
Lake Bogoria[7]	-	0.20-0.92	0.48	1.95-2.92	1.95-4.68
Lake Nakuru[7]	-	0.39-0.57	0.17-0.39	1.94-1.96	1.46-3.70
Lake Elementaita[7]	-	0.05-1.18	0.48-1.09	2.92	5.85-13.0
Lake Naivasha[7]	-	0.73	0.17	1.95	10.3
International threshold for heavy metal contamination in sediments					
CSQG	5.9	0.6	-	37.3	35.7
Location	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Lake Koka[1]	113744	1859	71.1	50.2	250
Lake Koka[3]	-	1337	67.0	17.0	161
Lake Hawassa[5,6]	-	-	20.2	-	93.8
Lake Hawassa[4]	-	-	2.80–48.8	24.4–66.5	166–669
Lake Hawassa[3]	-	2792	11.0	11.0	149
Lake Ziway[4]	-	-	7.51–68.0	10.1–35.7	107–243
Lake Ziway[3]	-	1230.0	15.0	14.0	166.0
Aba Samuel Reservoir[2]	469.3	464	20.6	136.8	10
Lake Baringo[7]	-	942-1464	25.7-39.7	16.6-21.8	171-207
Lake Bogoria[7]	-	2627-3947	14.6-28.3	21.4-39.0	172-195
Lake Nakuru[7]	-	702-741	11.7-17.5	10.9-18.5	106-199
Lake Elementaita[7]	-	667-877	22.4-36.7	14.7-22.8	96.2-171
Lake Naivasha[7]	-	1118	11.7	25.3	230
International threshold for heavy metal contamination in sediments					
CSQG (1995)	-	-	-	35	123

[1]This study; [2]Alemnew Berhanu *et al.* (2018); [3]Yetneberk Ayalew *et al.* (2016); [4]Kebede Nigussie *et al.* (2015); [5]Yared Beyene (2014); [6]Yared Beyene *et al.* (2013), [7]Ochieng *et al.* (2007), CSQG = Canadian Sediment Quality Guideline)

Lake Koka[1] - Average of 6 sampling sites on the lake during the sampling period

5.4.3 Concentration of Heavy Metals in *E. crassipes* Organs and its Potential for Phytoremediation

The concentrations of the heavy metals in the root samples of *E. crassipes* were greater than those in the leaf samples. This is in line with Deng *et al.* (2004), who reported that metals accumulated by wetland plants were mostly concentrated in root tissues. Similar results of higher heavy metal concentration in below-ground organs than above-ground, was reported by several authors (Mishra and Tripathi, 2009; Zhang *et al.*, 2009; Štrbac *et al.*, 2014; Eid *et al.*, 2019). Absorption of metal ions by aquatic plants is an important physiological pathway with environmental implications for cheap and effective pollution control (Nor, 1990). Even though *E. crassipes* approaches being a scourge in many parts of the world (Schneider *et al.*, 1995), it has attracted considerable attention because of its ability to grow in heavily polluted water (Smolyakov, 2012; Ashok *et al.*, 2014) and its capacity for metal accumulation (Odjegba and Fasidi, 2007; Anzeze, 2011; Bais *et al.*, 2015). In this study, the concentrations of heavy metals in the root and leaves of *E. crassipes* were high indicating its potential to be used as phytoremediation agent for heavy metals.

Comparison of metals concentration in the leaf of different macrophytes from Lakes Koka, Hawassa and Ziway showed that *E. crassipes* is better in absorbing As, Cd, Co, Cu, Mn and Ni (**Table 5.9**). Moreover, different studies also reported *E. crassipes* as an effective absorbent of Cd and Cu (Odjegba and Fasidi, 2007; Anzeze, 2011; Smolyakov, 2012), Cd, Cu and Ni (Ashok *et al.*, 2014) and moderate accumulator of Zn (Lu *et al.*, 2004). The possible reason for its effectiveness might be its efficiency to withstand all negative effects of metal contamination giving it tolerance higher than more sensitive species (Borker *et al.*, 2013; Ashok *et al.*, 2014). Comparing the accumulated concentration in the leaf with reference concentrations, the concentrations of Cr (1.24µg/g), Mn (493.38µg/g) and Ni (5.73µg/g) were 2.5-12, 1.6-16 and 1-16 and 1-57 times above the normal level in plant leaves, respectively. But none of them were beyond the excess/toxic level for plants (**Table 5.9**). However, in the presence of higher-than-toxic level of metal concentration *E. crassipes* might have an internal detoxification metal tolerance mechanism (Ashok *et al.*, 2014). Besides this, it is almost exclusively annual or perennial herbaceous species and produce relatively large amount of biomass. Therefore, its utilization for phytoremediation of heavy metal pollutants is unquestionable and its use in the case of Lake Koka is highly recommended considering its appropriate disposal.

Table 5. 9 Comparison of heavy metal absorption by different macrophytes in Ethiopian Rift Valley Lakes

Lake Koka macrophytes	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
Eichhornia crassipes[1]	1.35	0.07	0.25	1.24	6.48	493.38	5.73	0.16	17.20
Eichhornia crassipes[2]	0.23	0.02	0.56	1.3	8.2	1200	11	0.16	19
Echinochloa stagnina[2]	0.08	0.004	0.16	4.1	7.3	58	2.5	0.21	20.9
Lake Ziway macrophytes	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
Aeschynomene elaphroxylon[2]	0.07	0.02	0.23	2.1	5.1	1600	1.4	0.24	40
Cyperus alopecuroides[2]	0.11	0.02	0.13	2.5	8.2	204	1.5	0.19	48
Paspalidium geminatum[2]	0.13	0.01	0.39	1.9	1.3	208	0.9	0.2	12
Phragmites karka[2]	0.08	0.003	0.07	3.2	1.4	78	1.4	0.12	14
Potamogeton schweinfurthii[2]	0.34	0.13	0.31	3.3	8.4	69	4.2	0.28	16
Lake Hawassa macrophytes	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
Nymphaea nouchalli[2]	0.31	0.01	0.12	1.7	1.9	82	0.9	0.15	19
Paspalidium geminatum[2]	0.14	0.01	0.07	1.9	1	149	0.9	0.14	8
Potamogeton thunbergii[2]	0.94	0.04	1.2	5.2	2.5	187	3	0.53	32
Schoenoplectus corymbosus[2]	0.07	0.002	0.04	2.1	0.8	153	0.7	0.16	9.5
Reference concentrations	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
Normal level in plant leaves[3]	1-1.7	0.05-0.2	0.02-1	0.1-0.5	5-30	30-300	0.1-5	5-10	27-150
Excess/Toxic level in plants[3]	5-20	5-30	15-50	5-30	20-100	400-1000	10-100	30-300	100-400

[1]This study; [2]Yetneberk Ayalew *et al.* (2016); [3]Kabata-Pendias (2000)

Eichhornia crassipes[1] – Average of 3 sampling sites

The phytoremediation efficiency of *E. crassipes* was examined using the bioaccumulation factor. Bioaccumulation defines the ability of a plant to accumulate heavy metals in its biomass and the bioaccumulation factor has thus been used to determine the effectiveness of plants in removing metals from a substrate (Gonzaga *et al.*, 2006). Plants showing a bioaccumulation factor of >2 are supposed to be efficient accumulators (Mellem *et al.*, 2009). In this study, the bioaccumulation factor of *E. crassipes* was >2 for all metals except for Cr (1.27) and Zn (0.59) (**Table 5.5**). But in all the cases (except Zn) bioaccumulation factor of *E. crassipes* was >1 and this is in line with the result of Eid *et al.* (2019). As a basis for assessing the bioaccumulation of metals, the scale described in Pachura *et al.* (2016) was used. Based on this scale, *E. crassipes* was high accumulator of all the heavy metals except Zn which was medium accumulator in this case. Among the examined metals, the highest accumulation was exhibited for Cd and Co, both in the above-ground parts and in the roots. It is therefore not surprising that different studies suggest *E. crassipes* as promising candidate for remediation of heavy metals from natural water bodies and/or wastewater polluted with heavy metals (Swain *et al.*, 2014; Saha *et al.*, 2017). Therefore, based on the above findings, *E. crassipes* can be a potential phytoremediation agent for removal of heavy metals from Lake Koka.

CHAPTER 6: GENERAL CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Lake Koka is under pressure from pollution, sedimentation and occurrence of the invasive *E. crassipes*. Like the other waterbodies of Ethiopia, previous studies on the lake focused on water quality, plankton, benthic fauna and fish. However, the importance of macrophytes in the ecology of the lakes has long been neglected and even only few studies regarding macrophytes have been conducted in Ethiopia. But knowledge on abundance and diversity of macrophytes and their consideration as biological management options for different problems is a key issue to be addressed. Therefore, this study evaluated the abundance and diversity of macrophytes in Lake Koka, the use of the dominant macrophytes as a biological management option for sedimentation problem, the impact of the dominant water hyacinth on water quality and macro-invertebrates and heavy metal contamination of the lake and the potential of *E. crassipes* as a phytoremediation agent.

Major conclusions from the study are:

1. The lake was characterized by higher number of macrophyte species than Lakes Hawassa and Ziway. *E. crassipes* was the dominant macrophyte followed by *L. caerulescens*, *E. stagnina*, *C. dives* and *T. angustifolia*. Factors including conductivity, pH, nitrate, and soluble reactive phosphorous were the main factors that governed the distribution of macrophytes in the lake. This result from environmental factors and macrophytes can be used in planning appropriate management options to improve the water quality of the lake and reduce the burden from the dominant *E. crassipes*.

