ADDIS ABABA UNIVERSITY
GRADUATE STUDIES
DEPARTMENT OF ZOOLOGICAL SCIENCES

HEAVY METALS IN LAKE KOKA FOOD CHAIN: POTENTIAL HEALTH RISK IMPLICATIONS

A Thesis Submitted to the Department of Zoological Sciences of Addis Ababa University in Partial Fulfillment of the Requirements for the degree of Masters of Science in Biology (Fisheries and Aquatic Sciences)

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Feb 2018

Addis Ababa, Ethiopia

Abstract

The present study was undertaken to investigate heavy metals in Lake Koka (Ethiopia) food chain and its potential health risk implications. Particularly the study examined the concentration of some heavy metals, their bioaccumulation factors in (water, bottom sediments) and their biomagnifications factors along the food chain of phytoplankton-Zooplankton-muscle tissues of fish species. In situ measurements of the physicochemical parameters (DO, Temperature, EC, and pH) were taken from seven sampling sites using portable Multimeter. The major inorganic nutrients (NO_3, NO_2, NH_3, PO_4, and TP) were analyzed in the laboratory using APHA method. The heavy metal analysis was performed using Graphite Furnance Atomic Absorption Spectrophotometer method. The results of the study indicated that the values of most of the physical, chemical and biological parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), Nitrate (NO_3) and Chromium (total Cr) were significantly higher at Modjo downstream site ($P<0.05$). The general distribution of heavy metals in sediment samples was ranked as Mn>Cr >Pb>Zn>Cu>Ni>Cd. Metal concentration in the muscle tissue of fish decreased in the sequence of Cr>Cu>Pb>Cd. Bioaccumulation factor of water for Cd and Pb increased as follow phytoplankton > Zooplankton > fish species. The Biomagnifications factor of Chromium for zooplankton, *C. garipinus, O. niloticus* and *C. carpio* are 1.63, 1.18, 1.36, and 2.28 respectively. The concentration of Cr was in the direction of fish species >Zooplankton> phytoplankton. The concentration of Cr at Modjo Upstream, Modjo Downstream, and Kentare sites were above the permissible limits. Similarly, the concentration of Pb at the riverine sites was above the permissible limits of WHO and USEPA prescribed. The concentration of Cr on *C. garipinus, O. niloticus,* and *C. carpio* was above the permissible Limits of WHO and FEPA. BAFW for (Cd, Pb and Cr) >1) and BAFS for the same metals <1 indicated that in the study lake there was bioaccumulation from water than sediment. Human exposure to heavy metals due to fish consumption from Lake Koka was also assessed. The results show that weekly intake estimates are considerably lower than the provisional tolerable human weekly intake values provided by WHO and FSA. Thus Cd, Pb, and Cu pose no public health hazard through consumption of the respective fish species. But no tolerable human intake values for Cr from food are provided by the organization, maybe because Cr is not very toxic when introduced by the oral route.

Keywords: Bioaccumulation, Biomagnifications, Heavy metals, Human intake exposure, Lake Koka.

Acknowledgements

My heartfelt thanks go to my advisors Prof. Brook Lemma and Dr. Tadesse Fetahi for their valuable advice and partial financial support of this research through the University of East London/EFASA Koka Project and AAU/Sida Block Grant Project. It is my pleasure to thank Prof. Seyoum Mengistou for all kind of resource support during the fieldwork. I am very grateful to all graduate students in the stream of Fisheries and Aquatic Sciences at Addis Ababa University. Especially to Mesfin GebreHiwot, Assefa Wosinie, Abinet W/senbet, Solomon Wagaw, Tarekegn Wondimagegn and Yirga Enawgaw (Ph.D. candidates) for their costly input during data collection, laboratory analysis and overall writing setup of the paper. I am thankful also for Addis Ababa Environmental Protection Authority (EPA), Ministry of Water Resources, Irrigation and Electricity (MWIE), Ethiopian Electric Power Authority (EEPA) and Ethiopian Metrological Agency (EMA) from where I received preliminary information about Lake Koka. I am indebted to all those who helped me during the fieldwork, especially the car driver Shimelis Seyoum and the field assistant Abadir. I thank the Department of Zoological Sciences for giving this opportunity to study M.Sc. degree at Addis Ababa University. Finally, I want to thank My Wife Sr. Sintayehu Shiferaw, My daughter Honalia and my son Nathan for their patience who served me as a source of strength throughout my study.

List of acronyms and abbreviation

ANOVA	Analysis of variance
APHA	American Public Health Association
BAF	Bioaccumulation factor
BAFS	Bioaccumulation factor from sediment
BAFW	Bioaccumulation factor from water
BOD	Biological oxygen demand
BMF	Biomagnifications factor
BMFP	Biomagnification factor from phytoplankton
BMFZ	Biomagnification factor from Zooplankton
COD	Chemical Oxygen demand
DCA	Detrended correspondence analysis
DO	Dissolved oxygen
EC	Electrical Conductivity
EEP	Ethiopian Electric Power
EPA	Environmental Protection Authority
FAO	Food and Agriculture Organization
FEPA	Federal Environmental Protection Agency
GFAAS	Graphite furnace atomic absorption spectroscopy
IAEA	International Atomic Energy Agency
ISQG	Interim Sediment Quality Guidelines
MWIE	Ministry of water, Irrigation, and Electricity
PCA	Principal Component analysis
PTE	Potential toxic elements
SPSS	Statistical Package for Social Science
USEPA	United States Environmental Protection Agency
WHO	World health organization

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1. INTRODUCTION

1.1 Background and Justification

Water pollution is the degradation of the quality of water that makes the water unsuitable for its intended purpose and is a widespread problem along the globe. Water pollutants can be broadly classified as organic, inorganic, suspended solids, sediments, heavy metals, radioactive materials and heat (Botkin and Keller, 1998). Aquatic environments, particularly lakes and reservoirs, that are located near industrial and/or urban areas are potential targets for the flow of environmentally harmful elements such as organic, inorganic and heavy metal contaminants (Davies *et al.*, 2006). Of these, heavy metal pollution is the growing problem and is associated with the rapid growth of population, increased urbanization and expansion of industrial activities, and exploitation of natural resources, extension of irrigation that uses different fertilizers, pesticides, herbicides and other modern agricultural practices as well as the lack of environmental regulation (Biney *et al.*, 1992). That is why the rapid economic development in Africa during the last decades has led to an increase in environmental pollution (Ochieng *et al.*, 2007; Akiwumi and Butler, 2008; Ololade and Oginni, 2010).

The pollution of aquatic ecosystems by heavy metals of anthropogenic origin is of great ecological and economic importance. In recent years, the concern over heavy metal pollution is increasing as a result of their non-biodegradable nature, long biological half-life and their potential to accumulate in different body parts of the organism (Edem *et al.*, 2009). Though metals could be essential for different physiological functions and required by aquatic fauna, they become toxic when taken in excess quantities causing cytotoxic, mutagenic and carcinogenic effects in animals (Wood and Talling, 1988). The toxicity can reduce the survival rate, growth, and reproduction of a species (Heath, 1987).

Aquatic organisms have the ability to accumulate heavy metals from various sources including sediments, soil erosion and runoff, air depositions of dust, and discharges of wastewater (Labonne *et al.*, 2001; Rauf *et al.*, 2009). Bioaccumulation of these heavy metals in living organisms and their bio-magnification nature describes the processes and pathways of these possible pollutants from one trophic level to another, exhibiting the higher bioaccumulation ability in the organisms concerned and producing their toxic effect at points far from the source of pollution (Svobodova *et al.*, 2004). Thus compared to

other types of aquatic pollution, heavy metals pollution and its effects on the ecosystem and humans can be intensive and very extensive (Edem *et al.*, 2009).

The concentration of pollutants in water samples only indicate the situation at the time of sampling, while concentrations in the organism are the result of past as well as current pollution levels in the environment in which the organism lives (Ravera, 2001). Concentrations of heavy metals in organs of aquatic organisms determine primarily the level of pollution in the water and food (Vinodhini and Narayanan, 2008).As a result, aquatic organisms have been widely used in biological monitoring and assessment of safe environmental levels of heavy metals. Fish occupies the highest trophic level and has a potential to accumulate heavy metals and other organic pollutants along the food chain (Shuhaimi-Othman *et al.*, 2010). Therefore, various fish species are widely used as bioindicators of metal contamination (Svobodova *et al.*, 2004). Fish is an important source of protein for millions and can cause acute and chronic effects in humans due to high accumulation of heavy metals (Ashraf *et al.*, 2012).

According to United State Environmental Protection Agency (USEPA, 2006) mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) are listed as the most common Potential Toxic Elements(PTE). Some of these PTEs are essential and some are non-essential for the metabolic activities of living organisms. Potential toxic elements such as Cr, Cu, Ni, and Zn are required by organisms at a low level and become toxic at some higher levels, while non-essential elements including As, Cd and Pb are toxic and not required by organisms at any level (Poggio *et al.*, 2009). The toxicity of trace metals will vary greatly between organisms for the same trace metals, and between trace metals for the same organisms. Furthermore, trace metals will not necessarily follow the same rank order of toxicities between organisms, depending on differences between uptake rate, detoxification rates and excretion rate of the different organisms compared. However, the general order of toxicity of heavy metals is Hg> Ag> Cu> Cd >Zn>Ni>Pb> Cr> Sn (Luoma and Rainbow, 2008). Certain Ethiopian surface water bodies have been contaminated with toxic industrial wastes, which are particularly true for Ethiopian rift valley lakes due to urbanization, intensive agriculture, and industries expansion. Level of mercury in fish from the Ethiopian rift valley lakes and its implications in dietary exposure was studied by (Ermias Deribe *et al.*, 2014a).

Zinabu GebreMariam and Pearce (2003) also reported the high concentration of trace metals (Cu, Zn, Pb and other related groups) contaminants from some of the Ethiopian inland surface waters. Ethiopian rift valley region comprises seven small to moderately large lakes and is an important area for commercial fisheries. The lakes are also used for recreation, irrigation, and industrial purposes. However, rivers that flow into some of these lakes are heavily loaded with contaminants from anthropogenic origin such as discharges from factories and domestic sources (Aweke Kebede and Taddese Wondimu, 2004).

Lake Koka is located in the central rift valley and receives highly polluted wastewaters from its major tributary rivers Modjo and Awash. Modjo River, for instance, receives a liquid waste from Modjo Tannery that contains chemical pollutants whose concentrations surpassed the permissible levels set by the National Environmental Quality Standards (Seyoum Leta *et al.*, 2003). Some investigations of (Dsikowitzky *et al.*, 2013) have indicated the occurrence of potentially harmful heavy metals in fish and in vegetables. However, there are no adequate studies on the concentration of heavy metals in the aquatic organisms of these water bodies. Moreover, there is no work conducted on bioaccumulation and biomagnifications of heavy metals along the food chain of aquatic organisms, which has potential health risk to human.

Thus the purpose of this study was to produce baseline data on the concentration of Potential Toxic Elements (PTEs) of heavy metals (Cr, Pb, Cd, Zn Cu, Ni, Mn, Ar, Hg) in water, sediment, plankton and commonly consumed fish species obtained from Lake Koka. The study also determines bioaccumulation factors (BAF) from water and bottom sediments, as well as biomagnifications factors (BMF) along the food chain of phytoplankton-zooplankton- muscle tissues of commercially important fish species (*O. niloticus*, C. *gariepinus, C. carpeo*) to assess the biomagnifications nature of the heavy metals. Ethiopia has set no guideline values on the levels of heavy metals in sediment, plankton and fish resources and this study will contribute to establishing the guideline.

1.2. Statement of the problem

Lake Koka has multiple purposes including hydroelectric power generation, domestic water supply, recreation, irrigation, and fishery. Commercially important fish species are Nile tilapia *(Oreochromis niloticus*), common carp (*Cyprinus carpio)*, African catfish (*Clarias gariepinus)*, and (*Labeobarbus intermedius)*.According to the Ethiopian Department of Fisheries and Aquaculture, the lake supports a fishing industry of 625 tons of fish each year. *O. niloticus* contributes about 327 tons per year, which is about 59% of the total landings (Elias Dadebo *et al.*, 2015). Agriculture is the main activity in the catchment and sparsely distributed *Acacia* trees are common(Solomon Kibret *et al.*, 2010). Water hyacinth *(Eichhornia crassies)* has invaded and established along the shore of the lake (Melaku Mesfin *et al.*, 1988).

The Lake Koka water is used for much socioeconomic importance (drinking, tourism, and fishing). However, it is under a serious threat because of point and nonpoint sources of effluents from industry and intense agricultural activities operating in the catchment. Akaki and Modjo Rivers are the two major sources of wastewater pollutants for the lake. Modjo River, which receives a liquid waste from Modjo Tannery, contains chemical pollutants whose concentrations have surpassed the permissible levels set by the National Environmental Quality Standards (Seyoum Leta *et al.*, 2003). The catchment of Akaki River is the site for industrial establishments, which releases their wastewater directly into the river. Akaki River (great and little Akaki), is the main tributary of Awash River that discharges its effluents to Lake Koka. Further, a large number of floriculture farms are located close to Lake Koka that also releases their untreated effluents directly to the lake (Jansen *et al.*, 2007; Dsikowitzky *et al.*, 2013). These effluents contain fertilizers and pesticides, which are the anthropogenic origin.

About 15,000 local inhabitants have been heavily relying on the lake as a source of water for drinking, animal watering, cleaning, fishing, small-scale irrigation, etc. However, the lake is becoming heavily-polluted and its use has been compromised. People suffer from poor sanitation and water-borne diseases such as chronic diarrhea that is resulting from drinking the "toxic water" (Teshome Akele Seyoum, 2011). Environmental contaminants from municipal, agricultural and industrial sources may enter the food chain, accumulate in organisms and can be acutely or chronically toxic to aquatic life affecting their survival and reproduction (Calamari and Naeve, 1994). Hence, the use of the commercially important fish species as a protein source, an important ecosystem service of the lake, is at risk.

Fish accumulates heavy metals in the tissue through absorption and humans can be exposed to heavy metals via consumption, which can cause acute and chronic effects in humans (Castro-González and Méndez-Armenta, 2008).Heavy metals are defined as metallic elements that have a relatively high density at least 5 times greater than that of water(Fergusson, 1990). The multiple applications of heavy metals to the industrial, domestic, agricultural, medical and technological area have raised concerns over their potential effects on human health and the environment (Tchounwou *et al.*, 2012). Some of these heavy metals are toxic and some of them increase progressively along food chain called biomagnification, i.e., the concentration of heavy metals increases from phytoplankton-zooplankton – fish, ultimately reaching top consumers including human being. When the concentration passes the threshold level, it affects the health of humankind.

Industrial effluents and increasing anthropogenic influences in the catchments affect Lake Koka making it an appropriate study site. There are reports that Lake Koka is under continuous threat of pollution resulting from intensive anthropogenic activities such as industrialization, urbanization and agricultural activities with heavy metals being among the major pollutants continuously discharged into the lake, (Zinabu GebreMariam and Pearce, 2003; Ermias Deribe *et al.*, 2011; Dsikowitzky *et al.*, 2013). Of heavy metals, Arsenic, Cadmium, Chromium, lead, and Mercury rank among the priority metals that are of public health significance because of their high degree of toxicity,(Tchounwou *et al.*, 2012). The purpose of this study was therefore to produce baseline information on the distribution of heavy metals (Cr, Pb, Cd, Zn, Cu, Ni, Mn, As, Hg) in water, sediment, plankton and commonly consumed fish species obtained from Lake Koka. It attempts to assess the biomagnifications nature of the heavy metals along the aquatic food chain. Currently, Ethiopia has set no guideline values on the levels of heavy metals in sediment, plankton and fish resources and this study will contribute to establishing the guideline.

1.3 Objectives

1.3.1 General objective

To investigate the bioaccumulation, biomagnifications and human health impact of some heavy metals and to produce baseline data on their distribution in water, bottom sediment, plankton and edible parts of commonly consumed fish species *(C.gariepinus, O.niloticus,* and *C.carpio*) in Lake Koka, Ethiopia.

1.3.2 Specific objectives

- To determine the concentrations of some PTEs of heavy metals (Cr, Cd, Pb, Mn, Ni, Zn, Cu, Hg, As) in water, bottom sediment and muscle tissue of edible fishes species (*C.gariepinus, O.niloticus, C.carpio*) collected from Lake Koka.
- To estimate the bioaccumulation factors of some selected heavy metals in water /sediment, plankton and fishes species in Lake Koka.
- To estimate the degree of biomagnifications along sequential trophic levels (phytoplankton, zooplankton, and muscle tissue of edible fishes species *(C.gariepinus, O.niloticus, C.carpio)* in Lake Koka.
- To compare the concentration of heavy metals with permissible limits proposed by WHO and USEPA.
- To determine the spatial variation and impacts of physicochemical parameters in relation to heavy metals concentration of the study sites.

1.4.Research Questions

- What is the concentration of heavy metals (Cd, Pb, Cu, Mn, Cr, Zn, Ni, Hg, As) in water, bottom sediment, and muscle tissue of edible fishes species *(C.gariepinus, O.niloticus, C.carpio)* collected from Lake Koka?

- What is the bioaccumulation of some selected heavy metals from water /sediment to plankton and fishes species in Lake Koka?

- What is the degree of biomagnifications along sequential trophic levels (phytoplankton, zooplankton, and muscle tissue of edible fish species (*C. gariepinus, O. niloticus, C. carpio)* in Lake Koka? Do all heavy metals biomagnify along the food chain?

- Do the concentration of heavy metals in water, sediment, and edible muscle of fish species within the permissible limits proposed by WHO and USEPA?

- Is there spatial variation in physicochemical characteristics of water in the study sites? How does the physicochemical variables in relation to heavy metals concentration in Lake Koka?

1.5. Significance of the study

The result obtained from this study would provide information for background levels of metals in the water, sediment, plankton, and fish, contributing to the effective monitoring of both environmental quality and the health of the organisms inhabiting Lake Koka. From literature survey, no work has been carried out on bioaccumulation and biomagnifications of heavy metal concentration from Lake Koka. So the result of this study will also serve as the basis for proposing possible courses of actions for better use and management practices of the lake and thereby improve the livelihoods of the local communities.

1.6 Limitation of the study

Due to the resource constraints such as laboratory facilities to conduct heavy metal analysis, the study was limited to food chain by excluding food web components and muscle tissue than other organs (liver, kidney) of fish species of Lake Koka. The absence of prior research on plankton, biomagnification as well as some other historical data, was partly limiting the study too.

2. LITERATURE REVIEW

This section of the study covers different ideas and information about heavy metals including heavy metals in the environment, accumulation of heavy metals in fish, plankton as well as the concentration of Heavy metals in sediments and in different water bodies.

2.1 Heavy Metals in the Environment

Heavy metals present in the environment in different forms such as solid phase and in solution, as free ions, or absorbed by solid colloidal particles. Metals are introduced into the environment by a wide range of natural and anthropogenic sources. The natural sources include rock weathering, soil erosion, and dissolution of water-soluble salts while the anthropogenic sources are municipal wastewater, manufacturing industries, and agricultural activities (Guven and Akinci, 2008).

Heavy metals occur naturally at levels that are considered not to have toxic effects on living organisms. The natural levels of metals are normally increased through various anthropogenic processes. Currently, anthropogenic inputs of metals are higher than the natural input and this may pose a great threat organisms particular, and to whole ecosystems in general (Liu *et al.*, 2011). Similarly, in natural aquatic ecosystems, heavy metals occur in low concentration. But in recent times, due to industrial development and rapid increase of human population, the occurrence of metal contaminants in excess of natural loads has become a problem of increasing concern.

