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Spatial and temporal water quality trend analysis using sediment cores and water samples from Aba Samuel Lake, south west of Addis Ababa, central Ethiopia

A thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of M.Sc. in Geo-Environmental system analysis

By Feven Solomon

July, 2007

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUTE STUDIES

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ACKNOWLEDGMENTS

First of all, I would like to thank ‘Almighty God’ who made it possible for me, to begin and finish this work successfully.

I am grateful to express my feelings of gratitude to my advisor Dr. Mohammed Umer whose generous guidance and encouragement helped me to complete the present research work successfully.

It is my pleasure to thank Dr. Asfawossen Asrat for his constructive comments during the present research study and he has also helped me by providing reference materials which are relevant for my work.

I would like to extend my acknowledgment to Dr. Feleke Zewge for his useful comments and for his help via facilitating laboratorical works.

I am thankful also, for Environmental protection Authority (EPA), Ministry of Water Resource (MoWR) and Ethiopian Electric Light and Power Authority (EELPA) from where I received all kind of resource support.

I would like to convey my thanks for all individuals who directly or indirectly supported me in this study.

Words can not express my feelings which I have for my family, my mom Seged Kifle , and my dad, Solomon Desta , I am very much thankful for their encouragement and support. I would like to thank also all other members of my family for their support and encouragement.

Abstract

The first objective of this work is to assess the temporal variation of Cu, Zn, Pb, Cd, Cr and Ni in sediments of the Aba Samuel Reservoir Lake, south west of Addis Ababa. Two sediment cores with 44 and 49 cm length were recovered at the proximity of the dam in the south (Core 1) and at the western shore (Core 2). Sediment slices have been taken from top, middle and bottom parts of the cores for analysis.

Sedimentation rate was estimated using constant rate and therefore by linear extrapolation using the age of the dam as a base line (68 yrs). Considering 4m average depth of sediment over the span of time the dam construction took, an average sedimentation rate of 6cm/yr has been calculated. The core bottom sediments contain therefore the history over the last 7 years.

The result of the analyzed heavy metals shows a general increasing trend from the bottom to the top samples in the cores. The amounts currently obtained, except for Nickel and copper, are still below the standard value. However, the value of all analyzed metals will be higher than the standard if the current concentration is to be projected towards the next 7 years.

Nickel concentration is higher than the standard value for both sediment cores. Comparing the concentrations in the respective sediment cores, sediment core 2 has an average value of 51.4 mg/kg and sediment core 1 contains 42.5 mg/kg on average. This shows the slight spatial variation within the lake. The variation could be due to differential trapping along the path of the water and the closeness of sediment core 2 to the inlet point of the lake than sediment core 1.

Nutrient analyses have been conducted for the lake water. Nitrate and phosphate show decreasing trends from the inlet towards the outlet of the lake; this could be due to the uptake of these nutrients by water hyacinth and the settlement of nutrients along with sediments. While, ammonia increases from the inlet to the outlet, possibly owing to the prevalence of a reducing environment which results in the formation of ammonia.

From this study it was possible to observe that, the pollution load in the Aba Samuel Lake is increasing. This confirms the importance of anthropogenic load becoming important in the background of possible constant natural supply. Therefore, proper monitoring of pollutants in the lake environment is crucial.

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LIST OF ACRONYMS

a.s.l –Above sea levels

AAWSA– Addis Ababa Water and Sewerage Authority

BOD–Biological oxygen demand

COD–Chemical oxygen demand

CSA-Central Statistical Agency

DDT–Dichlorodiphenyltrichloroethane

DO–Dissolved oxygen

DS – Dissolved Solid

EC –Electrical conductivity

EELPA–Ethiopian Electric Light and Power Authority

EPA–Environmental protection Authority

EPB–Environmental Protection Bureau of Addis Ababa

FAO–Food and Agriculture organization

GIS– Geographic Information System

HCN– Hydrocyanic acid

MEC- Midpoint Effect Concentration

MoWR–Ministry of water resources

M.Y– million years

PCBs–polychlorinated biphenyls

PEC-Probable Effect Concentration

Ppm– parts per million

PVC–Polyvinyl chloride

SC-1 –sediment core 1

SC-2 – Sediment core 2

SS–Suspended Solid

TEC- Threshold Effect Concentration

TT–Treatment Technique

VS–Volatile Solid

WWDSE –Water Works Design and Supervision Enterprise

WHO–World health organization

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1. INTRODUCTION

1.1 Background

Comprising over 70% of the Earths surface, water is undoubtedly the most precious natural resource that exists on our planet. Without it life on Earth would be non-existent: it is essential for everything on our planet to grow and prosper. Though it is important, it becomes polluted deliberately or accidentally. The major sources of water pollution can be classified as municipal, industrial, and agricultural and there are also other sources of water pollution like petroleum, radioactive substances and heat.

Big and Little Akaki Rivers, with their tributaries drains the Addis Ababa city and they serve as natural sewerage line for domestic, agricultural chemicals and industrial wastes. The two rivers with their pollutant loads flow in to Aba Samuel artificial reservoir and Aba Samuel reservoir served as a sink for pollutant load from the two rivers and from other small tributaries which directly drain into the lake with out joining the Akaki Rivers.

Aba Samuel hydroelectric power dam was built in 1939, on the Akaki River by Italian occupants, to serve Addis Ababa with electric power. At the time it was the only hydroelectric plant operating in Ethiopia. The station met the electricity demands of Addis Ababa region until major power generating facilities Koka, Awash II and Awash III, and Finchaa came in to existence.

In 1953 the plant was up-graded with the installation of an additional unit. Aba Samuel hydropower generating station had an installed capacity of 6MW and it supplied the needs of the Addis Ababa region during the 1950's. Due to damages on the water conveying system and operational difficulties the plant was put out of operation in the Mid 1970s. (EELPA, 2003)

The actual storage capacity of the main reservoir, impeded by a 22m high concrete masonry dam, may be estimated to be 35 million m^3. Owing to the part of the storage capacity filled with sediment, the present capacity of the reservoir is inferior to the original one. Due to siltation the initial storage capacity of the reservoir was reduced approximately by 30% (EELPA, 1983).

Studies that have been conducted on water and soil quality around Addis Ababa have indicated that there is a major pollution problem at present (Tamiru et.al, 2005). This has been attributed to man made causes (urbanization, industrial growth and agricultural sources) as well as to natural geological factors.

A major outcome of increasing industrial, agricultural and domestic water use has been the increase in conflict between local communities and the industry on issues ranging from water pollution to water scarcity.

The major issue in the case of Aba Samuel Lake is water pollution as most people living around the lake use the lake water for their daily activity (domestic purposes). Of the total households of the dam area, 40% use the lake and river water for drinking/cooking, while 70% of them use it for bathing/washing and about 93% of their animals depend on the lake and river water (Tassew, 2005). Furthermore, the dam area community health problem perception views show that 31.5%, 60.3%,4.8% and 3.4% due to water pollution, water hyacinth cases, sanitary problems and other problem case, respectively (Tassew, 2005).

Polluted water is unsuitable for drinking, recreation, agriculture, and industry. It diminishes the aesthetic quality of lakes and rivers; contaminated water destroys aquatic life and reduces its reproductive ability. Eventually, it is a hazard to human health. Since there is interaction between environmental systems the effect goes to all parts of the environment.

For the understanding of pollution trends in time and for the effective management (because it is vital to reliably monitor the quality of our environment for present and future generations) of the water resource in the lake there is a need to understand the temporal variation of water quality. However in order to do so a temporal data set of water quality analysis is lacking. Therefore, to overcome this constraint analysis of indicators of pollution was conducted on sediment samples from short cores taken in the reservoir.

In this study the purpose of the sediment core investigation is to systematically assess the patterns of change in heavy metals within the Aba Samuel Lake over time.

The advantage of sediment core analysis for water quality is due to the fact that most trace elements and many anthropogenic organic compounds are known to associate with sediments rather than dissolving in water (US. Geological survey, 1996). Thus analyzing lake bed sediments compliments water analysis data.

The spatial variation of nutrients in the lake has been analyzed from the primary data collected and other secondary data. This work also presents a conceptual frame work for possible nutrient pollutant sources and the characteristics of water hyacinth in the lake have been investigated.

1.2 Previous works

Various works have been conducted in the study area by different researchers, including studies on the degradation of the Abo-Kebena River in Addis Ababa. (Tesfaye Berhe, 1988); Surface and ground water pollution status in Addis Ababa (Tamiru Alemayehu, et al. 2003); preliminary survey of pollutant load on Great Akaki, little Akaki and Kebena rivers, (Environmental protection Agency, 1997); extent and significance of low quality water in agriculture in the Addis Ababa catchment of the upland Awash Basin, (Girma Tadesse et al.); Chemical, physical & microbiological characteristics of various sources of water in and around Addis Ababa (Yeshak Worku et al.,1999); the application of GIS/RS for the study of water pollution and water hyacinth coverage in Lake Aba Samuel and its catchments (Tassew, 2005); effect of water hyacinth on the level of dissolved oxygen in Aba Samuel Reservoir (Zeleke, 1992) ; environmental study of the redevelopment of the Aba Samuel Hydropower production project (EPA, 2000); metal concentration of some vegetables irrigated with industrial liquid waste at Akaki (Fisseha, 1988); and on the hydrogeology, water quality and the degree of ground water vulnerability to pollution in Addis Ababa, Ethiopia (Tamiru et.al, 2005).

Although the above indicated works addressed major issues on hydrogeology, environment, geology, and land degradation, temporal water quality analysis using sediment archive have not been attempted. The prevailing conditions in the lake calls for temporal water quality analysis for sustainable management of resources in the lake.

1.3 Objectives

1.3.1 Major objectives

The major objectives of the study are to

- conduct spatial and temporal water quality trend analysis using sediment core and water samples from Aba Samuel Lake;
- show the status of eutrophication in the lake; and
- propose possible intervention to water pollution

1.3.2 Specific objectives

The specific objectives of the study include:

- To investigate the temporal variation of heavy metals using sediment core from streambed sediments of Aba Samuel Lake
- To investigate the spatial trend of nutrients in the lake water
- To develop conceptual model of nutrient emission for the lake environment
- To investigate the characteristics of the water hyacinth in the lake

1.4 Significance of the study

Scientifically the result will provide sub-base line information on heavy metal input into the lake. Through trend analysis it will indicate to what extent human sources are comparable to the natural back ground.

Knowing the relative contributions of human and natural sources will help to devise appropriate mechanisms for future intervention.

1.5 Scope and limitation

Due to technical, time, resource and financial constraints, it was not possible to recover the whole sequence of sediment deposited in the reservoir. Therefore the temporal variation of heavy metals does not represent the whole history during which the reservoir sediment was deposited which is supposed to be about 4m thick and 68 years.

In this study it has been also tried to see the spatial variation of nutrients in water samples of the reservoir lake. However due to inaccessibility of the area (sampling was conducted at the beginning of a rainy season) it was not possible to collect water samples from all representative locations of the lake surface. Due to this reason additional secondary data were incorporated from previous sources.

1.6 Additional Data Sources

In addition to the primary data generated during this study, data from the following sources has been used:

-Published scientific literature;

-Government reports; and

-Unpublished data, conducted in the field and laboratory

2- DESCRIPTION OF THE STUDY AREA

2.1 Location

The study area is located in the Akaki catchment 37 km south west of Addis Ababa, in central Ethiopia. It is situated between coordinates of $8^{0}45^{1}$ to $8^{0}54^{1}$ N and $38^{0}38^{1}$to $38^{0}45^{1}$ E , encompassing a total area of 117sq.km as shown in Figure 1.

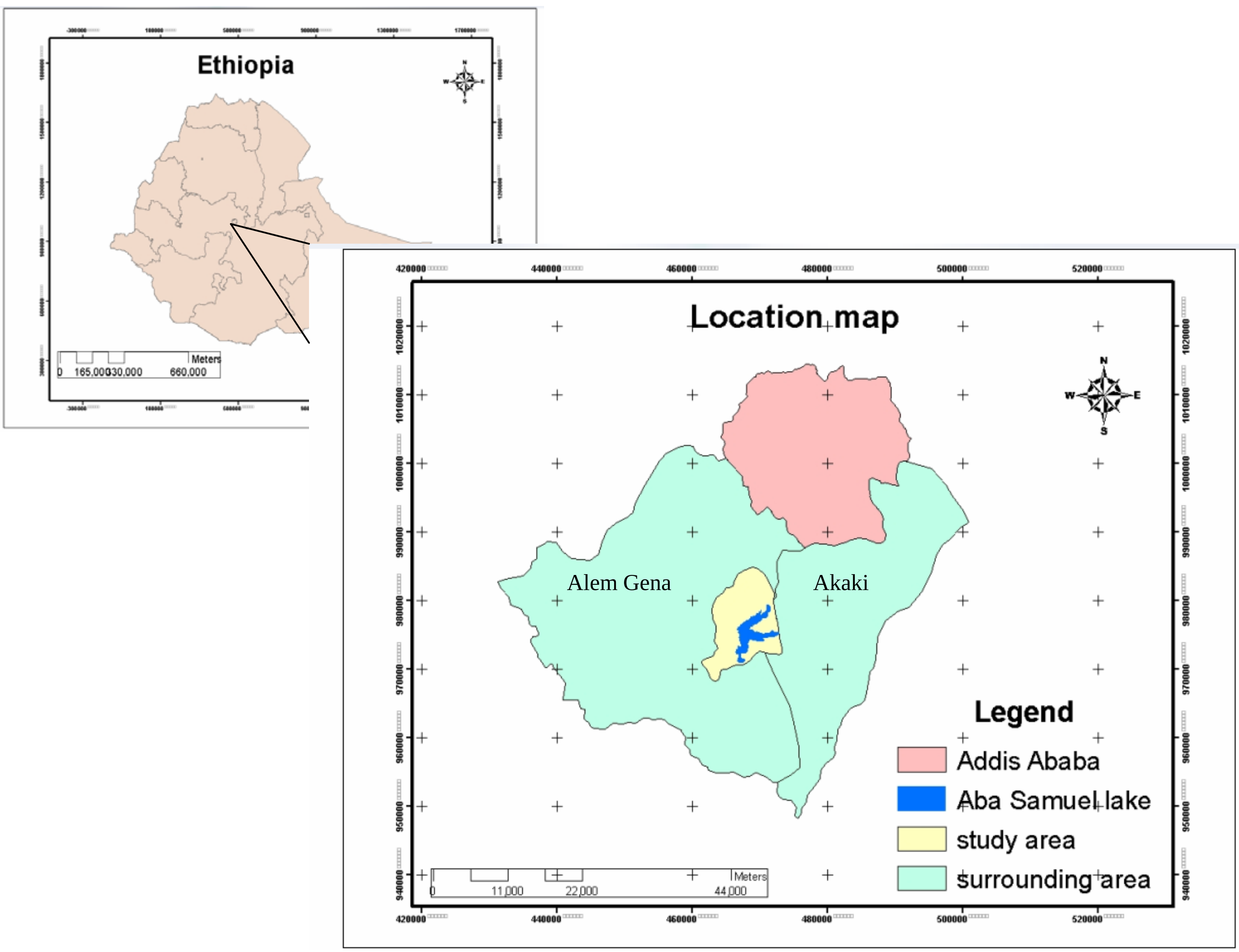


Figure 1. Location map of the study area

2.2 Physiography

The Akaki river catchment, which includes the city of Addis Ababa and the Aba Samuel lake area, is an extensive drainage system which covers an area of 11,454 km^2 and has an elevation drop (towards the great East Africa rift system) of over 1000m in a space of about 30 km. In the catchment there are mountain peaks such as Mt.Intoto; (3200m a.s.l,) Mt.Bereh (3,228 m a.s.l.) and the Wechecha range (3,391 m a.s.l.) (Brehanu, 2002)
The topography in the north eastern and southwestern parts of the study area is nearly flat with an average elevation of about 2100m, and the highest peak around the studied site reaches 2,839 m a.s.l. (Furi Mountain)
The south eastern part of the lake is also almost flat with an average elevation of 2050 m a.s.l., the north western part of the study area is relatively rugged and has a peak which reaches up to 2839 m a.s.l. and the western part of the lake is generally flat with an average elevation of 2100m a. s. l. near the lake there are small scoria cones rising above the generally flat landscape.