2. All the four macrophytes (*E. stagnina*, *Pancium sp*., *T. angustifolia* and *E. crassipes*) had a considerable effect on retaining sediment and restraining re-suspension, the effect of *E. stagnina* and *T. angustifolia* being stronger than the other two species.
3. *E. crassipes* did not significantly affect the water quality of Lake Koka and supported relatively greater abundance and high taxa richness of macro-invertebrates than *E. stagnina* stand. It significantly affected evenness favoring gastropods and families like *Chironomidae* and *Hirudinae*.
4. There is a remarkable increase in heavy metal pollution of Lake Koka and the feeder probably due to the intensive agricultural and industrial activities along the side of the rivers and around the lake.
5. Concentrations of As in the lake water sample surpassed the WHO guideline limit for drinking water, Pb, Cr, Cu, Pb and Zn, concentrations surpassed the limit for the protection aquatic life and Mn concentration in the lake water surpassed the FAO limit for irrigation. Therefore, drinking water from Lake Koka is unsafe to human health.
6. Heavy metals concentration in sediments of Lake Koka and its feeder rivers was higher than the Canadian Sediment Quality Guideline (CSQG) limit for protection of aquatic life. Moreover, literature review indicated that heavy metal concentration of Lake Koka is increasing over time and the lake was more polluted than other Rift Valley Lakes.
7. *E. crassipes* was high accumulator of most of the studied metals and in comparison with other macrophytes from previous studies, it was found to be

better in absorbing As, Cd, Co, Cu, Mn and Ni. Therefore, *E. crassipes* can be utilized as phytoremediation agent in the lake.

6.2 Recommendations

The following further investigations and continuous monitoring are recommended:

1. The distribution and abundance of *E. crassipes*, its impact on macrophyte diversity, fisheries, recreational use and hydroelectricity generation should be further investigated
2. Development and maintenance of wetlands from *E. stagnina*, *and T. angustifolia* may be an effective management tool for limiting the sediment load on the lake. However, the results for this study were obtained from a 3- month experiment and sedimentation and re-suspension rates may change among different months because of the largescale fluctuations in water level in the study area. Therefore, long-term investigations which consider these and other macrophytes and measuring other factors (wind speed and direction and morphological traits of macrophytes) are necessary to fully underpin the role of macrophytes in trapping sediment and preventing re-suspension in Koka Lake. Then the result from this and other studies may apply for other Ethiopian waterbodies where sedimentation is a serious threat, including the newly constructed and under-construction dams (GERD for instance).
3. Continuous monitoring of heavy metal concentrations in water and sediment of the lake, their potential for bioaccumulation and likely adverse effects on aquatic

organisms and humans is recommended. Moreover, all the concerned bodies should comply with the environmental rules and regulations:

- The floriculture farms and the industries should effectively treat their waste before discharging into the lake or the inflowing rivers
- The concerned environmental office should inspect whether these farms and industries allow the maximum permissible discharge limit or not and are using legal products

4. The local communities and different stakeholders should find possible access for clean drinking water. Additionally, the application of different filtration mechanisms is recommended. *E. crassipes* was a potential phytoremediation agent for heavy metal pollution. But before application, further investigation on the phytoremediation efficiency of *E. crassipes* and other dominant macrophytes in the lake like *Echinochloa stagnina*, *Thypha angustifolia* and *L. caerulescens* is suggested. At the same time, safe utilization of *E. crassipes* containing high amounts of heavy metals needs to be investigated for the context of Ethiopia.
5. Further investigation on the ecological impact of the water residence time on biological integrity of the lake is necessary

REFERENCES

Adane Melaku (2017). *Water Quality and phytoplankton community structure in the Southern Gulf of Lake Tana, Ethiopia*. MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 99pp.

Agizew Nigussie (2010). *Hydrological and suspended sediment modeling in the Lake Tana Basin, Ethiopia*. PhD Thesis, Université Joseph-Fourier-Grenoble I, France, 264pp.

Agnew, A. D. (2013). *Upland Kenya wild flowers and ferns: A flora of the flowers, ferns, grasses, and sedges of highland Kenya*. Third completely rev. edition Nature Kenya-The East Africa Natural History Society, Nairobi, Kenya, 530pp.

AL-Hadeethi, M. A., Al-Obaidi, B. M., Khalaf, F. K., and Saleh, B. H. (2017). Anatomical Features of (*Eichhornia Crassipes* (Mart.) Solms) Growing in Iraq, Dubai (UAE).

Albright, T. P., Moorhouse, T., and McNabb, T. (2004). The rise and fall of water hyacinth in Lake Victoria and the Kagera River Basin, 1989-2001. *Journal of Aquatic Plant Management.* **42**(JUL.)**:** 73-84.

Alemnew Berhanu, Tarekegn Berhanu, Okonkwo, J. O., and Seyoum Leta (2018). Distribution and ecological risk assessment of trace metals in surface sediments from Akaki River catchment and Aba Samuel Reservoir, Central Ethiopia. *Environmental Systems Research.* **7**(24)**:** 1-15.

Aloo, P., Ojwang, W., Omondi, R., Njiru, J. M., and Oyugi, D. (2013). A review of the impacts of invasive aquatic weeds on the biodiversity of some tropical water bodies with special reference to Lake Victoria (Kenya). *Biodiversity Journal.* **4**(4)**:** 471-482.

Altınsaçlı, S., Altınsaçlı, S., and Paçal, F. P. (2014). Species composition and qualitative distribution of the macrophytes in three Turkish lakes (Kandira, Kocaeli, Turkey). *Phytologia Balcanica.* **20**(1)**:** 89-98.

Altun, Ö., Saçan, M. T., and Erdem, A. K. (2009). Water quality and heavy metal monitoring in water and sediment samples of the Küçükçekmece Lagoon, Turkey (2002–2003). *Environmental monitoring and assessment.* **151**(1-4)**:** 345-362.

Alvarez, M., Becker, M., Böhme, B., *et al.* (2012). Floristic classification of the vegetation in small wetlands of Kenya and Tanzania. *Biodiversity & Ecology.* **4:** 63-76.

Amde Eshete, Hailu Fekadu, Solomon Tejineh, and Tafa, M. (2016). The pollution profile of Modjo River due to industrial wastewater discharge, in Modjo Town, Oromia, Ethiopia *Environmental & Analytical Toxicology.* **6**(3)**:** 363.

Ansari, A. A., Al Ghanim, S., Trivedi, S., *et al.* (2015). Seasonal dynamics in the trophic status of water, floral and faunal density along some selected coastal areas of the Red Sea, Tabuk, Saudi Arabia. *International Aquatic Research.* **7**(4)**:** 337-348.

Anzeze, A. D. (2011). *Biosorption of heavy metals using water hyacinth Eichhornia crassipes (Mart.) solms-Laubach: adsorption properties and technological assessment*. MSc. Thesis, University of Nairobi, Nairobi, Kenya, 164pp.

APHA (1995). Standard methods for the examination of water and wastewater. **In**: *"Standard Methods"*. 19th Edition, American Public Health Association, Washington DC, USA.

APHA (1999). Standard methods for the examination of water and wastewater. **In**: *"Standard Methods"*. 20th Edition. American Public Health Association, Washington DC, USA.

Ashok, I., Balaji, R., Sakthivel, S., and Sasikumar, S. (2014). Efficacy of Accumulation on Heavy Metals from Aqueous Solution Using Water Hyacinth (*Eichhornia Crassipes*). *Asian Journal of Microbiology, Biotechnology and Environmental Sciences.* **16**(1)**:** 115-120.

Avila-Pérez, P., Balcázar, M., Zarazúa-Ortega, G., Barceló-Quintal, I., and Dıaz-Delgado, C. (1999). Heavy metal concentrations in water and bottom sediments of a Mexican Reservoir. *Science of the total environment.* **234**(1-3)**:** 185-196.

Ayalew Wondie (2006). *Dynamics of the major phytoplankton and zooplankton communities and its role in the food web of Lake Tana, Ethiopia*. PhD Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 164pp.

Bais, S. S., Lawrence, K., and Nigam, V. (2015). Analysis of heavy metals removal by *Eichhornia crassipes* (mart.) Solms. *World Journal of Pharmacy Pharmaceutical Sciences.* **4**(9)**:** 665-672.

Barker, J. E., Hutchens Jr, J. J., and Luken, J. O. (2014). Macroinvertebrates associated with water hyacinth roots and a root analog. *Freshwater science.* **33**(1)**:** 159-167.

Barko, J. W., Gunnison, D., and Carpenter, S. R. (1991). Sediment interactions with submersed macrophyte growth and community dynamics. *Aquatic Botany.* **41**(1-3)**:** 41-65.

Bazrafshan, E., Mostafapour, F. K., Esmaelnejad, M., Ebrahimzadeh, G. R., and Mahvi, A. H. (2016). Concentration of heavy metals in surface water and sediments of Chah Nimeh water reservoir in Sistan and Baluchestan province, Iran. *Desalination and Water Treatment.* **57**(20)**:** 9332-9342.

Berhan Teklu, Amare Hailu, Wiegant, D. A., Scholten, B. S., and Van den Brink, P. (2018). Impacts of nutrients and pesticides from small-and large-scale agriculture on the water quality of Lake Ziway, Ethiopia. *Environmental Science and Pollution Research.* **25**(14)**:** 13207-13216.

Bini, L. M., Thomaz, S. M., Murphy, K. J., and Camargo, A. F. (1999). Aquatic macrophyte distribution in relation to water and sediment conditions in the Itaipu Reservoir, Brazil. *Hydrobiologia.* **415:** 147-154.

Bloesch, J. (1982). Inshore–offshore sedimentation differences resulting from resuspension in the eastern basin of Lake Erie. *Canadian Journal of Fisheries and Aquatic Sciences.* **39**(5)**:** 748-759.

Bloesch, J. (1996). Towards a new generation of sediment traps and a better measurement/understanding of settling particle flux in lakes and oceans: a hydrodynamical protocol. *Aquatic Sciences.* **58**(4)**:** 283-296.

Bloesch, J., and Burns, N. M. (1980). A critical review of sedimentation trap technique. *Schweizerische Zeitschrift für Hydrologie.* **42**(1)**:** 15-55.

Blomqvist, S. (1981). Sediment trapping—a subaquatic in situ experiment. *Limnology and Oceanography.* **26**(3)**:** 585-590.

Bolpagni, R., and Piotti, A. (2015). Hydro-hygrophilous vegetation diversity and distribution patterns in riverine wetlands in an agricultural landscape: a case study from the Oglio River (Po Plain, Northern Italy). *Phytocoenologia.* **45**(1-2)**:** 69-84.