Heavy metals contamination of the aquatic environment may lead to deleterious effects from localized inputs which may be acutely or chronically toxic to aquatic life within the affected area (Calamari and Naeve, 1994). Some of the major metals in natural water and their chemical species are put in table 1. Some of these elements are required by most living organisms in small amounts and they are also referred to as micronutrients. All metals, however, can be toxic to the aquatic organism when they present at high levels, causing direct effects such as histological Reservoir age, reduction in survival, growth, and reproduction of the species (Heath, 1987).

Table 1: Major chemical species found in natural water

Name of the heavy metal	Compound form
Chromium	$Cr(OH)_2(H2O)^{4+}$, CrO_4^{2-}
Lead	Pb^{2+}, $PbCO_3$ $PbCl^+$, $PbCl_2$, $PbCl^{3-}$, $Pb(OH)^+$, $Pb(OH)_2$, $Pb(OH)^{3-}$, $Pb3(OH)_4^{2+}$, $Pb(OH)_4^{4+}$
Cadmium	$CdCl^+$, $CdCl_2$, $CdCl^{3-}$, Cd^{2+}
Copper	Cu^{2+}, $Cu(OH)^+$, $Cu^{2+}SO_4^{2+}$, $Cu^{2+}CO_3^{2-}$
Zinc	$Zn(OH)^+$, $Zn(OH)_2$, $ZnCl^+$, $ZnCl_2$, $ZnCO_3$, Zn^{2+}
Molybdenum	MoO_4^{2-}
Aluminum	$Al(H2O)_6^{3+}$, $[Al(OH)_4]^-$
Mercury	$HgCl_2$, $HgCl^{3-}$, $HgCl_4^{2-}$, HgOHCl, $Hg(OH)_2$
Manganese	Mn^{2+}, $MnSO_4$, $MnCl^+$
Lithium	Li^+
Selenium	Se (IV), Se((VI)
Nickel	Ni^{2+}
Cobalt	Co_2^+
Cesium	Cs^+

Source: (Ward, 1995).

2.2 Accumulation of heavy metals in aquatic organisms and their effect

2.2.1 Phytoplankton

Plankton play pivotal roles in the responses of the aquatic ecosystem to pollution. They are themselves directly affected by pollution, but it can also act as either a conduit to or a shield for higher animals. The plankton are agate way between the aquatic ecosystem and the land, by which food is transported to people, and through which waste travels in return including heavy metals. There are three classes of interactions between plankton and pollution. First, pollutants of various kinds have direct effect usually toxic but sometimes stimulatory on planktonic plant and animals. Second, plankters in return influence the physical and chemical conditions of pollutants in aquatic ecosystems, and can significantly affect their ultimate fate. Finally, of perhaps greatest interest is the possible role of plankton in the biomagnifications of pollutants and in pollution effects both on the aquatic food web and humans. Altındağ and Yiğit (2005) reported that the concentration of Cu, Zn, Fe, Mn, Cd, Pb, and Co, in phytoplankton as Cu 11.3 µg g^{-1}, Zn 822.5 µg g^{-1}, Fe 2202.5 µg g^{-1}, Mn1286.1 µg g^{-1}, Cd 0.2 µg g^{-1}, Pb 6.5 µg g ,Co 0.3µg g^{-1}.

The concentration of Cu, Zn, Cd, and Pb in plankton was much higher than those of water. This may be related to the large surface of plankton organisms (phyto- and zooplankton) in relation to their mass unit, and their active metabolism leading to rapid adsorption of various pollutants. Some algal species protect themselves by trapping and accumulating pollutants (e.g. metals) in their polysaccharide walls. The order of abundance of metals in plankton was Zn > Cu >Pb> Cd (Ravera, 2001).

2.2.2 Zooplankton

Assessment of heavy metal concentrations in Zooplankton is very important because they often used as the main diet by many predators and may remarkably contribute to the transfer of heavy metals to higher trophic levels. According to Dsikowitzky *et al*. (2013), heavy metal concentration for zooplankton was reported as Cu 39.9µg g^{-1}, Zn 926µg g^{-1} Fe 2186µg g^{-1} Mn177.7µg g^{-1} Cd1.1 Pb9.3µg g^{-1} Co 0.2µg g^{-1}.

2.2.3. Fish

Fish are used as bio-indicators of aquatic ecosystems for estimation of heavy metal pollution and potential risk for human consumption (Agarwal *et al.*, 2007). Bioaccumulation of metals in fish takes place directly from the water by gills and indirectly from food (Barron, 1990). The metals such as copper, zinc, iron, and cobalt are essential and have important biochemical functions in fish as opposed to non-essential metals like Lead, Cadmium, Mercury, and Arsenic. Essential metals are used either as an electron donor system or function as ligands in complex enzymatic compounds. The essential trace metals are only used in trace amount by the organism and usually, they are found in small concentration in the environment. The amount of heavy metals in the organism does not exceed the level which allows the enzyme system to function without interference. An excess amount of heavy metal in organisms can be regulated by homeostasis. But, if the heavy metal concentration at the source of supply such as water and food is too high, the homeostasis mechanism ceases to function and the essential heavy metals act in either an acutely or chronically toxic manner (Bryan and Hummerstone, 1973).

The function of uptake and excretion in fish determine the accumulation of metal in fish. The degree of accumulation in different tissues is dependent on the binding of the metal to specific ligands. Dallinger *et al*. (1987) stated that as far as fish is concerned, the rare three possible ways by which metals may enter the body (i) through the body surface, (ii) through the gills, and (iii) the alimentary tract.

Table 2. Concentration of heavy metals in different fish species collected from different water bodies in ng g^{-1}

Fish Species	Water Body	Heavy metals and their concentration											Reference
		Cr	Pb	Cd	Zn	Cu	Ni	Mn	As	Co	He	Se	
O.niloticus	Koka reservoir	110-203	30.1-54.2	0.45-8.4	-	-	-	-	34.3-56.1		59.2-65.3	0.72-0.85	(Dsikowitzky *et al.*, 2013)
	Tekeze Reservoir	1310	1850	560	28,440	1,090	720	2180	-	1390	-	-	(Mulu Berhe Desta *et al.*, 2012)
C.garipinus	Koka Reservoir	211-1449	31.7-247	1.3-9.6	-	-	-	-	43.8-103	-	39.5-384	0.81-1.8	(Dsikowitzky *et al.*, 2013)
	Tekeze Reservior	640	1620	340	23,880	850	380	2,360	-	1330		-	(Mulu Berhe Desta *et al.*, 2012)

2.3 Heavy metals in sediment

Depending on the environmental conditions, sediments are a sink or a source of trace metals. However, metals are not fixed by the sediment as they may be recycled via biological agents and/or chemical and physical changes within the sedimentary phase and in the water column. Aquatic processes have enormous influences on the fate of these elements, owing to their particular characteristics (sharp changes in salinity, pH gradients, type of organic matter, etc.) and evidence on the trapping of trace elements of river-borne material occurring in lakes has been reported. Lake sediments via biological, chemical and physical processes provide the major sink for heavy metals in the aquatic environment. The increasing levels of these elements have been a matter of concern owing to the accumulation effects of some metals in living organisms and in food chains leading to humans. Therefore, studies on the distribution of heavy metals in sediments are of great importance in the context of environmental pollution (Salomons, 1995).

Table 3: Concentration of heavy metals in sediments collected from different water bodies in mg/Kg

Water Body	**Heavy metals and their concentration**											**Reference**
	Cr	**Pb**	**Cd**	**Zn**	**Cu**	**Ni**	**Mn**	**As**	**Co**	**He**	Se	
Tekeze River Reservoir	33.00	12.75	1.00	80.00	36.00	53.50	437.50	-	17.00	-		(Mulu Berhe Desta *et al.*, 2012)
Lake Gudbahri	**31.33**	**-**	**-**	**43,**	**22,**	**-**	**-**	**-**	**-**	**-**		(Mulu Berhe Desta and Mehari Muuz, 2013)

2.4 Heavy Metals in Water

Table 4: Concentration of heavy metals from different water bodies in µg/L

Water Body	Heavy metals and their concentration											Reference
	Cr	**Pb**	**Cd**	**Zn**	**Cu**	**Ni**	**Mn**	**As**	**Co**	**He**	Se	
koka	1.6 4.2	0.24-0.96	<0.1	-	-	-	-	0.572.8	- -	<0.1	<0.1-0.2	(Dsikowitzky *et al.*, 2013)
Tekeze Reservoir	22.17	22.99	16.17	90	13.33	13.62	2.14	-	46.5	-	-	(Mulu Berhe Desta *et al.*, 2012)
Modjo river	141.1-	3.4	ND	-	-	-	-	14.8	-	ND	19.2	(Zinabu GebreMariam and Pearce, 2003)
Tikur wuha	42.6	7.5	1.2	-	-	-	-	43.2	-	5.1	5.4	(Zerihun Desta *et al.*, 2008)
Lake Gudbahri	7	-	-	197	11	-	-	-	-	-	-	(Mulu Berhe Desta and Mehari Muuz, 2013)
Ziwai	-	280	600	-	-	-	-	-	-	77	-	(Abayneh Ataro *et al.*, 2003)
Hawassa	-	360	660	-	-	-	-	-	-	95	-	(Abayneh Ataro *et al.*, 2003)

2.5 Heavy metals V_s physicochemical parameters

Heavy metals have an effect on different aquatic organisms like phytoplankton, zooplankton, and fish but their effect is often complex and difficult to interpret. Dissolved oxygen, pH, salinity, temperature and hardness of water have been shown to be factors that influence the physiology of an organism and the rate of uptake of heavy metals. "The main factors concerned in determining the seasonal variation of heavy metal levels in aquatic biota are the extent of pollutant delivery into the aquatic environment, the weight change occurring in the organisms and the direct effects of salinity, temperature and other water qualities which vary seasonally"(Chaudhari *et al.*, 1996). Physico-chemical characteristics of Lake Koka have been recorded in many studies. Literature indicated that it is highly turbid and eutrophic (Table 5).

Table 5: Some limnological features of Lake koka

Parameters	Range	Data source
Sechi depth(m)	0.12–0.18	(Seyoum Leta *et al.*, 2003; Fasil Degefu *et al.*, 2011; Yeshiemebet Major *et al.*, 2017),.
Chl a($\mu g\ L^{-1}$)	155.1-222.8	
pH	6.29-9	
Conductivity($K_{25,\mu s\ cm^{-1}}$)	203-393	
DO ($mg\ L^{-1}$)	4-12	
Temperature (o_c)	21–26.2	
Sio_2($mg\ L^{-1}$)	17.7	
NH4-N($\mu g\ L^{-1}$)	89.3–394.3	
No_3-N , NO_2-N ($\mu g\ L^{-1}$)	36.6–83.6	
PO_4-p((µg L-1)	36.10–193.2	
TP($\mu g\ L^{-1}$)	218.7–477.2	

2.6. Some heavy metals in the study

2.6.1. Cadmium

Cadmium is a heavy metal of considerable environmental and occupational concern. It is widely distributed in the earth's crust at an average concentration of about 0.1 mg kg^{-1}. The highest level of cadmium compounds in the environment is accumulated in sedimentary rocks, and marine phosphates contain about 15 mg cadmium kg^{-1} (Tchounwou *et al.*, 2012). Cadmium is frequently used in various industrial activities. The major industrial applications of cadmium include the production of alloys, pigments, and batteries (Wilson, 1988). Although the use of cadmium in batteries has shown considerable growth in recent years, its commercial use has declined in developed countries in response to environmental concerns. In the United States, for example, the daily cadmium intake is about 0.4µg kg^{-1}/day, less than half of the U.S. EPA's oral reference dose (Tchounwou *et al.*, 2012). This decline has been linked to the introduction of stringent effluent limits from plating works and, more recently, to the introduction of general restrictions on cadmium consumption in certain countries.

Cadmium is a severe pulmonary and gastrointestinal irritant, which can be fatal if inhaled or ingested. After acute ingestion, symptoms such as abdominal pain, burning sensation, Nausea, vomiting, salivation, muscle cramps, vertigo, shock, loss of consciousness and Convulsions usually appear within 15 to 30 min (Okparaocha *et al.*). Acute cadmium ingestion can also Cause gastrointestinal tract erosion, pulmonary, hepatic or renal injury and coma, depending on the route of poisoning (Baselt, 2000). Chronic exposure to cadmium has a depressive effect on levels of no epinephrine, serotonin, and acetylcholine (Singhal *et al.*, 1976). Rodent studies have shown that chronic inhalation of cadmium causes pulmonary deno carcinomas. It can also cause prostatic proliferative lesions including deno carcinomas, after systemic or direct exposure (Chioma *et al.*, 2017). Cadmium compounds are classified as human carcinogens by several regulatory agencies. The International Agency for Research on Cancer (Loprieno, 1975). And the U.S. National Toxicology Program has concluded that there is adequate evidence that cadmium is a human Carcinogen.

2.6.2. Lead

Lead is a naturally occurring bluish-gray metal present in small amounts in the earth's crust. Although lead occurs naturally in the environment, anthropogenic activities such as fossil fuels burning, mining, and manufacturing contribute to the release of high concentrations. Lead has many different industrial, agricultural and domestic applications. It is currently Used in the production of lead-acid batteries, ammunition, metal products (solder and pipes), and devices to shield X-rays. An estimated 1.52 million metric tons of lead were used for various industrial applications in the United States in 2004. Of that amount, lead-acid batteries production accounted for 83 percent, and the remaining usage covered a range of products such as ammunition (3.5 percent), oxides for paint, glass, pigments, and chemicals (2.6 percent), and sheet lead (1.7 percent) (Gabby, 2006). Experimental studies have indicated that lead is potentially carcinogenic, inducing renal tumors in rats and mice (Waalkes *et al.*, 1995). and is therefore considered by the IARC as a probable human carcinogen (Steenland and Boffetta, 2000). Lead exposure is also known to induce gene mutations and sister chromatid exchanges (Lin *et al.*, 1994).

2.6.3. Chromium

Chromium is an essential nutrient metal, necessary for metabolism of carbohydrates (Farag *et al*., 2015). Chromium enter the aquatic ecosystem through effluents discharged from leather tanneries, textiles, electroplating, metal finishing, mining, dyeing and printing industries, ceramic, photographic and pharmaceutical industries etc (Arunkumar *et al*., 2000). Poor treatment of these effluents can lead to the presence of Cr (VI) in the surrounding water bodies, where it is commonly found at potentially harmful levels to fish (Li *et al*., 2011; Pacheco *et al*., 2013). In surface waters, depending on physicochemical characteristics, the most stable forms of chromium are the oxidation states trivalent Cr (III) or (Cr^{3+}) and the hexavalent Cr (VI) or (Cr^{6+}). Hexavalent chromium (Cr^{6+}) is considered to be toxic (i.e. carcinogenic) because of its powerful oxidative potential and ability to cross cell membranes. Fish assimilate Cr by ingestion or by the gill uptake tract and accumulation in fish tissues, mainly liver, occurs at higher concentrations than those found in the environment (Pacheco *et al*., 2013). The overall toxic impact on organs like gill, kidney and liver may seriously affect the metabolic, physiologic activities and could impair the growth and behavior of fish.

Toxic effects of Cr in fish include: morphological alterations, reduction of growth, production of reactive oxygen species (ROS) and impaired immune function. Acute poisoning by chromium compounds causes excess mucous secretion, damage in the gill respiratory epithelium and the fish may die with symptoms of suffocation (Benoit, 1976). On chronic exposures, hexavalent chromium severely affected the renal tubules causing hypertrophy of epithelial cells, reduction of tubular lumen, contraction of glomeruli and epithelial and glomerular necrosis (Farag *et al*., 2006).

According to Pacheco *et al*. (2013) chromium compounds also cause renal failure leading to the loss of osmoregulatory ability and respiration in fish. Sublethal effects of chromium in fish were directly related to the inhibition of various metabolic processes. Like, the hexavalent chromium induced depletion in the profiles of liver glycogen, total protein and total lipid has been report

2.7. Diet and trophic position of Fishes

The diet of *C. carpio, O. niloticus, and C. gariepinus* is composed of plants, animals, and detritus. The plants consisted of both phytoplankton (blue-green algae, green algae, and diatoms) and macrophytes. Items of animal origin were quite diverse and include fish, insects, and zooplankton. Fish eggs and unidentified fragments are also possible food items (Ermias Deribe *et al.*, 2011). The stomach content of *C. carpio* was diverse, mostly composed of macrophytes, detritus, phytoplankton, aquatic insects, fish eggs, and zooplankton. Most of the stomach volume was however dominated by macrophytes and detritus, with a mean volume of 40.5 and 18.2%, respectively (Ermias Deribe *et al.*, 2011). Regardless of size, algae were the most important diet of *O. niloticus* in Lake Koka and contributed to 86.2% by volume of the total stomach content, of which diatoms, blue-green algae, and green algae accounted for 50.5%, 33.3% and 2.4%, respectively. Zooplankton contributed with 13.9% of the mean volume and was found in 16.7% of the stomachs (Ermias Deribe *et al.*, 2011).in addition, as reported by Tadesse Fetahi *et al.* (2017) the dietary source of *Oreochromis niliticus* incorporates 49% POM and 51% Zooplankton. The diet of *C. gariepinus* had also be very diverse composition that includes food items extending from detritus to fish. Aquatic insects, and fish and fish eggs made up 24.2% and 36.4% of the stomach contents by volume, respectively. The insects recorded as food items of *C. gariepinus* were mainly Hemiptera, Coleoptera, and Diptera. Zooplankton (Copepods and Cladocerans) contributed to 16.9% of the stomach contents by volume. Macrophytes and detritus were also observed frequently in the diet of *C. gariepinus* (Ermias Deribe *et al.*, 2011).

The food items consumed by *C. carpio* were detritus, insects, macrophytes, phytoplankton, Ostracods, zooplankton, and gastropod. Detritus, insects, and macrophytes were the dominant food items. Phytoplankton, Ostracods, and zooplankton were also relatively common, whilst gastropods were of minor importance in the diet of *C. carpio*. The overall stomach content analysis suggests that *C. carpio* is omnivorous in its feeding habits (Elias Dadebo *et al.*, 2015).

3. MATERIALS AND METHODS

3.1 Description of study area

Lake Koka (also known as Lake Gelila), is located around 93km from Addis Ababa in the South Eastern part of Ethiopia. The reservoir lies between latitudes 8°18′–8°28′N and longitudes 38°59′–39°09′E and has an elevation of 1590 m.a.s.l. It is a man-made lake formed by the construction of dam the Awash River for hydroelectricity production in 1960. The inflow to the reservoir comes from two rivers: Awash (major) and Modjo (minor). The surface area of the reservoir is 200 km^2 and the mean depth is 9 m (Wood and Talling, 1988). The water column does not have any marked thermal stratification and the mean surface water temperature is 19°C (Melaku Mesfin *et al.*, 1988).

3.1.1. Meteorological Features

3.1.1.1. Rainfall

Lake Koka is generally characterized by moist sub-humid to semi-arid climate. The region experiences alternating wet and dry season with seasonal and inter-annual fluctuation in rainfall (Fig. 1).The rainy period extends from (March to September) with two peaks (bimodal): one between March and June(minor rainy period) with a mean rainfall of 59.7mm and the other from July to September (major rainy period) with a mean rainfall of 204.0mm. The dry season, which is also mostly the coldest, occurs between October and February with a mean rainfall of 13.1mm (ENMA, 2017).