2.3 Geology

The area is underlain by various basic and silicic volcanic flows in association with pyroclastic depositions that are inter-bedded with fluvio-lacustrine sediments.
These volcanics are considered as the Aden volcanic serious which itself predates the Ethiopian rift system formation (Mhor, 1971). Recent to sub resent volcanics, scoriaceous basalts in particular, are observed on the right banks of the Aba Samuel dam site. Analogous younger volcanics and lacustrine sediments of which the latter is regarded to attain pluvial age (Mohr, 1971 and Kazmin, 1978 as cited in Tamiru et.al, 2005) are described to occur in the Mojo and Bishoftu areas.
The Miocene-Pleistocene volcanic succession in Addis Ababa area from bottom to top are: Alaji basalts, Entoto silcics, Addis Ababa basalts, Nazareth group, and Bofa basalts.

The Alaji group volcanic rocks (Alaji rhyolite and basalts) which were out pored from the end of Oligocene until middle Miocene (Zanettin et.al., 1974) have an age of 22.8 M.Y (Morton et.al., 1979 as cited in Tamiru et.al, 2005).

Entoto silcics are composed of rhyolite and trachyte with mionor amount of welded tuff and obsidian (Haileselassie Girmay and Getaneh Assefa, 1989). It is thickness is quite variable as it is frequently forms dome structure. In this rock unit flow banding, folding and jointing are common. The rhyolites are overlain by feldsparporphyritic trachyte and underlain by a sequence of tuff and ignimbrites. Tuff and ignimbrites are welded and characterized by columnar jointing. The Entoto silicis are dated at 21.5M.Y by Morton (1974) and 22 M.Y by Morton et.al (1974) both the rhyolites and trachytes of Entoto silicics belong to the “Miocene Alaji Rhyolite and Basalt” sequences.

In Addis Ababa, the oldest visible rocks post dating the Entot silicic are the Addis Ababa basalts. These units, which are mainly present in the central part the town, are underlain by the Entoto silicics and overlain by lower welded Tuffs of the Nazareth group. Addis Ababa basalts yield ages clustering around 7 M.Y and seem to have no time/composition equivalent (Morton et.al, 1979).

The units identified in Nazareth group are denoted as lower Welded Tuffs, Aphanitic basalts and Upper Welded Tuffs. The group is underlain by the Addis Ababa basalt and is overlain by the Bofa basalts. The rocks outcrop mainly in the area south of Filowha and extend towards southeast of Addis Ababa (Morton et.al, 1979).

The area in the northeast is dominated mainly by ignimbrite outcrops (at the base of Intoto Mountain, Legedadi Area and southern part of the city). Younger volcanic rocks belonging to the Wechecha and Furi volcanoes comprising Rhyolites, ignimbrigtes, trachytes and trachybasalts are found in the north western parts of the Akaki catchment.

Porphyritic to aphantic basalts, Known as the Addis Ababa basalts, outcrop mainly on the Inoto Mountains, in Central Addis Ababa and along the Akaki river course.

And basalts associated with rhyolites, trachytes Ignimbrights, tuffs and agglomerates cover mainly the Intoto Mountain and extend to the north beyond the catchment.

2.3.1 Geological structure

Elongated fault lines running east west via Kassam river, Addis Ababa and Ambo cut across the western rift escarpment and uplifted its northern block at about 8 M.Y ago (Zanettin et.al,1978).This fault marks the upper (outer) boundary of the western Ethiopia rift margin immediately north of Addis Ababa –Ambo road (Zanettin et.al., 1974). The fault has a down throw to the south in the Addis Ababa area (Haileselassie G., 1989 as cited in Tamiru et.al, 2005). Another prominent normal fault in the city is the Filowha fault. The Filowha fault having a trend of $N55^0E$ (Haileselassie G., 1989) is thought to be a major NE trending fault that continues up to Debre Berehan (Mohr, 1964).

The other major structural features are joints, which have different spacing, opening and orientation. The dominant preferred orientation of joints occurring in different rock unit is NNE-SSW, which is sub-parallel with the general trend of rifting.

2.4 Soil

The climatic condition and topography of the area favor the development of thick soil profiles mostly due to the physical disintegration and chemical decomposition of volcanic rocks on which it lies (Tamiru, et.al.2005). The weathering products either remain in place and form residual soils or are transported and deposited to form alluvial deposits in low-lying areas. In the localities where the topography is plain to gently slopping (central and southern parts) the area is covered by thick soils. In general, the types of soils which are found in the study area are Black cotton soil, lacustrine and alluvial soil. Of which the Black cotton soil dominates the area. The thickness of lacustrine and alluvial silt and clay deposits in the area range between 5 to 50m (Birehanu, 2002)

2.5 Climate

Ethiopia has a wide climatic variability. The National Atlas of Ethiopia (1981) defined five traditional climatic zones: "Kur" (Alpine) ,3000m and above "Dega" (Temperate),2300m to about 3000m :"Weina Dega"(sub tropical),1500to about 2300m:"Kolla" (Tropical),800m to about 1500m and "Bereha"(Desert),less than 800m. From this classification the studied catchments lie in the Woina Dega and Dega Climatic zones.

In general rainfall in the Addis Ababa region can be classified in to three distinict seasonal periods. The period of heavy rains (Kiremt) occurs between June to September. The dry season (Bega) is between October to February and the small rains (Belg) occur between March to May.

Seasonal variations of the air Temperature in Addis Ababa are not large throughout the year .The city has an average maximum and minimum temperatures of 23 ^{o}C and 10^{0}C respectively and an average temperature of 16^{O}C.

For the Addis Ababa area, the monthly temperature is maximum during the months of March through May, about 24.4 ^{0}C, and it is minimum in the months of November through January, 7.8 ^{0}C (Figure2).

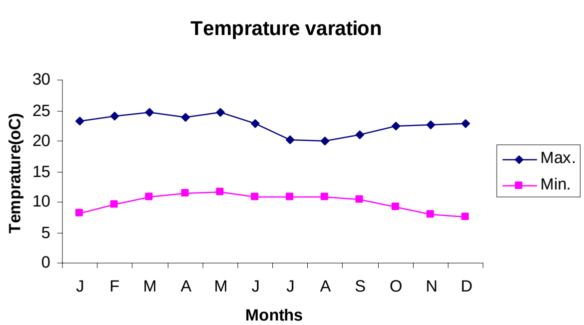


Figure 2. Monthly maximum and minimum temperature (^{0}C) for Addis Ababa area (source; Tamiru et.al, 2005)

2.6 Land use/land cover

The general land use pattern of the whole Akaki catchment is very diverse. Most of the upper part of the catchment is occupied by settlement, mixed land use practices and there are planted trees (eucalyptus) further up on the Intoto ridge. In the southern parts of the catchment non-irrigated agriculture dominates.

Most industries are concentrated along the Little and big Akaki rivers; which offer prospect for their effluents to get easily in to the rivers and end up into the reservoir under study. Around the study site the dominant land use practice is agriculture.

The land cover in the Akaki catchment is changing due to urbanization, which results in deforestation and agricultural practices.

2.7 Drainage

The Akaki River is a tributary of the Awash in its Upper Basin. This Basin covers a total area of 110 000 km^2 and covers the regions of Oromia, Afar, Amhara, Addis Ababa City Administration and Dire Dawa Council. Awash Basin is an intensively used river basin in Ethiopia due to its strategic location, access roads, and availability of land and water resources.

Akaki River consists of two main branches, the confluence of which is at the Aba-Samuel reservoir. The western branch of the river, the Little Akaki, raises north-west of Addis Ababa on the flanks of Wechacha Mountain and flows for 40 km before it reaches the reservoir. The eastern branch of the river, the big Akaki, rises north-east of Addis Ababa and flows into the Aba-Samuel reservoir after 53 km flow.

In the Addis Ababa city, there are different perennial and intermittent streams which are tributaries of the Little or Big Akaki rivers, and towards the south almost all streams/or big tributaries crossing the city in different direction join either of the rivers. The two rivers flow on either side of Addis Ababa –Debrezeit road and end up at the artificial lake Aba Samuel. Other perennial streams in the city are Bantyiktu, Kurtume, Kebena and Ginfile. The remaining streams are intermittent in nature.

Streams are dense on the top of the mountain forming radial and dendritic drainage patterns.

All the major streams of the catchment originate in its northern part and retain the name Akaki as they leave the lake passing through a gorge up to 100m deep which extends for about 8 km before joining the Awash River. And this makes Aba Samuel Lake an open catchment lake, since Akaki River is going out of it (Figure 3).

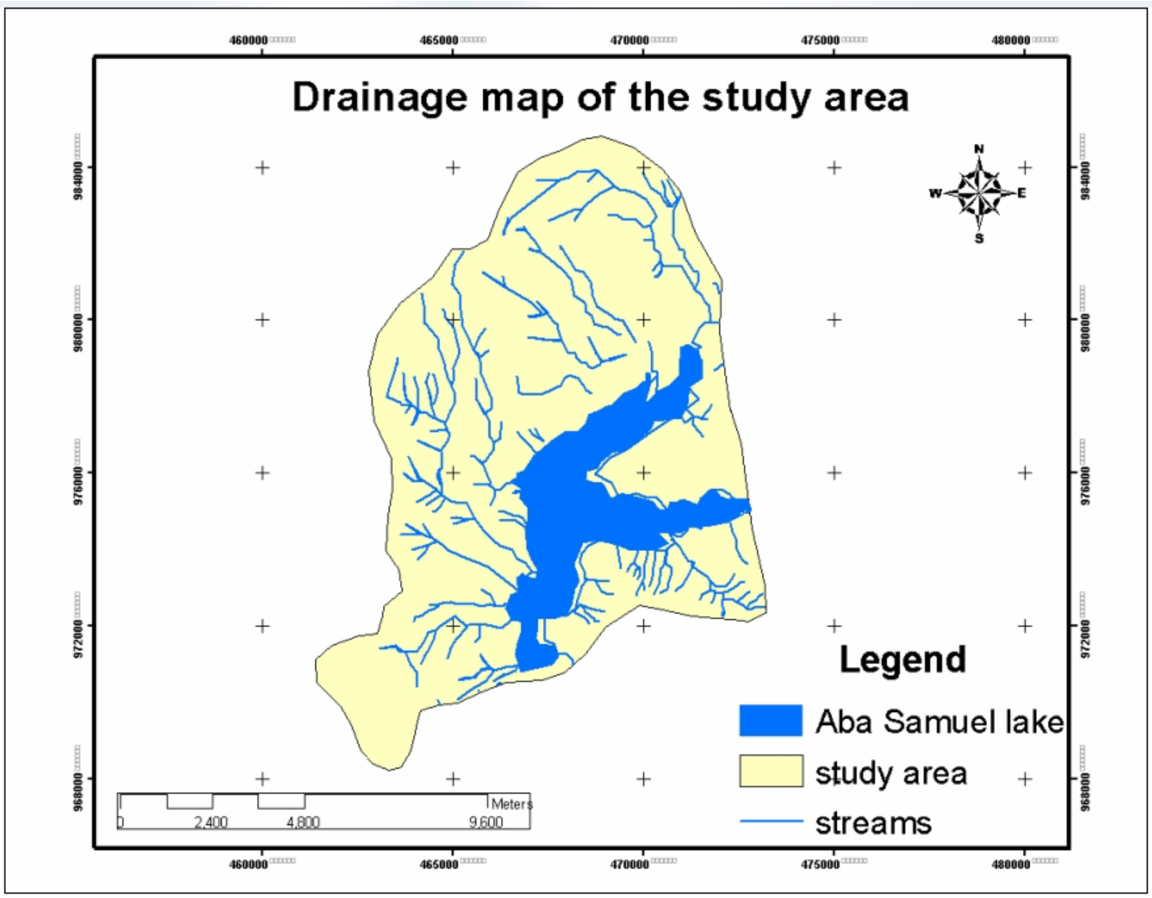


Figure 3.Drainage map of the study area

3. MATERIALS AND METHODS

3.1 Data compilation from available literature

Previous works on hydrogeological, hydrochemical and any relevant topics concerning the study area have been revised. Relevant maps and secondary data have been collected from relevant institutions. After setting the research objectives, proper field planning has been conducted for taking water and sediment cores samples.

3.2 Field work

Water and sediment cores samples have been taken for nutrient and heavy metals analysis, respectively. Two representative sites were selected for sediment core sampling which are proximal to the dam and at the western shore of the lake.

Six water samples for nitrate, phosphate, and ammonia concentration analysis have been collected in order to determine the effect of these anions on the eutrophication process observed in the lake (Figure 4). In addition, other parameters of water chemistry are considered from secondary data which were collected by different institutions (EPA and MoWR).

Water samples have been collected from different locations using polyethylene containers. However, due to inaccessibility of the area the samples could not be taken from representative locations. Fast changing parameters have been determined as soon as possible on site in order to avoid changes that will take place related to pressure, temperature and the exposure of water to the atmospheric oxygen. Such parameters are EC, pH and T, while the conservative parameters, including nitrate, ammonia and phosphate have been determined in laboratory.

Hanna Ph meter is used to determine the pH, temperature and electrical conductivity test. The pH instrument is calibrated in the field before taking readings by two buffer solutions in order to have a good reading. The buffer solution is selected from the expected pH result of the lake water in the study area. The selected buffer solutions are pH 4 and pH 7.

Sediment cores from the lake bed have been taken from representative locations using transparent PVC sampling tubes by pushing them in to the sediment up to a penetrable depth. The tubes were then sealed and brought to the laboratory for storage in a refrigerator.