Borker, A. R., Mane, A. V., Saratale, G. D., and Pathade, G. R. (2013). Phytoremediation potential of *Eichhornia crassipes* for the treatment of cadmium in relation with biochemical and water parameters. *Emirates Journal of Food Agriculture.* **25**(6)**:** 443-456.

Bouchard, R. W. (2004). *Guide to aquatic invertebrates of the Upper Midwest: identification manual for students, citizen monitors, and aquatic resource professionals*. University of Minnesota, Water Resources Research Center, USA.

Bragato, C., Brix, H., and Malagoli, M. (2006). Accumulation of nutrients and heavy metals in *Phragmites australis* (Cav.) Trin. ex Steudel and *Bolboschoenus maritimus* (L.) Palla in a constructed wetland of the Venice lagoon watershed. *Environmental pollution.* **144**(3)**:** 967-975.

Braskerud, B. (2001). The influence of vegetation on sedimentation and resuspension of soil particles in small constructed wetlands. *Journal of Environmental Quality.* **30**(4)**:** 1447-1457.

Brendonck, L., Maes, J., Rommens, W., *et al.* (2003). The impact of water hyacinth (*Eichhornia crassipes*) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). II. Species diversity. *Archiv für Hydrobiologie.* **158**(3)**:** 389-405.

Brix, H. (1994). Functions of macrophytes in constructed wetlands. *Water Science and Technology.* **29**(4)**:** 71-78.

Brueske, C. C., and Barrett, G. W. (1994). Effects of vegetation and hydrologic load on sedimentation patterns in experimental wetland ecosystems. *Ecological Engineering.* **3**(4)**:** 429-447.

Burlakoti, C., and Karmacharya, S. B. (2004). Quantitative analysis of macrophytes of Beeshazar Tal, Chitwan, Nepal. *Himalayan Journal of Science* **2**(3)**:** 37-41.

Capers, R. S., Selsky, R., and Bugbee, G. (2010). The relative importance of local conditions and regional processes in structuring aquatic plant communities. *Freshwater Biology.* **55**(5)**:** 952-966.

Cazzanelli, M., Warming, T. P., and Christoffersen, K. S. (2008). Emergent and floating-leaved macrophytes as refuge for zooplankton in a eutrophic temperate lake without submerged vegetation. *Hydrobiologia.* **605:** 113-122.

Chambers, P., Lacoul, P., Murphy, K., and Thomaz, S. (2008). Global diversity of aquatic macrophytes in freshwater. *Hydrobiologia.* **595**(1)**:** 9-26.

Chandra, R., and Yadav, S. (2010). Potential of *Typha angustifolia* for phytoremediation of heavy metals from aqueous solution of phenol and melanoidin. *Ecological Engineering.* **36**(10)**:** 1277-1284.

Chao, W., Cun, W., and Ze, W. (2010). Effects of submerged macrophytes on sediment suspension and NH4-N release under hydrodynamic conditions. *Journal of Hydrodynamics.* **22**(6)**:** 810-815.

Chatterjee, S., Singh, L., Chattopadhyay, B., Datta, S., and Mukhopadhyay, S. (2012). A study on the waste metal remediation using floriculture at East Calcutta Wetlands, a Ramsar site in India. *Environmental monitoring and assessment.* **184**(8)**:** 5139-5150.

Cheng, S., Grosse, W., Karrenbrock, F., and Thoennessen, M. (2002). Efficiency of constructed wetlands in decontamination of water polluted by heavy metals. *Ecological engineering.* **18**(3)**:** 317-325.

Cheruvelil, K. S., Soranno, P. A., Madsen, J. D., and Roberson, M. J. (2002). Plant architecture and epiphytic macroinvertebrate communities: the role of an exotic dissected macrophyte. *Journal of the North American Benthological Society.* **21**(2)**:** 261-277.

Cilliers, C. J., Hill, M. P., Ogwang, J. A., and Ajuonu, O. (2003). Aquatic weeds in Africa and their control. **In**: *Biological control in IPM systems in Africa* (P. Neuenschwander, C. Borgemeister, and J. Langewald, Eds.), pp. 161-178. CABI Publishing, Wallingford, UK.

Clifford, H. F. (1991). *Aquatic invertebrates of Alberta: An illustrated guide*. The University of Alberta Press, Edmonton, Alberta, Canada.

Cook, C. D. (2004). *Aquatic and wetland plants of southern Africa*. Backhuys Publ, Leiden, The Netherlands.

CSQG (1995). Protocol for the derivation of Canadian sediment quality Guidelines (CSQG) for the protection of aquatic life. CCME EPC-98E. Prepared by Environment Canada, Guidelines Division, Technical Secretariat of the CCME Task Group on Water Quality Guidelines.

Cummins, K. W. (1973). Trophic relations of aquatic insects. *Annual review of entomology.* **18**(1)**:** 183-206.

Dar, N. A., Pandit, A. K., and Ganai, B. A. (2014). Factors affecting the distribution patterns of aquatic macrophytes. *Limnological Review.* **14**(2)**:** 75-81.

De Marco, P., Reis Araújo, M. A., Barcelos, M. K., and Santos, M. B. L. (2001). Aquatic invertebrates associated with the water-hyacinth (*Eichhornia crassipes*) in an eutrophic reservoir in tropical Brazil. *Studies on Neotropical Fauna and Environment.* **36**(1)**:** 73-80.

Degytnu Tilahun (2012). *Socio-economic and Environmental Impact of Floriculture Industry in Ethiopia*. MSc. Thesis. Humboldt University, Berlin, Germany, 63pp.

Demirak, A., Yilmaz, F., Tuna, A. L., and Ozdemir, N. (2006). Heavy metals in water, sediment and tissues of *Leuciscus cephalus* from a stream in southwestern Turkey. *Chemosphere.* **63**(9)**:** 1451-1458.

Deng, H., Ye, Z., and Wong, M. (2004). Accumulation of lead, zinc, copper and cadmium by 12 wetland plant species thriving in metal-contaminated sites in China. *Environmental pollution.* **132**(1)**:** 29-40.

Dereje Tewabe , Erkie Asmare, Wondie Zelalem, and Brehan Mohamed (2017). Identification of impacts, some biology of water hyacinth (*Eichhornia crassipes*) and its management options in Lake Tana, Ethiopia. *Net Journal of Agricultural Science.* **5**(1)**:** 8-15.

Devi, R., Esubalew Tesfahune, Worku Legesse, Bishaw Deboch, and Abebe Beyene (2008). Assessment of siltation and nutrient enrichment of Gilgel Gibe dam, Southwest Ethiopia. *Bioresource Technology.* **99**(5)**:** 975-979.

Dhote, S., and Dixit, S. (2007). Role of macrophytes in improving water quality of an aquatic ecosystem. *Journal of Applied Sciences & Environmental Management.* **11**(4)**:** 131-135.

Dieter, C. D. (1990). The importance of emergent vegetation in reducing sediment resuspension in wetlands. *Journal of Freshwater Ecology*. **5**(4)**:** 467-473.

Dikaso Unbushe (2013). *Wetland Vegetation Composition and Ecology of Abaya and Chamo in Southern and Fincha'a- Chomen and Dabus in Western Ethiopia*. PhD Thesis Addis Ababa University, Addis Ababa, Ethiopia, 174pp.

Dillon, P. J., Evans, R. D., and Molot, L. A. (1990). Retention and Resuspension of Phosphorus, Nitrogen, and Iron in a Central Ontario Lake. *Canadian Journal of Fisheries and Aquatic Sciences.* **47**(7)**:** 1269-1274.

Dsikowitzky, L., Mesfin Mengesha, Elias Dadebo, de Carvalho, C. E. V., and Sindern, S. (2013). Assessment of heavy metals in water samples and tissues of edible fish species from Awassa and Koka Rift Valley Lakes, Ethiopia. *Environmental monitoring and assessment.* **185**(4)**:** 3117-3131.

Ebrahimpour, M., and Mushrifah, I. (2008). Heavy metal concentrations in water and sediments in Tasik Chini, a freshwater lake, Malaysia. *Environmental monitoring and assessment.* **141**(1-3)**:** 297-307.

Edwards, S., Mesfin Tadesse, and Hedberg, I. (1995). *Flora of Ethiopia and Eritrea, volume 2, part 2: Canellaceae to Euphorbiaceae*. The National Herbarium, Addis Ababa, Ethiopia, and Uppsala, Sweden. 420pp

Eid, E. M., Shaltout, K. H., Moghanm, F. S., *et al.* (2019). Bioaccumulation and translocation of nine heavy metals by *Eichhornia crassipes* in Nile Delta, Egypt: perspectives for phytoremediation. *International journal of phytoremediation.* 1-10.

El-lil, A. A. (2006). Evaluation of the efficiency of some hydrophytes for trapping suspended matters from different aquatic ecosystems. *Biotechnology.* **5**(1)**:** 90-97.

Elias Dadebo, Alamrew Eyayu, Solomon Sorsa, and Girma Tilahun (2015). Food and feeding habits of the common carp (*Cyprinus carpio L*. 1758)(Pisces: Cyprinidae) in Lake Koka, Ethiopia. *Momona Ethiopian Journal of Science.* **7**(1)**:** 16-31.

Elliott, A. (2000). Settling of fine sediment in a channel with emergent vegetation. *Journal of Hydraulic Engineering.* **126**(8)**:** 570-577.

Erkie Asmare (2017). Current Trend of Water Hyacinth Expansion and Its Consequence on the Fisheries around North Eastern Part of Lake Tana, Ethiopia. *Journal of Biodiversity and Endangered Species.* **5**(2)**:** 1-4.

FAO (1985). Water Quality for Agriculture. Irrigation and Drainage, Paper No. 29, Rev. 1. Food and Agriculture Organization of the United Nations, Rome.

Fasikaw Atanaw, Mamaru Ayalew, Muluken Alemu, *et al.* (2016). Calculating the sediment budget of a tropical lake in the Blue Nile basin: Lake Tana. *SOIL Discussion.* 1-32.

