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Assessment of the Ecological Condition of Aba Samuel Reservoir Using Water Quality and Trophic Status Indices

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA:	American Public Health Association
Chl *a*:	Chlorophyll a
CFU	Colony Forming Unit
DO:	Dissolved Oxygen
FC:	Fecal Coliforms
NH_{4}-N:	Ammonium
NO_{3}- N:	Nitrate
NSFWQI:	National Sanitation Foundation Water Quality Index
NTU:	Nephelometric turbidity units
RDA:	Redundancy analysis
rmp	Revolution per minute
SRP:	Soluble reactive phosphate
TDS:	Total Dissolved Solid
TP:	Total Phosphorus
TSI:	Trophic State Index
TSS:	Total Suspended Solid
WHO	World Health Organization
WQI:	Water Quality Index

ABSTRACT

Aba Samuel Reservoir (ASR) has been degraded by various types of environmental pollution released from domestic, industrial and agricultural activities. This research aimed at evaluating the ecological condition of ASR using water quality and trophic status indices. *In situ* measurements of physicochemical parameters (DO, Temperature, EC, and pH) were taken from five sampling sites using portable Multimeter. The major inorganic nutrients (NO_3-N, NO_2-N, NH_4, PO_4, and TP) were analyzed in the limnology laboratory using APHA methods and microbial analyzed in biomedical laboratory at AAU. Relationships between plankton and environmental variables were analyzed using Principal Component Analysis (CANOCO for Windows 4.5). Water quality indices of ASR calculated using National Sanitation Foundation Water Quality Index (NSFWQI) had overall mean $\pm$ SE values of turbidity (105.94 + 39.27 NTU), TSS (745.73 $\pm$ 222.74 mg L^{-1}), pH (7.96 $\pm$ 0.049), Temp. (21.9015 $\pm$ 0.29 °C), DO (3.4615 + 0.25 mg L^{-1}), NO_3- N (0.25 $\pm$ 0.015 mg L^{-1}), TP (0.12 $\pm$ 0.008 mg L^{-1}) and FC (225 CFU 100 mL^{-1}). According to NSFWQI, bad ecological condition of 37.14, WQI was calculated for ASR recorded from all sampling sites. Trophic status index was calculated by Lamparelli (2004) and Cunha *et al*., (2013) methods proposed for tropical environments. The overall mean phytoplankton biomass as chlorophyll *a* was (Chl *a*, 15.08 $\pm$ 0.94 µg L^{-1}) and Total phosphorus (62.92 $\pm$ 0.42 µg L^{-1}). Overall ASR WQI is poor and TSI (56.81 – 61.80) state that sites has TSI values ranging from eutrophic to supereutrophic and that the overall TSI is in the eutrophic category. Lack of industrial and municipal wastewater treatment plants of the Addis Ababa towns and cities in the basin has caused serious pollution to Aba Samuel Reservoir.

Keywords: Aba Samuel Reservoir, NSFWQI, Lamparelli, Water quality index, Trophic status index.

1. INTRODUCTION

Water is a crucial prime natural resource and vital to the existence of all living organisms. Fresh water is finite resource, essential for agriculture, industry, fishery, recreation and even human existence, without fresh water of adequate quantity and quality, sustainable development will not be possible (UN-Water, 2016).

Reservoirs are one source of freshwater used for municipal water supply, electrical power generation and other ecosystem services (Nigatu Ebisa, 2010; UN-Water, 2016). However, the availability and quality of surface or ground water have been deteriorated predominantly due to anthropogenic sources including rapidly population growth, agricultural, uncontrolled municipal and industrial waste disposal (Habtamu Haile, 2007; Shaka Nugusu, 2015). Water quality deterioration in reservoirs usually comes from excessive nutrient inputs, heavy metal contamination, organic pollution and obnoxious fishing practices (WHO, 2001, Keke, 2008).

Pollution is strongly linked to economic development with population growth and the expansion of agriculture, industry and energy production all in turn producing wastewater, much of which goes into surface and groundwater bodies uncontrolled or untreated (UN-Water, 2016).

In developing countries, such as in Latin America, Africa and Asia economic and demographic changes have been triggering an increase in water pollution, posing a risk to public health, food security, biodiversity and other ecosystem services. Major pollutants include nutrients, heavy metals, organic pollutants and micro-pollutants found in wastes and wastewater from humans and economic activities such as agriculture, industry and other sectors such as pharmacy. Indeed untreated wastewater is one of the biggest sources of water pollution. Globally, up to 90% of wastewater is dumped into water bodies untreated (UN-Water, 2016).