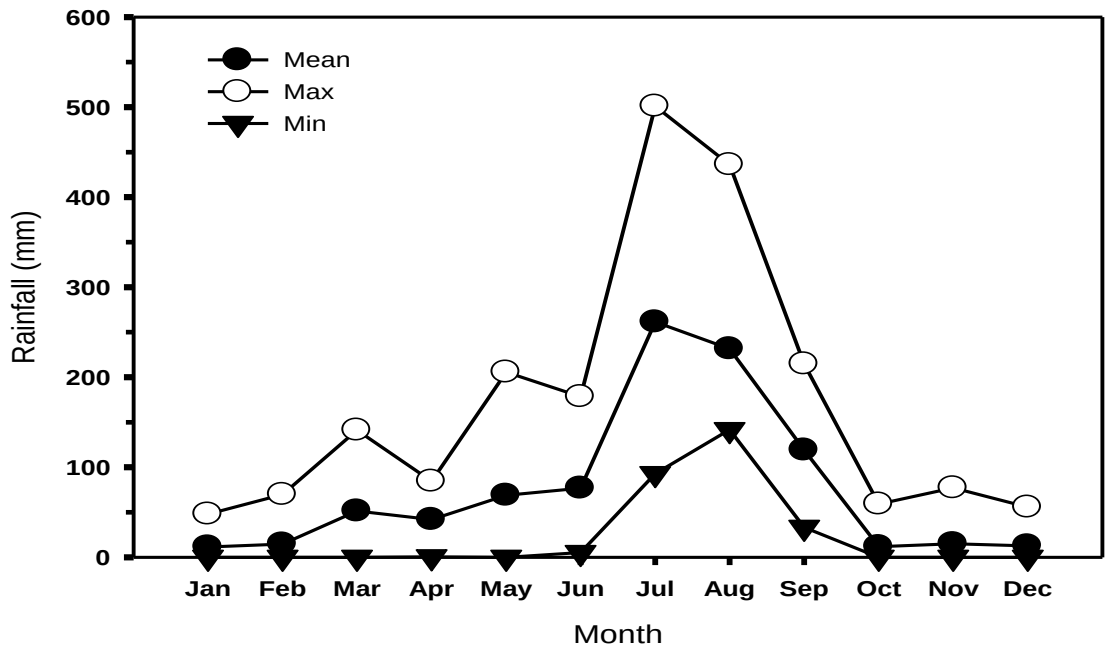


Figure 1: Mean, maximum and minimum monthly rainfall around Lake Koka during 2000-2015 (ENMA, 2017) .

3.1.1.2 Air temperature

During years 2000-2015, the mean maximum monthly air temperature varies between 29.5^{o}C (November & December) and 33.9^{o}C (May), while the mean minimum monthly air temperature ranges from 10.4^{o}C (December) to 15.5^{o}C (May) (Fig.2).

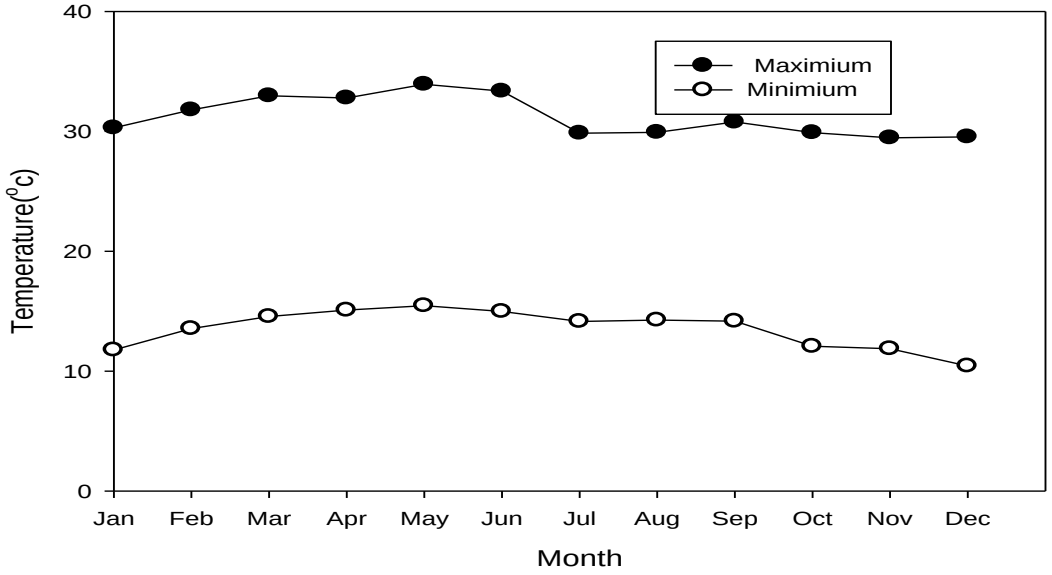


Figure 2: Maximum and minimum monthly air temperature around Lake Koka during 2000-2015 (ENMA, 2017).

3.1.2 Hydrological features

The mean monthly discharge of Awash River into Koka Reservoir is 22, 30 and 358 million m^3 during the dry, minor rainy and major rainy seasons respectively (MoWIE, 2017). The mean monthly runoff from Modjo River, the maximum and minimum flow rate of the two inlet Rivers, as well as the outflow rate from the reservoir, is indicated in figures 3, 4 and 5 below.

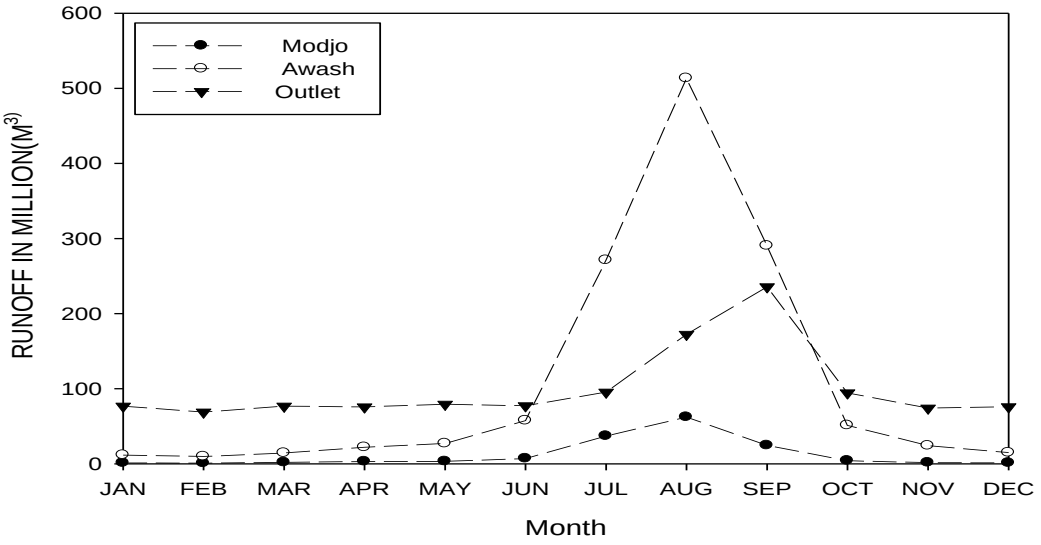


Figure 3: Monthly Runoff in million meter cube from 2000-2013 ((MoWIE, 2017).

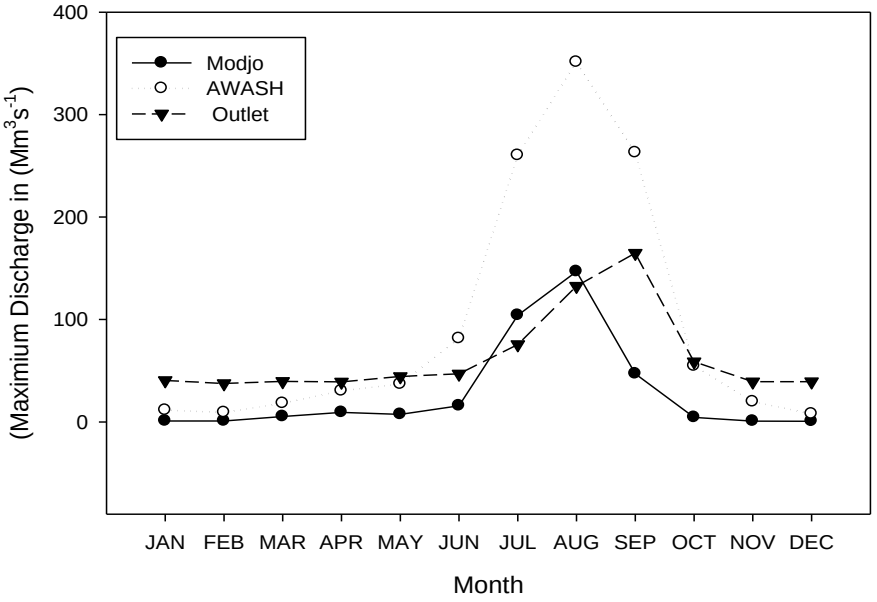


Figure 4: Maximum flow rate in meter cub per second from 2000-2013 (MoWIE, 2017).

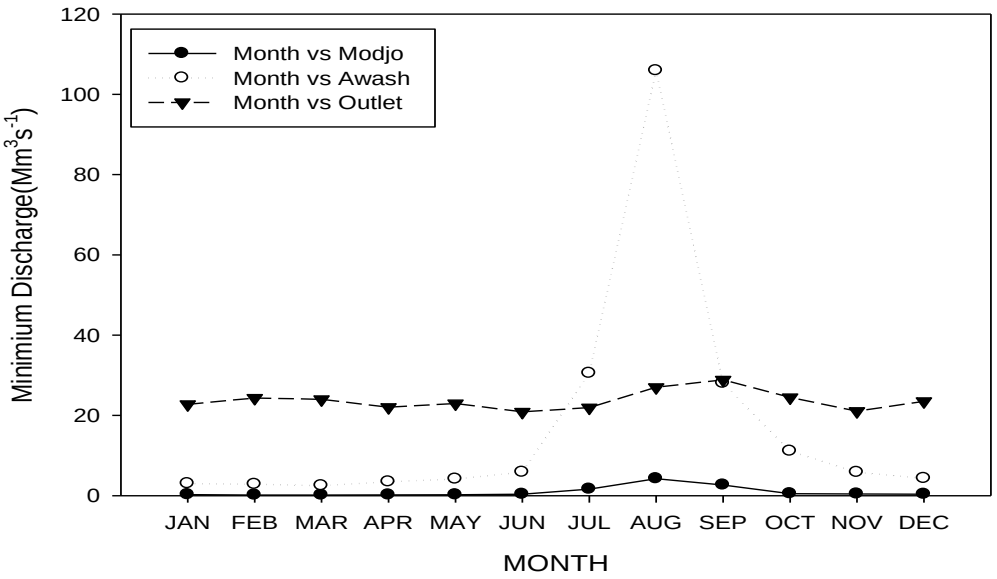


Figure 5: Minimum flow rate in meter cub per second from 2000-2013 ((MoWIE, 2017).

3.2. Selection of sampling sites

Seven Sampling sites (Fig. 6) were selected based on proximity to expected anthropogenic origin sources. The sampling sites (Modjo Upstream, Modjo downstream and Awash) were riverine sites, whereas (Tannery, Awash mouth, Kintare, and Amude were lake sites. Table 6 provides the specific location of sampling sites and their geographical positions.

Table 6: Sampling sites, its location, and geographical positions

Site Name	**Description**	**Coordinate**	**Altitude**
Modjo Upstream	Immediately above the Modjo Tannery	N=08^{0}36.538' E=039^{0}06.786'	1764m
Modjo Downstream	Immediately below the point of discharge of Modjo Tannery wastewater	N=08^{0}36.53' E=039^{0}06.786'	1759m
Tannery	Around the location of Ethio-Tannery	N=08'26'03.9 E=039'05'10.0"	
Awash	Above the bridge of Awash River (on the way to Hawassa)	N=0824'22.0" E=039'01'12.1"	1580 m
Awash mouth	At the point where Awash River joins the Koka Reservoir	N=08,19'10.5" E=039^{0}05'02.5"	1587m
Kintare	Around the Kentare Village	N=08^{0}21.280' E=039^{0}00.080'	1597m
Amude	Around Amude village	N=08^{0}1905.8" E=039^{0}05'03.7"	1586m

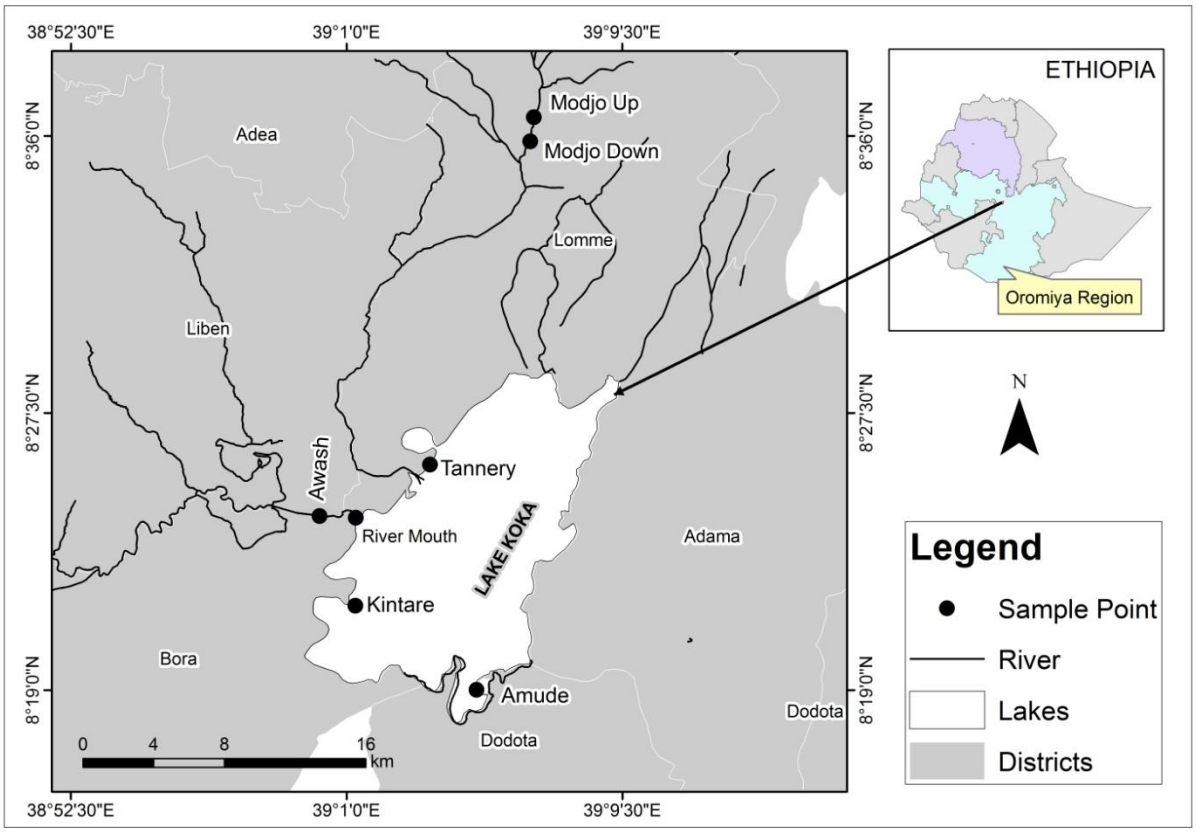


Figure 6: Map of Lake Koka and Sampling sites

3.3. Sampling protocol

The study was conducted between January to March 2016, and samples of water, sediment, phytoplankton, and zooplankton and muscle tissue of three commercially important fish species (*O. niloticus, C.carpio, and C. gariepinus)* were collected for the present study. Water samples were collected from various depths using 2L Kemmerer water sampler, well-mixed in a bucket and one-liter composite water sample was taken in polythene bottle for analysis. Sediment, plankton and fishes sample were collected from tannery and Amude sites. Samples were transported on the same day with icebox to Limnology Laboratory of Addis Ababa University. All equipment for the collection, storage, and filtration of the samples was soaked in ultrapure 0.7 % HNO3 for 48 h and rinsed four times with deionized water before use APHA and AWWA (1998).

3.3.1. Sampling and laboratory analysis of physicochemical parameters

Dissolved oxygen, water temperature, pH, and conductivity were measured *in situ* using a Multimeter probe (model HQ40d) at all sampling sites. The values of conductivity were corrected to 25^{o}C using a temperature coefficient of 2.3% per degree Celsius(Talling and Talling, 1965).Turbidity and water transparency (vertical visibility) were estimated using a turbido meter (T100 Oakaton) and a 20 cm diameter standard Sechi disk, respectively. The maximum depth of the reservoir was measured with Echotest II depth sounder. Concentrations of inorganic nutrients were determined in the limnology laboratory of Addis Ababa University following the procedures outlined in (APHA *et al.*, 1999). All samples used for nutrient analyses were filtered through glass fiber filters (What man GF/F) except total phosphorus (TP), for which unfiltered water sample was used. Nitrate (NO3-N) was analyzed by sodium salicylate method APHA (1995) while ammonia was determined by phenate method. Soluble reactive phosphorus (SRP) and TP (after persulfate digestion) by the ascorbic acid method. Reactive silica (SiO_2) was estimated using filtrates molybido-silicate method (APHA *et al.*, 1999).The concentrations of BOD_5 and COD were analyzed by the Azide modification of the Winkler titrimetric method and APHA 5220B. Open Reflux Methods, respectively in Environmental Protection Authority (EPA) of Ethiopia.

3.3.2. Biological parameters

3.3.2.1 Phytoplankton sampling

Phytoplankton samples were collected with the aid of a plankton net (mesh size: 30 μm) through vertical hauls. Duplicate phytoplankton samples were taken from the euphotic depth (0.2m) of the tannery and Amude sites, one sample was preserved with Lugol's solution for identification and the other phytoplankton sample was acidified with HCl and kept for heavy metal analysis.

3.3.2.2. Zooplankton sampling

Zooplankton samples were collected with the aid of a plankton net (mesh size: 55 μm) through vertical hauls from 1m depth. Duplicate samples were taken from both the tannery and Amude site, one sample was preserved with 5% formalin solution for identification and the other sample was acidified with HCl and kept for heavy metal analysis.

3.3.2.3 Fish sampling

The fishes were bought from local fishermen who were collected at Tannery and Amude sites. Adult individuals of similar size were selected from the three fish types of the lake and the samples were immediately dissected in the field and only the edible muscle tissue (fillet) was transferred to plastic bags and kept in the icebox.

3.3.3 Sediment sampling

Sediment samples were collected from the lake using bottom sediment Grab Sampler. Subsamples were taken from the central part of the grab to avoid metal contamination and kept in plastic boxes, which were deep-frozen until oven drying prior to analysis.

3.4. Sample preparation for heavy metal analysis

About 100 ml of water sample was filtered through glass fiber filter (GF/F). The filtrate and unfiltered water samples were preserved in concentrated nitric acid by making the pH<2, to prevent precipitation of metals and growth of algae. Metals were determined from the filtered water samples of nitric acid digestion. Finally, 20 ml of filtered water samples were taken for analysis after digestion (APHA and AWWA, 1998).

Phytoplankton and zooplankton samples were oven dried at 65^{o}C, powdered and aliquots of about 300 mg were digested for 3 hours at 80°C with 300 µ L^{-1} HNO3 (65%, supra pure, Merck) in tightly closed 2 mL Ep-pendrof reaction tubes. The digests were made up to 25 mL with HCl (0.1N) and kept for heavy metal analysis (Kalay and Canli, 2000).

Fish muscle samples were washed with deionized distilled water to remove slime and drained, then the water was removed by tissue paper. They were then dried on white cardboard sheets in the laboratory oven at an initial temperature of 70^{o}C, which was increased to about 105^{o}C after 3 hours. Heating continued for another 12 hours at this temperature. After allowing to cool overnight, the samples were further heated for 8hours at 105 ^{o}C, cooled and then exposed to ambient laboratory temperatures to air-dry for three days. The sample was then packed into a clean dry screw cap bottle and stored in a freezer pending chemical analysis. About 1g of the samples already dried to constant weight was weighed and mixed with 20 ml of nitric acid –

hydrogen peroxide (3:1) in a 100 ml digestion flask, swirled to ensure proper dispersion and left to stand for 48 hours at room temperature to digest. The mixture was then refluxed on a heating mantle until fuming ceased. 5ml of per-chloric acid was added and further refluxed for 30 minutes. After cooling, the resulting digest was made up to 100ml with de-ionized distilled water. The digested samples were stored in pre-cleaned polyethylene bottles until analysis.