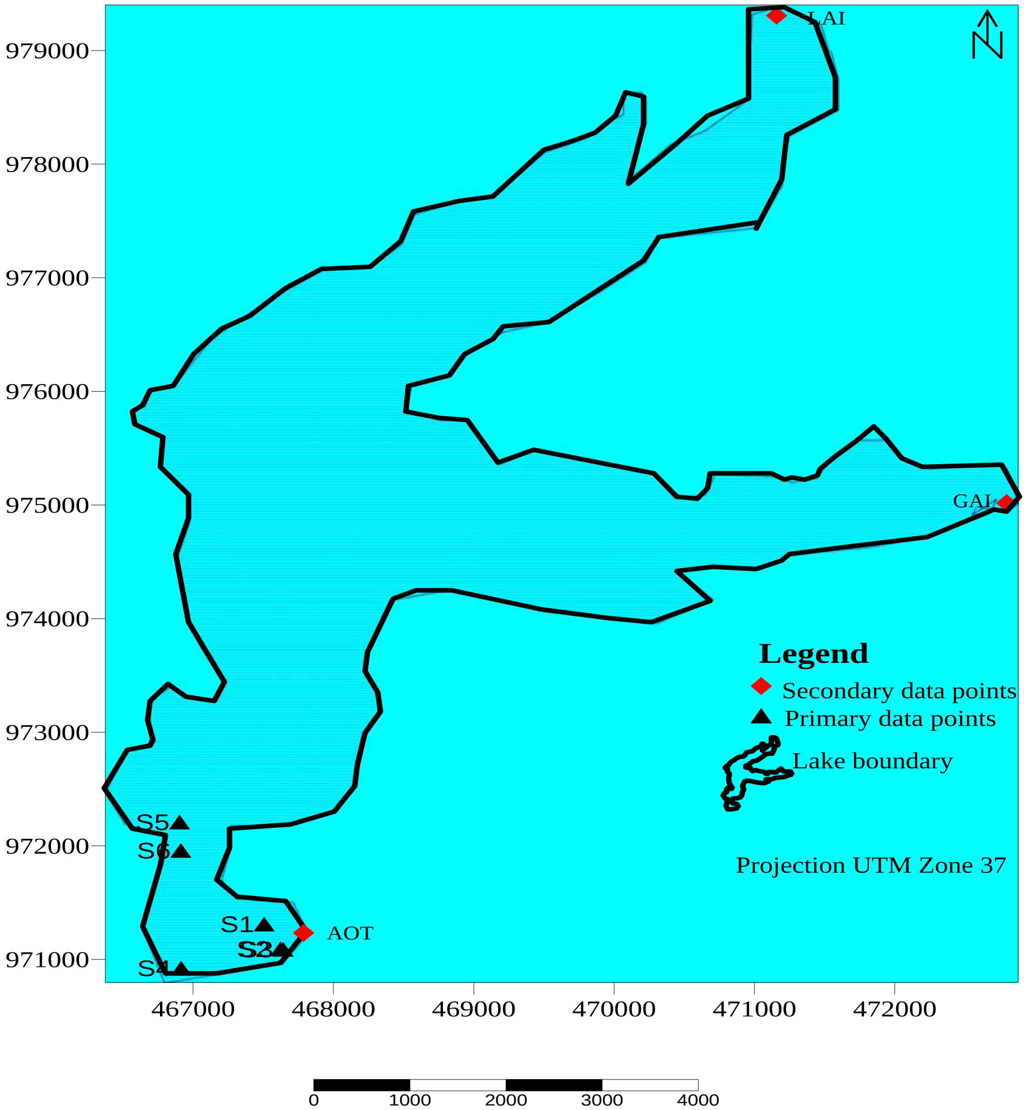


Figure 4. Location map of primary and secondary water data points

For both water and sediment core sampling detailed descriptions of the samples were taken during the field work as shown in Appendix 6.

For both types of samples (water and sediment cores) the necessary precaution were taken during sample collection in order to avoid sample disturbance and contagion.

3.3 Laboratory analysis

3.3.1 Trace metals analysis in sediment cores

Heavy metal analysis has been conducted on the sediment cores, in order to investigate the temporal variation. Trace metals namely Cd, Cu, Cr, Ni, Pb, and Zn were chosen for analysis taking into consideration the existing analytical methods of determination of the metals, the industrial activity in the city and to make comparison between metals analyzed in the Little and Great Akaki river streambed sediments previously by other researchers.

The analysis has been done after taking sediment slices from the top, middle and bottom parts of the sediment cores.

The sediment slices were well mixed in order to homogenize the distribution of the metals. Then the sediment samples were dried (in Digitheat oven at $120^{O}C$). The sediment samples were later digested by the optimized method of digestion (A method adopted by Belachew et.al, 2006). In this method 0.5 g of sediment sample was dissolved in 6 mL conc. HNO_3. Then the mixture was heated until semi-dry and the residue was dissolved in 4 mL conc. $HClO_4$ and heated to semi-dry then the residue was dissolved in 30% H_2O_2. After cooling, the mixture was dissolved in 30% HNO_3 acid and filtered using Whatman type # 41 filter paper to remove any silicate residue. The mixture was diluted to 50 mL with 3% HNO_3 in a volumetric flask. Blank digestion was performed in the same way.

Extracted solution from streambed sediments were analyzed for trace metals using FAAS (BUCK SCIENTIFIC MODEL 210VGP, East Norwalk, USA) with air-C_2H_2 flame at Addis Ababa University, Chemistry department, laboratory. Wavelength, energy, lamp and burner alignment and slit width were optimized for Cd, Pb, Zn, Cu, Ni and Cr analysis.

The mean recoveries for all elements are in the range of 80 – 115 % thus; the laboratory performance for each analyte is in control (Theodore, 2003 as it is cited in Belachew et.al, 2006). Recoveries values in the above range are acceptable for environmental investigations and the digestion procedure is believed to remove metals fractions associated with carbonate, sulfides, soluble salts, organic mater, and Fe-Mn oxide phase (Awofolu *et al.*, 2005 as it is cited in Belachew et.al, 2006).

3.3.2 Water quality analysis

Water chemistry analyses in the laboratory have been conducted for selected chemical parameters like phosphate, Nitrate and Ammonia. Biological test (for total coliform and fecal coliform) has also been conducted. Different standard methods are employed to measure the selected chemical parameters. For nitrate analysis Cadmium Reduction Method has been employed with the estimated detection limit of 0.01 mg/l. Ammonia is analyzed by Nessler Method (WWDSE, laboratory). Phosphate is analyzed by PhosVer 3 Method (WWDSE, laboratory).

3.3.3 Microbiological testing

For bacteriological testing, specifically for total and feacal coliform membrane filtration method has been employed, as it is one of the best methods recommended by WHO to detect these coliform indicators.

3.3.4 Identification of the water hyacinth

The water hyacinth covers large part of the lake. And knowing the characteristics of the weed is very essential. So identification of the water hyacinth family name and specious name has been done by flora key method, at Addis Ababa University, Herbarium.

3.4 Sediment analysis

3.4.1 Lakebed sediments for temporal water quality investigation

The strong association of numerous toxic chemicals both organic (such as Dichlorodiphenyltrichloroethane and polychlorinated biphenyls) and inorganic (such as chromium, cadmium, and lead) with sediments means that much of the downstream transport of these materials can not be detected or evaluated solely through the sampling and analysis of water (Bradford and Horowitz, 1982).

Today resources are under constant stress from industrial development and population growth, so it is vital to reliably monitor the quality of the environment for present and future generations. In order to have effective monitoring, there is a need to investigate the pollutant load in the Lake Environment. It has been shown that most trace elements and many anthropogenic organic compounds are known to associate with sediments rather than dissolving in water (US. Geological survey, 1996).For this reason, researchers have recognized that studies of water quality that include trace metal constituents must necessarily include studies of sediment chemistry. As a lake is a complex system, there is a need to use as many alternatives as possible for water quality analysis and monitoring.

Water-quality trends are of interest because trend analyses can improve the understanding of the influence of human activities on water-quality, can indicate the effectiveness of environmental regulations in controlling undesirable chemical inputs, and can provide an indication of potential future water-quality conditions. Though a common approach for determining water-quality trends in streams is to apply statistical tests to historical data; such data may have several limitations. In the case of this study, such limitations include lack of data, and numerous measurements below detection levels. As a result, water-quality records for the Lake are reconstructed using sediment cores to the depth which can be penetrated using a sampling tuber. This method has an additional advantage of detecting the effect of non-dissolved pollutants.

3.4.2 Sediment cores

In this study the purpose of the sediment cores investigation is to systematically assess chemical patterns in the Aba Samuel Lake within a given period of time.

It is generally assumed that reservoir-core sediments provide the baseline concentration of pollutants if the very bottom was to be obtained corresponding to minimum anthropogenic activity relatively from the current state of pollution. The dating of the sediment cores is based on the assumption of uniform rate of deposition per year. Vertical segmentation of the sediment core and chemical (heavy metal) analysis of core segments has been conducted as the chemistry of discrete slices of the sediment can provide historical information on water-quality conditions (Charles and Hites, 1987). Chemical levels with respect to sediment quality have also been assessed.

Two sediment cores (SC-1 and SC-2) have been taken using tube corer (the tube corer is 7 cm in diameter and can take cores as long as 110 cm.) from different locations with in the lake, one proximal to the dam, and the other from the western shore of the lake. The two sediment cores have a height of 44 cm (SC-1) and 49 cm (SC-2). These samples have about 7 and 8 years of records, respectively.

3.4.3 The importance of investigating Heavy Metals in the Sediment Cores

The available data of water quality investigation in Addis Ababa catchment focused on water sample analysis. Though, the total load of pollutants is the sum of the load in the dissolved phase and the associated particle phase. All pollutants do not dissolve in water. There are those such as heavy metals which adsorb on suspended particles and be deposited.

In order to have a clear picture on the state of water quality degradation in Aba Samuel Lake and to see the temporal variation of pollutant load, sediment core analysis for heavy metals has been conducted.

When suspended sediment concentrations are less than several hundred mg/L it will be difficult to detect contaminants in whole –water (unfiltered) samples.

Heavy metals are rarely detected in whole-water samples, even in those that contain highly contaminated suspended sediment. For example, if a sample contains 50 mg/L of suspended sediment, and the sediment contains 17 µg/kg lead, the concentration of lead in the whole-water sample will be 0.00085 µg/L. This concentration is orders of magnitude below most laboratory methods detection limits.

Moreover, heavy metals in sediment are of great concern because they are generally dissolved and bioavailable for bionetwork if the chemical and physical state of the water changes. For example Cadmium is fairly mobile in soil and become even more mobile with falling pH levels. Continuing sediment acidification therefore involves a risk of rising cadmium concentration in nearby waters.

4. RESULTS AND DISCUSSION

4.1 Heavy metals in Aba Samuel lakebed sediment

4.1.1 Reservoir Sedimentation and Core recovery

According to the Aba Samuel rehabilitation study (1987) a maximum sediment thickness of up to 4m (at the central part) and an average thickness of 2m for the entire lake bed has been estimated for the case up to 1983 (48 years since dam construction in 1939). For this current study (2007) an average estimate of 3m thick sediment deposit is taken in order to consider the maximum scenario and to incorporate the time between 1983 to the present day (14 years).

If within 48 years, (from 1939 to 1983), a 3m thick sediment has been deposited, therefore the amount of deposit comprising the whole span of the age of the dam (68 years) is estimated to be 4.25m.

When the above is converted to sediment deposition rate per year the value becomes 6cm deposited annually. This rate was calculated by dividing the expected total thickness of lake-bed sediment by the age of the dam (68 years).

From the reservoir deposit two sediment cores have been taken at the proximity of the dam (SC-1) and at the opposite side on the western shore near Dika village (SC-2). The two sediment cores have length of 44 cm (SC- 1) and 49 cm (SC-2). Therefore, according to the above calculation for sedimentation rate, these samples date back to 7 and 8 years of record respectively.

In order to see the temporal variation of heavy metals during the above-mentioned period, heavy metal analysis has been conducted for the top (SC-1t, SC-2t), middle (SC-1m, SC-2m), and bottom (SC-1b, SC-2b) parts of the sediment cores . The sediment slices taken from the sediment cores have a length of 6cm each, in order to make them representative for each year of deposition.

Therefore, the top part of sediment cores represent the year 2006/2007, and the bottom of the cores represent the years 2001 and 2000 for sediment SC-1 and SC- 2 respectively (Figure 5).

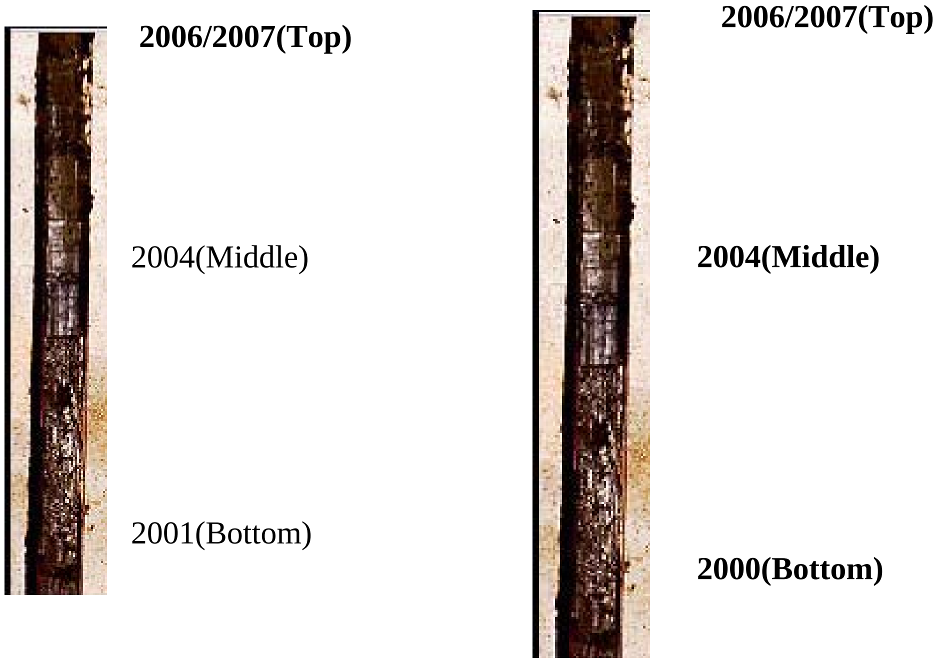


Figure 5. Sediment core 1 and sediment core 2

The material in the sediment core 1 is dominantly clay-silt while that of SC- 2 is dominated by sand, particularly in the upper portion.

4.1.2 Concentration of heavy metal in the sediment

Heavy metals are those whose density exceeds 5 g/cm^3. Even though there are many metals which fulfill this criterion, the most important heavy metals from environmental context are Arsenic (As), Cadmium (Cd), Chromium (Cr) , Cobalt (Co), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), Tin (Sn), Vanadium (V) and Zinc (Zn). In this study, the concentrations Zn, Cd, Cr, Cu, Pb and Ni have been analyzed, and the concentration of these heavy metals shows an increasing trend within the last 7 and 8 years in both sediment cores (Table 1 and Table 2).