Fasil Degefu, Kibru Teshome, Gashaw Tesfaye, Fikadu Tefera, and Aschalew Lakew (2011). Some limnological aspects of Koka Reservoir, a shallow tropical artificial lake, Ethiopia. *Journal of Recent Trends Bio-Science.* **1**(1)**:** 94-100.

Feleke Zewge, Daniel Woldemichael, and Seyoum Leta (2011). Potential of water hyacinth (Eichhornia crassipes (Mart.) Solms) for the removal of chromium from tannery effluent in constructed pond system. *SINET: Ethiopian Journal of Science.* **34**(1)**:** 49-62.

Fernández-Aláez, C., Fernández-Aláez, M., and Bécares, E. (1999). Influence of water level fluctuation on the structure and composition of the macrophyte vegetation in two small temporary lakes in the northwest of Spain. *Hydrobiologia.* **415:** 155-162.

Firehun Yirefu, Abera Tafesse, Tariku Gebeyehu, and Taye Tessema (2007). Distribution, impact and management of water hyacinth at Wonji-Shewa Sugar Factory. *Ethiopian Journal of Weed Management.* **1:** 41-52.

Firehun Yirefu, Struik, P., Lantinga, E., and Taye Tessema (2014). Water hyacinth in the Rift Valley water bodies of Ethiopia: Its distribution, socio-economic importance and management. *International Journal of Current Agricultural Research.* **3**(5)**:** 67-75.

Fischer, W., and Fechter, H. (1982). Analytische Bestimmung und Fraktionierung von Cu, Zn, Pb, Cd, Ni und Co in Böden und Unterwasserböden. *Zeitschrift für Pflanzenernährung und Bodenkunde.* **145**(2)**:** 151-160.

Flower, R. (1991). Field calibration and performance of sediment traps in a eutrophic holomictic lake. *Journal of Paleolimnology.* **5**(2)**:** 175-188.

Fortino, K., Hershey, A. E., Keyse, M. D., and Whalen, S. C. (2009). Summer sedimentation in six shallow arctic lakes. *Hydrobiologia.* **621:** 75-84.

Gardner, W. D. (1980). Field assessment of sediment traps. *Journal of Marine Research.* **38**(1)**:** 41-52.

Gardner, W. D. (1985). The effect of tilt on sediment trap efficiency. *Deep Sea Research.* **32**(3)**:** 349-361.

Gashaw Tesfaye (2016). *Population and Ecosystem-based Fisheries Assessment of the Rift Valley Lake Koka, Ethiopia*. PhD Thesis. Universität Bremen, Bremen, Germany, 228p.

Gashaw Tesfaye, and Wolff, M. (2015). Stock assessment of fishery target species in Lake Koka, Ethiopia. *Revista de biologia tropical.* **63**(3)**:** 755-770.

Getu Dida (2017). *Floristic Composition of Wetland Plants and Ethnomedicinal Plants of Wonchi District, South Western Shewa, Oromia Regional State, Ethiopia*. MSc. Thesis. Addis Ababa University, Addis Ababa, Ethiopia, 113pp.

Ghosh, D., and Biswas, J. K. (2015). Biomonitoring Macrophytes Diversity and Abundance for Rating Aquatic Health of an Oxbow Lakeecosystem in Ganga River Basin. *American Journal of Phytomedicine and Clinical Therapeutics.* **3**(10)**:** 602-621.

Gichuki, J., Omondi, R., Boera, P., *et al.* (2012). Water hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach dynamics and succession in the Nyanza Gulf of Lake Victoria (east Africa): implications for water quality and biodiversity conservation. *Scientific World Journal.* **2012:** 1-10.

Girma Taddese, Sonder, K., and Peden, D. (2003). *The water of the Awash River basin a future challenge to Ethiopia*. International Livestock Research Institute, Addis Ababa, Ethiopia, 13pp.

Girma Tilahun, and Ahlgren, G. (2010). Seasonal variations in phytoplankton biomass and primary production in the Ethiopian Rift Valley lakes Ziway, Awassa and Chamo–The basis for fish production. *Limnologica.* **40**(4)**:** 330-342.

Girum Tamire, and Seyoum Mengistou (2012). Macrophyte species composition, distribution and diversity in relation to some physicochemical factors in the littoral zone of Lake Ziway, Ethiopia. *African Journal of Ecology.* **51**(1)**:** 66-77.

Gonzaga, M. I. S., Santos, J. A. G., and Ma, L. Q. (2006). Arsenic phytoextraction and hyperaccumulation by fern species. *Scientia Agricola.* **63**(1)**:** 90-101.

Gooderham, J., and Tsyrlin, E. (2002). *The waterbug book: a guide to the freshwater macroinvertebrates of temperate Australia*. Csiro publishing. guidance manual. Wisconsin department of natural resources. Madison, WI 53707.

Habtamu Getnet (2019). *Effects of water hyacinth (Eichhornia crassipes) on water quality and composition and abundance of phyto- and zooplankton in the littoral region of Koka Reservoir, Ethiopia*. MSc. Thesis. Addis Ababa University, Addis Ababa, Ethiopia, 95pp.

Hadgembes Tesfay (2007). *Spatio- Temporal Variations of the Biomass and Primary Production of Phytoplankton in Koka Reservoir.* MSc. Thesis. Addis Ababa University, Addis Ababa, Ethiopia, 92pp.

Haines, R. W., and Lye, K. A. (1983). *Sedges and rushes of east Africa*. East African Natural History Society, Nirobi, Kenya, 404pp.

Håkanson, L. (1984). Suspension and calibration of a sediment trap. *Schweizerische Zeitschrift für Hydrologie.* **46**(1)**:** 171-175.

Håkanson, L. (1994). A model to predict gross sedimentation in small glacial lakes. *Hydrobiologia.* **284**(1)**:** 19-42.

Hargrave, B. T., and Burns, N. M. (1979). Assessment of sediment trap collection efficiency. *Limnology and Oceanography.* **24**(6)**:** 1124-1136.

Hedberg, I., and Edwards, S. (1989). *Flora of Ethiopia: Pittosporaceae to Araliaceae*. 3 The National Herbarium, Addis Ababa and Asmara, Ethiopia; Upsala, Sweden.

Heinrichs, H., Brumsack, H. J., Loftfield, N., and König, N. (1986). Verbessertes Druckaufschlußsystem für biologische und anorganische Materialien. *Zeitschrift für Pflanzenernährung und Bodenkunde.* **149**(3)**:** 350-353.

Horppila, J., Kaitaranta, J., Joensuu, L., and Nurminen, L. (2013). Influence of emergent macrophyte (*Phragmites australis*) density on water turbulence and erosion of organic-rich sediment. *Journal of Hydrodynamics.* **25**(2)**:** 288-293.

Horppila, J., and NiemistÖ, J. (2008). Horizontal and vertical variations in sedimentation and resuspension rates in a stratifying lake - effects of internal seiches. *SED Sedimentology.* **55**(5)**:** 1135-1144.

Horppila, J., and Nurminen, L. (2001). The effect of an emergent macrophyte (*Typha angustifolia*) on sediment resuspension in a shallow north temperate lake. *Freshwater Biology.* **46**(11)**:** 1447-1455.

Horppila, J., and Nurminen, L. (2003). Effects of submerged macrophytes on sediment resuspension and internal phosphorus loading in Lake Hiidenvesi (southern Finland). *Water research.* **37**(18)**:** 4468-4474.

Horppila, J., and Nurminen, L. (2005a). Effects of calculation procedure and sampling site on trap method estimates of sediment resuspension in a shallow lake. *Sedimentology.* **52**(4)**:** 903-913.

Horppila, J., and Nurminen, L. (2005b). Effects of different macrophyte growth forms on sediment and P resuspension in a shallow lake. *Hydrobiologia.* **545**(1)**:** 167-175.

Huang, P., Han, B., and Liu, Z. (2007). Floating-leaved macrophyte (*Trapa quadrispinosa* Roxb) beds have significant effects on sediment resuspension in Lake Taihu, China. *Hydrobiologia.* **581**(1)**:** 189-193.

Hudon, C., Lalonde, S., and Gagnon, P. (2000). Ranking the effects of site exposure, plant growth form, water depth, and transparency on aquatic plant biomass. *Canadian Journal of Fisheries and Aquatic Sciences.* **57:** 31-42.

James, W., and Barko, J. (1991). *Influences of submersed aquatic macrophytes on zonation of sediment accretion and composition, Eau Galle Reservoir*.Wisconsin. Technical Report A-91-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

James, W. F., and Barko, J. W. (1994). Macrophyte influences on sediment resuspension and export in a shallow impoundment. *Lake and Reservoir Management.* **10**(2)**:** 95-102.

Jessup, B. K., Markowitz, A., Stribling, J. B., *et al.* (1999). *Family-level key to the stream invertebrates of Maryland and surrounding areas*. Maryland department of natural resources Chesapeake Bay and watershed program resource assessment service monitoring and non-tidal assessment division, CBWP-MANTA-EA-99-2.

Julien, P., and Shah, S. (2005). *Sedimentation Initiatives in Developing Countries Draft Report presented to UNESCO-ISI* Colorado State University, USA, 74pp.

Kabata-Pendias, A. (2000). *Trace elements in soils and plants*. CRC press, Boca Raton, London, New York, 403pp.

Kaitaranta, J., Niemistö, J., Buhvestova, O., and Nurminen, L. (2013). Quantifying sediment resuspension and internal phosphorus loading in shallow near-shore areas in the Gulf of Finland. *Boreal Environment Research.*

Kassahun Tessema (2017). *Heavy metals in the food chain and its potential health risk assessment in Lake Koka, Ethiopia*. MSc Thesis. Addis Ababa University, Addis Ababa, Ethiopia, 59pp.

Kateregga, E., and Sterner, T. (2009). Lake Victoria fish stocks and the effects of water hyacinth. *Journal of Environment and Development.* **18**(1)**:** 62-78.