The Sub sampled Sediment were air-dried, mixed, quartered and one-fourth of each sample was dried in an oven at 105 ^{o}C for 12 hours. The dried samples were then ground and sieved with 2 mm mesh size. A 20 pulverized (2 mm) sample was weighed into a 400 ml beaker. An acid mix of 50 ml HCl and 20 ml HNO_3 was slowly added to the sample while swirling, to ensure the sample is properly wetted and simmered on the hot plate for a minimum of 45 minutes at 160^{o}c stirring with a glass rod. It was removed from the hot plate before dryness, cooled and diluted in a 200 ml volumetric flask with distilled water, shaken and poured back into the beaker and settled for 30 minutes. Finally, some amount was taken by 16x150 mm test tubes and analyzed for heavy metal (Hagedorn, 2008).

Heavy metals from water, sediment, zooplankton, phytoplankton, and fishes samples were analyzed in Environmental Protection Authority (EPA) of Ethiopia and Bless Agri-food Laboratory Services PLC using Graphite Furnance Atomic Absorption Spectrometry (GFAAS) on both organizations.

3.5. Human exposure estimates

Estimate of human exposure to heavy metals through eating fish was made using estimation methods of (FAO, 2011). According to FAO, in the communities where fish-eating habit, annual fish consumption can exceed 10 kg person^{-1}. This value is equivalent to 0.19 kg week^{-1}. This assumption was used to calculate the estimated weekly intake (EWI) of heavy metals through fish from Lake Koka. The EWI was calculated by multiplying mean concentrations in fish muscles (edible part, wet weight) with 0.19kg. Measured dry weight values were converted to wet weight values by dividing the values by factor 5.56, as water content in the sampled fish species was around 82% (Table 11).

3.6. Data Analysis

Descriptive statistics were used to analyze physicochemical data and heavy metal concentration in water, sediment, plankton and fish samples. Spatial variation in physicochemical parameters and heavy metal concentrations were analyzed using Kruskal-Wallis ANOVA followed by multiple comparison tests. The concentrations of Cr, Cu, Pb and Cd among the three fish species were also compared using Kruskal-Wallis ANOVA with Statistica Version 7. P-values <0.05 were considered significant.

Relationships between environmental data and sampling sites were assessed using canonical multivariate analysis with the package CANOCO 4.5 (Ter Braak and Smilauer, 2002).To explore the relationship between sampling sites and physicochemical parameters, a detrended correspondence analysis (DCA) was performed. Since physicochemical parameters exhibit linear responses (gradient length 0.979) to sampling sites, we performed principal component analysis (PCA). Prior to ordination analysis, the log (X+1) transformation Legendre and Gallagher (2001) was employed for environmental variables.

Derived variables for Cr, Pb and Cd were calculated to estimate the degree of enrichment and bioaccumulation at each trophic level in Lake Koka. Bioaccumulation factor (BAF) from medium (sediment or water) and Biomagnifications factor (BMF) along the trophic sequence was calculated as described in equations below (Keating *et al.*, 1997).

$$BAFW = \frac{(\text{Mean metal concentration for each trophic group in ng g}-1)}{(\text{Mean metal concentraton in water in ng g}-1)} \quad \text{.....eqn (1)}$$

$$BAFS = \frac{(\text{Mean metal concentration of each trophic group in ng g}-1)}{(\text{Mean metal concentraton of water (sediment) in ng g}-1)} \quad \text{.....eqn (2)}$$

$$BMFZ = \frac{(\text{Mean metal concentration of Zooplankton in ng g}-1)}{(\text{Mean metal concentraton of Phytoplankton in ng g}-1)} \quad \text{.....eqn (3)}$$

$$BMFF = \frac{(\text{Mean metal concentration of Fish in ng g}-1)}{(\text{Mean metal concentraton in Phytoplankton in ng g}-1)} \quad \text{.....eqn (4)}$$

4. Results

4.1. Physicochemical characteristics

The mean (±SE) value of water temperature at the sampling sites ranged from 21.7±0.1 °C at Modjo Upstream Site to 26.87±0.1°C at Awash River and there is no significant variation in the value of temperature among the sampling sites (Kruskal-Wallis ANOVA, $p>0.05$) (Table 7). The mean (±SE) value of specific conductivity at the sampling sites ranged from 180±154 µS cm^{-1} at Modjo Upstream to 1197±137 µS cm^{-1} at Tannery Site. Tannery and Modjo Downstream sites showed significantly higher value of specific conductivity than the other sampling sites ($p <0.05$).

The mean (±SE) value of dissolved oxygen (mgL^{-1}) ranged from 3.67±0.41 at Modjo downstream to 9.15±2.47 at Amude site. ANOVA results indicated that there was significant variation in dissolved oxygen concentration among sampling sites ($p<0.05$), Amude site exhibited significantly higher value than the other sampling sites (Table 7). The mean (±SE) value of pH ranged from 7.60±0.3 at Modjo Upstream site to 9.5 ±0.1 at Modjo downstream ($P<0.05$). Modjo downstream exhibited significantly higher value than other sites.

The concentration of nutrients Ammonia, Nitrate, soluble reactive phosphate and total phosphorus also indicated significant variation among the sampling sites (Table 7). However, higher values of Ammonia and Nitrate were found at the Modjo downstream site. The concentrations of ammonia mean (±SE) (mg L^{-1}) ranged from 0.04±0.001 at Awash site to 18.09±1.37 at Modjo downstream site ($p<0.05$). The NO_3–N mean value in mgL^{-1}ranged from 0.31 ±0.01 to 10.09±0.07 at Awash River mouth and Modjo Downstream sites, respectively ($p<0.05$). Similarly, the PO_4-P and TP concentrations (mg L^{-1}) were shown significant variation in modjo up and downstream sites ($p<0.05$).

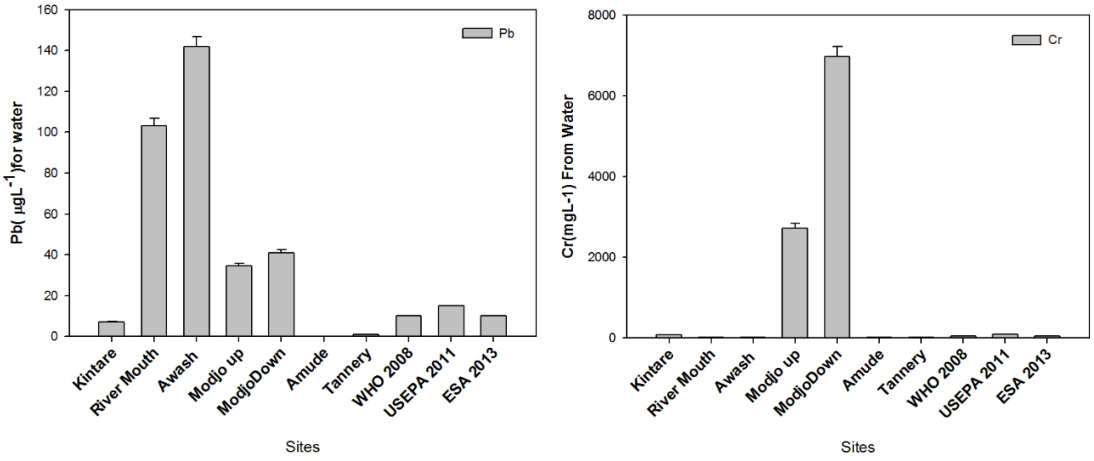
Table 7: Variation in physicochemical parameters among sampling sites: Means within a column designated by the same letter are not significantly different (P>0.05) (Kruskal-Wallis ANOVA)

Sites	Physicochemical parameters								
	DO (mg l^{-1})	Temp (°C)	pH	Cond (µS cm^{-1})	NH_3 (mg L^{-1})	NO_3 (mg L^{-1})	SRP (mg L^{-11})	TP (mg L^{-1})	SiO_2 (mg $^{-1}$)
AM	9.15^{a}	24.10^{a}	8.38^{a}	293.18^{a}	0.09^{a}	0.39^{a}	0.003a	0.005^{a}	0.35^{a}
TAN	5.37^{b}	22.83^{a}	8.04^{a}	1171.47^{b}	0.11^{a}	0.50^{a}	0.003^{a}	0.005^{a}	0.33^{a}
MO	6.82^{abc}	24.37^{a}	8.14^{a}	331.68^{a}	0.13^{a}	0.31^{a}	0.004^{a}	0.005^{a}	0.37^{a}
AW	5.23^{bc}	26.87^{a}	7.64^{a}	289.76^{a}	0.04^{a}	0.66^{a}	0.003^{a}	0.025^{a}	0.36^{a}
MjUp	7.70^{ab}	21.70^{a}	7.60^{a}	180.41^{a}	0.0531^{a}	0.545^{a}	0.70^{b}	4.12^{b}	0.58^{a}
MjD	3.67^{c}	23.20^{a}	9.50^{b}	1197.22^{b}	18.095^{b}	10.099^{b}	1.35^{c}	3.44^{b}	1.95^{b}

Where; AM=Amude, TAN=Tannery, MO=Awash mouth, AW=Awash, MjUP=Modjoup, MJD=Modjo down

4.2. Concentrations of heavy metals in water

The concentration of Cd, Cr and Pb were analyzed from all sampling sites and the maximum concentrations of Pb, Cr and Cd were measured at Awash, Modjo down and Modjo-Upstream, which all are river sampling sites. In contrary, the minimum values of the same heavy metals were recorded at Amude, Awash and Kentare sites, sites at Lake Koka, respectively (Fig. 7). The concentration of Cr ranged from 11.46 µg/L at Awash to 6968 µg/L at Modjo downstream site. The concentration of Pb also ranged from 0.11 µg/L at Amude site to 141.9 µg/L at Awash Site. The level of Cd concentration ranged from 0.13 µg/L at Kentare to 8.13µg/L at Modjo upstream.



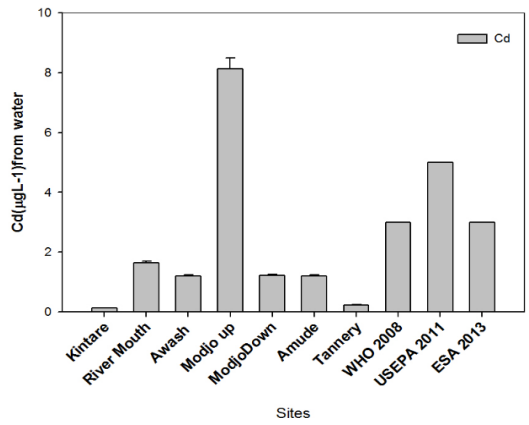


Figure 7: Concentration of heavy metals (Pb-Lead, Cr-Chromium, and Cd-Cadmium) from water samples at the sampling sites and compared with threshold values of (WHO, 2008; USEPA, 2011; ESA, 2013)

Although the three metals concentrations were computed to all sampling sites, several heavy metals like As, Hg, Cu, Zn, Ni, and Mn were also analyzed for the lake sites only (Amude, Tannery and Kintare). Accordingly, Mn, Ni, Zn, and Cr showed the highest concentration. The concentration of heavy metals (in ugL-1) in Lake Koka ranges from Mn*(416.5)>Ni*(126.17) >Zn(33.05) > Cr(22.34) > Cu(5.77) >Hg(1.65) >Cd(0.73) >Pb(0.39) >As(0.127),(Fig.8).

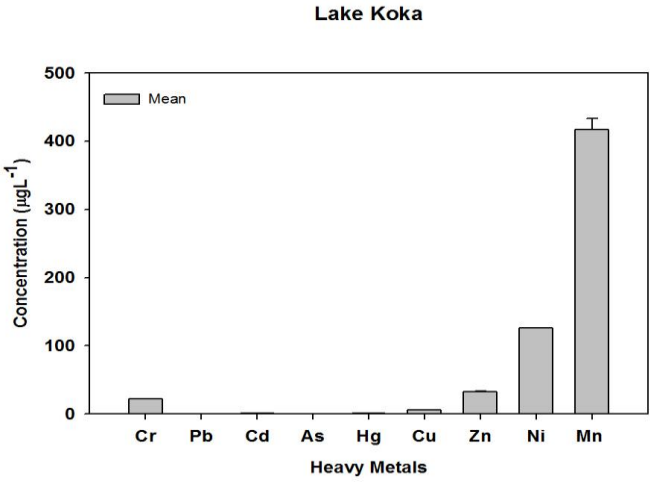


Figure 8: Concentration of heavy metals from water samples of L. Koka sampling sites.

4.3. Ordination analysis

Principal component analysis (PCA) of physicochemical data showed a clear clustering of sampling sites into Modjo sites (modjo up and down), Awash sites (Awash and River mouth) and Lake sites (Amude, Tannery, and Kintare) sites (Fig. 9). The first two axes explained 89.2% of the data distribution (axis 1= 61.3%, axis 2= 27.9%). Axis 1 separated Modjo sites from all other sites. The second axis of this PCA separated Awash and River mouth from Lake Sites. The concentration of nitrate and phosphate, Cd, Cr, COD, and BOD characterized Modjo sites (modjo up and down). Dissolved oxygen was correlated with Lake Sites, while Pb characterized Awash and River mouth sites.

Table 8: Values of Ordination analysis

Axes	**1**	**2**	**3**	**4**	**Total Variance**
Eigenvalues	0.613	0.279	0.085	0.021	1
Cumulative percentage variance of species data	61.3	27.9	97.6	99.7	

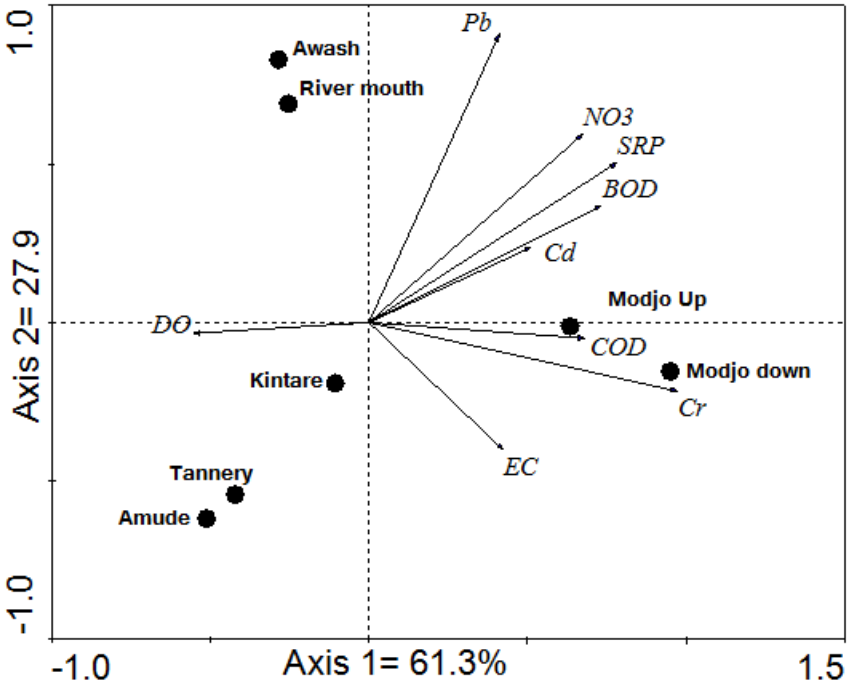


Figure 9: PCA biplot of sampling sites and environmental variables

4.4. Heavy metals Concentration in bottom sediment samples

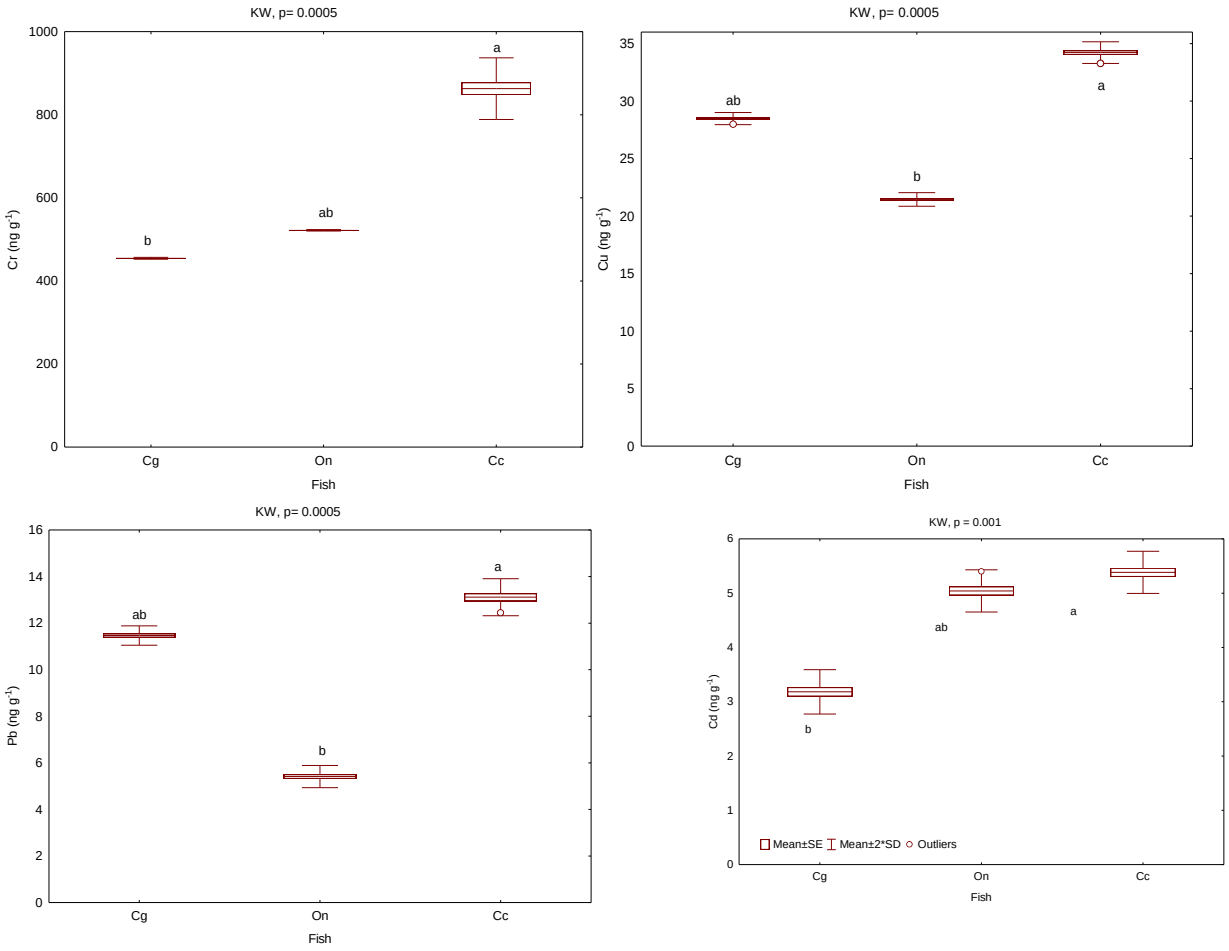
The metals concentrations in bottom sediment varied widely and exhibit fluctuation among elements. The concentration of heavy metals in sediment samples were ranked as Mn> Cr >Pb>Zn>Cu>Ni>Cd. The results showed that the values of all the seven heavy metals in sediment samples were lower than the respective reference values of (ISQG, 2002; USEPA, 2010).