Table 1. Heavy metals concentrations in sediment core 1

sediment core 1						
	Pb(mg/kg)	Ni(mg/kg)	Zn(mg/kg)	Cr(mg/kg)	Cd(mg/kg)	Cu(mg/kg)
Bottom	15.99	32.53	87.8	20.93	0.24	31.03
Middle	19.45	57	106.5	20.35	0.47	33.83
Top	19.62	37.9	104.33	27.35	0.51	34.45

Table 2. Heavy metals concentration in sediment core 2

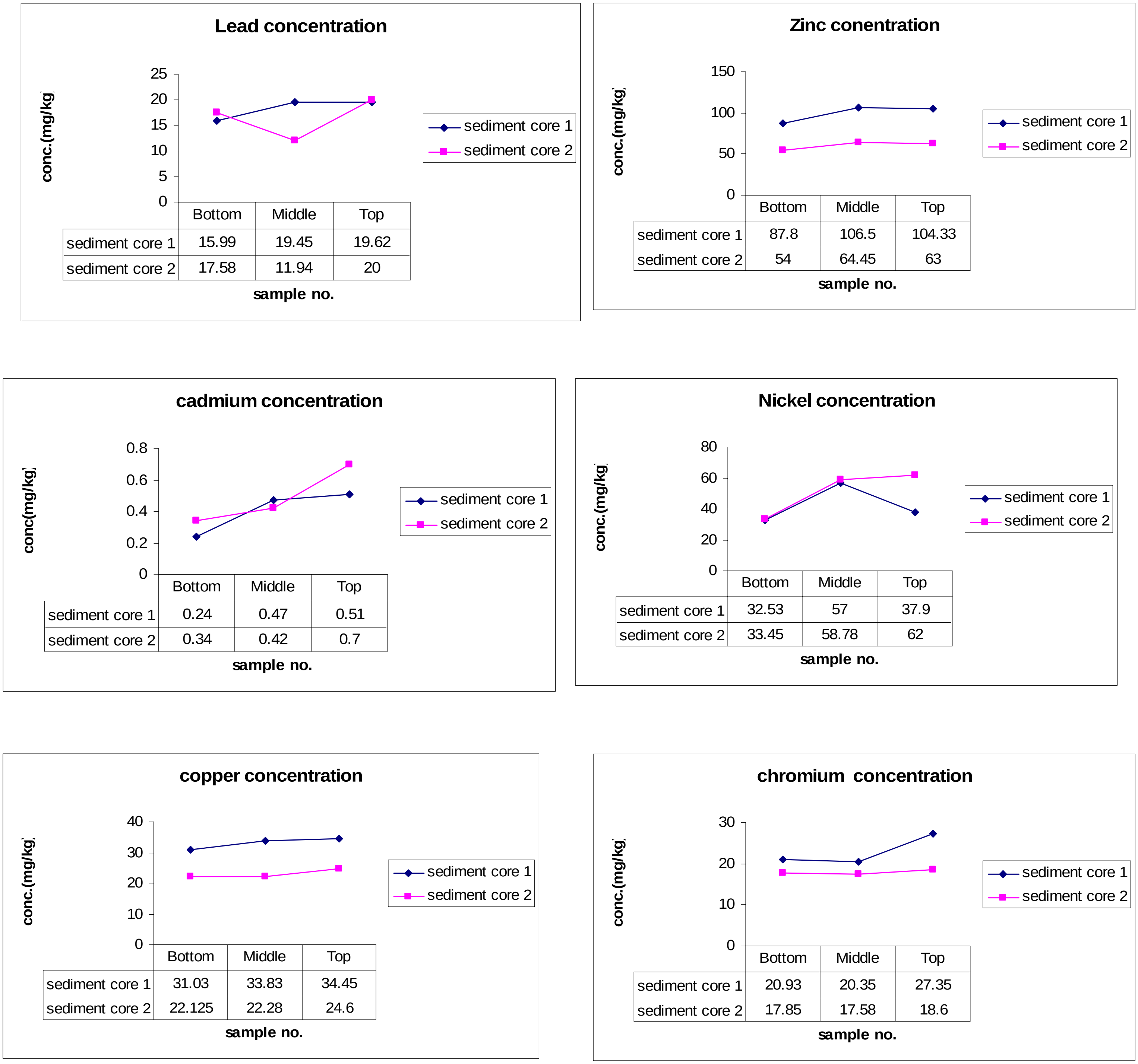
sediment core 2						
	Pb(mg/kg)	Ni(mg/kg)	Zn(mg/kg)	Cr(mg/kg)	Cd(mg/kg)	Cu(mg/kg)
Bottom	17.58	33.45	54	17.85	0.34	22.125
Middle	11.94	58.78	64.45	17.58	0.42	22.28
Top	20	62	63	18.6	0.7	24.6

The increasing trend of the heavy metals vary from metal to metal some metals shows more than 45 percent increase only with in 3 and half years, for example Nickel .The others like copper shows a ten percent increase within 7 years (Table 3).

Table 3.Heavy metals percentage increase in sediment cores

Heavy metals	**Percentage Increase**		
	In sediment core 1		**In sediment core 2**
	with in 3 and half years	with in 7 years	with in 8 years
Cd		53%	51%
Cu		10%	10%
Zn		16%	15%
Pb		19%	12%
Cr		24%	5%
Ni	45%		46%

The increasing pattern of heavy metals for sediment core 1 and sediment core 2 is almost the same except for nickel where it showed a decreasing trend at core 1 site (Figure 6). Although, the spatial patterns of the metals can be assessed by correlating the concentration between the two sediment cores, the small size of the reservoir sediment data set limits on the degrees of freedom for the correlations. In general, there is slight variation on spatial distribution of heavy metals on the Aba Samuel Lake. This can be due to the sediment-trapping effect that occurs along a series of paths.



Lead concentration

	Bottom	Middle	Top
sediment core 1	15.99	19.45	19.62
sediment core 2	17.58	11.94	20

Zinc conentration

	Bottom	Middle	Top
sediment core 1	87.8	106.5	104.33
sediment core 2	54	64.45	63

cadmium concentration

	Bottom	Middle	Top
sediment core 1	0.24	0.47	0.51
sediment core 2	0.34	0.42	0.7

Nickel concentration

	Bottom	Middle	Top
sediment core 1	32.53	57	37.9
sediment core 2	33.45	58.78	62

copper concentration

	Bottom	Middle	Top
sediment core 1	31.03	33.83	34.45
sediment core 2	22.125	22.28	24.6

chromium concentration

	Bottom	Middle	Top
sediment core 1	20.93	20.35	27.35
sediment core 2	17.85	17.58	18.6

Figure 6. Concentration of heavy metals in sediment cores

The value of heavy metals from sediment cores compared to the standard values for each metal (Table 4) shows that:

- Cd, Cr, and Zn are below the standard values for both sediment cores;
- Cu concentration shows spatial variation and the amount obtained for the SC-2 is below the standard value while for SC-1 it is above the standard value, even for the sample taken from the bottom of sediment core.
- Ni concentration is higher than the standard value for both sediment cores, and shows spatial variation within the lake where SC-2 shows higher concentration than SC-1.
- Pb in both sediment cores is below the standard value and shows nearly the same trend in both cores. Of particular interest is that in SC-2, the concentration of Pb increased during a period of 8 years by 12%. However, in the middle part of the sediment core, the concentration has been lower and eventually shows abrupt increase to the present. In SC-1, the Pb concentration shows an increasing trend from the bottom to the middle and becomes nearly constant afterwards.

Table 4. Recommended sediment quality guideline values for metals

Developed by the Wisconsin Department of Natural Resources, Washington, December 2003

Metal	Threshold effect concentration (mg/kg) dry weight
Cadmium	0.99
Chromium	43
copper	32
Lead	36
Nickel	23
Zinc	120

4.1.3 Sedimentation Rate

Sedimentation is the sinking of a molecule under the opposing forces of gravitation and buoyancy. Sedimentation on streambed is important because of the significant effect of sediment accumulation on the quality of water and watershed characteristics. For example, large volumes of sediment coming into reservoirs from agricultural areas can transport and deposit certain agricultural chemicals (such as phosphorus from fertilizer applications and some pesticides used in crop production) that are adsorbed to fine sediment particles.

The rate of sediment deposition on streambed varies greatly; due to several possible reasons. Precipitation contributes to stream flow and ultimately the transport of suspended sediment into the reservoir under certain conditions. Larger volumes of sediments would more likely be deposited in reservoirs having watersheds that receive more precipitation. For example, in the Little Akaki River, it was found out that sediment concentration increases with increasing flow rate (Figure 7). However, precipitation alone does not account for all the differences in sediment deposition. Other variables such as land use, topography, soil types, geology, and drainage area, are also important in the evaluation of sediment transport.

Sediment deposition and accretion rates are important for maintaining marsh surface elevation as well, as observed in the case of the Aba Samuel Lake. The lake is becoming a wetland due to this uncontrolled sedimentation problem.

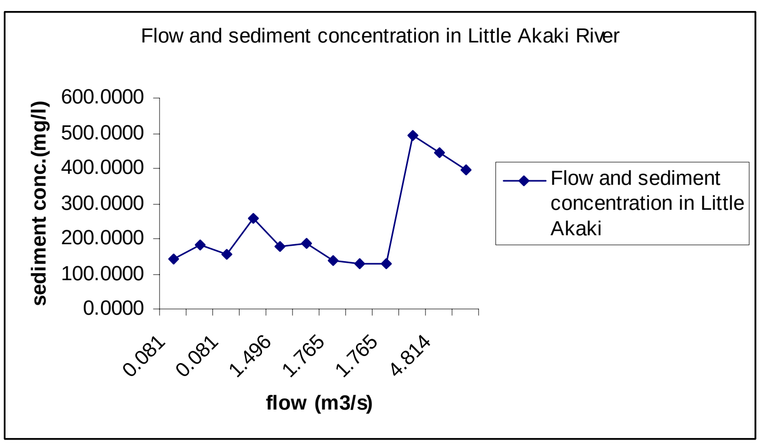


Figure 7. The relation between flow and sediment concentration in Little Akaki River (source Ministry of water resource, 1990-1994)

Although sedimentation rate is a non linear phenomenon, governed by factors such as variation in rainfall amount and intensity, for the purpose of this study a constant rate has been assumed. This assumption is based on the fact that variability will be smoothened over time. It should also be noted that the amplitude of rain fall variability is slight (Figure 8), justifying a sedimentation rate that should approach a constant value.

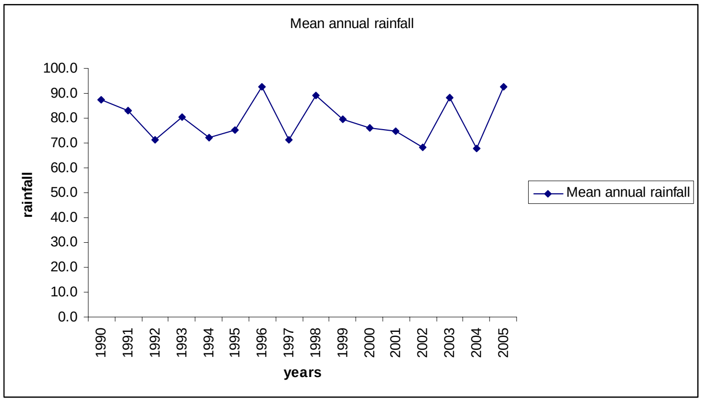


Figure 8. Mean annual rainfall of the Akaki area (mm) (source, MoWR)

It can also be perceived that the lake level variability is low for the years which support the assumption of constant rate of deposition (Figure 9).The lake level is more or less constant especially for years from 1999 to 2005, the minimum value of lake level is 0.6m in 2004 and the maximum value is 1.03m in 1998.

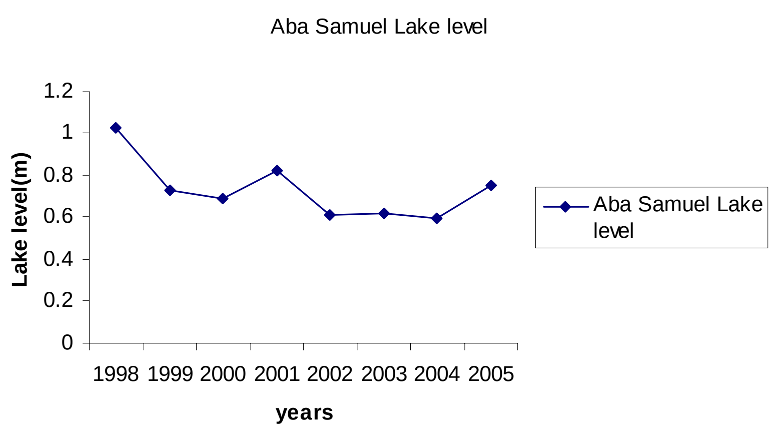


Figure 9.Aba Samuel Lake level (Source, MoWR)

Sedimentation rates for most natural lakes vary from 0.05 to 10 millimeters per year. In contrast, reservoirs rates range from 10 to 200 millimeters per year. (Peter et.al, 1997). The sedimentation rates in Aba Samuel artificial lake is higher (6cm per year); this is due to the high concentration of sediment load from two rivers which flows in to the lake and perhaps due to the increase in land use practice mainly agricultural in the area around the Lake. For agricultural activities in the study area, soil conservation practices are uncommon; so soil erosion adversely affects the watershed. Sediment washed off the land surface during rainstorms is deposited partly along its path and mainly in the Aba Samuel Lake.

4.1.4 Heavy metals in Akaki rivers streambed and Aba Samuel lakebed sediments

Analysis of the concentration of heavy metals in the sediment and water, taken from the same location, in Little Akaki and Great Akaki rivers has been conducted by Belachew, 2006 (Table 5). His result shows the variation in the concentration of heavy metals between water and sediments. The concentration of trace metals in water is almost nil for all samples but in the river sediments they have a substantial concentration. The higher concentration of heavy metals in sediment is a great concern because the metals could subsequently return back into the water from the sediment layers during runoff and when the physicochemical characteristics of the water changes.

Concentration of the trace metals in the sediment cores from Aba Samuel lake generally show lower concentration than the Little Akaki and Big Akaki rivers streambed sediments .This can be attributed to the fact that Aba Samuel Lake is farther downstream from the major contaminant sources, which leads to trapping of the heavy metals in stream bed sediments of the Akaki Rivers. However, there is an increasing trend of heavy metal concentration in the Aba Samuel lakebed sediment with time.

Table 5.Mean concentration *(± standard deviation) of trace metals dissolved in water (mg/L) and in surface sediments (mg/kg) for sampling sites along Little and Big Akaki River. The values in brackets are for the surface sediment, BA is Big Akaki and LA is little Akaki (Source Belachew, 2006)

Sites	**Elements**					
	Cd	**Cu**	**Co**	**Ni**	**Pb**	**Zn**
LA1	nd	nd	nd	nd	nd	0.022±0.002
	(0.43±0.02)	(86.62±0.89)	(31.26±3.04)	(95.77±3.13)	(55.73±7.35)	(415.93±11.43)
LA2	nd	nd	Nd	nd	nd	0.050±0.003
	(0.62±0.01)	(66.90±2.54)	(26.13±1.80)	(70.26 ±1.17)	(40.33±4.13)	(218.41± 12.05)
LA3	nd	nd	nd	nd	nd	0.19±0.009
	(0.69±0.02)	(64.60±5.79)	(44.02±2.44)	(110.80±1.90)	(78.2±11.23)	(323.33±15.35)
LA4	nd	nd	nd	nd	nd	0.053±0.004
	(0.44 ± 0.01)	(59.67±0.95)	(39.72±2.47)	(119.82±2.27)	(39.86±8.73)	(271.29±14.35)
BA1	nd	nd	nd	nd	nd	0.038 ± 0.001
	(0.37±0.13)	(30.51±1.82)	(30.47±3.11)	(66.97±11.29)	(49.44 ± 5.43)	(238 ± 24.85)
BA2	nd	nd	nd	nd	nd	0.082 ±0.007
	(0.51±0.21)	(39.43±1.41)	(25.79±2.13)	(70.93 ±11.07)	(62.22 ± 5.86)	(172.9 ± 21.24)
BA3	nd	nd	nd	nd	nd	0.067 ± 0.005
	(0.56±0.13)	(47.52±1.93)	(22.66±0.99)	(55.94±9.42)	(63.0±6.23)	(223.67±25.68)
BA4	nd	nd	nd	0.049±0.005	nd	0.058±0.003
	(0.51±0.12)	(35.58±2.52)	(24.38±1.39)	(61.85 ± 2.88)	(43 ± 3.85)	(179.22±20.18)

4.1.5 Temporal variation of heavy metals in Aba Samuel Lake bed sediments

To have a comprehensive insight into the temporal variation of trace metals, it will be of great importance to synthesize information on the sediment associated deposition of metals on Aba Samuel Lake lakebed sediments.

The temporal distribution of heavy metals concentrations in dated reservoir cores suggests that there are significant source of these metals that persist to the present with increasing trend of the amount they release. The observed temporal change in lakebed sediment is associated with the increment of number of industries (Figure 10), agricultural activities and the increase of population (Figure 11) with in the watersheds.