Kebede Nigussie, Abayneh Ataro, Chandravanshi, B. S., Mesfin Redi-Abshiro, and McCrindle, R. I. (2015). Occurrence, distribution, and ecological risk assessment of potentially toxic elements in surface sediments of Lake Awassa and Lake Ziway, Ethiopia. *Environmental Science and Pollution Research Part A.* **50**(1)**:** 90-99.

Kebede Wolka (2012). Watershed management: an option to sustain dam and reservoir function in Ethiopia. *Journal of Environmental Science and Technology*. **5**(5)**:** 262-273.

Khayatzadeh, J., and Abbasi, E. (2010). The effects of heavy metals on aquatic animals **In**:*The 1st International Applied Geological Congress, Department of Geology, Islamic Azad University–Mashad Branch, Iran,* pp. 26-28.

Khedr, A.-H. A. (1996). Aquatic macrophyte distribution in Lake Manzala, Egypt. *International Journal of Salt Lake Research.* **5**(3)**:** 221-239.

Knight, R., McKim, T., and Kohl, H. (1987). Performance of a natural wetland treatment system for wastewater management. *Journal (Water Pollution Control Federation).* **59**(8)**:** 746-754.

Kõrs, A., Vilbaste, S., Käiro, K., *et al.* (2012). Temporal changes in the composition of macrophyte communities and environmental factors governing the distribution of aquatic plants in an unregulated lowland river (Emajõgi, Estonia). *Boreal environment research.* **17:** 460-472.

Kouamé, M., Diétoa, M., Da Costa, S., *et al.* (2010). Aquatic macroinvertebrate assemblages associated with root masses of water hyacinths, *Eichhornia crassipes* (Mart.) Solms-Laubach, 1883 (Commelinales: Pontederiaceae) in Taabo Lake, Ivory Coast. *Journal of Natural History.* **44**(5-6)**:** 257-278.

Kouamé, M., Dietoa, M., Edia, E., *et al.* (2011). Macroinvertebrate communities associated with macrophyte habitats in a tropical man-made lake (Lake Taabo, Côte d'Ivoire). *Knowledge and Management of Aquatic Ecosystems.*(400)**:** 03.

Kovalenko, K. E., Dibble, E. D., and Slade, J. G. (2010). Community effects of invasive macrophyte control: role of invasive plant abundance and habitat complexity. *Journal of Applied Ecology.* **47**(2)**:** 318-328.

Kuchapski, K. A., and Rasmussen, J. B. (2015). Surface coal mining influences on macroinvertebrate assemblages in streams of the Canadian Rocky Mountains. *Environmental toxicology chemistry and Ecology.* **34**(9)**:** 2138-2148.

Lakew Wondimu (2014). Studies on Hydrobiological Features of Koka Reservoir and Awash River in Ethiopia. *International Journal of Fisheries and Aquatic Studies* **1**(3)**:** 158-162.

Lalisa Gemechu (2018). Comparison of macrophytes distribution in Lake Hawassa at different pollution entry points, Hawassa, Ethiopia. *Ethiopian Journal of Environmental Studies and Management.* **11**(6)**:** 742-750.

Lasat, M. M. (2002). Phytoextraction of toxic metals: a review of biological mechanism. *Journal of Environmental Quality.* **31**(1)**:** 109-120.

Lewis, W. M. (2009). Ecological Zonation in Lakes. **In**: *Lake Ecosystem Ecology: A Global Perspective; A Derivative of Encyclopedia of Inland Waters* (G. E. Likens, Ed.), Vol. 1. Academic Press, Elsevier Inc., USA, p416-422.

LFDP [Lake Fisheries Development Project] (1997). Lake Fisheries Development Project; Lake Management Plans, Phase II.Vol. Working Paper Number 23, 2nd Edition, Project No 6100.36.20.032. pp. 11-15

Li, E.-H., Li, W., Liu, G.-H., and Yuan, L.-Y. (2008). The effect of different submerged macrophyte species and biomass on sediment resuspension in a shallow freshwater lake. *Aquatic Botany.* **88:** 121–126.

Li, F., Pan, Y., Xie, Y., *et al.* (2016). Different roles of three emergent macrophytes in promoting sedimentation in Dongting Lake, China. *Aquatic Sciences.* **78**(1)**:** 159-169.

Lougheed, V. L., Crosbie, B., and Chow-Fraser, P. (2001). Primary determinants of macrophyte community structure in 62 marshes across the Great Lakes basin: latitude, land use, and water quality effects. *Canadian Journal of Fisheries Aquatic Sciences.* **58**(8)**:** 1603-1612.

Lu, X., Kruatrachue, M., Pokethitiyook, P., and Homyok, K. (2004). Removal of cadmium and zinc by water hyacinth, *Eichhornia crassipes*. *Science Asia.* **30**(93)**:** 103.

Madsen, J. D., Chambers, P. A., James, W. F., Koch, E. W., and Westlake, D. F. (2001). The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia*. **444**(1)**:** 71-84.

Madsen, J. D., and Wersal, R. (2017). A review of aquatic plant monitoring and assessment methods. *Journal of Aquatic Plant Management*. **55:** 1-12.

Mäkelä, S., Huitu, E., and Arvola, L. (2004). Spatial patterns in aquatic vegetation composition and environmental covariates along chains of lakes in the Kokemäenjoki watershed (S. Finland). *Aquatic Botany*. **80**(4)**:** 253-269.

Maltchik, L., Rolon, A. S., and Schott, P. (2007). Effects of hydrological variation on the aquatic plant community in a floodplain palustrine wetland of southern Brazil. *Limnology*. **8:** 23-28.

Masifwa, W. F., Twongo, T., and Denny, P. (2001). The impact of water hyacinth, *Eichhornia crassipes* (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. *Hydrobiologia*. **452**(1)**:** 79-88.

Masresha Alemayehu, Skipperud, L., Rosseland, B. O., *et al.* (2011). Speciation of selected trace elements in three Ethiopian Rift Valley Lakes (Koka, Ziway, and Awassa) and their major inflows. *Science of the total environment.* **409**(19)**:** 3955-3970.

McCartney, M. (2007). *Decision support systems for large dam planning and operation in Africa. International Water Management Institute*. IWMI Working Paper 119), Sri Lanka, Colombo, 47 p

Melaku Mesfin, Tudorancea, C., and Baxter, R. (1988). Some limnological observations on two Ethiopian hydroelectric reservoirs: Koka (Shewa administrative district) and Finchaa (Welega administrative district). *Hydrobiologia.* **157**(1)**:** 47-55.

Mellem, J., Baijnath, H., and Odhav, B. (2009). Tanslocation and accumulation of Cr, Hg, As, Pb, Cu, and Ni by *Amaranthus dubius* (Amaranthaceae) from contaminated sites. *Journal of Environmental Sciences and Health.* **44:** 568-575.

Merritt, R. W., and Cummins, K. W. (1996). *An introduction to the aquatic insects of North America*. (3rd, Ed.) Kendall/Hunt Publishing Company, USA, 34pp.

Mesay Adugna (2017). Review on Environmental Effects of Ethiopian Floriculture Industry. *Asian Research Journal of Agriculture*. **4**(2)**:** 1-13.

Mesfin Mergia, Keesstra, S., Baartman, J., Ritsema, C., and Assefa Melesse (2015). Evaluating sediment storage dams: structural off-site sediment trapping measures in northwest Ethiopia. *Cuadernos de investigación geográfica.* **41**(1)**:** 7-22.

Mikulyuk, A., Sharma, S., Van Egeren, S., *et al.* (2011). The relative role of environmental, spatial, and land-use patterns in explaining aquatic macrophyte community composition. *Canadian Journal of Fisheries and Aquatic Sciences.* **68**(10)**:** 1778-1789.

Minbale Aschale, Yilma Sileshi, Kelly-Quinn, M., and Dereje Hailu (2016). Evaluation of potentially toxic element pollution in the benthic sediments of the water bodies of the city of Addis Ababa, Ethiopia. *Journal of Environmental Chemical Engineering.* **4:** 4173-4183.

Mironga, J. M., Mathooko, J. M., and Onywere, S. M. (2012). Effect of water hyacinth infestation on the physicochemical characteristics of Lake Naivasha. *International Journal of Humanities and Social Science.* **2**(7)**:** 103-113.

Mishra, S., and Maiti, A. (2017). The efficiency of *Eichhornia crassipes* in the removal of organic and inorganic pollutants from wastewater: a review. *Environmental Science and Pollution Research.* **24**(9)**:** 7921-7937.

Mishra, V. K., and Tripathi, B. (2009). Accumulation of chromium and zinc from aqueous solutions using water hyacinth (*Eichhornia crassipes*). *Journal of Hazardous Materials.* **164**(2-3)**:** 1059-1063.

Mitsch, W. J., and Reeder, B. C. (1992). Nutrient and hydrologic budgets of a Great Lakes coastal freshwater wetland during a drought year. *Wetlands Ecology and Management.* **1**(4)**:** 211-222.

Mohammed, A., May, T., Echols, K., *et al.* (2012). Metals in sediments and fish from Sea Lots and Point Lisas Harbors, Trinidad and Tobago. *Marine pollution bulletin.* **64**(1)**:** 169-173.

Mudd, S. M., D'Alpaos, A., and Morris, J. T. (2010). How does vegetation affect sedimentation on tidal marshes? Investigating particle capture and hydrodynamic controls on biologically mediated sedimentation. *Journal of Geophysical Research: Earth Surface.* **115:** 1-14.

Mulatie Mekonnen (2016). *Sustaining reservoir use through sediment trapping in NW Ethiopia*. PhD Thesis. Wageningen University, Wageningen, The Netherlands, 140pp.

Mulugeta Getu (2009). Ethiopian floriculture and its impact on the environment. *Mizan law review.* **3**(2)**:** 240-270.

Mulugeta Getu (2013). Defiance of environmental governance: environmental impact assessment in Ethiopian floriculture industry. *Journal of Environmental Research and Management.* **4**(4)**:** 219-229.

Muluneh Imru (1992). *Sedimentation in the Koka reservoir, Ethiopia; possibilities of prediction and control*. MSc thesis. International Institute for Hydraulics and Environmental Engineering, Delft, The Netherlands.