Table 9: Heavy Metals concentration (ng g-1) in Lake Koka sediment and comparison with Sediment Quality Guidelines

Parameters	Cr (ng g^{-1})	Pb (ng g^{-1})	Cu(ngg^{-1})	Ni (ng g^{-1})	Zn (ngg$^{1)}$	Mn (ng g^{1})	Cd (ngg$^{1)}$
L.Koka	15,768±538	2682±98	905±12	568±23	2199±99	64300±3115	347±15
ISQG (2002)	37300	35000	35700	16000	123,000	460,000	600
USEPA(2010)	43,400	35,800	31,600	22,700	121,000	----	990
***Levels above ISQG (Interim Sediment Quality Guidelines) and USEPA Water Quality Guidelines**							

4.5. Heavy metals concentration in fish muscle tissue

In this study, it was found that concentration of each heavy metal varied among fish species. Cr and Cd are highest and lowest concentrations of heavy metal in muscle tissue of fish samples, respectively. Heavy metal concentration decreases in the sequence of Cr> Cu>Pb>Cd. The mean concentration of Cr and Cd were significantly higher in the muscle tissue of *C.carpio*. (Cr- 874, Cd- 5.38) compared to *C. garipanus* (Cr- 454, Cd- 3.180) (Kruskal-Wallis ANOVA, p= 0.0005 and p=0.001, respectively). The concentration of Pb and Cu was significantly higher in *C. carpio* (Pb-13.11, Cu- 34.21) than *O. niloticus* (Pb- 5.42, Cu- 21.45) (Kruskal Wallis ANOVA, p= 0.0005).



Cg-*Clarias garipinus*, On-*Oreochromis niloticus*, *Cc-cyprinus carpeo*

Figure 10: Concentration of Chromium, Lead, Cadmium, and Copper (ng g-1) in Muscle tissue of the three fish species (Cg, On, Cc)in ng g^{-1} (For all fishes n=26)

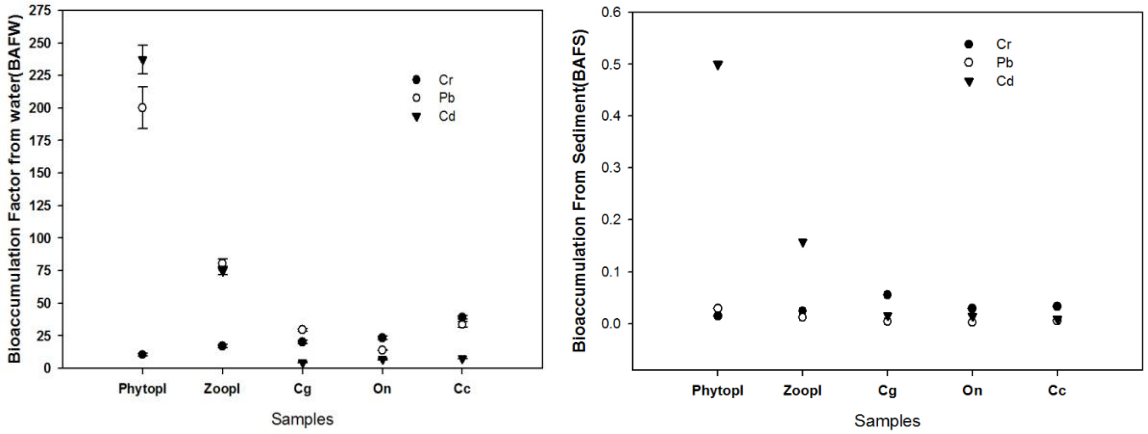
The Concentration of Cr on *C.garipinus (Cg), O.niloticus and C.carpio* were beyond the permissible Limits of (WHO, 1985; FEPA, 2003). However, the concentrations of Cu, Pb, and Cd were below the permissible limits (Table 10).

Table 10: Heavy metals in muscle tissues of fish species with Permissible limits (ngg-1).

Fish	Cr	Cu	Pb	Cd
Clarias garipinus	454±18	28±0.2	11±0.4	3.18±0.14
Oreochromis niloticus	521±22	21±0.9	5±0.2	5.04±0.16
Cyprinus carpio	874±38	34±1.67	13±0.3	5.38±0.06
WHO(1985)	150	3000	200	2000
FEPA(2003)	150	1300	200	2000

4.6. Bioaccumulation and biomagnifications of heavy metals

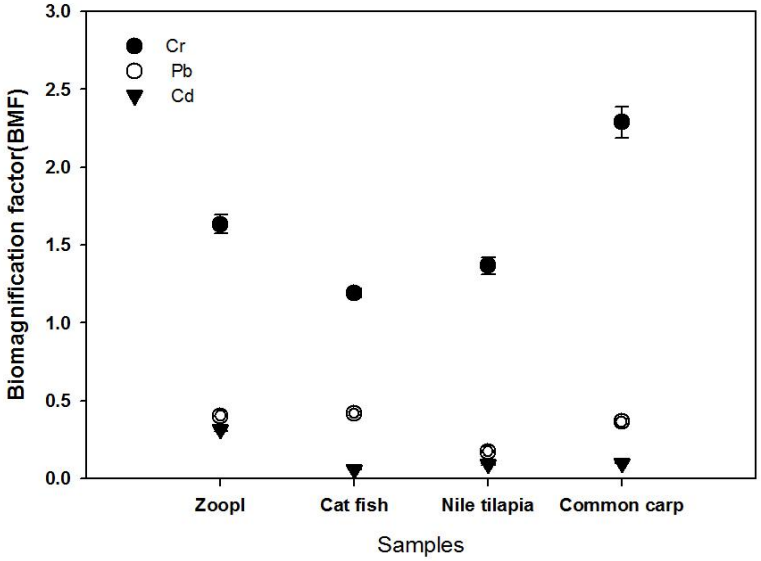
Bioaccumulation factor (BAF) for Cr, Pb, and Cd were examined from the water and sediment samples of the lake ecosystem. Bioaccumulation factor of water (BAFS) for Cd and Pb were highest in phytoplankton than zooplankton, which are followed by fish species. In the contrary, Cr in the three fish species has highest Bioaccumulation factor than plankton (Fig 12). The bioaccumulation factor for all samples was also identified the sediment samples and Bioaccumulation factor of sediment (BAFS for Cd was ranked as Phytoplankton>Zooplankton >Fish species while the Cr and Pb have no significant pattern of increment or decline (Fig 12).



Phytopl-Phytoplankton,Zoopl-Zooplankton, Cg-*Clarias garipinus*, On-*Oreochromis niloticus*, Cc-*Cyprinus carpio*.

Figure 11: Bioaccumulation factors (Means of BAF±SE) of metals (Cr, Pb, and Cd) with respect to water and sediment

The Biomagnifications factor of Chromium for zooplankton, *C.garipinus, O.niloticus, and C.carpio* are 1.63, 2.28, 1.36, and 1.18 respectively. This indicates chromium along the trophic state is Biomagnifying from phytoplankton to Zooplankton and from Zooplankton to Fishes (BMF>1). Compared to the three fish species Chromium biomagnifications factor is in the order of Cg>On>Cc.(Fig.12).On the other hand, the biomagnifications factor for Pb was recorded as 0.4,0.36,0.17, and 0.4 for Zoo, Cg, On and Cc. respectively. Thus from the Figure above Pb was Bio diminish along the trophic state.



Zoopl= Zooplankton

Figure 12: Biomagnifications factors (means of BMF ±SE) for Zooplankton and Fish. Values >1.0 show enrichment of the metal at the respective trophic level and values <1.0 show a diminution

Table 11: Mean weight, Mean length and water content of the sampled fish species

Fish species	**Mean weight(g)**	**Mean length(cm)**	**Water content (%)**
***O.niloticus*(Nile tilapia)**	205±10	20.4±1	81±2.5
***C.gariepinus*(African catfish)**	375±8	38.1±1.5	83±1.4
C.carpeo(Common carp)	275±13	27.2±1.3	82±1.9

Estimated weekly intake of metals in µg was calculated as described in section "human exposure estimates". Provisional tolerable weekly intake (PTWI) for Cd and Pb in microgram per kilogram human body weight was given by (WHO, 1993), and for Cu by ((FSA, 2003) calculated for an adult of 60kg PTWI was withdrawn in 2010 (Table 12). No new tolerable intake label.

Table 12: Mean concentration of heavy metals in muscle tissue of the three fish species from Lake Koka in µLkg^{-1} Wet weight.

Heavy metals	Fish Species	Mean content fish muscle dry wt (µgkg^{-1})	Mean content fish muscle wet weight(µLkg^{-1})	Estimated human intake (EWI)	Tolerable human intake (PTWI)
Cd	*O.niloticus*	5.0417	0.9067	0.172	420
	C.gariepinus	3.1833	0.58	0.1087	420
	C.carpeo	5.3833	0.97	0.19	420
Pb	*O.niloticus*	5.4143	0.98	0.19	1,500
	C.gariepinus	11.47	2.07	0.391	1,500
	C.carpio	13.1150	2.36	0.45	1,500
Cr	*O.niloticus*	454.487	81.75	15.53	
	C.gariepinus	521.87	93.87	17.83	
	C.carpio	874.27	157.25	29.87	
Cu	*O.niloticus*	21	3.78	0.717	1120
	C.gariepinus	28	5.03	0.96	1120
	C.carpio	34	6.11	1.17	1120

5. Discussion

Heavy metals samples were collected from three distinct sites: River Modjo (Modjo up and Modjo downstream), Awash River (Awash and River mouth) and Lake Koka sites (Amude, Tannery, and Kintare). Plankton and fish muscles were taken only from the later sites-Lake Koka sites.

5.1. Physicochemical Parameters

As shown in (Table7), the lowest oxygen concentration at Modjo downstream which was far below the level capable of supporting aerobic heterotrophs and aquatic life. In general it was significantly different from those of other sampling sites and coincided with the present highest levels of BOD_5 and COD (WHO, 2004). This is mainly due to the discharge of untreated effluents of the tannery into the river water that contains high organic content and the microbial activity to decompose the dead macrophytes. Though the level of dissolved oxygen was less in tributaries below the tannery sites, high DO concentration was measured towards lake sites. This could be because of continuous mixing and dilution effect of the river (Assefa Wosnie and Ayalew Wondie, 2014; Ermias Deribe *et al.*, 2014b).

In this study, the BOD5 at Modjo downstream site (the junction point of Modjo tannery wastewater with Modjo river) exhibited the highest value compared to all other sites and even beyond the discharge limits of (EEPA, 2003), which is consistent with other findings (Seyoum Leta *et al.*, 2003; Akan *et al.*, 2009; Marghade *et al.*, 2011; Assefa Wosnie and Ayalew Wondie, 2014). BOD5 normally gives an indication of the amount of biodegradable organic matter (Chapman *et al.*, 1982) and it is the most widely used parameter to assess organic pollution applied to surface waters. The higher BOD5 at Modjo downstream is due to the discharge of organic effluents by the Modjo Tannery, which releases hairs, fats, pieces of skins (Seyoum Leta *et al.*, 2003). COD also demonstrated a similar trend to BOD, though the high COD levels imply toxic state and the presence of biologically resistant organic substances (Reid *et al.*, 1995).

Ammonia concentrations were high (18.09±1.37mgL^{-1}) at Modjo downstream. ammonia(NH_3) is much more toxic in alkaline water (pH >8.5) than acidic to aquatic biota (Källqvist and Svenson, 2003). The pH value of 9.5 at Modjo and high NH_3-N concentration is an indication of toxicity to aquatic biota and downstream users (through drinking and fishing). Due to its toxicity to aquatic biota, the European Union has set a safe limit of 0.005-0.025mgNH_3-N/L(Chapman and Organization, 1996). This result is in agreement with (Seyoum Leta *et al.*, 2003). On the other hand, ammonia nitrogen discharge in to a receiving stream will undergo oxidation process in the presence of dissolved oxygen and denitrifying bacteria (Seyoum Leta *et al.*, 2004), which will cause depletion of DO in the receiving water affecting aerobic aquatic life. In fact, the DO value at Modjo downstream is significantly lower than the other sites (Table 7). Similarly, high nitrate nitrogen was exhibited at Modjo downstream site in the present study. The presence of nitrate nitrogen in excess promotes eutrophication and algal blooming in the receiving waters (Powlson *et al.*, 2008). In addition to this, nitrate in drinking water above the maximum limits of 10mgL^{-1} can cause a human health condition known as methemoglobinemia (Gerardi, 2002). This disease is also known as "blue baby syndrome", which refers to the disease experienced by infants, who consume groundwater contaminated with nitrate nitrogen.

The nitrate ion is quickly reduced to nitrite in the infant's digestive tract and binds to the haem iron within the red blood cells. This prevents the hemoglobin from binding and transporting oxygen throughout the infants' body and causes the infant's skin to turn blue, hence the term "blue baby syndrome". Methemoglobinemia usually associated with rural communities where potable water is obtained from groundwater. About 15,000 inhabitants around Lake Koka use the lake water directly without any treatment (Teshome Akele Seyoum, 2011) and permissible limit of nitrogenous waste from tanneries final effluent needs to be in place. The phosphorous content in this study was within the standard provisional limit set by (EEPA, 2003). Though Modjo upstream and downstream sites had relatively higher phosphorous content than other sites and significantly different (Table 7). Thus, the tannery effluent was not responsible for this nutrient pollutant. The high phosphorus concentration at upper and downstream Modjo sites might be due to the addition of municipal wastewater and chemical fertilizer from agricultural land. Electrical Conductivity was high at Modjo downstream and Tannery sites (1197±137 and 1171±124, respectively). Conductivity is generally a very good predictor of both total cations and salinity in

Ethiopian water bodies (Zinabu GebreMariam *et al.*, 2002). Thus, the discharges from the two tanneries (Modjo and Ethio Tanneries) effluent showed fivefold higher conductivity than the other sites. The result is in agreement with several authors (Seyoum Leta *et al.*, 2003; Birenesh Abay, 2007; Deepali *et al.*, 2009; Assefa Wosnie and Ayalew Wondie, 2014).

5.2. Heavy metal concentrations in water

Heavy metals were sampled from Modjo river (Modjo up and Modjo downstream), Awash river (Awash and River mouth) and Lake Koka sites (Amude, Tannery, and Kentare) (Fig 7&8). The concentrations of Cr, Pb, and Cd in water from Amude and tannery sites of Lake Koka were within the same range as background values of (WHO, 2008; USEPA, 2011), which is in agreement with previous studies on the same lake (Dsikowitzky *et al.*, 2013). However, the concentration of Cr at Modjo Upstream, Modjo Downstream, and Kentare sites were above the permissible limits (WHO, 2008; USEPA, 2011), which is consistent with other studies (Seyoum Leta *et al.*, 2003; Ermias Deribe *et al.*, 2014b). The high concentration of Cr could be due to the effluent of the two tanneries (Modjo and Ethio tanneries), which use Cr containing compound for tanning. The concentration of Pb at Modjo upstream, Modjo downstream, Awash and River mouth were above the limits (WHO, 2008; USEPA, 2011). The level of Cd concentration at Modjo upstream is above the permissible limit (WHO, 2008; USEPA, 2011). These showed that the heavy metal concentrations in the lake water were relatively low, even though the systems receive a constant input of wastewaters containing all investigated metals.

The observed low concentrations of the metals in the lake sites could be attributed to dilution effects. Dilution masks the local concentration effects of the low and chronic exposure of the metals, by quickly reducing the concentration levels in the water (Zinabu GebreMariam and Pearce, 2003). Furthermore, the retention time of the lake is only due to Awash river. In the present study, Mn and Ni exhibited higher values (Mn 416.5 and Ni 126.17 ngg^{-1}), even beyond permissible limit of (WHO, 2008; USEPA, 2011). The current values are greater than studies made by (Zinabu GebreMariam and Pearce, 2003), who reported 56.3 ngg^{-1} for Mn and 5.1 ngg^{-1} for Ni, demonstrating an increasing trend. These might be due to the discharges of industrial and municipal wastes that released manganese and nickel into ambient waters (Eisler, 1998).

Agricultural fertilizer and biocides (pesticides, herbicides, preservatives) are known to contain Cd, Hg, Pb, Al, As, Cr, Cu, Mn, Ni, and Zn and it is likely that these metals get introduced into the aquatic environment via surface run-off (Biney *et al.*, 1994). Therefore, the higher concentrations of Mn and Ni detected at the lake site might have been the result of the non-point source of pollution, especially surface run-off from nearby agricultural fields that use fertilizers and pesticides.

5.3. Distribution pattern of metals in Lake Koka sediment

Heavy metals are introduced into the bottom sediments of aquatic environment through various routes including atmospheric fallout, dumping wastes, accidental leaks, runoff of industrial and domestic effluents and geological origins (Al-Yousuf *et al.*, 2000). In the present study, the general distribution of heavy metals in sediment samples was ranked as Mn> Cr >Pb>Zn>Cu>Ni>Cd showing highest concentration of manganese and the lowest concentration of cadmium (Table 9). Sediments have been reported to form the major repository of heavy metals in the aquatic system while both allochthonous and autochthonous sources could be ecologically significant. Influences the distribution of heavy metals in bottom sediments of this study was higher than the heavy metal concentration in the water column at the same site. Olowu *et al*., **(**2010), reported that the levels of heavy metals in the bottom sediments are usually higher than the water columns, which shows that sediments act as a sink of heavy metals. Although all the values for heavy metals of sediments were greater than from the water samples in L. Koka, the concentrations in the sediments are not beyond the permissible limits of (ISQG, 2002) and (USEPA, 2010).

The heavy metal concentration on the sediment samples of this study was low compared to the results of previous studies in lakes Hawassa and Ziway, and Tekeze reservoir (Kebede Nigussie *et al.*, 2010; Mulu Berhe Desta *et al.*, 2012). These metals might be form complexes with organic compounds because of the high formation constants of organic metal compounds, which make them rather stable in the environment (Zhou *et al.*, 1998). In the case of zinc, it can be associated with carbonate, mainly calcium carbonate, by forming the double salt of $CaCO_3.ZnCO_3$ in the sediment. On the other hand, cadmium is not found in organic fraction for low adsorption constant and liable complexion with organic matter (Zhou *et al.*, 1998).

5.4. Heavy metal concentrations in fish species

Fish attracted a lot of attention as bioindicators for monitoring aquatic pollution and intuitively their use for human consumption (Zhou *et al*., 2008). Nile tilapia, catfish, and common carp are commercially exploited fish species, However, heavy metal concentration is a concern and accordingly a couple of studies about heavy metal levels in different tissues of these three-fish species were published (Table 2).In the present study, the heavy metals concentration in the muscle tissue of fishes decreases in the following sequence Cr>Cu>Pb>Cd (Fig.10). The Concentration of Cr on catfish, Nile tilapia, and common carp were beyond the permissible limits of (EEPA, 2003; WS and WHO, 2004). However, the concentrations of Cu, Pb, and Cd were below the permissible limits. All the metals in the muscle tissue of common carp were exhibited higher concentration than the two other fishes, which could be related to its habitat and dietary content.

In fact, different concentration of heavy metals in different fish species might be a result of different ecological needs, metabolism and feeding patterns (Yilmaz, 2003). Romeo *et al*. (1999) pointed out that Cd and Cu contents in edible muscles of pelagic fish species (*O. niloticus)* were lower than for benthic fish species (*C. carpio)*. Even though catfish is considered as benthic fish, less content of Cr and Cd were recorded compared to Nile tilapia in this study. This could be related to the feeding habits of catfish and tilapia. Nile tilapia consumes phytoplankton and zooplankton, which uptakes heavy metals from the water column. On the other hand, catfish consume more detritus (24%), insects (14.1), macrophytes (14.5), zooplankton (19.3) and fish (21.8). Further, it might be associated with dilution effect of metals in the muscles of catfish, where total length is much higher than Nile tilapia. Amundsen et al. (1997) demonstrated that the accumulation pattern of Cr in freshwater fish is pH-dependent. At a pH of 6.5, Cr contents in the gills exceeded those in other organs whereas, at a pH of 7.8, considerably more Cr was accumulated in the internal organs than in the gills. Since the P^H value at Lake Koka during the present study period was ranged from 7.6-9.5, higher Chromium concentration was recorded in the muscle tissue of the three-fish species. The Cr concentration in the muscle of Catfish from the present study was lower than the values recorded in Lake Hawassa and Koka reservoir for the same fish (Dsikowitzky *et al*., 2013).