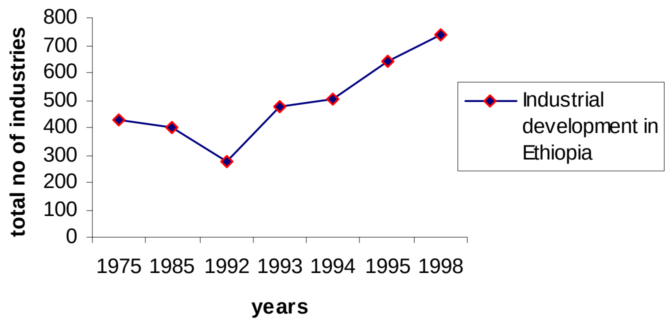


Figure 10. Industrial development in Ethiopia (after Mohammed, 2002)

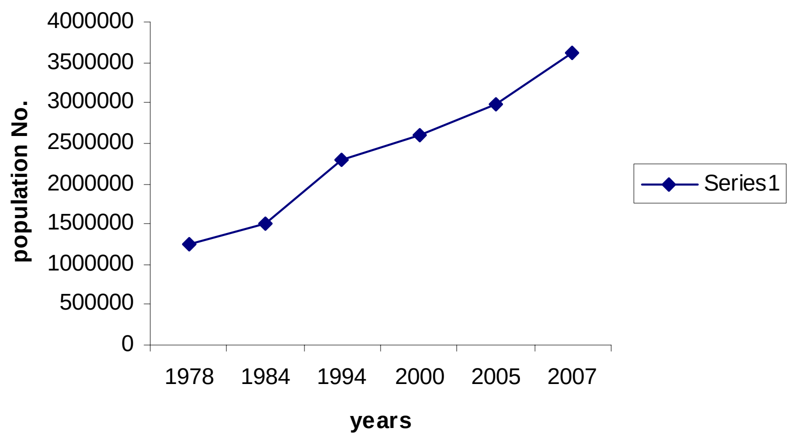


Figure 11. Population projection in Addis Ababa (Source CSA, 2005)

Industries discharges significant amount of heavy metals to the environment as it is inferred from table 6. For example for Cd, Cr, Cu, Pb, Ni and Zn, the possible sources of industries include metal plating, tanneries, paint factories, wood preservation, leaded gasoline etc. These industries discharge their effluents directly into Little and Big Akaki rivers and the two rivers with their pollutant load end up in Aba Samuel Lake.

Table 6.Heavy metals from industry in Addis Ababa (source EPA, 2001) All units are in mg/l

Industry	**Date of analysis?**	**Cd**	**Cr**	**Pb**	**Ni**	**Zn**	**Cu**	**Fe**	**Mn**
Awash Tannery	03/01/01	0.1	280	<0.1	0.4	0.2	0.1	2.7	0.5
Gullele soap	03/02/01	0.3	0.2	<0.1	0.9	1	0.2	116	0.1
Nifas Silk paint	27/12/00	<0.1	0.1	0.7	<0.1	0.1	<0.1	0.8	0.1
National Alcohol and liquor	13/12/00	0.1	0.1	0.1	0.4	5.5	1.1	68	5.1
Awash Winery	14/02/01	<0.1	<0.1	<0.1	<0.1	0.9	0.7	5.4	0.2
Dire Tannery	03/02/01	0.4	1.5	3	1.2	2.1	0.2	18	1.7

The abandoned reservoir of Aba Samuel plays significant role as a sink for heavy metals generated from different human activities in the city as it can be inferred from table 7. Heavy metal concentration is higher in the inlet than the outlet. However, in some cases the situation reverses and heavy metals concentration increases at the out let than the inlet, which may be due to the longer residence time of the heavy metals in the artificial lake, or the re-releasing of metals in sediments into the water when the physical and chemical characteristics of the water changes.

Table.7 heavy metal concentration at Aba Samuel reservoir as measured in the year 2004 (Tamiru et al., 2005)

Heavy metals	Big Akaki before Aba Samuel reservoir(ppb)	Akaki, outlet Aba Samuel reservoir (ppb)
Li	4.9319	1.2592
V	4.3	6.3492
Cr	2.2844	0
Mn	1190.2278	2043.9683
Co	2.7122	2.4186
Ni	5.0562	8.8964
Cu	0	0
Zn	0	0
As	0.4232	2.1833
Rb	8.8402	12.3671
Sr	235.0636	241.9829
Cd	0	0
Sn	0	0
Cs	0.4887	0.6131
Ba	106.9022	152.9571
Pb	0	0
U	0.6907	0.5986

4.1.6 Implications of heavy metals from sediment cores

Heavy metal concentration in sediment is resulted from many sources like for example agricultural, industrial, urban effects and geological input. In Aba Samuel lakebed sediment, heavy metals show an increasing trend from time to time, and the case is attributed to agricultural, industrial and urban input. Though, there is a background value from geological input of heavy metal concentration in lakebed sediment, the observed amount and increasing trend suggests that there is a good contribution from anthropogenic sources (agricultural, industrial, urban effects). This assumes that the geological input to be relatively constant for those years (7 and 8 years the representative age of sediment core 1 and sediment core 2 respectively).

The increasing trend of the metals is expected to aggravate if environmental monitoring is not taken properly. If we project the current state of pollution for the next 7 years keeping all other factors constant all trace metals overpass the threshold effect concentration set by Wisconsin Department of Natural Resources (2003). Therefore, strong Environmental regulations are needed for eliminating or reducing the entry of contaminants into the lake.

From an environmental perspective, many of these metals are quite stable in aquatic environments and susceptible to biotic uptake and bioaccumulation. Both the toxicity of a metal and its uptake from solution strongly depend on the chemical state of the metal (i.e. whether it is present free in solution, or adsorbed onto other materials, including sediments).Thus, a number of these substances can remain in the environment for long periods of time and can increase in concentration within biota. Lead is very easily fixed in the layer of soil and only migrates out very slow. Even though we have now seen an increase in lead deposition, it appears likely that the concentrations of lead in sediment remain strongly elevated. And the leaching from the soil will remain long after even if the water quality becomes managed properly.

4.1.7 Concentrations of heavy metals in soil taken from Farm land

For the soil sample taken from a nearby farmland (Table 8), the concentrations of Pb, Cr, Zn and CU are below the standard, where as Ni and Cd show higher value than the standard set for agricultural soils by EPA (Appendix 2).

Table 8. Concentration of heavy metals in soil taken from farmland near Aba Samuel Lake.

Trace metals	conc.(mg/kg)
Pb	9.6
Ni	30.83
Zn	60.1
Cr	16.68
Cd	0.63
Cu	16.65

Heavy metals analysis from the farm land suggested that except Ni and Cd the rest are with in acceptable concentration range. Cadmium might result from agricultural chemicals since it occurs as an impurity in artificial fertilizers. As a result, cadmium levels might have gradually risen, not only in the farmland but there is also a chance of its bioaccumulation in cereals and other crops. Cadmium level is higher in soil from the farm land than the lakebed sediments this also validate the idea of agricultural chemical input of the trace metal.

According to Fissha (1998) nine metals with appreciable concentrations have been identified in the Akaki soils. These are As, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn. Total Cr and total Ni contents have reached "toxic level", according to limits set by Hein and Schwedt (1991) with a concentration of 100ppm and 50ppm, respectively .Regarding metal uptake, comparing the heavy metal contents (As, Cd, Cr, Cu, Hg, Ni and Zn) of potato grown under contaminated conditions at Akaki with that of tolerable minimum, mean and maximum values, the potato grown at Akaki contains values exceeding the maximum contents tolerable for all elements except for arsenic (Fisseha, 1988) and all vegetables contain much higher Hg content than maximum tolerable level in food staffs on the contaminated Akaki soils (Fisseha, 1988).This suggests that high levels of Ni and Cd in the soil from the farmland have the chance to bioaccumulate in cereals and other crops.

4.2 Nutrients in Aba Samuel Lake

4.2.1 Concentration of Nutrients

In order to see the spatial variation of nutrient in the Aba Samuel lake six water samples have been taken and analyzed for nutrient concentration. Among the different nutrients ammonia, phosphate and nitrate have been selected for the analysis (Table 9) by taking in to consideration the following: phosphorous is the key nutrient for eutrophication, Nitrate (NO_{3-}) is usually the most important inorganic form of nitrogen because it is an essential nutrient for the growth and reproduction of many algae and other aquatic plants, in addition nitrate is very soluble in water and ammonia, which exists in two forms either as ammonia molecule (NH_3) or as the ammonium ion NH_4+is unwanted in surface water principally because it is toxic to fish even when present in very low concentration .The molecule ammonia (NH_3) is appreciably more toxic than the positively charged ammonium NH_4+. For this reason the molecule ammonia is analyzed for the water samples taken from the lake.

Table 9. Chemical and physical water quality parameters of water samples from Aba Samuel Lake

Sample ID	**Coord. N**	**Coord. E**	**Conductivity** µS/cm	**pH**	**T water (°C)**	**Ammonia** (mg/l of NH_3)	**Nitrate (mg/l)**	**Phosphate (mg/l)**	**Total fecal per 100ml**	**Total coliform per 100ml**
Water sample 1	971311	467507	-	-	-	-	2.28	0.46	-	-
Water sample 2	971093	467623	684	7.2	20.3	-	4.5	0.24	-	-
Water sample 3	971088	467643	693	7.2	21.2	5.96	4.4	0.19	Nil	400
Water sample 4	970923	466915	635	7.3	21.4	2.87	3.23	0.2	-	-
Water sample 5	972209	466904	605	6.91	20.7	3.15	0.81	0.71	Nil	20
Water sample 6	971959	466913	673	7.1	22.7	-	4.7	0.13	-	-

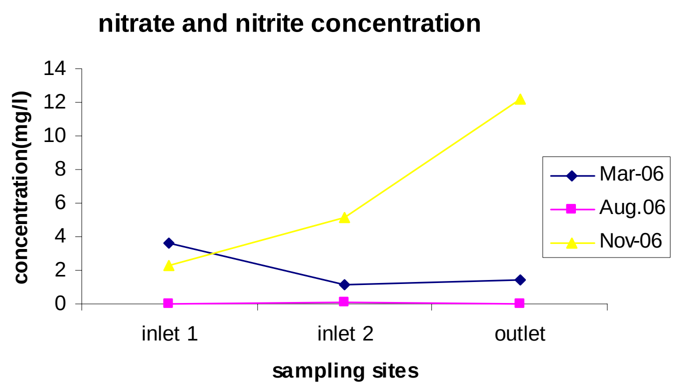
The extent of acidification or alkalinization is important in determining the pollution state of the lake, according to EPA the acceptable pH range for drinking water, is 6 to 9. (Appendix 3).All water samples taken from the lake have pH values with in EPA'S range; accordingly pH value with in the lake is up to standard. The electrical conductivity range for the water samples from the lake is 605 to 693 µS/cm, and EPA'S standard value is 1000 µS/cm.

The average values of nitrate, phosphate and ammonia around the dam (in this study) are 3.32, 0.3 and 4 mg/l, respectively. Nitrate and phosphate amounts are below the standard value set by WHO (Appendix 8), whereas ammonia concentration for all water samples with in the lake is above the standard value. (According to WHO, the standard value for ammonia is 1.5 mg/l.)

4.2.2 Spatial variation of nutrients in Aba Samuel Lake

Knowledge of the spatial distribution of nutrients is important to identify the major sources of nutrients and to understand the process. The water analysis results of nutrients (ammonia, phosphate and nitrate) from the lake show that there is a spatial variation of nutrient concentration where ammonia values are higher at the outlet than in the reservoir while phosphate and nitrate values decrease at the outlet of the artificial lake than in central and inlet point of the lake. The location of emission sources, settling of nutrients along with suspended sediment and possibly the differential up take of nutrients by water hyacinth along the water path in the lake may cause such spatial variation of nutrients in the lake.

The spatial trend observed from primary data is further deep-rooted via secondary data. From figure 12 we clearly see that nitrate and phosphate concentrations decreases from the inlet point to the outlet area. However, ammonia concentration increases at the outlet just after the dam than the inner side of the dam.



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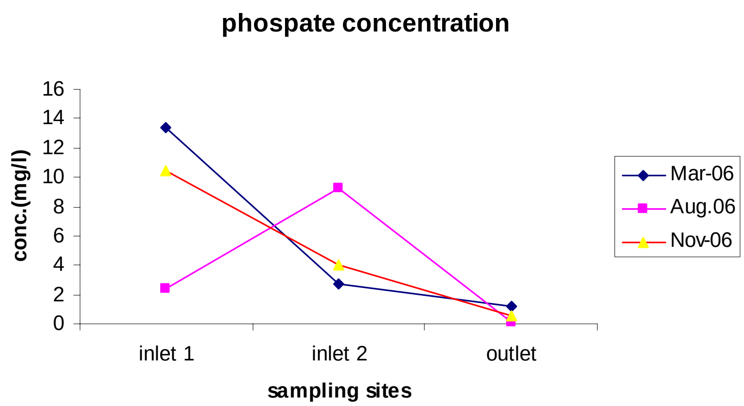

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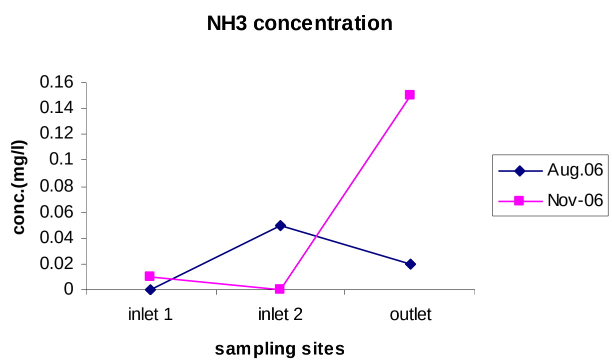


C

Figure 12. The spatial variation of nutrients in Aba Samuel Lake (source EPA, 2006)
1 is Greater Akaki, at the inlet point to Aba Samuel Lake, near Mekane Biruh Vegetable
2 is Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station and
3 is at the outlet point of Aba Samuel Lake
A -Nitrate and nitrite concentration for March, August and November 2006
B-Phosphate concentration for March, August and November 2006
C-Ammonia concentration for August and November 2006

Previously the value of ammonia was higher at the inlet than the outlet in 2002, Table 11. However now a days the case is reversed, according to Tassew (2005), the concentration of NH_3, increased instead of decreasing from the inlet to the outlet of the lake. This is also confirmed from the acquired data which shows higher concentration of ammonia at the outlet than the value obtained with in the reservoir (Table 9).

Due to depletion of DO, anaerobic situation prevails in given water body; the releases of that degradation are ammonia and hydrogen sulfide compounds which are often detected by their foul odor, this might be one possible reason for the observed increasing trend of ammonia concentration towards the outlet of the lake.

4.2.3 Conceptual Model for Nutrient Emission to Aba Samuel Lake

Nutrients occur naturally in soil, animal waste, plant material, and even in the atmosphere. In addition to these natural sources, sewage treatment plants, industries, acid rain, and runoff from agricultural, residential and urban areas contribute nutrients to water body. Generally, nutrient concentrations of water are related to land use in the upstream watershed or to the area adjacent to the water body.

Nutrient concentration in Aba Samuel lake can be attributed to natural run-off of nutrients from the soil and the weathering of rocks, run-off of inorganic fertilizer manure from farm lands, municipal waste water, discharge of partially treated or untreated sewage and industrial inputs and atmospheric deposition through rainfall.