Muzzi, R. W., and Eadie, B. J. (2002). The design and performance of a sequencing sediment trap for lake research. *Marine Technology Society Journal.* **36**(2)**:** 23-28.

Namminga, H. E., and Wilhm, J. (1976). Effects of high discharge and an oil refinery cleanup operation on heavy metals in water and sediments in Skeleton Creek **In**:*Proceedings of the Oklahoma Academy of Science*, pp. 133-138.

Ngari, A., Kinyamario, J., Ntiba, M., and Mavuti, K. (2009). Factors affecting abundance and distribution of submerged and floating macrophytes in Lake Naivasha, Kenya. *African Journal of Ecology.* **47**(1)**:** 32-39.

Niguse Bekele, Yan, X., Wu, H., Colebrooke, L., and Wang, J. (2018). Occurrences and ecotoxicological risk assessment of heavy metals in surface sediments from Awash River Basin, Ethiopia. *Water.* **10**(5)**:** 535.

Nigussie Haregeweyn, Poesen, J., Nyssen, J., *et al.* (2006). Reservoirs in Tigray (Northern Ethiopia): characteristics and sediment deposition problems. *Land Degradation and Development.* **17**(2)**:** 211-230.

Nolte, S., Koppenaal, E. C., Esselink, P., *et al.* (2013). Measuring sedimentation in tidal marshes: a review on methods and their applicability in biogeomorphological studies. *Journal of Coastal Conservation.* **17**(3)**:** 301-325.

Nor, Y. M. (1990). The absorption of metal ions by *Eichhornia crassipes*. *Chemical Speciation and Bioavailability.* **2**(2)**:** 85-91.

Nurminen, L. (2003a). Macrophyte species composition reflecting water quality changes in adjacent water bodies of Lake Hiidenvesi, SW Finland. *Annales Botanici Fennici* **40:** 199-208.

Nurminen, L. (2003b). *Role of macrophytes in a clay-turbid lake: Implication of different life forms on water quality*. PhD Thesis. University of Helsinki, Finland, 37pp.

Ochieng, E., Lalah, J., and Wandiga, S. O. (2007). Analysis of Heavy Metals in Water and Surface Sediment in Five Rift Valley Lakes in Kenya for Assessment of Recent Increase in Anthropogenic Activities. *Bulletin of Environmental Contamination and Toxicology.* **79:** 570-576.

Odjegba, V. J., and Fasidi, I. O. (2007). Phytoremediation of heavy metals by *Eichhornia crassipes*. *Environmentalist.* **27**(3)**:** 349-355.

Ogendi, G., Maina, G., Mbuthia, J., *et al.* (2014). Heavy metal concentrations in water, sediments and common carp (*Cyprinus carpio*) fish species from Lake Naivasha, Kenya. *Research Journal of Environmental and Earth Sciences.* **6**(8)**:** 416-423.

Ogwang, J., and Molo, R. (1998). Impact studies on *Neochetina bruchi* and *Neochetina eichhorniae* in Lake Kyoga, Uganda **In**:*Proceedings of the 1st IOBC Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth. November16-19,* pp. 10-13.

Pachura, P., Ociepa-Kubicka, A., Skowron-Grabowska, B. J. D., and Treatment, W. (2016). Assessment of the availability of heavy metals to plants based on the translocation index and the bioaccumulation factor **57**(3)**:** 1469-1477.

Pattnaik, S. (2014). Species Diversity of Lake Hawassa, Ethiopia. *International Journal of Scientific Research.* **3**(11)**:** 33-35.

Peters, J., and Lodge, D. (2009). Littoral zone. **In**: *Lake Ecosystem Ecology: A Global Perspective; A Derivative of Encyclopedia of Inland Waters* (G. E. Likens, Ed.), Vol. 1. Academic Press, Elsevier Inc., USA, p19-26.

Petrucio, M., and Esteves, F. (2000). Uptake rates of nitrogen and phosphorus in the water by *Eichhornia crassipes* and *Salvinia auriculata*. *Revista Brasileira de Biologia.* **60**(2)**:** 229-236.

Pielou, E. J. N. Y. (1975). *Ecological Diversity*. Wiley & Sons, Interscience, New York.

Pirini, C. B., Karagiannakidou, V., and Charitonidis, S. (2011). Abundance, diversity and distribution of macrophyte communities in neighboring lakes of different trophic states and morphology in north-central Greece. *Archives of Biological Sciences.* **63**(3)**:** 763-774.

Poi de Neiff, A., and Carignan, R. (1997). Macroinvertebrates on *Eichhornia crassipes* roots in two lakes of the Paraná River floodplain. *Hydrobiologia.* **345**(2)**:** 185-196.

Pointier, J., Guyard, A., and Mosser, A. (1989). Biological control of *Biomphalaria glabrata* and *B. straminea* by the competitor snail *Thiara tuberculata* in a transmission site of schistosomiasis in Martinique, French West Indies. *Annals of Tropical Medicine and Parasitology*. **83**(3)**:** 363-369.

Pompeo, M., and Moschini-Carlos, V. (1996). Seasonal variation in the density of the macrophyte *Scirpus cubensis* POEPP & KUNTH (Cyperaceae) in the Lagoa do Infernao, State of Sao Paulo, Brazil. *Limnetica.* **12:** 17-23.

Rai, P. K. (2009). Heavy metals in water, sediments and wetland plants in an aquatic ecosystem of tropical industrial region, India. *Environmental monitoring and assessment.* **158**(1-4)**:** 433-457.

Ramírez, A., and Gutiérrez-Fonseca, P. E. (2014). Functional feeding groups of aquatic insect families in Latin America: a critical analysis and review of existing literature. *International Journal of Tropical Biology and Conservation.* **62**(Suppl. 2)**:** 155-167.

Rezene Fessehaie (2005). Water hyacinth (*Eichhornia crassipes*): A Review of its weed status in Ethiopia. *Arem* **6:** 105-111.

Robarge, W., Edwards, A., and Johnson, B. (1983). Water and waste water analysis for nitrate via nitration of salicylic acid. *Communications in Soil Science Plant Analysis.* **14**(12)**:** 1207-1215.

Rocha-Ramírez, A., Ramírez-Rojas, A., Chávez-López, R., and Alcocer, J. J. A. E. (2007). Invertebrate assemblages associated with root masses of *Eichhornia crassipes* (Mart.) Solms-Laubach 1883 in the Alvarado lagoonal system, Veracruz, Mexico. *Aquatic Ecology.* **41**(2)**:** 319-333.

Rolon, A. S., and Maltchik, L. (2006). Environmental factors as predictors of aquatic macrophyte richness and composition in wetlands of southern Brazil. *Hydrobiologia.* **556**(1)**:** 221-231.

Rommens, W., Maes, J., Dekeza, N., *et al.* (2003). The impact of water hyacinth (*Eichhornia crassipes*) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). I. Water quality. *Archiv für Hydrobiologie.* **158**(3)**:** 373-388.

Rooney, N., Kalff, J., and Habel, C. (2003). The role of submerged macrophyte beds in phosphorus and sediment accumulation in Lake Memphremagog, Quebec, Canada. *Limnology and Oceanography.* **48**(5)**:** 1927-1937.

Saha, P., Shinde, O., and Sarkar, S. (2017). Phytoremediation of industrial mines wastewater using water hyacinth. *International journal of phytoremediation.* **19**(1)**:** 87-96.

Salem, Z. B., Laffray, X., Ashoour, A., Ayadi, H., and Aleya, L. (2014). Metal accumulation and distribution in the organ of reeds and cattails in a constructed treatment wetland (Etueffont, France). *Ecological engineering.* **64:** 1-17.

Sand-Jensen, K. (1998). Influence of submerged macrophytes on sediment composition and near-bed flow in lowland streams. *Freshwater biology.* **39**(4)**:** 663-679.

Schillereff, D. N. (2015). A review of in situ measurement techniques for investigating suspended sediment dynamics in lakes. *Geomorphological Techniques (Online Edition), British Society for Geomorphology, London.* 2047-0371.

Schneider, I., Rubio, J., Misra, M., and Smith, R. (1995). *Eichhornia crassipes* as biosorbent for heavy metal ions. *Minerals engineering.* **8**(9)**:** 979-988.

Schulz, M., Kozerski, H.-P., Pluntke, T., and Rinke, K. (2003). The influence of macrophytes on sedimentation and nutrient retention in the lower River Spree (Germany). *Water Research.* **37:** 569–578.

Seleshi Bekele, McCartney, M., Steenhuis, T. S., and Ahmed, A. A. (2009). *A review of hydrology, sediment and water resource use in the Blue Nile Basin*. International Water Management Institute, Working Paper 131 Colombo, Sri Lanka, 93pp.

Sender, J. (2012). The dynamics of macrophytes in a lake in an agricultural landscape. *Limnological Review.* **12**(2)**:** 93-100.

Seyoum Tegegne (2011). *The practice and challenges of lake management in Ethiopia-the case of lake Koka*. MSc. Thesis. Swedish University of Agricultural Sciences, SLU, Uppsala, Sweden, 115pp.

Shah, A. I. (2017). Heavy metal impact on aquatic life and human health–an over view **In**: *37th Annual Conference of the International Association for Impact Assessment*, pp. 4-7.

Shahin, M. (1993). An overview of reservoir sedimentation in some African river basins **In**: *Sediment problems: strategies for monitoring, prediction and control. Proceedings of the Yokohama symposium*, pp. 93-100.

Shannon, C., and Weiner, W. (1963). *The mathematical theory of communication Urban University Illinois Press. 125pp*.

Silva, S. C. A. d., Bona, C., Cervi, A. C., and Padial, A. A. (2014). Aquatic macrophyte community varies in urban reservoirs with different degrees of eutrophication. *Acta Limnologica Brasiliensia.* **26**(2)**:** 129-142.

Singh, K. K., Sharma, B. M., and Usha, K. (2013). Inventory of the Aquatic Macrophytes in Lake Kharungpat, India. *Journal of Energy Technologies and Policy* **3**(11)**:** 64-75.