Table 13: Concentrations of heavy metals in fish muscle from this study in comparison to other studies from Ethiopian aquatic systems, ngg, ngg^{-1}

Species	Location	Cr	Pb	Cd	Cu	Reference
O. niloticus	Lake Koka	520-522.79	5.1-5.4	4.98.-5.4	21.2-21.8	This Study
	Lake Koka	110-203	30.1–54.2	0.45–8.4	-	(Dsikowitzky *et al.*, 2013).
	Lake Hawassa	-	<1,660	<240	1.39 – 1.85	(Abayneh Ataro *et al.*, 2003)
	L Ziway	-	<1,660	<240	-	(Abayneh Ataro *et al.*, 2003).
	Lake Hawassa	-	1650-2450	440-890	-	(Kebede Nigussie *et al.*, 2010)
	Tekeze Dam	1310	1850	560	1,090	(Mulu Berhe *et al.*, 2012)
C. gariepinus	Lake Koka	453-455	11.3-11.7	2.9-3.5	28-28.7	This study
	Lake Koka	803-895	11.46	5.38	-	(Dsikowitzky *et al.*, 2013)
	Lake Hawassa	179-430	21.7-339	1.2-3.7	-	(Dsikowitzky *et al.*, 2013)
	Tekeze Dam	640	1620	340	850	(Mulu Berhe Desta *et al.*, 2012)
	Lake Hawassa	211-1449	31.7-247	1.3-9.6	(Dsikowitzky *et al.*, 2013)	(Dsikowitzky *et al.*, 2013)
C. carpio	Lake Koka	803-895	12.44-13.58	5.2-5.7	34.2-34.6	This study
	Lake Ashangea	650	1240	530	1400	(Abraha Gebrekidan *et al.*, 2012)

5.5. Bioaccumulation and Biomagnifications of heavy metals

Bioaccumulation and biomagnifications are capable of leading heavy metals in the fish to a toxic level, even when they are exposed to low concentration. The presence of metal pollutants in fresh water can potentially disturb the delicate balance of the aquatic ecosystem. Canli and Atli (2003) indicated that the concentration of metals was a function of the fish species involved because they accumulate more in some fish species than in others.Similarly, Dural *et al*. (2006) pointed out that the efficiency of metal uptake from contaminated water and food could differ, influenced by ecological needs, metabolism and its concentration in water, food, and sediment, as well as other Environmental factors, such as salinity, temperature, and interacting agents.

5.5.1. Bioaccumulation from water and sediment

Bioaccumulation, the increase in the concentration of a chemical in tissue compared to the environment, often occurs with materials that are more soluble in lipids and organic (lipophilic) than in water (hydrophilic). The bioaccumulation factor (BAF) is used to evaluate the ability of an aquatic organism to accumulate chemicals from the aquatic environment, indicating which organisms have a potential to accumulate chemicals. BAFs exceeding 1 or 100% are considered significant (USEPA, 1991).

5.5.1.1. Bioaccumulation from water

In this study, all Cr, Cd, and Pb were bioaccumulated from the water to the phytoplankton, zooplankton, and fish species. Bioaccumulation factor of water (BAFW)>1 as seen in (Fig.11). The highest bioaccumulation of Pb and Cd were exhibited on phytoplankton and the least in fish species. The bioaccumulation was ranked as phytoplankton > zooplankton > fish species. The highest accumulation of Pb and Cd could be due to the higher capability of algae to uptake inorganic elements directly from water that uses several uptake mechanisms, in addition to their stronger metabolic capability. Furthermore, it was shown that dead algae could remain to accumulate metals through adsorption to cell surfaces (Tao *et al*., 2012a). For fish, due to their high mobility, the average BAF of each species for the entire lake was evaluated without

considering a spatial variation. However, this may become an advantage if the interest is in the mean conditions of a large area (Waheed *et al*., 2014).

Among the three fish species, the highest bioaccumulation of Pb and Cd were found in common carp and the rank of Pb bioaccumulation was C.carpeo (Common carp) > C.garipinus (Catfish)>O.niloticus (Nile Tilapia), whereas for Cd Common carp > Nile tilapia >Cat fish, On the other hand, chromium bioaccumulation was ranked as fish species >Zooplankton >phytoplankton. Among the fish species chromium ranked as C.carpeo>O. niloticus >C.garipinus. Briefly, all Pb, Cd, and Cr were bioaccumulating from water to plankton and fish species.

The highest bioaccumulation of chromium and cadmium in *C. carpeo* and *O. niloticus* compared to *C. garipinus* could be associated with the dilution effect of catfish (Mulu Berhe *et al*., 2012). The highest bioaccumulation of Cr and Cd in O.niloticus than *C.garipinus* is in agreement with (Dsikowitzky *et al.*, 2013). The highest Pb and Cd on phytoplankton was in agreement with (Tao *et al.*, 2012b) In this study Pb bioaccumulation on benthic fishes of *C. carpeo* and *C. garipinus* was higher than the pelagic fish (*O. niloticus*)These is in agreement with(Salami *et al.*, 2008) (Tao *et al.*, 2012b).

5.5.1.2. Bioaccumulation from sediment

In this study, all Cr, Pb, and Cd were not bioaccumulated to plankton and fish species .Because their bioaccumulation factors for sediment(BAFS) values was < 1(one)(Fig. 11). This indicates that Lake Koka sediment is not responsible for bioaccumulation of the metals (Pb, Cd, Cr).Though at these study the heavy metals concentration of the sediment is below the guideline of (ISQG, 2002; USEPA, 2010). As well as it was not bioaccumulated to plankton and fish species. There is an indication that benthic fish like *C carpeo* and *C.garipinus* has shown higher values of accumulation than pelagic fish of *O.niloticus*. The bioaccumulation of Pb and Cr from the sediment is in line with Mulu Berhe *et al*. (2012) whereas Cd was in opposition with (Mulu Berhe *et al*., 2012). Generally, the water of Lake Koka was responsible than its sediment to bioaccumulation of metals (Pb, Cd, and Cr) in lake Koka.

5.5.2. Biomagnifications of heavy metals

This study demonstrates the value of comparing metal predictors along trophic state in Lake Koka in order to contrast pathways by which different heavy metals move from land to water and from water and phytoplankton to zooplankton as well as from water and zooplankton to fish. *Predictors of metal concentrations in zooplankton*—this study is one of the few that demonstrates the importance of investigating lower trophic levels to understand the relationships in metal accumulation among water, plankton, and fish. Our primary finding was that metal in water was not an effective predictor for levels in zooplankton but metal in food was a good predictor. In fact, several lines of evidence suggest that concentrations of all these metals in phytoplankton and zooplankton were related probably through dietary transfer from the smaller to the larger size fraction. These trophic relationships differed significantly among metals, with some biomagnifying (Cr) and others diminishing (Cd and Pb) with trophic level (Fig.12).

Biomagnifications factors greater than 1 indicated accumulation from prey to predator, while values lower than 1 suggested active elimination of the element or interrupted trophic transfer (Hoekstra *et al.*, 2003). In this study, Pb and Cd were not biomagnified along the trophic level rather they were bio diminished. Since the BMF from phytoplankton to Zooplankton as well as from Zooplankton to fish species was <1.Though Pb and Cd were bioaccumulated much on phytoplankton but they were not biomagnified to zooplankton and then to fish. The possible reason for these may be either zooplankton in lake Koka feed small seston particles <20µm (Yeshiemebet Major *et al.*, 2017).

The biomagnifications of total chromium was significantly different from these. Total chromium was the one that biomagnified along the trophic level. The BMF of total chromium from phytoplankton to zooplankton was 1.63 and from zooplankton to fish species was from 1.18, 1.36 and 2.28 to *C.garipinus*, *O.niloticus* and *C.carpeo* respectively, which indicates that the BMF for Zooplankton and fish species was >1. BMF from zooplankton to fish species was ranked as *C.carpeo* >*O.niloticus*>*C.garipinus*. The higher value of biomagnifications of total chromium on *C.carpeo* and *O. niloticus* than *C. garipinus* was because of biodilution effect as reported by (Mulu Berhe *et al.*, 2012).

Higher concentration of Cr in *C.carpio* than *O.niloticus* was associated with higher proportion of benthic prey other than zooplankton on Lake Koka of Awash basin. On the other hand, the higher BMF for *O. niloticus* than *C.garipinus* was associated with food shift of *O. niloticus* to macrophyte((Tadesse Fetahi *et al.*, 2017). Though chromium was biomagnified along the trophic level.There is no reported health effect of chromium through the oral root. No tolerable human intake values for Cr from food are provided by WHO, maybe because Cr is not very toxic when introduced by the oral route(Shrivastava *et al.*, 2002).

5.6. Human health impact implications

Human exposure to heavy metals due to fish consumption from Lake Koka was also assessed. To get this, the estimated weekly intake of heavy metals were calculated considering the amount of consumed fish and the measured metal levels in the fish muscle (Table 12). The results show that these weekly intake estimates are considerably lower than the tolerable human intake values provided by the WHO. This implies that Cd, Pb, and Cu pose no public health hazard through consumption of the respective fish species. No tolerable human intake values for Cr from food are provided by WHO, maybe because Cr is not very toxic when introduced by the oral route (Shrivastava *et al.*, 2002).

6. Conclusion and Recommendations

6.1. Conclusion

Pb, Cd and Cu are not a threat to human health through biomagnifications from Lake Koka. Unlike this Cr magnified along the trophic levels but WHO and FSA do not provide tolerable human intake limit for it. The measured different parameter levels on Modjo downstream site were all above reference values and the provisional standards set by EPA. Significant pollution of the river was indicated for COD, Nitrate-nitrogen, ammonia-nitrogen, total chromium and electrical conductivity on Modjo downstream site. The high nitrogen level would be harmful; since it stimulates eutrophication. On Lake Koka, this would impair the sustainable utilization of Lake Koka's water. This fact must regularly be brought to public awareness in developing countries like Ethiopia where tanneries in particular and industries in general discharge their wastes directly into the environment without considering its due ecological consequences. The development of tanning industries in livestock rich developing countries like Ethiopia is an encouraging phenomenon from an economic and social development point of view. Such development prospects, however, can be threatening, and it can lead towards a devastating environmental condition unless industrial wastes are managed properly. Proper disposal of tannery wastes is primarily necessary to safeguard the aquatic environment from heavy loads of pollutants and toxic substances.

6.2. Recommendations

- Even though the result of this study indicated there is no that match human health risk due to bioaccumulation and magnification, as prevention is better that cure, mitigation and possible measures on point and nonpoint sources of pollution is necessary.

- Further research on biomagnifications of heavy metals on a human being by taking actual samples (hair) is required to track their concentration along the trophic gradient.

- Further study on bioaccumulation and biomagnifications of heavy metals by taking liver and kidney samples is recommended

- There should be a coordinated work by policymakers, scientists, investors, and local community to The lake and the inflowing rivers by
  - ✓ Creating awareness to the local community
  - ✓ Implementing the the rules and regulations devised by the responsible Authority (permissible limits)
  - ✓ Preventing the lake shore by having a buffer zone and also constructing arteficial wetlands

7. References

Abayneh Ataro, Taddese Wondimu & Chandravanshi BS (2003). Trace metals in selected fish species from lakes Awassa and Ziway, Ethiopia. *SINET: Ethiopian Journal of Science* **26**(2): 103-114.

Abraha Gebrekidan, Mulu Berhe & Yirgaalem Weldegebriel (2012). Bioaccumulation of heavy metals in fishes of Hashenge Lake, Tigray, Northern Highlands of Ethiopia. *American Journal of Chemistry* **2**(6): 326-334.

Agarwal, R., Kumar, R. & Behari, J. (2007). Mercury and lead content in fish species from the river Gomti, Lucknow, India, as biomarkers of contamination. *Bulletin of Environmental contamination and Toxicology* **78**(2): 118-122.

Akan, J., Abdulrahman, F., Sodipo, O. & Akandu, P. (2009). Bioaccumulation of some heavy metals of six fresh water fishes caught from Lake Chad in Doron Buhari, Maiduguri, Borno State, Nigeria *Journal of Applied Sciences in Environmental Sanitation* **4**(2).

Akiwumi, F. A. & Butler, D. R. (2008). Mining and environmental change in Sierra Leone, West Africa: a remote sensing and hydrogeomorphological study. *Environmental monitoring and assessment* **142**(1): 309-318.

Al-Yousuf, M., El-Shahawi, M. & Al-Ghais, S. (2000). Trace metals in liver, skin and muscle of Lethrinus lentjan fish species in relation to body length and sex. *Science of the total environment* **256**(2): 87-94.

Altındağ, A. & Yiğit, S. (2005). Assessment of heavy metal concentrations in the food web of lake Beyşehir, Turkey. *Chemosphere* **60**(4): 552-556.

Amundsen, P.-A., Staldvik, F. J., Lukin, A. A., Kashulin, N. A., Popova, O. A. & Reshetnikov, Y. S. (1997). Heavy metal contamination in freshwater fish from the border region between Norway and Russia. *Science of the Total Environment* **201**(3): 211-224.

APHA (1995).APHA (1995) Standard methods for the examination of water and wastewater. In *American Public Health Association, American Water Works association, Water Environment Federation, Washington*.

APHA & AWWA (1998). Wpcf. *Standard methods for the examination of water and wastewater* **20**.

APHA, AWWA, WPCF & WEF (1999). *Standard methods for the examination of water and wastewater*. American Public Health Association.

Ashraf, M. A., Maah, M. & Yusoff, I. (2012). Bioaccumulation of heavy metals in fish species collected from former tin mining catchment. *International Journal of Environmental Research* **6**(1): 209-218.

Assefa Wosnie & Ayalew Wondie (2014). Bahir Dar tannery effluent characterization and its impact on the head of Blue Nile River. *African Journal of Environmental Science and Technology* **8**(6): 312-318.

Aweke Kebede & Taddese Wondimu (2004). Distribution of trace elements in muscle and organs of tilapia, Oreochromis niloticus, from Lakes Awassa and Ziway, Ethiopia. *Bulletin of the Chemical Society of Ethiopia* **18**(2).

Barron, M. G. (1990). Bioconcentration. Will water-borne organic chemicals accumulate in aquatic animals? *Environmental science & technology* **24**(11): 1612-1618.

Baselt, R. C. (2000). *Disposition of toxic drugs and chemicals in man*. Chemical Toxicology Institute.

Biney, C., Amuzu, A., Calamari, D., Kaba, N., Mbome, I., Naeve, H., Ochumba, P., Osibanjo, O., Radegonde, V. & Saad, M. (1994). Review of heavy metals in the African aquatic environment. *Ecotoxicology and environmental safety* **28**(2): 134-159.

Biney, C., Amuzu, A., Calamari, D., Kaba, N., Mbome, I., Naeve, N., Ochumba, P., Osibanjo, O., Radegonde, V. & Saad, M. (1992). Review of heavy metals in the African aquatic environment. Committee for inland fisheries of Africa. Report of the third session of the working party on pollution and fisheries. Accra, Ghana, 25–29 November 1991. *FAO Fisheries Report. No. 471 Rome, FAO*.

Birenesh Abay (2007). Assessment of downstream pollution profiles of Awassa textile factory effluent along Tikur Wuha river using physico-chemical and macroinvertebrate indicators.

Botkin, D. B. & Keller, E. A. (1998). *Environmental science: earth as a living planet*. John Wiley & Sons Ltd.

Bryan, G. & Hummerstone, L. (1973). Adaptation of the polychaete Nereis diversicolor to estuarine sediments containing high concentrations of zinc and cadmium. *Journal of the Marine Biological Association of the United Kingdom* **53**(4): 839-857.

Calamari, D. & Naeve, H. (1994). *Review of pollution in the African aquatic environment*. Food & Agriculture Org.

Canli, M. & Atli, G. (2003). The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. *Environmental pollution* **121**(1): 129-136.

Castro-González, M. & Méndez-Armenta, M. (2008). Heavy metals: Implications associated to fish consumption. *Environmental toxicology and pharmacology* **26**(3): 263-271.

Chapman, D. V. & Organization, W. H. (1996). Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring.

Chapman, P. M., Farrell, M. A. & Brinkhurst, R. O. (1982). Relative tolerances of selected aquatic oligochaetes to individual pollutants and environmental factors. *Aquatic Toxicology* **2**(1): 47-67.

Chaudhari, A., Sahu, N. & Pandey, P. (1996). Factors affecting heavy metal toxicity in aquatic organisms. *Fish. Chimes* **16**(3): 49.

Chioma, O., Emmanuel, A. & Peter, A. (2017). Accumulation and toxicological risk assessment of Cd, As, Pb, Hg, and Cu from topsoils of school playgrounds at Obio-Akpor LGA Rivers State Nigeria. *International Journal of Scientific World* **5**(1): 38-46.

Dallinger, R., Prosi, F., Segner, H. & Back, H. (1987). Contaminated food and uptake of heavy metals by fish: a review and a proposal for further research. *Oecologia* **73**(1): 91-98.

Davies, O., Allison, M. & Uyi, H. (2006). Bioaccumulation of heavy metals in water, sediment and periwinkle (Tympanotonus fuscatus var radula) from the Elechi Creek, Niger Delta. *African Journal of Biotechnology* **5**(10).

Deepali, K., Gangwar, R. & Joshi, B. (2009). Comparative study of physico-chemical properties of effluent from tannery industries. *Indian Journal of Environmental Sciences* **3**(2): 49-152.

Dsikowitzky, L., Mesfin Mengesha, Elias Dadebo, de Carvalho, C. E. V. & 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.

Dural, M., Göksu, M. L., Özak, A. A. & Derici, B. (2006). Bioaccumulation of some heavy metals in different tissues of Dicentrarchus labrax L, 1758, Sparus aurata L, 1758 and Mugil cephalus L, 1758 from the Camlik lagoon of the eastern cost of mediterranean (turkey). *Environmental Monitoring and Assessment* **118**(1-3): 65-74.

Edem, C., Vincent, O., Grace, I., Rebecca, E. & Joseph, E. (2009). Distribution of heavy metals in bones, gills, livers and muscles of (Tilapia) Oreochromis niloticus from Henshaw Town Beach market in Calabar Nigeria. *Pakistan Journal of Nutrition* **8**(8): 1209-1211.

EEPA (2003).Provisional standards for industrial pollution control in Ethiopia. Prepared under the ecologically sustainable industrial development (ESID) project - US/ETH/99/068/Ehiopia, EPA/UNIDO. Addis Ababa, Ethiopia.

Eisler, R. (1998).Nickel hazards to fish, wildlife, and invertebrates: a synoptic review. GEOLOGICAL SURVEY WASHINGTON DC.

Elias Dadebo, Alamrew Eyayu, Solomon Sorsa & 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.

ENMA (2017).Meteorological Data of Koka and Ziway Areas. Ethiopian National Meteorological Agency, Addis Ababa, Ethiopia: .

Ermias Deribe, Alemayehu Masresha, August, G. P., Siri, B., Olav, R. B., Reidar, B., Elias Dadebo, Zinabu Gebremariam, Martin, E. O. & Lindis, S. (2014a). Bioaccumulation of mercury in fish species from the Ethiopian Rift Valley Lakes. *International Journal of Environmental Protection* **4**(1): 15.