Industries in the upstream part of the watershed emit nutrients that ultimately reach the lake through the Akaki Rivers which serve as receivers of untreated industrial, municipal, clinical and other types of liquid wastes from the city. Table 10 shows the nitrate, pH and sulphate concentrations of industrial discharge from various factories in the city. The table indicates that many of the factories release substantial amount of nitrate which reaches up to 200mg/l and sulphate value from industrial influent reaches up to 1576.25mg/l.

Addis Ababa has an improper sewage system where most of the septic tanks in the city are connected to end up in rivers, which finally flow to the lake. Sewage can, therefore, be an additional source of nitrate to the lake.

Table 10. Pollutants from beverage, chemical, metal, tanneries and textile industries as indicated in the situation analysis report of ESID (2001). Units are in mg/l.

Factory	pH	Nitrate	Sulphate
Awash Winery	7.46	9	40.5
Moha Soft Drinks	12.3	13.5	277.5
St.George Brewery	6.64	1.05	5.95
Gullele Soap	13.5	200	80
Nefas Silk Paint	6.58	23.75	350
Repi Soap	9	7	25
Ethiopia Metal foundry	7.51	11.12	24.2
Kaliti Metal products	8.64	7	87.8
Akaki spare parts	6.47	7.65	25.95
Awash tannery	3.8	6.25	1576.25
Dire Tannery	5.96	375	3276.5
Walia tannery	10.5	17.64	1447
Akaki textile	9.07	50	57.85

Moreover, soil erosion and weathering of rocks potentially contribute for nutrient enrichment in rivers and lakes. For example, erosion from high P soils may be a major contributing factor to surface water nutrient enrichment. Nitrate, phosphate and other organic compounds are some of the possible agricultural chemicals that should be considered as environmental pollutants. Erosional process may wash nutrients from farmland into rivers and lakes. Aba Samuel Lake is surrounded by farmland where use of agricultural chemicals is high. The small streams draining the farmlands directly flow to the lake loaded with agricultural nutrients.

The deposition of airborne nitrogen compounds does not exceed the critical load for nutrient enrichment of soil and water in most parts of the world; however it contributes for the nutrient concentration in water body (David et.al, 1996).

The actual and potential sources of nutrient enrichment in water bodies, specifically in the Aba Samuel Lake are given in a generalized Conceptual model (Figure 13).

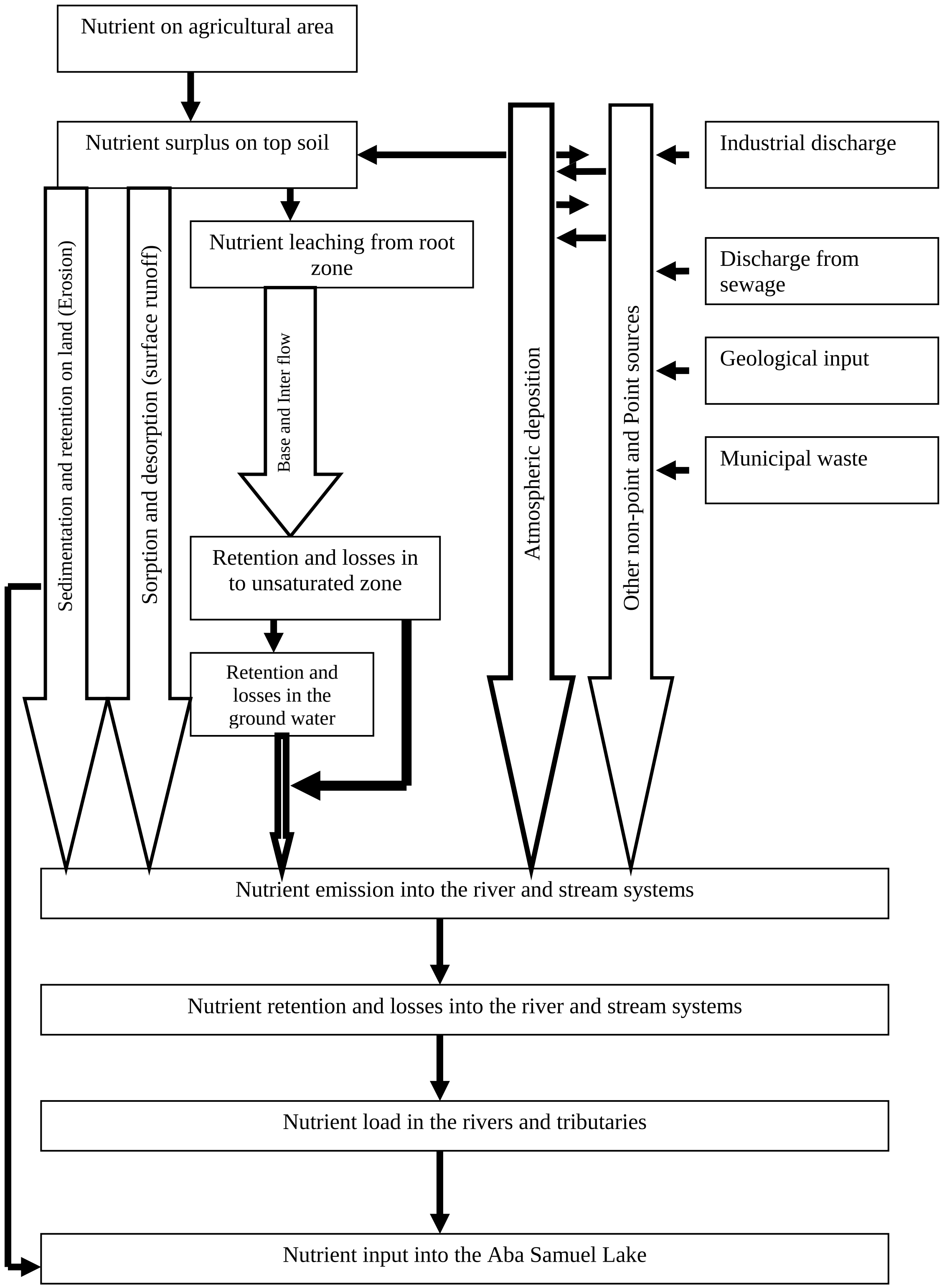


Figure 13.Conceptual model for possible sources of nutrients in Aba Samuel Lake

4.2.4 Nutrient and Eutrophication

Nutrients are lower in the lake water than the expected value. Though, they are adequate enough to support eutrophication process, it has been indicated that lake water concentrations of P above 0.02 ppm generally accelerate eutrophication (David et.al, 1996). These values are an order of magnitude lower than P concentrations in soil solution critical for plant growth (0.2 to 0.3 ppm), emphasizing the disparity between critical lake and soil P concentrations and the importance of controlling P losses to limit eutrophication.

The lower concentration of nutrients in the lake is possibly attributed for many cases like for example; phosphate has a characteristic to adsorb in to fine suspended sediment which then settles out of the water to become streambed sediments. Another possible reason is the uptake of nutrients by water hyacinth which resulted in lower concentration of nutrient in the lake.

4.3 Eutrophication in the Aba Samuel Lake

Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients (carbon, nitrogen, and phosphorus) that stimulate excessive plant growth (algae, periphyton attached algae, and nuisance plants weeds . This enhanced plant growth reduces dissolved oxygen in the water when dead plant material decomposed by decomposers, which in turn, can cause other organisms to die by inhibiting light from penetrating into the water body. Even though, optimum amount of nutrients especially nitrogen and phosphorus are vital for life in rivers and lakes; excessive nutrient load (eutrophication) disturbs the ecological balance. Eutrophication restricts water use for fisheries, recreation, industry, and drinking because of increased growth of undesirable algae and aquatic weeds and the oxygen shortages caused by their death and decomposition.

Nutrient levels in soil and water must not be such that they adversely affect human health, the conditions for biological diversity or the possibility of varied use of land and water. Large part of the Aba Samuel Lake is covered by water hyacinth (*Eichornia*

Crassipes). As a result, dissolved oxygen in the lake is lower, because organisms in the lake acquire dissolved oxygen to decompose died water hyacinth. The dissolved oxygen value in the inlet point of the lake (where water hyacinth covers most of its portion) is generally lower than its value at the outlet point at the tail of the dam (where the water hyacinth does not exist at all). The value of dissolved oxygen shows an increase by about 46% in March (dry season) and 62% in August (rainy season) at the outlet point of the lake (Figure 14).

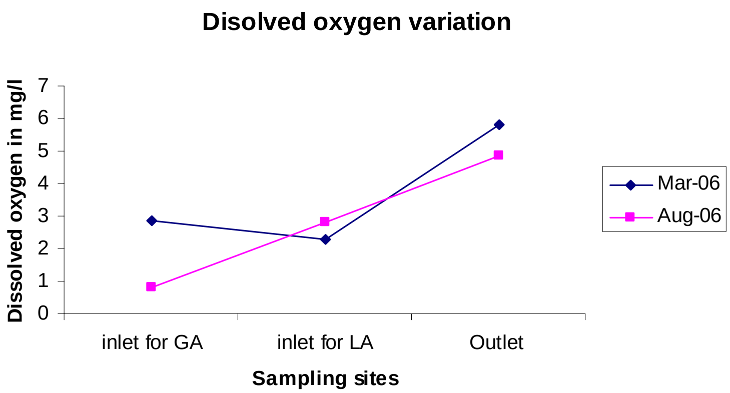


Figure 14. Dissolved oxygen distribution in 2006 for two months March and August, Inlet for GA is Greater Akaki, at the inlet point to Aba Samuel Lake, Inlet for LA is Little Akaki at the inlet point to Aba Samuel Lake and Outlet is Outlet Point of Aba Samuel Lake. (Source EPA, 2007)

Even though, the data is collected from the inlet and outlet point of the lake, the value of dissolved oxygen is expected to be much lower within the lake because water hyacinth covers much of the lake area. When the amount of dissolved oxygen decreases in Aba Samuel Lake the fishing activities decline. The toxic contaminants accumulating in the lake may also affect the fish. The lack of oxygen can cause stress or death in bottom-dwelling organisms that cannot escape to more oxygen-rich areas of the lake.

4.3.1 Water hyacinth

Water hyacinths (*Eichornia Crassipes*) obtain their nutrients directly from the water and have been used in wastewater treatment facilities. They prefer and grow most prolifically in nutrient-enriched waters. New plant populations often form from rooted parent plants and wind movements and currents help contribute to their wide distribution.

Water hyacinth is one of the worst weeds in the world because it greatly reduces biological diversity: mats eliminate native submersed plants by blocking sunlight, alter immersed plant communities by pushing away and crushing them, and also alter animal communities by blocking access to the water and/or eliminating plants the animals depend on for shelter and nesting (Gowanloch, 1944). In general, water hyacinth mats degrade water quality by blocking the air-water interface and greatly reducing oxygen levels in the water, eliminating underwater animals such as fish, it makes boating difficult. The dense floating mats impede water flow and create good breeding conditions for mosquitoes and it makes all other water activates like navigation, recreation, irrigation, and power generation impossible (Penfound & Earle 1948).

Aba Samuel Lake is severely affected by eutrophication. According to Tassew (2005) about 48% (6.35 sq.km of the total 13.2sq.km of the lake surface area) of the lake is covered by water hyacinth (*Eichhornia Crassipes*), a weed which generally grows in lakes, rivers, ponds, and ditches of temperate to tropical climates. It is average height ranges from a few centimeters to over a meter (plate 1).

Plate1. Water hyacinth in Aba Samuel Lake

An acre (4,000 square meters) of water hyacinth can weigh more than 200 tons; and mats may double their size in as little as 6-18 days (Mitchell, 1976).An acre (4,000 square meters) of water hyacinth can weigh more than 200 tons; and mats may double their size in as little as 6-18 days (Mitchell, 1976). Accordingly, it can be estimated that the Aba Samuel Lake hosted more than 317,500 tons of water hyacinth in 2005.

Currently, the weight of water hyacinth is expected to be much higher, as mats may double their size in as little as 6-18 days (Mitchell, 1976). Moreover, under ideal conditions, each plant can produce 248 offspring in 90 days (Matai and Bagchi, 1980).
This is confirmed by the fact that almost all part of the Aba Samuel Lake is covered by water hyacinth (plate 3) In addition, it was identified that one tone of water hyacinth can lose 1437.5 liters of water per day by evapotranspiration, leading to drying of the lake or reservoir in the long run (Zeleke, 1992). This implies that Lake Aba Samuel loses about 456,406,250 liters of water each day due to water hyacinths.

4.3.2 Positive aspect of the water hyacinth

It has been found that water hyacinths are good absorbers of water pollutants. Water hyacinth roots naturally absorb pollutants, including such toxic chemicals as lead, mercury, and strontium, as well as some organic compounds believed to be carcinogenic in concentrations 10,000 times higher than that in the surrounding water (Bioscience, 1976).
The removal of contaminants from water by the *Eichornia Crassipes* is dependent on pH, concentration and temperature. Its minimum growth temperature is 12^{o}C; optimum growth temperature is 25-30^{o}C; and its maximum growth temperature is 33-35^{o}C (Kasselmann, 1995 as it is cited in Hafez et al., 2002).Water hyacinth tolerates an estimated pH of 5.0 to 7.5. However, maximum uptake of ions by the *Eichornia Crassipes* occurs at pH 4 to 6 ± 0.5 at 25±3 °C (Hafez et al., 2002). The pH and temperature in Aba Samuel Lake on average are 7.2 and 21^{o}C, respectively. Accordingly, maximum up take of ions by the water hyacinths is not expected, although the higher temperature conditions during some months may facilitate higher intake of ions.

The hyacinths can also be converted to fertilizer, food, fuel, paper, fiber, and energy. Through an anaerobic fermentation process, polluted hyacinths can be converted to the natural gas methane, although it is costly process (Wolverton, year, as quoted in Bioscience, 1976).

4.3.3 Prevention and Control

Water hyacinth is controlled through a number of methods including harvesting (mechanical control), aquatic herbicides (chemical control) and biological control agents. But the best way to manage water hyacinth is to prevent it from becoming established.

4.3.4 Toxicity

The water hyacinth is generally considered to be a toxic plant as it contains HCN, alkaloid, and triterpenoid, which may induce itching on cattle (as it is commonly observed around the Aba Samuel lake) feeding on them (Perry, 1980). The fresh plants contain prickly crystals as well. The contaminants trapped by the hyacinths (bioaccumulates) may also affect cattle feeding on them, which may eventually transfer to humans.

In general, the water hyacinth is a troublesome aquatic plant. Whatever benefits this plant provides they are greatly overshadowed by the environmental invasiveness of this noxious species. Moreover, the seed of this plant may be transported by water flow downstream affecting river systems, like in this case, the Awash River system.

Plate 2.Aba Samuel Lake covered by water hyacinth

Plate 3. Eutrophication in Aba Samuel Lake

4.3.5 Causes and effects of eutrophication in the Aba Samuel Lake

The enhanced plant growth over Aba Samuel Lake causes many problems including the following:

- According to the local people, fishing activity has declined due to the reduced dissolved oxygen level in the water as a consequence of eutrophication;
- The oxygen shortages cause other aquatic organism to die resulting in decline of the biological diversity in the lake;
- The dense floating mats of water hyacinth over the lake creates good breeding conditions for mosquitoes, which is the major health problem for the local people living in the area;
- Eutrophication restricts water activities in the lake like recreation;
- According to the local population, livestock are dying after feeding on the water hyacinths due to the toxicity of the water hyacinth. This causes a serious economic problem. Furthermore, water hyacinth has contaminant trapping tendency and the bioaccumulated contaminant may transfer to humans from cattle up on feeding on their meat;
- The high water losing (by evapotranspiration) capacity of the water hyacinth facilitating the changing of the lake to a wet land;
- No bird species are observed in the area as a result of eutropication along with the degraded water quality of the lake;
- Any plan of rehabilitation of the lake may be hampered by the thick water hyacinth growth, incurring additional cost of clearing them.