Sires, J. (2017). *A Review of Potential Zinc and Copper Pollution Sources in the Kenai River Watershed*. Kenai Watershed Forum for the Alaska Department of Environmental Conservation, (907) 260 5449 x1207.

Sisay Misganaw, and Seyoum Leta (2017). Assessment of the ecological impacts of floriculture industries using physico-chemical parameters along Wedecha river, Debrezeit, Ethiopia. *Water Utility Journal.* **15:** 53-65.

Smolyakov, B. S. (2012). Uptake of Zn, Cu, Pb, and Cd by water hyacinth in the initial stage of water system remediation. *Applied geochemistry.* **27**(6)**:** 1214-1219.

Solomon, F. (2008). Impacts of metals on aquatic ecosystems and human health.

Solomon Kibret, McCartney, M., Lautze, J., and Jayasinghe, G. (2009). *Malaria Transmission in the Vicinity of Impounded Water: Evidence from the Koka Reservoir, Ethiopia.* . .International Water Management Institute Colombo, Sri Lanka.

Sousa, W. T., Thomaz, S. M., and Murphy, K. J. (2011). Drivers of aquatic macrophyte community structure in a Neotropical riverine lake. *Acta oecologica.* **37**(5)**:** 462-475.

Spliethoff, P., Wudneh, T., Tariku, E., and Senbeta, G. (2009). *Past, current and potential production of fish in lake Ziway-Central Rift Valley in Ethiopia*.Wageningen UR Centre for Development Innovation, Capacity

Development and Institutional Change Programme, Wageningen International, The Netherlands, 31pp.

Stoltz, E., and Greger, M. (2002). Accumulation properties of As, Cd, Cu, Pb and Zn by four wetland plant species growing on submerged mine tailings. *Environmental and Experimental Botany* **47** 271–280.

Štrbac, S., Šajnović, A., Kašanin Grubin, M., *et al.* (2014). Metals in sediment and *Phragmites australis* (common reed) from Tisza River, Serbia. *Applied ecology and environmental research.* **12**(1)**:** 105-122.

Swain, G., Adhikari, S., and Mohanty, P. (2014). Phytoremediation of Copper and Cadmium from Water Using Water Hyacinth," *Eichhornia Crassipes*". *International Journal of Agricultural Science Technology.* **2**(1)**:** 1-7.

Takele Zeleke, Moussa, A. M., and El-Manadely, M. S. (2013). Prediction of sediment inflows to Angereb dam reservoir using the SRH-1D sediment transport model. *Lakes and Reservoirs: Research and Management.* **18**(4)**:** 366-371.

Tamene Fite, and Seyoum Leta (2013). Temporal and Spatial Variations on Heavy Metals Concentration in River Mojo, Oromia State, East Ethiopia. *International Journal of Science and Research.* **4**(1)**:** 1424-1432.

Tamiru Alemayehu (2001). The impact of uncontrolled waste disposal on surface water quality in Addis Ababa, Ethiopia. *SINET: Ethiopian Journal of Science.* **24**(1)**:** 93-104.

Teklu Gebretsadik, and Kassahun Mereke (2017). Threats and opportunities to major rift valley Lakes Wetlands of Ethiopia. *Agricultural Research and Technology.* **9:** 1-6.

Temesgen Eliku, and Seyoum Leta (2017). Heavy metals bioconcentration from soil to vegetables and appraisal of health risk in Koka and Wonji farms, Ethiopia. *Environmental Science and Pollution Research.* **24**(12)**:** 11807-11815.

Ter Braak, C. J., and Smilauer, P. (2002). *CANOCO reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5).*www. canoco. com.

Thomaz, S. M., Bini, L. M., Souza, M. C. d., Kita, K. K., and Camargo, A. F. M. (1999). Aquatic macrophytes of Itaipu Reservoir, Brazil: survey of species and ecological considerations. *Brazilian Archives of Biology and Technology.* **42**(1)**:** 15-22.

Tigist Ashagre, Girma Tilahun, and Kassaye Balkew (2014). Assessment of Metals Concentration in Water, Sediment and Macrophyte Plant Collected from Lake Hawassa, Ethiopia. *Environmental and Analytical Toxicology.* **5**(1)**:** 247.

Toft, J. D., Simenstad, C. A., Cordell, J. R., and Grimaldo, L. F. (2003). The effects of introduced water hyacinth on habitat structure, invertebrate assemblages, and fish diets. *Estuaries.* **26**(3)**:** 746-758.

Topuzović, M., Pavlović, D., and Ostojić, A. (2009). Temporal and spatial distribution of macrophytes in the Gruža Reservoir (Serbia) *Archives of Biological Sciences, Belgrade.* **61**(2)**:** 289-296.

USEPA 3010A (1992). Method 3010A, Acid digestion of aqueous samples and extracts for total metal for analysis of by FLAA or ICP-Spectroscopy, Office of Solid, Waste, 5pp.

VDLUFA (1991). Methods Book for the Analysis of Compost.Vol. Translation of the 3rd edition, supplemented and revised, January, 2003 Federal Compost Quality Assurance Organisation (FCQAO), 94pp.

Vermaat, J. E., Santamaria, L., and Roos, P. J. (2000). Water flow across and sediment trapping in submerged macrophyte beds of contrasting growth form. *Archiv für Hydrobiologie.* **148**(4)**:** 549-562.

Viljoen, A., Cyrus, D., and Wepener, V. (2001). Comparison of the density and species composition of aquatic invertebrates found between the roots of *Eichhornia crassipes* plants from two coastal lakes in northern KwaZulu-Natal. *African Journal of Aquatic Science.* **26:** 57-66.

Villamagna, A., and Murphy, B. (2010). Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater biology.* **55**(2)**:** 282-298.

Villamagna, A. M. (2009). *Ecological effects of water hyacinth (Eichhornia crassipes) on Lake Chapala, Mexico*. PhD Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, 195pp.

Waithaka, E. (2013). Impacts of water hyacinth (*Eichhornia crassipes*) on the fishing communities of Lake Naivasha, Kenya. *Journal of Biodiversity and Endangered Species.* **1**(2)**:** 1-4.

Walker, P. D., Wijnhoven, S., and van der Velde, G. (2013). Macrophyte presence and growth form influence macroinvertebrate community structure. *Aquatic Botany.* **104:** 80-87.

Wang, Z., and Yan, S. (2017). Direct and Strong Influence of Water Hyacinth on Aquatic Communities in Natural Waters. **In**: *Water Hyacinth*, pp. 44-65. CRC Press.

Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems*. 3rd ed. Academic Press, USA, 1006pp.

WHO [World Health Organization] (2008). Guidelines for drinkingwater quality. 3rd edition, incorporating the first and second addenda; Recommendations.Vol. 1. pp. 515

Wondie Zelalem (2013). *Assessment of Water Hyacinth (Eichhornia crassipes (Mart) Solms) in Relation to Water Quality, Composition and Abundance of Plankton and Macro-invertebrates in the north-eastern part of Lake Tana, Ethiopia.* MSc. Thesis. Addis Ababa University, Addis Ababa, Ethiopia, 105pp.

Wondie Zelalem, Demeke Kifle, Seyoum Mengistu, and Ayalew Wondie (2017). Weed-bed Macro-invertebrate Composition and Abundance in Relation to Water Hyacinth (*Eichhornia crassipes* (Mart) Solms) in the North-Eastern Lake Tana, Ethiopia. *Journal of Agriculture and Environmental Sciences.* **2**(1)**:** 52-66.

Xu, C., Xulei, S., Pengjie, H., *et al.* (2015). Concentrations of heavy metals in suburban horticultural soils and their uptake by *Artemisia selengensis*. *Pedosphere.* **25**(6)**:** 878-887.

Yang, Y., Wei, L., Cui, L., Zhang, M., and Wang, J. (2017). Profiles and Risk Assessment of Heavy Metals in Great Rift Lakes, Kenya. *Clean Soil Air Water.* **45**(3)**:** 1-8.

Yared Beyene (2014). *Levels and Effects of Organochlorine Pesticides and Heavy Metals in Aquatic Ecosystem from the Rift Valley Region, Ethiopia*. PhD Thesis. Hokkaido University, Sapporo, Japan, 124pp.

Yared Beyene, Ikenaka, Y., Saengtienchai, A., *et al.* (2013). Occurrence, distribution, and ecological risk assessment of DDTs and heavy metals in surface sediments from Lake Awassa—Ethiopian Rift Valley Lake. *Environmental Science and Pollution Research.* **20**(12)**:** 8663-8671.

Ye, Z., Baker, A., Wong, M. H., and Willis, A. (2003). Copper tolerance, uptake and accumulation by *Phragmites australis*. *Chemosphere.* **50**(6)**:** 795-800.

Yen, L. V., and Saibeh, K. (2013). Phytoremediation using *Typha angustifolia L.* for mine water effluence treatment: Case study of ex-Mamut copper mine, Ranau, Sabah. *Borneo Science.* **33:** 16-22.

Yetneberk Ayalew, Skipperud, L., Einset, J., and Salbu, B. (2016). Aquatic macrophytes in Ethiopian Rift Valley lakes; Their trace elements concentration and use as pollution indicators. *Aquatic Botany.* **134:** 18-25.

Yetneberk Ayalew, Skipperud, L., Meland, S., *et al.* (2012). Trace element mobility and transfer to vegetation within the Ethiopian Rift Valley lake areas. *Journal of Environmental Monitoring.* **14**(10)**:** 2698-2709.

Yezbie Kassa (2016). *Macrophyte Ecology, Nutrient Dynamics and Water Quality of the Littoral Zone, and Yitamot Wetland, Lake Tana, Ethiopia*. PhD Thesis. Addis Ababa University, Addis Ababa, Ethiopia, 205pp.

Yigrem Mengist, and Yohannes Moges (2019). Distribution, Impacts and Management Option for Water Hyacinth (Eichhnornia Crassipes [Mart.] Solms) in Ethiopia: A Review. *Journal of Advances in Agriculture.* **10:** 1764-1771.