Ermias Deribe, Elias Dadebo & Martin, E. O. (2014b). Level of mercury in fish from the Ethiopian Rift Valley Lakes: its implications in dietary exposure. *Ethiopian Journal of Biological Sciences* **13**(1): 25-35.

Ermias Deribe, Olav, R. B., Reidar, B., Brit, S., Zinabu Gebremariam, Elias Dadebo, Ragnar, N. H. & Martin, E. O. (2011). Bioaccumulation of persistent organic pollutants (POPs) in fish species from Lake Koka, Ethiopia: the influence of lipid content and trophic position. *Science of the Total Environment* **410**: 136-145.

ESA (2013).Compulsary Ethiopian Standard: Drinking Water-Specifications. First Edition.

FAO (2011).Fisheries and Aquaculture Country Profiles of Ethiopia.

Fasil Degefu, Kibru Teshome, Gashaw Tesfaye, Fikadu Teshome & Aschalew Lakew (2011). Some limnological aspects of Koka reservoir, a shallow tropical artificial lake, Ethiopia.

FEPA (2003).Guidelines and Standards for Environmental Pollution Control in Nigeria. Federal Environmental Protection Agency, p.238.

Fergusson, J. (1990).The heavy metals, chemistry. Environmental impact and health effect. Pergamon Press, Oxford.

FSA (2003).Safe upper levels for Vitamins and Minerals. Report of the expert group on Vitamins and Minerals, Food Saftey Act.

Gabby, P. (2006). Lead: in Mineral Commodity Summaries. Reston, VA. *US Geological Survey*.

Gerardi, M. H. (2002). Nitrogen: environmental and wastewater concerns. *Nitrification and denitrification in the activated sludge process*: 1-9.

Guven, D. E. & Akinci, G. (2008). Heavy metals partitioning in the sediments of Izmir Inner Bay. *Journal of Environmental Sciences* **20**(4): 413-418.

Hagedorn, B. (2008). Acid digestion of sediments, sludge and soil (EPA 3050). *Applied Science, Engineering and Technology Laboratory, University of Alaska, Anchorage*.

Heath, A. (1987). Behavior and nervous system function. *Water pollution and fish physiology. CRC Press Inc, Boca Ratón*: 181-200.

Hoekstra, P., Braune, B., Wong, C., Williamson, M., Elkin, B. & Muir, D. (2003). Profile of persistent chlorinated contaminants, including selected chiral compounds, in wolverine (Gulo gulo) livers from the Canadian Arctic. *Chemosphere* **53**(5): 551-560.

ISQG (2002).Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Interim freshwater sediment quality guidelines, Canadian Council of Ministers of the Environment.

Jansen, H., Hengsdijk, H., Legesse, D., Ayenew, T., Hellegers, P. & Spliethoff, P. (2007).Land and water resources assessment in the Ethiopian Central Rift Valley: Project: Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley. Alterra.

Kalay, M. & Canli, M. (2000). Elimination of essential (Cu, Zn) and non-essential (Cd, Pb) metals from tissues of a freshwater fish Tilapia zilli. *Turkish Journal of Zoology* **24**(4): 429-436.

Källqvist, T. & Svenson, A. (2003). Assessment of ammonia toxicity in tests with the microalga, Nephroselmis pyriformis, Chlorophyta. *Water research* **37**(3): 477-484.

Keating, M. H., Mahaffey, K., Schoeny, R., Rice, G. & Bullock, O. (1997).Mercury study report to Congress. Volume 1. Executive summary. Environmental Protection Agency, Research Triangle Park, NC (United States). Office of Air Quality Planning and Standards.

Kebede Nigussie, Chandravanshi, B. S. & Taddese Wondimu (2010). Correlation among trace metals in tilapia (Oreochromis niloticus), sediment and water samples of lakes Awassa and Ziway, Ethiopia. *International Journal of Biological and Chemical Sciences* **4**(5).

Labonne, M., Othman, D. B. & Luck, J.-M. (2001). Pb isotopes in mussels as tracers of metal sources and water movements in a lagoon (Thau Basin, S. France). *Chemical Geology* **181**(1): 181-191.

Legendre, P. & Gallagher, E. D. (2001). Ecologically meaningful transformations for ordination of species data. *Oecologia* **129**(2): 271-280.

Lin, R. H., Lee, C. H., Chen, W. K. & Lin-Shiau, S. Y. (1994). Studies on cytotoxic and genotoxic effects of cadmium nitrate and lead nitrate in Chinese hamster ovary cells. *Environmental and molecular mutagenesis* **23**(2): 143-149.

Liu, J., Zhang, X.-H., Tran, H., Wang, D.-Q. & Zhu, Y.-N. (2011). Heavy metal contamination and risk assessment in water, paddy soil, and rice around an electroplating plant. *Environmental Science and Pollution Research* **18**(9): 1623.

Loprieno, N. (1975). International Agency for Research on Cancer (IARC) monographs on the evaluation of carcinogenic risk of chemicals to man:"Relevance of data on mutagenicity". *Mutation Research/Environmental Mutagenesis and Related Subjects* **31**(3): 201.

Luoma, S. N. & Rainbow, P. S. (2008). *Metal contamination in aquatic environments: science and lateral management*. Cambridge university press.

Marghade, D., Malpe, D. & Zade, A. (2011). Geochemical characterization of groundwater from northeastern part of Nagpur urban, Central India. *Environmental Earth Sciences* **62**(7): 1419-1430.

Melaku Mesfin, Tudorancea, C. & 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.

MoWIE (2017).Hydrological features of Koka Reservoir. Ministry of Water, Irrigation and Electricity, Addis Ababa, Ethiopia.

Mulu Berhe, Abraha Gebrekidan & Yirgalem Weldegebriel (2012). Health risk assessment of heavy metals bioaccumulation in water, sediment and three fish species (Labeobarbus spp., Clarias gariepinus and Oreochromis niloticus) of Tekeze River Dam, Tigray, Northern Ethiopia. *Journal of Atmospheric and earth Environment* **1**(1): 19-29.

Mulu Berhe Desta, Abrah Gebrekidan & Yergalem Woldegebriel (2012). Health risk assessment of heavy metals bioaccumulation in water, sediment and three fish species (Labeobarbus spp., Clarias gariepinus and Oreochromis niloticus) of Tekeze River Dam, Tigray, Northern Ethiopia. *Journal of Atmospheric and earth Environment* **1**(1): 19-29.

Mulu Berhe Desta & Mehari Muuz (2013). Distribution of trace metals in two commercially important fish species (Tilapia zilli and Oreochromis niloticus) sediment and water from lake Gudbahri, Eastern Tigray of Northern Ethiopia. *International Journal of Scientific and Research Publications* **3**(9): 1-7.

Ochieng, E., Lalah, J. & Wandiga, S. (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**(5): 570-576.

Okparaocha, F. J., Oyeleke, P. O. & Abiodun, O. A. Determination of Heavy Metals in Public Tap Water in Ibadan Metropolis, Southwestern Nigeria.

Ololade, I. & Oginni, O. (2010). Toxic stress and hematological effects of nickel on African catfish, Clarias gariepinus, fingerlings. *Journal of environmental chemistry and Ecotoxicology* **2**(2): 014-019.

Poggio, L., Vrščaj, B., Schulin, R., Hepperle, E. & Marsan, F. A. (2009). Metals pollution and human bioaccessibility of topsoils in Grugliasco (Italy). *Environmental Pollution* **157**(2): 680-689.

Powlson, D. S., Addiscott, T. M., Benjamin, N., Cassman, K. G., de Kok, T. M., van Grinsven, H., L'hirondel, J.-L., Avery, A. A. & Van Kessel, C. (2008). When does nitrate become a risk for humans? *Journal of environmental quality* **37**(2): 291-295.

Rauf, A., Javed, M. & Ubaidullah, M. (2009). Heavy metal levels in three major Carps (Catla catla, Labeo rohita and Cirrhina mrigala) from the River Ravi, Pakistan *Pakistan Veterinary Journal* **29**(1).

Ravera, O. (2001). Monitoring of the aquatic environment by species accumulator of pollutants: a review. *Journal of Limnology* **60**(1s): 63-78.

Reid, M., Tibby, J., Penny, D. & Gell, P. (1995). The use of diatoms to assess past and present water quality. *Austral Ecology* **20**(1): 57-64.

Romeo, M., Siau, Y., Sidoumou, Z. n. & Gnassia-Barelli, M. (1999). Heavy metal distribution in different fish species from the Mauritania coast. *Science of the Total Environment* **232**(3): 169-175.

Salami, I. R. S., Rahmawati, S., Sutarto, R. I. H. & Jaya, P. M. (2008). Accumulation of heavy metals in freshwater fish in cage aquaculture at Cirata reservoir, West Java, Indonesia. *Annals of the New York Academy of Sciences* **1140**(1): 290-296.

Salomons, W. (1995). Environmental impact of metals derived from mining activities: processes, predictions, prevention. *Journal of Geochemical exploration* **52**(1-2): 5-23.

Seyoum Leta, Fasil Assefa, Lena, G. & Gunnel, D. (2004). Biological nitrogen and organic matter removal from tannery wastewater in pilot plant operations in Ethiopia. *Applied microbiology and biotechnology* **66**(3): 333-339.

Seyoum Leta, Fassil Assefa & Dalhammar Gunnel (2003). Characterization of tannery wastewater and assessment of downstream pollution profiles along Modjo River in Ethiopia. *Ethiopian Journal of Biological Sciences* **2**(2): 157-168.

Shrivastava, R., Upreti, R., Seth, P. & Chaturvedi, U. (2002). Effects of chromium on the immune system. *Pathogens and Disease* **34**(1): 1-7.

Shuhaimi-Othman, M., Nadzifah, Y. & Ahmad, A. (2010). Toxicity of copper and cadmium to freshwater fishes. *World Acad Scie Engin Tech* **65**: 869-871.

Singhal, R., Merali, Z. & Hrdina, P. (1976).Aspects of the biochemical toxicology of cadmium. In *Federation proceedings*, Vol. 35, 75-80.

Solomon Kibret, Yihenew Alemu, Boelee, E., Habte Tekie, Dawit Alemu & Petros, B. (2010). The impact of a small-scale irrigation scheme on malaria transmission in Ziway area, Central Ethiopia. *Tropical Medicine & International Health* **15**(1): 41-50.

Steenland, K. & Boffetta, P. (2000). Lead and cancer in humans: where are we now? *American journal of industrial medicine* **38**(3): 295-299.

Svobodova, Z., Celechovska, O., Kolarova, J., Randak, T. & Zlabek, V. (2004). Assessment of metal contamination in the upper reaches of the Ticha Orlice River. *Czech Journal of Animal Science-UZPI (Czech Republic)*.

Tadesse Fetahi, Rothhaupt, K. O. & Peeters, F. (2017). Dietary map of Nile tilapia using stable isotopes in three tropical lakes, Ethiopia. *Ecology of Freshwater Fish*.

Talling, J. & Talling, I. B. (1965). The chemical composition of African lake waters. *International Review of Hydrobiology* **50**(3): 421-463.

Tao, Y., Xue, B., Zhong, J., Yao, S. & Wu, Q. (2012a). Influences of pH, heavy metals and phosphate and their co-influences on the sorption of pentachlorophenol on cyanobacterial biomass. *Water research* **46**(11): 3585-3594.

Tao, Y., Yuan, Z., Xiaona, H. & Wei, M. (2012b). Distribution and bioaccumulation of heavy metals in aquatic organisms of different trophic levels and potential health risk assessment from Taihu lake, China. *Ecotoxicology and environmental safety* **81**: 55-64.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. & Sutton, D. J. (2012).Heavy metal toxicity and the environment. In *Molecular, clinical and environmental toxicology*, 133-164: Springer.

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

Teshome Akele Seyoum (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.

USEPA (2006).National Recommended Water Quality Criteria Correction Office of water. EPA 822-2-99-001.

USEPA (2010).Guidance on Evaluating Sediment Contaminant Results. Division of Surface Water, Standards and Technical Support Section. US Environmental Protection Agency.

USEPA (2011). Drinking water quality, Heavy metals, Maximum admissible limit. **3**: 105-121.

Vinodhini, R. & Narayanan, M. (2008). Bioaccumulation of heavy metals in organs of fresh water fish Cyprinus carpio (Common carp). *International Journal of Environmental Science & Technology* **5**(2): 179-182.

Waalkes, M. P., Diwan, B. A., Ward, J. M., Devor, D. E. & Goyer, R. A. (1995). Renal tubular tumors and atypical hyperplasias in B6C3F1 mice exposed to lead acetate during gestation and lactation occur with minimal chronic nephropathy. *Cancer research* **55**(22): 5265-5271.

Waheed, S., Kamal, A. & Malik, R. N. (2014). Human health risk from organ-specific accumulation of toxic metals and response of antioxidants in edible fish species from Chenab River, Pakistan. *Environmental Science and Pollution Research* **21**(6): 4409-4417.

Ward, N. (1995). Trace Elements Enviromental Analytical Chemistry. *Edited by FW Fifield and PJ Haines. Blackie Academic and Professional. Champman and Hall*.

WHO (1985).Guidelines for Drinking Water Quality. Vol.1, Recommendation WHO: Geneva, p. 130.

WHO (1993).Evaluation of certain food additives and contaminants. Forty-first report of the Joint FAO/WHO Expert Committee on Food Additives. Technical Report Series 837, pp. 53.

WHO (2004). *Guidelines for drinking-water quality*. World Health Organization.

WHO (2008). Guidelines for drinking-water quality. *World Health Organization, Geneva*.

Wilson, D. (1988).Cadmium–market trends and influences. In *Cadmium 87–. Proceedings of the 6th International Cadmium Conference*, 9-16.

Wood, R. & Talling, J. (1988).Chemical and algal relationships in a salinity series of Ethiopian inland waters. In *Saline Lakes*, 29-67: Springer.

WS & WHO (2004). Guidelines for drinking-water quality. Vol. 1, Recommendations.

Yeshiemebet Major, Demeke Kifle, Niedrist, G. H. & Sommaruga, R. (2017). An isotopic analysis of the phytoplankton–zooplankton link in a highly eutrophic tropical reservoir dominated by cyanobacteria. *Journal of Plankton Research* **39**(2): 220-231.

Yilmaz, A. B. (2003). Levels of heavy metals (Fe, Cu, Ni, Cr, Pb, and Zn) in tissue of Mugil cephalus and Trachurus mediterraneus from Iskenderun Bay, Turkey. *Environmental research* **92**(3): 277-281.

Zerihun Desta, Borgstrøm, R., Zinabu Gebremariam & BO, R. (2008). Habitat use and trophic position determine mercury concentration in the straight fin barb Barbus paludinosus, a small fish species in Lake Awassa, Ethiopia. *Journal of Fish Biology* **73**(3): 477-497.

Zhou, J., Huang, P. & Lin, R. (1998). Sorption and desorption of Cu and Cd by macroalgae and microalgae. *Environmental Pollution* **101**(1): 67-75.

Zhou, Q., Zhang, J., Fu, J., Shi, J. & Jiang, G. (2008). Biomonitoring: an appealing tool for assessment of metal pollution in the aquatic ecosystem. *Analytica chimica acta* **606**(2): 135-150.

Zinabu GebreMariam, Chapman, L. J. & Chapman, C. A. (2002). Conductivity as a predictor of a total cations and salinity in Ethiopian lakes and rivers: revisiting earlier models. *Limnologica-Ecology and Management of Inland Waters* **32**(1): 21-26.

Zinabu GebreMariam & 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): 171-178.

Appendices

Appendix I Summary of Hydrometric Discharge Data

STATION NAME: **Awash below koka dam** BASIN DRAINAGE AREA **11219**

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2000	I	66.397	61.715	69.52	55.241	121.272	99.289	50.512	116.471	102.883	103.403	61.811	77.614
	II	31.849	31.354	60.283	36.532	59.541	59.541	38.745	104.167	71.297	44.029	31.354	38.184
	III	18.324	19.035	15.335	14.412	1.604	8.925	15.651	34.926	34.401	24.08	9.377	26.223
2001	I	69.111	60.732	63.415	59.283	68.148	59.572	62.849	73.373	96.687	81.65	77.63	65.954
	II	46.516	33.88	44.643	34.401	38.745	47.793	29.897	49.748	64.083	41.628	51.753	25.352
	III	11.074	23.254	20.508	17.631	20.508	11.332	14.716	3.592	21.658	28.022	19.035	23.254
2002	I	77.863	70.001	77.645	72.711	77.803	74.764		77.183	76.959	80.253	57.921	82.485
	II	31.354	31.849	39.311	31.354	31.354	33.88		34.926	53.809	37.077	33.88	32.855
	III	27.113	26.666	18.677	2.573	27.113	24.923		25.785	24.08	22.447	16.294	28.022
2003	I	94.542	85.461	99.832	86.835	-	72.496	102.332	123.33	229.574	122.704	114.386	121.356
	II	53.809	51.753	44.643	45.887	-	47.793	57.348	83.505	123.061	58.073	59.541	51.079
	III	30.378	30.378	31.354	21.658	-	22.051	22.051	19.763	44.643	32.855	33.88	35.991
2004	I	117.49	93.443	98.833	112.879	120.166	116.496	130.274	133.851	92.543	93.546	77.555	91.056
	II	53.809	50.411	47.793	51.079	61.031	58.073	62.545	62.545	45.887	47.793	40.459	46.516
	III	33.88	33.365	32.855	35.991	38.745	33.365	34.926	36.532	26.223	27.565	27.113	28.022
2005	I	101.384	99.166	106.577	105.023	84.882	86.441	91.31	110.208	130.946	86.164	70.099	78.803
	II	51.079	69.652	47.793	61.031	44.643	54.505	61.785	55.915	64.86	44.643	35.456	51.079
	III	28.484	28.484	33.365	30.863	26.223	23.254	21.27	28.022	28.95	23.665	21.658	21.658
2006	I	96.508	95.601	107.957	108.462	109.952	89.587	81.257	278.883	487.383	122.309	77.172	87.739
	II	54.505	44.643	47.793	49.748	44.643	47.793	44.643	312.777	300.272	120.734	38.745	47.793
	III	22.849	33.365	35.991	38.184	37.628	20.508	20.887	33.365	0.757	31.849	19.763	18.677
2007	I	67.407	58.859	67.838	78.59	59.847	64.438	69.359	283.664	616.536	61.137	56.728	60.038
	II	40.459	38.184	38.184	41.628	81.686	58.073	39.882	203.35	359.12	32.855	23.254	24.08
	III	18.324	18.324	19.035	18.324	18.324	18.324	21.658	22.051	22.051	20.508	20.508	20.887

2008	I	-	-	84.856	87.172	67.345	65.152	66.444	106.986	454.457	118.223	55.422	57.118
	II	-	-	62.545	64.86	54.505	49.091	43.421	76.38	475.238	118.436	22.849	22.051
	III	-	-	21.658	21.27	21.27	20.133	21.27	21.27	55.915	20.133	19.763	20.133
2009	I	56.82	51.105	56.608	55.51	57.382	53.719	55.803	58.662	56.381	-	55.975	57.827
	II	22.849	22.051	22.051	22.051	22.051	22.051	22.051	22.849	22.849	-	22.051	24.499
	III	20.133	20.133	20.508	20.508	20.133	18.324	19.035	20.887	20.887	-	20.508	20.887
2010	I	57.748	52.642	59.647	58.228	60.478	59.384	70.969	95.235	469.357	66.465	57.711	70.998
	II	22.849	22.849	22.849	23.665	23.665	25.785	47.793	78.124	363.746	55.915	23.254	64.083
	III	20.887	20.133	21.658	21.658	21.658	22.051	22.051	23.665	23.254	21.658	20.887	22.051
2011	I	67.51	58.98	62.526	62.167	66.435	78.697	139.164	301.514	196.004	134.623	109.715	83.843
	II	44.029	42.22	29.897	31.354	39.311	60.283	142.7	262.774	193.847	74.661	72.967	66.434
	III	22.051	22.051	22.051	22.051	22.051	22.051	22.051	34.926	33.88	22.849	22.849	20.887
2012	I	59.176	54.079	58.595	58.233	60.108	57.782	149.56	452.266	56.485	60.136	57.029	58.729
	II	23.665	22.849	22.849	24.08	24.499	24.08	230.116	392.296	22.447	25.352	22.849	22.849
	III	21.27	20.133	21.27	21.658	21.27	21.27	23.254	21.27	20.887	20.508	20.887	21.27
2013	I	65.071	53.411	60.004	58.269	77.13	103.974	170.852	200.943	233.167	96.415	109.972	67.979
	II	48.439	26.223	24.08	27.565	50.411	68.031	161.419	116.165	145.285	63.311	69.652	33.88
	III	20.887	20.887	21.27	21.658	22.051	25.785	26.223	51.753	46.516	22.051	22.051	21.27