4.4 Biological Test

Microorganisms such as fecal coliform bacteria and total coliform are among the most important water quality indicators. Total and fecal coliform were determined for water samples from the lake.

There are three different groups of coliform bacteria; each has a different level of risk. Total coliform, fecal coliform, and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. The fecal coliform group is a sub-group of total coliform and has fewer kinds of bacteria. E. coli is a sub-group of fecal coliform.

Total coliform and fecal coliform analysis on water samples from the lake (Table 9) shows that fecal coliform is Nil. However, the concentration of total coliform is much higher than the standard set by WHO (1984) and/or MoWR (2002). Though, the sample taken at the outlet of the dam shows a concentration of up to 400 total coliform per 100ml. This is a very large deviation from the standard value which is Nil. When we see the spatial variation of the total coliform their number shows instant increase after the dam. The value of total coliform in the reservoir is 20 per 100ml. Even though it is still higher than the standard value, it is much lower than the value obtained at the outlet. This can be attributed to the fact that dissolved oxygen is more abundant at the outlet than the reservoir body (Figure 14), where the hyacinth consume more dissolved oxygen causing its general decline in the water body, in turn, affecting the growth of the bacteria. In general, as water needs to be free from coliforms which are the main indicators of pathogenic diseases such as Cholera, Typhoid, Hepatitis dysentery and other diarrhoeal related disease, the total coliform count of the lake is significant, the water is not safe to be utilized for domestic purpose.

4.5 Assimilation capacity of the lake

Aba Samuel Lake was served as a sink system for years but currently the lake is losing its absorption capacity due to siltation ,excessive pollutant load and eutrophication problems. For years there where substantial difference of pollutant load at the inlet and the outlet area of the lake while the lake served as purifying system table 11. At present, as it is inferred from table 13 there is no difference as such, between the inlet and outlet value of water quality parameters; even for some parameters like COD higher values are observed at the outlet than the inlet. The COD test measures the oxygen demand of biogradable pollutants plus the oxygen demand of non-biodegradable oxidizable pollutants. In environmental chemistry, the chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water.

Table 11. Dry season chemical analysis results at the inlet and outlet of Aba Samuel Lake (Source EPB, 2002) 1. Henchu Kebele farmers association at the inlet point to the catchment area of the Aba Samuel dam. 2. Dewera Tino Kebele farmers association at the out let just after Aba Samuel Dam

Samp. site	Date	COD mg/l	BOD mg/l	DO mg/l	Alkalinity mg/l	Total hardness mg/l	Chloride mg/l	SO_4 mg/l	PO_4 mg/l	NH_3 mg/l	NO_2 mg/l	NO_3 mg/l	H_2S mg/l
1	04/04/97	209	32	Nil	382	258	142.5	40	21.2	57	Nil	Nil	0.07
2	04/04/97	17	20	6.7	226	204	57.5	Nil	0.624	0.662	Nil	Nil	0.004

Table 12. Some of water quality parameters at the inlet and outlet of Aba Samuel Lake (Source EPA, 2005). All units are in mg/l

S.No.	**Sampling Site**	DO_2	**Po_4^{3-}**	**SO_4^{2-}**	**Cl^-**	**NO_2^-, NO_3-**	**COD**
3	Greater Akaki, at the inlet point to Aba Samuel Lake, near Mekane Biruh Vegetable	2.84	2.67	8	31	1.1	44
4	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	2.3	13.4	14	124	3.6	116
5	Outlet point of Aba Samuel Lake	5.8	1.23	35	64	1.4	33

Table 13. Some of water quality parameters at the inlet and outlet of Aba Samuel Lake (Source EPA, 2006). All units are in mg/l

S.No.	**Sampling Site**	DO_2	NH_3	**Po_4^{3-}**	**SO_4^{2-}**	**Cl^-**	**COD**
1	Greater Akaki, at the inlet point to Aba Samuel Lake, near Mekane Biruh Vegetable	-	Nil	4	4	83	13
2	Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station	-	0.01	10.5	65	373	128
3	Outlet point of Aba Samuel Lake	-	0.15	0.5	20	170	190

Comparison has been done for the dry season chemical analysis of COD value for year 2002, 2005 and 2006 at the inlet and outlet of Aba Samuel Lake. Graphically the COD variation at the inlet and outlet is represented as;

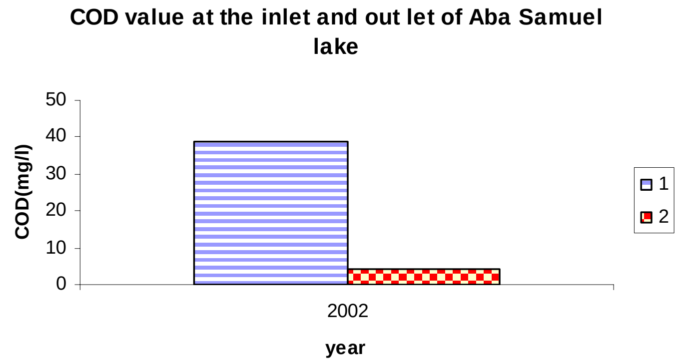
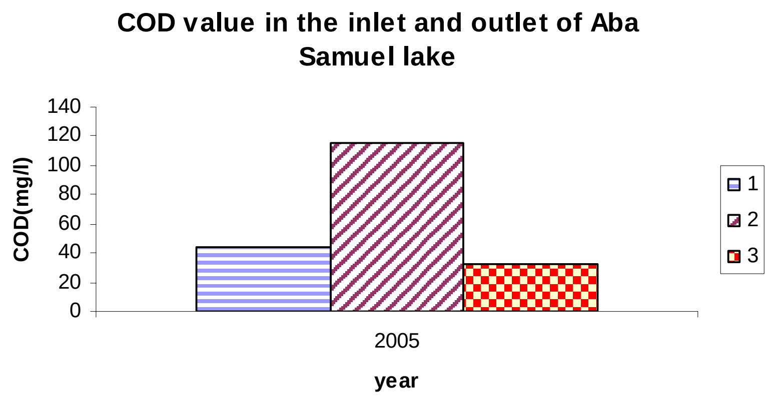


Figure 15. COD value in 2002 at the inlet and outlet Point of Aba Samuel Lake, 1 is at the inlet point and 2 is at the out let



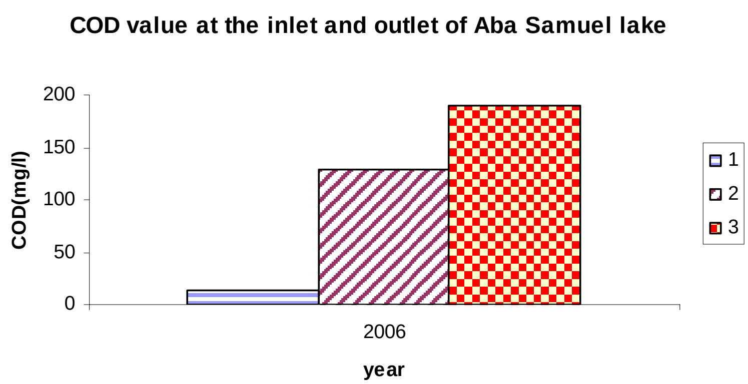


Figure 16. **COD** value in 2005 and 2006 at the inlet and outlet Point of Aba Samuel Lake, 1 is Greater Akaki, at the inlet point to Aba Samuel Lake, near Mekane Biruh Vegetable,**2 is** Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station and **3** is Outlet point of Aba Samuel Lake

In year 2002, according to the data from EPA the inlet value of COD was 209 mg/l and at the outlet the COD value became 17 mg/l ,this is 8 % of the inlet value (Figure 15), whereas, when we see COD values for year 2005 and 2006 the case is quite different, for year 2005 the COD value of little Akaki at the inlet of Aba Samuel was 116mg/l and the value obtained at the outlet was 33 mg/l which means the value obtained at the outlet is 29 % of the value acquired at the inlet .

And in year 2006 the case reversed, the outlet value is higher than the inlet value by 32% and 93% for Little Akaki at the inlet point of the lake and Great Akaki at the inlet point of the lake respectively (Figure 16).

In general, COD value at the outlet is getting higher and higher than the inlet value from year to year. That is to say; spatially the organic pollutant (since COD value is the indirect measure of organic pollutants concentration) is getting higher towards the outlet of the lake. If the value at the inlet and outlet is the same or have no difference as such it means the pollutant load which gets in to the lake is getting out with out being purified in the lake but when the outlet value is higher than the inlet value it is evidenced for; other source of organic pollutant in the lake .Consequently, the possible organic source in the lake is water hyacinth, when these plants die they add organic pollutant load for the lake.

And also when organisms in the lake die; due to low DO as a result of eutrophication or due to a change in physical parameters of the lake or any other reason, they add organic pollutant load to the lake.

In general, almost all water quality parameters have the same general trend (Table 13), there is no difference as such between the inlet and outlet area values and even for some parameters (like COD) the outlet concentration is higher than the inlet and this reveals that the lake cannot undergo oxidation, rather the water which flows in to the lake leaches the surrounding immediately gets out through the outlet channel.

Previously, Aba Samuel lake was acting as a oxidizing environment but at the present the lake is becoming a reducing environment, one characterized by little or no free oxygen (dissolved or as a gas). The lake was served in minimizing the pollution load before joining the Awash River earlier however due to its current condition it is losing its absorption capacity.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This work has shown the potential of applying the study of heavy metal analysis in sediment cores for understanding the historical trends of sedimentation and pollution for the studied reservoir. An estimate of sedimentation rate was made and indicates ranges expected in reservoirs. In most cases the heavy metal concentrations were below the standard, but the increasing trend with time indicates, this can shortly be surpassed. Because of this situation the study indicates that anthropogenic sources are putting their signature over the natural background. High sediment and nutrient inputs into the lake from various suggested sources led the lake to be transformed into a swamp in which water hyacinth proliferate depleting dissolved oxygen and degrading the system.

For the soil sample taken from a nearby farmland the value of Cu, Pb, Zn and Cr are below the standard value set by EPA, where as Cd and Ni are higher than the standard value.

Eutrophication in Aba Samuel Lake restricts water use for fisheries, recreation, and drinking because of increased growth of undesirable aquatic weeds and the oxygen shortage caused by their death and decomposition.

In the lake, fecal coliform is Nil; however the concentration of total coliform is much higher than the standard set by WHO and/or EPA. Especially for the water sample taken at the outlet of the dam the concentration reaches up to 400 total coliform per 100ml.

In general, the major problems observed and investigated in the Aba Samuel lake are eutrophication (nutrient pollution), siltation (high rate of sediment deposition) and pollution by inorganic species (like trace metals, and other inorganic specious like SO_4^-, Cl^-, F^-). The lake is losing its ecological imbalance due to the above mentioned problems; and the indirectly determined organic pollutant load.

5.2 Recommendation

Scientifically there is a need to obtain a complete sequence of the record indicating changes over the span of the reservoir age and integrate this information with all potential sources in order to link source and sink in time.

For practical purposes of combating pollution the following will be necessary

- Reducing waste water discharge in the nearby streams or rivers has to get attention.
- Establishing water quality monitoring database system is essential
- Promoting environmental education and public participation is needed in order to develop environmentally responsible behavior
- strengthening research on water pollution and its effects is vital for better understanding of the case
- providing safe drinking water for the population around the Aba Samuel lake is the first action to be taken
- Controlling siltation problem of the lake by conducting appropriate water shade management.
- Maintain appropriate retention time of the lake water for effective oxidation and sedimentation processes to protect the lower catchments of Akaki Rivers below the dam, from toxic heavy metals and element pollution.
- For the time being encourage the dam area community to harvest rain water at least for their animals and other domestic purposes since the pollutant load is higher especially in the wet seasons.
- Controlling the growth of water hyacinth is necessary; and water hyacinth should never be deliberately introduced to lakes, rivers, streams, or drainage ditches in any parts of the country.
- Along the lake courses it is advisable to produce pondscaping zones to minimize the erosional problem which comes from the farm land in adjacent side of the lake.
- Monitoring new contaminants
- Rehabilitate the lake for recreational purposes

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Appendix

Appendix 1 ABA SAMUEL LAKE LEVEL(m) (SOURCE ,MoWR)

Year: 1998

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean			0.352	0.373	0.385	0.581	2.454	2.783	1.303	0.888	0.761	0.455
maximum			0.38	0.38	0.42	1.04	2.97	3.28	1.7	1.8	0.86	0.65
minimum			0.33	0.37	0.35	0.42	1.15	1.82	1	0.66	0.65	0.44

Year: 1999

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	0.445	0.451	0.437	0.39	0.3	0.374	1.023	2.077	1.257	0.91	0.602	0.513
maximum	0.45	0.485	0.46	0.43	0.34	0.4	2.05	4	2.22	1.35	0.74	0.53
minimum	0.44	0.44	0.43	0.27	0.24	0.34	0.39	1.12	0.69	0.74	0.5	0.49

Year: 2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	0.487	0.473	0.298	0.367	0.406	0.398	0.794	1.574	1.478	0.86	0.58	0.551
maximum	0.499	0.53	0.44	0.51	0.51	0.44	1.78	2.4	2.35	1.39	0.61	0.57
minimum	0.47	0.45	0.27	0.24	0.39	0.39	0.4	1	1	0.55	0.55	0.54

Year: 2001

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	0.539	0.491	0.431	0.51	0.525	0.593	1.59	2.041	1.395	0.678	0.667	0.385
maximum	0.54	0.53	0.51	0.52	0.54	0.82	2.21	2.38	1.84	0.72	0.69	0.57
minimum	0.53	0.32	0.28	0.5	0.5	0.53	0.7	1.64	0.8	0.67	0.63	0.35

Year: 2002

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	0.383	0.337	0.56	0.475	0.418	0.491	0.709	1.24	1.041	0.708	0.658	0.35
maximum	0.46	0.43	0.56	0.56	0.45	0.6	1.06	1.47	1.24	0.71	0.7	0.35
minimum	0.34	0.31	0.56	0.44	0.4	0.4	0.6	1.09	0.71	0.7	0.35	0.35

Year: 2003

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	0.321	0.316	0.354	0.427	0.416	0.446	0.848	1.465	1.14	0.67	0.652	0.404
maximum	0.35	0.4	0.45	0.58	0.59	0.62	1.2	2.03	1.75	0.7	0.68	0.57
minimum	0.31	0.25	0.27	0.27	0.32	0.3	0.57	1.16	0.7	0.62	0.57	0.3

Year: 2004

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	0.33	0.288	0.288	0.489	0.503	0.39	0.736	1.317	1.014	0.702	0.722	0.469
maximum	0.37	0.37	0.36	0.54	0.54	0.48	1.15	1.42	1.27	0.72	0.73	0.67
minimum	0.31	0.25	0.25	0.36	0.36	0.36	0.45	1.18	0.74	0.68	0.68	0.3

Year: 2005

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean	0.315	0.336	0.341	0.353	0.575	0.636	1.463	2.026	1.181	0.724	0.689	0.371
maximum	0.35	0.34	0.36	0.39	0.74	0.7	2.35	2.95	1.98	0.8	0.7	0.48
minimum	0.3	0.32	0.34	0.34	0.39	0.63	0.7	1.5	0.75	0.7	0.54	0.35

Appendix 2 <u>Guideline Soil Quality Standards.</u>

Substance	**Guideline Standard (mg/kg dry weight)**
Acetone	8
Arsenic	20[1(2)]
Cadmium	0.5[2]
Chloroform	50[2]
Chromium, total	500
Chromium (VI)	20
Copper	500[1]
Cyanide, total	500
Fluorides, inorganic	20[1]
Lead	40[2]
Mercury	1
Molybdenum	5
Nickel	30[1]
PAH, total	1.5[2,3]
Benzo(a)pyrene	0.1[2]
Tetrachloromethane	5[2]
1,1,1-trichloroethane	200[2]
Trichloroethylene	5[2]
Vinyl chloride	0.4[2]
Zinc	500

[1]: Based on acute harmful effects

[2]: Based on chronic harmful effects

[3]PAH, total defined as the sum of individual components: fluoranthene, benzyl(b+j+k)fluoranthene, benzyl(a)pyrene, dibenzyl(a,h)anthracene, and ideno(1,2,3-cd)pyrene.