Yongo, E., Outa, N., and Ngodhe, S. O. (2017). Effects of Water hyacinth (*Eichhornia crassipes* Solm) Infestation on water quality, fish species diversity and abundance in the Nyanza Gulf of Lake Victoria, Kenya. *International Journal of Fisheries and Aquatic Research.* **2**(1)**:** 8-10.

Zekaryas Fanta (2016).*Study of Duckweed-Based Pond System for the Treatment of Domestic Wastewater*. Addis Ababa University.

Zhang, M., Cui, L., Sheng, L., and Wang, Y. (2009). Distribution and enrichment of heavy metals among sediments, water body and plants in Hengshuihu Wetland of Northern China. *Ecological engineering.* **35**(4)**:** 563-569.

Zhu, M., Zhu, G., Nurminen, L., *et al.* (2015). The influence of macrophytes on sediment resuspension and the effect of associated nutrients in a shallow and large lake (Lake Taihu, China). *PloS one.* **10**(6)**:** 1-20.

Zia, H., Harris, N. R., Merrett, G. V., Rivers, M., and Coles, N. (2013). The impact of agricultural activities on water quality: A case for collaborative catchment-scale management using integrated wireless sensor networks. *Computers electronics in agriculture.* **96:** 126-138.

Zinabu GebreMariam, and Pearce, N. J. (2003). Concentrations of heavy metals and related trace elements in some Ethiopian rift-valley lakes and their in-flows. *Hydrobiologia.* **492**(1-3)**:** 171-178.

APPENDIX

Appendix 1. Relative abundance of macrophytes at each sites

Macrophyte	**Meto Aleka**	**Awash I**	**Awash II**	**Awash III**	**Ayage I**	**Ayage II**	**Tulu Bofa**	**Ashewa**	**HEPP**
A. sessilis	2.53	1.04	2.35	2.61	-	1.77	1.43	1.21	0.96
E. prostrata	0.76	-	-	-	-	0.51	0.65	-	-
G. maderaspatana	-	-	-	-	-	0.29	0.27	-	-
Sphaeranthus sp.	-	3.16	3.25	3.80	-	-	-	-	-
Heliotropium sp.	-	-	-	-	-	0.45	0.58	-	-
R. sinuata	0.99	2.86	1.07	0.71	-	1.05	1.30	0.59	-
C. ambrosioides	0.64	-	-	-	-	0.67	-	-	-
C. articulatus	2.55	1.46	3.00	8.19	1.11	1.73	1.47	4.77	-
C. dives	1.06	11.9	9.89	2.83	1.68	3.32	8.28	1.30	-
C. rotundus	6.77	2.06	2.02	5.54	1.29	2.59	2.71	4.42	-
Schoenoplectiella sp.	-	0.92	0.99	-	-	-	-	-	-
Cyperus sp.	1.31	-	-	-	-	-	-	-	-
C. assimilis	0.92	-	-	-	-	-	-	-	-
A. baccifera	1.51	0.59	0.49	0.47	-	0.86	0.65	-	-
Hibiscus sp.	0.46	-	-	-	-	0.19	0.65	-	-
G. lotoides	1.10	0.55	0.74	1.42	-	1.41	0.79	-	-
L. adscendens	0.58	1.24	1.39	0.95	0.45	0.48	0.52	0.88	1.03
D. abyssinica	0.46	-	-	-	-	0.58	0.76	-	-
E. colona	1.02	1.21	1.89	0.71	-	1.92	1.36	1.45	-
E. stagnina	3.75	15.9	8.59	3.16	17.6	9.03	9.79	3.03	-
E. indica	0.83	-	-	-	-	0.58	1.08	-	-
L. caerulescens	2.14	7.50	7.28	21.2	13.0	11.1	9.54	9.74	4.49
P. australis	-	-	-	-	-	0.58	-	-	-
P. decipiens	-	-	-	0.47	0.74	0.54	0.48	0.37	1.39
P. senegalensis	0.46	0.51	0.45	0.47	0.65	0.72	0.51	0.45	-
E. crassipes	70.2	44.8	54.3	45.7	58.7	58.5	56.7	71.0	92.1
Physalis sp.	-	-	-	-	-	0.38	0.43	-	-
T. angustifolia	-	4.28	2.27	1.74	4.71	0.77	-	0.78	-

Appendix 2. Seasonal macrophyte distribution in Lake Koka (+ = Present, - = Absent)

Macrophyte			**Dry Season**	**Wet Season**
Family	**Species**	**Common Name**		
Amaranthaceae	*Alternanthera sessilis* (L.) R. Br. ex DC.	Sessile joy weed	+	+
Asteraceae	*Eclipta prostrata* (L.) L.	False daisy	+	-
	Grangea maderaspatana (L.) Desf.	Madras carpet	+	-
	Sphaeranthus sp.	-	+	-
Boraginaceae	*Heliotropium sp.*	-	+	-
Brassicaceae	*Rorippa sinuate* (Nutt.) A.S. Hitchc.	Yellow cress	+	-
Chenopodiaceae	*Chenopodium ambrosioides* (L.)	Wormseed	+	-
Cyperaceae	*Cyperus articulates* (L.)	Jointed flat sedge	+	+
	Cyperus dives Delile	-	+	+
	Cyperus rotundus (L.)	Nut Sedge	+	+
	Schoenoplectiella juncea (Willd.) Lye	-	+	-
	Cyperus sp.	-	+	-
	Courtoisina assimilis (Steud.) Maquet	-	+	-
Lythraceae	*Ammannia baccifera* (L.)	Blistering ammannia	+	-
Malvaceae	*Hibiscus sp.*	-	+	-
Molluginaceae	*Glinus lotoides* (L.)	Lotus sweet juice	+	-
Onagraceae	*Ludwigia adscendens* (L.) H. Hara	Water primrose	+	+
Poaceae	*Digitaria abyssinica* (Hochst. ex A. Rich.) Stapf	Couch grass	+	-
	Echinochloa colona (L.) Link	Jungle rice	+	+
	Echinochloa stagnina (Retz.) P. Beauv.	Hippo. grass	+	+
	Eleusine indica (L.) Gaertn.	Indian goose grass	+	-
	Leptochloa caerulescens Steud.	-	+	+
	Phragmites australis (Cav.) Trin. ex Steud.	Common reed	+	+
Polygonaceae	*Persicaria decipiens* (R. Br.) K. L. Wilson	Knot weed	+	+
	Persicaria senegalensis (Meisn.) Soják	-	+	+
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.	Water hyacinth	+	+
Solanaceae	*Physalis sp.*	-	+	-
Thyphaceae	*Typha angustifolia* (L.)	Narrowleaf-cattail	+	+

Appendix 3. Pics showing major groups of identified macro-invertebrates

Ephemeroptera (Mayflies)

Amelotopsidae

Baetidae

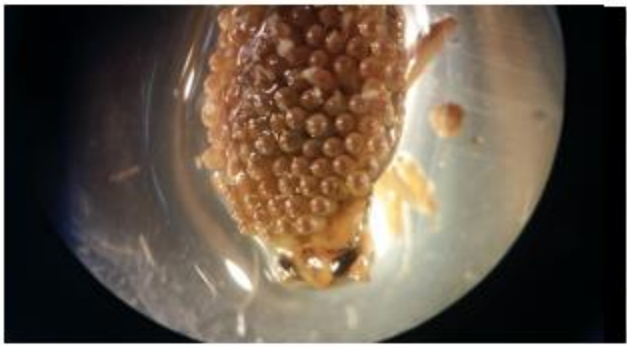
Canidae

Odonata (Damselflies & Dragonflies)

Coenagrionidae

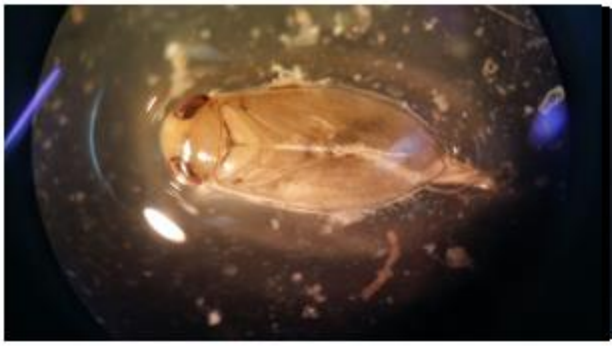
Libellulidae

Hemiptera (Water or true bugs)

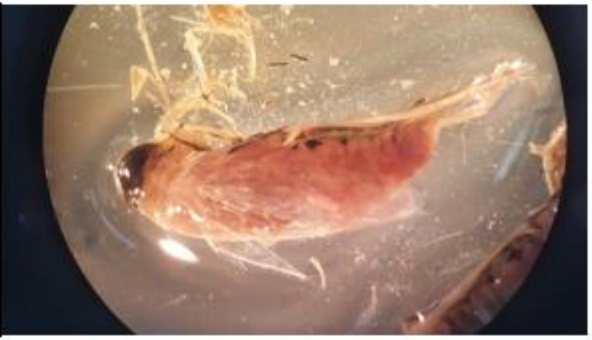


Belostomatidae

Belostomatidae (Lethocerus sp.)



Corixidae (Boatman)

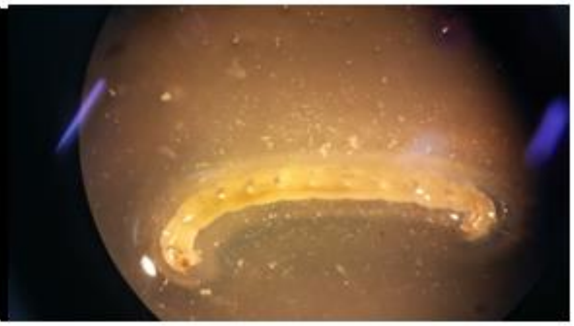


Notonectidae (Backswimmer)

Pleidae (Pygmy Backswimmer)

Diptera (Two winged /True flies)

Ceratopogonidae



Chironomidae

Coleoptera (Aquatic Beetles)

Dytiscidae

Hydrophilidae

Gastropods

Gastropod associated with root masses of *Eichhornia crassipes*