Appendix II Summary of Hydrometric Discharge Data

STATION NAME: **Awash Hombel** Nr./@ _____ BASIN _____ DRAINAGE AREA _____ Sq.KM. Stn. No. _____

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MP	MMD
2000	I	11.104	9.057	5.306	8.177	15.193	32.812	168.994	478.354	235.837	82.454	32.343	16.170	1095.800		
	II	4.596	4.345	3.208	12.919	14.334	47.121	140.164	313.332	205.341	173.973	90.027	6.739			313.332
	III	3.984	3.313	1.636	1.782	2.904	3.208	14.334	53.540	32.100	8.793	6.582	5.259			
2001	I	13.172	10.720	27.676	17.383	29.306	110.577	369.754	497.814	201.159	29.241	19.140	14.230	1340.172		
	II	5.259	6.273	43.400	23.965	29.482	188.245	471.923	370.238	325.989	14.334	8.251	7.060			471.923
	III	4.596	3.752	1.782	4.223	4.470	10.744	48.561	102.130	15.324	8.429	6.898	2.711			
2002	I	13.430	8.359	10.947	12.716	11.695	29.202	157.551	379.233	126.212	23.483	17.489				
	II	15.324	13.616	6.739	14.824	11.161	33.261	182.050	294.206	126.451	11.587	7.389				
	III	0.000	2.348	2.177	2.348	3.105	2.526	13.149	89.342	12.022	7.224	6.426				
2003	I	0.654	0.527	1.936	8.669	4.132	32.601	232.189	372.274	188.878	16.915	5.810	8.183	872.768		
	II	0.629	1.934	3.004	10.539	5.973	131.500	216.454	268.059	170.997	25.620	2.711	4.856			268.059
	III	0.104	0.021	0.028	0.044	0.053	0.044	7.060	66.048	15.324	2.711	1.857	2.436			
2004	I	1.563	0.647	2.503	17.016	2.974	28.498	165.927	338.608	156.310	19.569	3.014				
	II	7.224	0.715	13.853	42.947	3.004	57.723	135.793	181.029	129.805	16.614	5.539				
	III	0.119	0.044	0.044	0.290	0.119	0.239	9.937	51.516	21.753	3.208	0.216				
2005	I	12.803	8.536	26.711	18.882	79.558	65.857	343.005	539.481	249.083	46.712	27.244	14.081	1431.953		
	II	6.405	5.585	49.792	31.383	127.391	85.916	234.734	448.728	233.550	42.953	11.540	9.273			448.728
	III	3.610	2.941	2.941	3.510	7.921	8.923	45.617	107.689	28.219	11.540	9.451	4.250			
2006	I	10.744	9.012	24.908	42.486	39.747	66.352	434.122	766.821	385.831	47.804	28.946	15.034	1871.807		
	II	4.250	6.405	52.204	40.383	46.985	105.455	303.981	455.706	322.241	32.481	15.027	7.446			455.706
	III	3.510	2.941	3.713	7.139	7.139	7.446	60.380	154.574	32.481	13.656	5.585	4.593			
2007	I	12.474	12.363	12.872	20.039	30.066	101.761	353.357	718.132	429.081	65.414	27.148	18.808	1801.515		
	II	12.784	15.027	9.812	25.251	26.876	85.261	362.188	398.405	411.480	86.573	11.540	9.631			411.480
	III	3.817	3.610	3.510	4.830	5.326	8.751	60.380	184.903	37.101	11.946	9.631	4.593			
2008	I	11.612	9.685	8.236	8.967	14.094	41.615	328.439	610.021	430.889	47.133	56.368	15.189	1582.248		
	II	5.074	4.139	3.713	5.199	9.631	37.502	382.408	387.167	365.257	26.219	51.231	6.405			387.167
	III	3.510	3.713	2.941	2.941	3.218	4.362	13.216	163.051	27.208	14.561	6.124	5.074			

2009	I	25.466	10.279	9.200	24.683	14.216	19.220	121.207	496.718	289.414	69.330	15.974	18.139	1113.846		
	II	73.247	6.267	7.156	49.038	17.027	24.895	168.455	462.484	268.991	101.694	12.843	16.039			462.484
	III	4.218	3.566	2.975	3.566	3.165	3.566	16.777	77.920	20.192	13.715	4.933	4.687			
2010	I	12.155	30.379	29.392	55.909	52.105	92.482	434.896	478.830	398.312	49.577	25.890	14.357			
	II	6.852	48.129	29.816	64.923	79.114	87.127	374.789	270.192	263.032	37.171	12.630	7.156			
	III	3.463	3.362	3.884	4.687	7.785	9.136	59.688	120.573	37.171	12.210	5.986	4.687			
2011	I	12.925	9.571	14.531	9.809	30.079	70.142	184.787	542.573	327.184	58.056	25.337	15.471			
	II	8.277	7.467	11.798	7.156	83.375	105.184	182.577	462.484	196.342	45.457	16.039	7.156			
	III	3.566	3.362	2.975	3.069	3.263	10.419	19.103	80.319	59.688	15.320	5.986	4.933			
2012	I	11.447	9.377	8.446	27.650	22.088	31.604	251.634	-	-	51.427	20.046	13.960			
	II	4.933	4.218	3.566	29.131	38.354	34.119	320.734	-	-	42.030	13.938	6.703			
	III	3.776	3.263	3.069	4.933	3.463	3.566	19.643	-	-	13.494	5.712	4.218			
2013	I	11.289	8.206	17.205	35.328	31.644	82.734	250.641	454.746	356.634	108.521	31.510	13.329			
	II	4.933	3.670	16.529	67.634	23.365	117.550	167.537	253.654	398.354	107.309	17.789	5.712			
	III	3.776	3.165	3.165	5.058	6.126	8.960	39.155	125.189	25.839	18.309	5.848	4.218			
2014	I	10.333	10.755	12.702	16.897	27.611	-	-	-	-	-	-	-			
	II	4.687	7.156	10.803	27.457	47.229	-	-	-	-	-	-	-			
	III	3.263	3.165	3.165	3.069	3.165	-	-	-	-	-	-	-			

1102.914

34.9732

I. MONTHLY RUNOFF IN MILLION M^3
II. MAXIMUM DISCHARGE IN M^3/sec
III. MINIMUM DISCHARGE IN M^3/sec

MP = MOMENTARY PEAK IN M^3/sec
MMD = MAX.MEAN DAILY IN M^3/sec

Appendix III Summary of Hydrometric Discharge Data

STATION NAME: **mojo @ mojo village** BASIN **2147483647** DRAINAGE AREA **1264** Sq.KM. Stn. No. **031014**

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MP	MMD
2000	I	0.11	0.083	0.074	0.075	0.181	2.182	20.236	30.648	3.611	0.325	0.133	0.785	58.443		
	II	0.041	0.041	0.031	0.094	0.211	8.185	25.009	57.929	9.728	0.734	0.129	0.426			57.929
	III	0.041	0.027	0.013	0.013	0.02	0.104	0.331	0.331	0.116	0.036	0.036	0.254			
2001	I	0.972	0.802	6.017	1.064	3.371	16.948	43.987	82.714	19.321	1.314	1.099	0.112	177.721		
	II	0.385	0.663	28.943	1.044	4.245	27.125	79.587	195.185	117.402	0.719	0.424	0.046			195.185
	III	0.313	0.15	0.28	0.313	0.313	0.719	1.74	5.848	0.719	0.424	0.424	0.036			
2002	I	1.17	0.918	1.268	1.043	1.185	4.31	29.782	34.61	5.375	1.14	0.958	1.136	82.895		
	II	0.559	0.385	0.84	0.559	1.364	7.532	145.145	184.817	16.857	0.467	0.424	0.424			184.817
	III	0.385	0.347	0.347	0.313	0.347	0.385	0.663	1.452	0.559	0.347	0.25	0.424			
2003	I	1.447	1.079	1.845	2.778	1.55	6.471	65.473	121.606	21.373	1.402	1.015	1.217	227.256		
	II	2.68	2.68	3.895	12.841	1.452	19.134	226.185	219.294	53.373	1.279	0.559	0.663			226.185
	III	0.28	0.222	0.222	0.25	0.196	0.385	1.951	5.416	0.973	0.313	0.313	0.25			
2004	I	1.071	0.586	1.597	4.379	0.792	3.112	17.24	65.542	7.432	1.464	1.011	1.161	105.387		
	II	0.973	0.84	5.848	14.761	0.663	8.34	47.2	174.809	19.612	0.973	0.467	1.545			174.809
	III	0.196	0.15	0.15	0.25	0.172	0.28	0.905	2.062	0.84	0.385	0.313	0.313			
2005	I	1.212	0.475	3.718	6.308	0.597	7.267	47.927	48.806	32.383	3.579	0.906	1.057	154.235		
	II	1.044	0.385	9.201	28.329	0.467	10.052	32.374	25.657	22.509	4.249	0.467	0.467			32.374
	III	0.25	0.112	0.196	0.15	0.162	0.295	6.793	14.659	5.38	0.488	0.295	0.313			
2003	I	0.714	0.524	0.863	1.036	0.471	2.334	32.293	58.363	48.211	11.438	1.143	0.856	158.246		
	II	0.405	0.578	0.754	0.894	0.33	2.42	25.657	35.252	30.534	18.228	0.602	0.626			35.252
	III	0.217	0.162	0.162	0.162	0.126	0.085	2.28	13.319	10.371	0.626	0.33	0.262			
2004	I	0.777	0.535	0.579	0.816	0.575	3.234	26.809	50.831	56.679	24.688	1.575	0.895	167.993		
	II	0.754	0.348	0.446	1.076	0.602	3.968	18.678	34.6	29.935	23.273	1.045	0.488			34.6
	III	0.231	0.175	0.162	0.175	0.138	0.202	3.51	10.371	14.463	1.108	0.367	0.247			
2005	I	1.29	0.464	4.183	7.01	14.699	7.09	36.476	56.117	20.909	1.578	1.467	1.278			
	II	1.166	0.403	10.504	31.591	46.609	21.033	177.067	140.98	26.569	1.166	0.928	0.497			
	III	0.251	0.099	0.19	0.14	0.497	0.285	1.166	4.086	1.083	0.403	0.497	0.403			

2006	I	1.172	1.516	2.197	6.486	4.241	6.41	53.777	51.404	21.939	1.735	1.339	1.302			
	II	1.004	3.726	6.212	19.04	19.04	10.504	156.587	90.874	31.591	1.344	0.723	0.723			
	III	0.321	0.19	0.321	0.285	0.251	0.497	1.344	3.385	1.083	0.449	0.403	0.285			
2007	I	1.001	1.173	1.206	2.855	8.535	19.655	36.382	94.632	48.221	3.07	1.679	1.82			
	II	1.538	1.439	2.913	8.327	23.151	29.013	74.075	132.745	121.73	4.086	0.856	0.856			
	III	0.251	0.119	0.119	0.285	0.19	0.497	1.538	1.748	2.221	0.549	0.604	0.604			
2008	I	1.729	0.568	0.248	1.312	1.935	5.595	32.057	115.945	19.184	2.069	2.696	1.446			
	II	0.856	0.497	0.14	2.096	2.221	7.762	53.658	476.643	21.033	1.344	2.35	0.662			
	III	0.497	0.099	0.053	0.067	0.19	0.285	0.321	0.856	1.166	0.604	0.662	0.497			
2009	I	1.457	0.527	0.459	2.347	1.245	1.17	17.715	47.626	21.083	4.012	1.035	1.291			
	II	1.083	0.449	1.344	5.295	2.096	1.004	50.942	197.062	70.75	10.173	0.449	0.497			
	III	0.285	0.14	0.099	0.011	0.099	0.285	0.723	1.748	0.604	0.497	0.361	0.403			
2010	I	0.907	0.764	1.795	5.932	8.66	8.346	39.045	-	34.14	1.813	1.178	0.986			
	II	0.497	0.788	6.212	19.04	13.779	19.04	109.86	-	85.856	1.166	0.497	0.497			
	III	0.099	0.099	0.053	0.099	0.662	0.285	2.484	-	0.856	0.403	0.403	0.251			
2011	I	0.617	-	-	-	2.248	8.748	36.931	39.019	-	-	2.497	1.436			
	II	0.497	-	-	-	3.726	57.417	207.563	76.345	-	-	2.221	0.788			
	III	0.011	-	-	-	0.011	0.497	0.285	1.166	-	-	0.497	0.497			
2012	I	1.274	0.647	0.559	1.87	1.411	4.89	22.639	70.645	14.668	1.556	1.239	1.08			
	II	0.788	0.723	0.549	2.221	3.065	17.625	94.755	171.326	42.512	1.004	0.497	0.403			
	III	0.403	0.14	0.14	0.285	0.251	0.285	1.166	0	1.004	0.497	0.403	0.403			
2013	I	0.861	0.489	1.721	1.624	1.823	10.475	68.41	25.132	17.127	3.088	2.866	2.224			
	II	0.403	0.251	6.212	1.641	2.221	17.625	245.844	134.368	50.942	1.166	1.166	1.004			
	III	0.251	0.082	0.082	0.403	0.403	0.723	0.285	1.166	1.166	1.083	1.004	0.788			
		1.814	2.317	1.507	1.117	-	-	-	-	-	-	-	-			
		0.856	9.849	1.976	0.856	-	-	-	-	-	-	-	-			
		0.497	0.19	0.14	0.321	-	-	-	-	-	-	-	-			

Appendix IV Rainfall data for Koka Dam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.0	0.0	1.6	57.9	122.7	90.6	337.0	264.9	212.1	0.0	67.8	10.1
2001	0.0		141.2	40.9	154.7	178.3	501.0	436.0	119.0	13.3	5.9	21.7
2002	19.8	32.3	13.1	58.3	8.9	13.0	217.0	175.6	63.1	0.6	0.0	13.9
2003	46.1	65.6	104.2	28.2	1.3	121.3	274.7	273.4	33.2	0.0	3.8	55.7
2004	6.3	0.0	68.8	84.5	0.0	103.4	153.9	272.1	47.5	35.7	4.2	0.0
2005	47.9	0.0	34.8	30.4	10.6		92.8	141.7	61.2	0.0	5.8	0.0
2006	0.3	11.0	38.1	68.3	62.0	131.3	234.5	171.4	86.6	4.5	0.0	25.0
2007	44.7	8.5	83.2	37.2		69.1	151.7	179.6	140.2	23.0	1.3	0.0
2008	5.1	0.0	0.0	26.5	100.3	94.2	302.3	292.0	165.7	59.0	77.0	
2010	0.0	69.7	90.1	80.4	80.2	87.5	236.8	272.3	201.7	0.0	1.4	0.0
2011	0.0	0.0	72.1	18.2	51.4		256.8		214.7	0.0		
2012	0.0		0.0		42.2	38.4	501.0					
2013	0.0	0.0	36.7	12.6		55.2	297.9	172.7	115.6	17.5	1.6	0.0
2014	0.0	3.5	87.3	0.5	54.9	5.3	260.5	195.9				
2015		0.0	0.0		205.6	10.7	103.1	162.2	86.1	0.0	11.0	
2016	0.0											

Appendix V Maximum Temperature Data of Koka Dam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	29.4	30.3	32.3	33.6	37.0	38.5	31.8	30.0	30.4	30.2	29.5	32.2
2001	30.1		36.2	36.3	37.0	36.3	33.4	33.4	36.2	27.3	28.3	28.2
2002	26.9	28.3	29.9	28.5	30.6	27.2	27.5	29.7	29.6	30.5	28.0	30.1
2003	32.0	30.9	31.4	30.5	32.2	29.9	30.6	31.2	31.1	29.5	30.3	29.9
2004	30.8	29.7	30.3	30.6	31.2	29.3	30.2	30.6	32.1	27.0	29.8	30.6
2005	31.1	32.5	34.6	28.7	34.7		29.6	30.4	30.6	30.9	29.8	29.0
2006	30.4	32.0	32.8	32.4	33.2	34.5	28.6	28.1	30.6	30.5	29.5	28.0
2007	30.2	32.7	33.7	33.3	33.5	31.4	29.8	29.0	30.3	29.4	29.1	29.2
2008	30.4	31.1			33.4	34.3	30.2	28.5	30.9	30.1	27.3	28.7
2009	30.7	33.5	34.2	35.4	35.6	34.4	30.7					
2010	31.2	32.0	31.1	34.2	34.1	34.4	29.1	29.0	28.3	30.9	31.1	29.1
2011	31.5	32.3	31.8	32.7	33.9		28.7		29.4	29.9		
2012	29.8	32.6	33.7	33.4	35.1	34.5	27.4					
2013	28.3	32.0	34.8	35.6	34.8	32.3	26.2	28.1	29.3	29.1	28.8	28.7
2014	31.8	33.7	33.6	33.7	33.0	35.7	31.7	29.0	30.1	29.4	30.3	30.7
2015	29.9	33.3	34.1		33.5	34.3	32.0	31.9	32.0	33.7	31.2	
2016	30.5											

Appendix V Minimum Temperature Data of Koka Dam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	11.1	12.5	14.9	16.1	16.4	15.9	15.1	15.3	15.3	13.9	13.2	10.9
2001	9.9		15.2	15.4	15.5	15.1	15.4	15.3	15.3	11.6	11.7	14.1
2002	12.8	14.7	15.5	15.2	15.0	14.7	14.7	15.3	14.8	14.5	13.6	14.4
2003	14.9	14.8	15.2	15.0	15.4	15.4	15.3	15.6	15.5	12.4	14.9	15.5
2004	13.9	14.0	14.5	15.3	14.6	14.6	14.4	14.5	15.3	12.1	14.3	12.7
2005	13.1	14.2	14.5	10.7	14.9		10.0	10.3	10.0	7.6	6.8	4.7
2006	8.0	9.8	15.2	15.9	16.8	16.8	16.1	16.2	15.6	15.2	13.1	14.0
2007	13.6	15.4	14.7	15.4	16.1	14.5	13.3	12.0	11.4	8.0	6.7	10.3
2008	12.2	12.9	14.0	15.5	15.3	13.7	14.4	13.4	14.9	12.5	13.2	0.0
2009	11.0	13.6	14.4	15.2	15.5	14.0	12.4					
2010	11.8	13.3	11.9	14.2	14.2	13.3	13.0	14.2	14.2	12.6	11.5	9.0
2011	11.2	12.6	13.0	14.1	14.3		13.5		14.0	10.7		
2012	10.5	12.1	13.2	15.9	16.6	15.4	14.7					
2013	12.6	14.4	15.6	15.6	15.8	15.2	14.5	14.6	15.6	13.9	13.6	9.1
2014	12.8	14.5	15.8	16.8	16.1	16.4	14.9	14.6	14.1	10.2	10.5	10.5
2015	10.1	14.5	15.3		14.9	14.6	14.6	14.1	12.3	13.8	11.2	
2016	10.5											