Appendix 3 Guideline Surface Water Quality Standards	
Guideline standards for priority surface water pollutants with regard to protection of aquatic species are given below.	
Compound	**Limit**
Aluminium	200 µg/l Al;
Ammonium	20 µg/l NH_3 un-ionised
	25 µg/l NH_3 un-ionised
Antimony	20 µg/l Sb
Arsenic	50 µg/l As
Barium	100 µg/l Ba
Benzene	10.0 µg/l
BOD_5 [Biochemical oxygen demand]	≤ 5 mg/l O_2
Cadmium	5.0 µg/l Cd [Total];
Chloride	250 mg/l Cl
Chlorine, Residual	5 µg/l as HOCl
Chromium	50 µg/l Cr
Conductivity	1000 µS/Cm (@ 20 °C)
Copper	5-112 µg/l dissolved Cu for hardness range 10-500 mg/l $CaCO_3$
Cyanide	50 µg/l CN
Dissolved oxygen	Game Fish - 50% samples ≥ 9 mg/l O_2[minimum 6 mg/l O_2]
	Course Fish - 50% samples ≥ 7 mg/l O_2[minimum 4 mg/l O_2]
Fluoride	1.0 mg/l F
Iron	1.0 mg/l dissolved Fe
Lead	50 µg/l Pb
Manganese	300 µg/l Mn
Mercury	1 µg/l Hg
Nickel	100 µg/l Ni AM
Nitrate	50 mg/l NO_3
Nitrite	Game Fish - 200 µg/l NO_2
	Course Fish - 400 µg/l NO_2
Nitrogen, Kjeldahl	2 mg/l N

PCBs and PCTs	1 μg/l AM
pH	6 to 9, but no change more than 0.2 units from natural level in 95% of samples
Selenium	10 μg/l Se
Silver	10 μg/l Ag
Total Suspended Solids,	≤ 25 mg/l [annual mean]
	50 mg/l [maximum value]
Sulphate	200 mg/l SO_4
Temperature	Game Fish - Discharge must not result in variation of more than 1.5^{o}C; temperature down stream of thermal discharge
	Course Fish - Discharge must not result in variation of more than 3^{o}C; temperature down stream of thermal discharge
Thallium	5 μg/l Tl AM
Uranium	20 μg/l U AM
Vinyl chloride	10 μg/l AM
Zinc	30 μg/l to 500 μg/l Zn @ hardness 10 to 500 mg/l

Appendix 4 Monthly rainfall

Element: Monthly Rainfall — Lat $08^{o}.52'$ — Altitude 2120mt

Region: SHOA — Long. $38^{o}.48'$

Station: AKAKI MISSION

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	0.0	0.0	3.8	107.2	58.5	175.2	347.2	308.3	281.6	19.9	0.0	0.0
1976	0.0	17.0	19.5	92.0	93.8	195.3	282.4	325.3	83.6	7.0	46.6	0.5
1977	80.5	29.9	80.8	67.4	108.2	158.0	289.7	329.4	108.4	225.7	5.0	0.0
1978	2.4	84.4	60.7	50.4	39.7	153.8	150.6	328.2	194.6	45.5	0.0	0.0
1979	106.4	28.2	107.6	57.6	122.0	75.9	243.2	241.4	96.5	13.0	0.0	4.0
1980	28.5	36.8	54.7	55.8	56.8	111.8	381.5	364.4	64.4	13.1	0.0	0.0
1981	0.0	13.3	179.8	143.9	1.3	46.2	402.6	186.5	219.0	5.0	0.0	0.0
1982	12.1	35.4	39.5	94.6	75.2	63.5	199.6	275.1	124.2	25.8	11.0	8.1
1983	1.8	33.3	15.0	147.3	175.0	83.0	278.0	275.0	138.7	9.2	0.0	0.0
1984	0.0	0.0	40.4	5.1	130.0	215.3	277.9	227.1	57.2	0.0	0.0	1.9
1985	3.6	0.0	32.4	71.8	96.6	96.5	294.0	324.1	164.3	1.6	0.0	0.0
1986	0.0	95.4	66.9	148.7	68.2	143.4	189.4	216.5	86.1	9.4	0.0	0.0
1987	0.0	65.6	181.9	80.7	187.7	69.3	202.0	246.9	81.7	4.4	0.0	0.0
1988	0.0	44.5	0.0	96.0	23.8	124.6	255.9	278.1	254.2	35.4	0.0	0.0
1989	2.1	63.8	53.8	226.3	7.1	58.6	264.2	301.0	170.9	37.9	0.0	0.0
1990	7.7	120.6	48.4	129.4	37.8	78.9	280.7	222.9	117.3	5.8	1.2	0.0
1991	0.0	37.6	62.4	11.6	45.6	90.4	263.7	308.5	113.4	4.4	0.0	56.5
1992	34.7	24.2	30.5	15.5	25.6	100.4	218.4	276.0	86.7	43.3	0.2	0.0
1993	1.2	53.9	5.6	118.4	62.5	116.5	218.0	251.5	118.3	20.5	0.0	0.0
1994	0.0	0.0	62.7	72.2	20.2	125.0	225.1	168.9	106.8	X	11.0	0.0
1995	0.0	25.4	63.7	102.1	20.9	95.7	269.2	242.3	79.5	0.0	0.0	4.8
1996	15.3	0.3	79.7	38.8	90.5	240.1	292.5	234.1	119.0	1.9	0.0	0.0
1997	27.6	0.0	29.5	102.7	25.2	57.0	203.6	203.4	82.5	114.9	10.3	0.0
1998	32.7	30.2	19.6	69.3	159.9	116.9	207.8	280.0	118.5	36.0	0.0	0.0
1999	1.3	1.8	91.8	12.1	44.7	92.8	282.6	300.7	61.7	65.0	0.0	0.0
2000	0.0	0.0	29.1	93.0	64.9	100.1	188.9	210.0	124.1	X	23.4	3.8
2001	0.0	20.7	121.2	23.6	118.0	142.6	257.5	145.0	64.9	2.2	0.0	0.0
2002	31.1	10.5	87.1	82.4	76.6	108.0	167.3	187.0	52.4	0.6	0.0	17.7
2003	19.6	24.3	23.9	114.0	2.9	125.4	325.1	307.4	112.4	0.0	1.9	0.0
2004	13.6	15.8	62.4	154.2	15.4	95.2	177.7	189.1	80.9	4.8	3.4	0
2005	31.4	7.3	33.9	119.0	140.7	139.9	234.8	231.0	149.7	9.1	15.2	0.0

Appendix 5. Physical and Chemical water quality parameters ,Source EPA

Year 1997 Ethiopian Calender,Aug

Sampling Site	easting	northing	elevation(m)	pH	EC	DO_2	Tem.(^{O}c)	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- , NO_3-	Pb	Cr	COD
1	38° 46.671	08⁰ 51.830	2053	7.05	366	4.56	20	-	-	9	16.69	14.52	2.5	Nil	Nil	14
2	38° 44.745	08⁰ 51.94	2060	7.66	487	3.23	19.8	-	-	38	39.05	9.18	3	Nil	0.02	25
3		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

November 1997 EC

Sampling Site	easting	northing	elevation(m)	pH	EC	DO_2	Tem.(^{O}c)	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- , NO_3-	Pb	Cr	COD
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	8.17	1447.8	-	-	-	-	390	310	-	15.6	-	-	34

March 1997 EC

Sampling Site	easting	northing	elevation(m)	pH	EC	DO_2	Tem.(^{O}c)	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- , NO_3-	Pb	Cr	COD
1	038° 45.611	08° 49.311	2052	6.85	570	2.84	22.8	5	2.67	8	31	0.28	1.1	Nil	Nil	44
2	038° 44.706	08° 51.966	2054	7.8	1416	2.3	23.5	25.9	13.4	14	124	0.85	3.6	Nil	Nil	116
3	38° 42.390	8° 47.245	2029	7.78	795	5.8	20.5	1.36	1.23	35	64	0.4	1.4	Nil	Nil	33

August 1998 Ethiopian Calender

Sampling Site	easting	northing	elevation(m)	pH	EC	DO_2	Tem.(^{O}c)	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- , NO_3-	Pb	Cr	COD
1	38° 45.152	8° 52.499	2060	7.5	1175	0.79	20.8	0.05	9.3	40	442	0.38	0.05	Nil	0.03	106
2	38° 46.917	8° 51.092	2048	6.73	624	2.82	20.3	Nil	2.43	8	77	0.61	Nil	Nil	Nil	3
3	38° 42.506	8° 47.210	2032	5.79	428	4.84	18.8	0.02	0.15	15	70	0.66	0.02	Nil	Nil	Nil

Noveber 1998 Ethiopian Calender

Sampling Site	easting	northing	elevation(m)	pH	EC	DO_2	Tem.(^{O}c)	NH_3	Po_4^{3-}	SO_4^{2-}	Cl^-	F^-	NO_2^- , NO_3-	Pb	Cr	COD
1	38° 46.688	08° 51,817	2055	7	638	-	-	Nil	4	4	83	0.6	5.1	Nil	-	13
2	38° 45.191	08° 52.48	2058	7.57	1550	-	-	0.01	10.5	65	373	0.48	2.3	Nil	-	128
3	039° 42.425	08° 47.260	2033	7.48	916	-	-	0.15	0.5	20	170	0.54	12.2	Nil	-	190

1 Greater Akaki, at the inlet point to Aba Samuel Lake, near Mekane Biruh Vegetable

2 Little Akaki at the inlet point to Aba Samuel Lake near by the EEPC Station

3 Outlet point of Aba Samuel Lake

Appendix 6 Sediment core samples

Sample ID	Date of sampling	Time	Sampling site	Sampling method	Coord. N	Coord. E	Elevation (m)	Sediment core height during sampling (cm)	T Air (°C)
Sediment core 1	6/9/99 EC	11:15pm	At the inner side of the dam	Penetrating to the depth using tube	971311	467507	2049	44	-
Sediment core 2	20/9/99 EC	6:45am	At Western side of the Lake	Penetrating to the depth using tube	972209	466904	2048	49	30

Appendix 7 Recommended sediment quality guideline values for metals and associated levels of concern to be used in doing assessments of sediment quality

Metal	mg/kg dry wt.++						
	Level 1 Concern ≤ TEC	TEC	Level 2 Concern > TEC ≤ MEC	MEC	Level 3 Concern > MEC ≤ PEC	PEC	Level 4 Concern > PEC
Antimony	⇦	2	⇔	13.5	⇔	25	⇨
Arsenic	⇦	9.8	⇔	21.4	⇔	33	⇨
Cadmium	⇦	0.99	⇔	3.0	⇔	5.0	⇨
Chromium	⇦	43	⇔	76.5	⇔	110	⇨
Copper	⇦	32	⇔	91	⇔	150	⇨
Iron	⇦	20,000	⇔	30,000	⇔	40,000	⇨
Lead	⇦	36	⇔	83	⇔	130	⇨
Manganese	⇦	460	⇔	780	⇔	1,100	⇨
Mercury	⇦	0.18	⇔	0.64	⇔	1.1	⇨
Nickel	⇦	23	⇔	36	⇔	49	⇨
Silver	⇦	1.6	⇔	1.9	⇔	2.2	⇨
Zinc	⇦	120	⇔	290	⇔	460	⇨

TEC- **Threshold Effect Concentration**
MEC- **Midpoint Effect Concentration**
PEC- **Probable Effect Concentration**

Developed by the Wisconsin Department of Natural Resources, Washington, December 2003

Appendix 8 STANDARDS & GUIDELINES OF DRINKING WATER QUALITY

WATER QUALITY PARAMETERS	GUIDELINES			
	WHO	EU	MoWR	AAWSA
1. Inorganic (mg/l)				
pH	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
Color (TU)	15	20	21.71	15
Turbidity(NTU)	5		7	
TDS	1000	500	2175.99	1000
Total alkalinity (as $CaCO_{3)}$	500			500
Total hardness (as Ca CO_3)	300		392	500
Calcium hardness(as Ca CO3)	300			500
Sodium (Na)	200	150	357053	200
Potassium (K)	10			
Calcium (Ca)	100			
Magnesium (Mg)	30			
Chloride (Cl^-)	250	25	532.67	250
Sulfate ($SO_4^{-2)}$	250	250	482.69	250
Fluride (@ 25 ºC)	1.6	1.5	3.02	1.6
Nitrate (NO_3^-)	50	50	130.57	50
Nitrite (NO_2^-)	3	0.1	7.52	
Ammonia (NH_3^+)	1.5		2.08	1.5
Sulfide (H_2S)	0.05		0.07	
Aluminum (Al)	0.2	0.2	0.43	0.2
Arsenic (As)	0.05	0.05		0.1
Barium (Ba)	0.7	1	1.8	
Boron (B)	0.3		0.3	
Cadmium (Cd)	0.005	0.005	0.003	0.003
Chromium (Cr)	0.05	0.05	0.1	0.05
Copper (Cu)	1	0.1-0.3	1.93	1
Cyanide (CN^-)	0.1	0.05		0.07
Iron (Fe)	0.3	0.2	0.38	0.3
Lead (Pb)	0.01	0.05	0.02	0.01
Manganese (Mn)	0.1	0.05	0.13	0.5
Mercury (Hg) total	0.001	0.001		0.001
Nickel (Ni)	0.02	0.05		0.02
Selenium (Se)	0.01		0.01	
Zink (Zn)	5	0.1 - 5.0	6.05	3
2. Microbiology				
E. Coli/100ml	0	0	0	0
Total coliform/100ml	0	0	0	0

WHO, 1984
MoWR, 2002

AAWSA= Addis Ababa Water & Sewerage Authority
EU= European Union

Appendix 9 Soil sample from farm land adjacent to Aba Samuel lake

Sample ID	**Date of sampling**	**Time**	**Sampling site**	**Sampling method**	**Coord.**	**Elevation**	**T Air (^oC)**	**T soil (^oC)**
					E	**(m)**		
Soil sample 1	20/9/99EC	7:20pm	Western side of the lake from the farm land	Surface	466841	2056	27	22.8

Declaration

I, the undersigned person, declare that this thesis is my original work, has not been presented for a degree in any other university and that all sources of materials used for the thesis have been duly acknowledged.

Name:	Feven Solomon
Signature:	----------------------
Date of submission:	August 2007