Ethiopia has rich inland water resources, consisting of both natural water bodies such as rivers and lakes and man-made reservoirs, which may provide admirable opportunities for comparative limnology owing to the considerable variations in their morphometric, physical and chemical features. Most cities and towns are established nearby aquatic ecosystems. Thus, water pollution is high due to domestic and industrial wastes originating from human activities (Nigatu Ebisa, 2010).

Among the reservoirs, Aba Samuel Reservoir is one of the first hydroelectric power generating stations in Ethiopia. It is located some 44 km away from the capital and its water quality is deteriorating due to rapid growth of human population, uncontrolled urbanization and inadequate sanitation infrastructure systems in Addis Ababa and surrounding area. Both Little Akaki and Big Akaki Rivers drain to Aba Samuel Reservoir, bringing a lot of urban wastes. Little Akaki River is the most polluted river because it is surrounded by industries and largest market of the country (Hamere Yohannes and Eyasu Elias, 2017). The reservoir was rehabilitated in recent years, after long years of closure due to fill-up with water hyacinth debris and silt. However, the water is used for irrigation purpose and small fishery activities.

Although there are studies on hydrogeology, temporal and spatial water quality analysis using sediment and effect of water hyacinth (Eshetu Gizaw *et al.*, 2004; Feven Solomon 2007; Abraham Hailemelekot, 2009). Ecological condition of Aba Samuel Reservoir using water quality and trophic status indices has not been attempted.

Water quality is a prerequisite for sustainable water and sanitation in sustainable development goal. Water quality and human health are closely related, and thus water analysis before any usage is of prime importance. Certain physical, chemical and microbiological standards, which are designed to ensure that the water is palatable safe for drinking and agricultural purpose, should be met before it can be described for the intended use (Shubhanath, 2012).

Water Quality Index (WQI) is a useful statistical tool for simplifying, reporting and interpreting complex information obtained from aquatic ecosystems. A simple number given by any WQI model explains the level of water contamination through fecal coliform bacteria, sediment and nutrient measures (Feven Solomon, 2007, Rubio-Arias, 2012). WQI indicates the quality of water in terms of index number which represents overall quality of water for any intended use.

WQI can be used to monitor water quality changes in a particular water supply over time or it can be used to compare water supply's quality with other water supplies in a region or from around the world (Srivastava and Kumar, 2013).

In parallel, the term trophic state (oligotrophic, mesotrophic, eutrophic, hypereutrophic) and trophic status indices (TSI) describe the level of eutrophication. The fertility level of a reservoir can be calculated based on several influential parameters in accordance with the trophic status index (Marselina and Burhanudin, 2017).

Trophic state indices provide an insight on how nutrient and light availability controls phytoplankton development (Cunha *et al*., 2013). It is an important property of the aquatic ecosystems it reflects the anthropogenic influence on water quality and the ecological functioning of rivers, lakes and reservoirs.

The index can be used as a predictive tool in freshwater-management programs (Carlson, 1977). Carlson's Trophic State Index is a common method for characterizing a lake's trophic state or overall health. A trophic state index for temperate lakes was proposed by Carlson (1977) considering empirical relationships among Chl *a*, total phosphorus (TP) and Secchi disk depth (Z_{SD}). But TSI and trophic boundaries established for temperate systems (Carlson 1977) are not suitable for tropical and subtropical waters because they may overestimate the effects of nutrient enrichment (Lamparelli 2004, Cunha *et al*., 2013). Thus, we used an adaptation of Carlson's (1977) TSI index for tropical environments proposed by Lamparelli (2004). The method is still based on the concentrations of TP and Chl *a*.

To provide the ecosystem services for the intended purpose, water quality monitoring of the reservoir is an important activity that can be assessed using WQI and TSI. Therefore, the main purpose of this study was to assess ecological condition of Aba Samuel Reservoir by using various indices. The study focuses on physico- chemical variables, and plankton composition and abundance, and bacteriological analysis. This study is the recent one which generates base line information on the water quality status and ecological condition of Aba Samuel Reservoir after rehabilitation. These baseline data can be used to gauge the ecological status of the reservoir and for eco-hydrological applications in conserving and rehabilitating the reservoir.

1.2. Statement of Problem

Aba Samuel Reservoir has multiple purposes including hydroelectric power generation, domestic water supply, irrigation and fishery. However, it is under a serious threat because of point and nonpoint sources of wastes from industry, municipal, domestic and agricultural activities operating in the catchment. Big Akaki and Little Akaki Rivers are the two major sources of wastewater pollutants for the reservoir. The catchment of Akaki River is the site for industrial establishments, which releases their wastewater directly into the river. Akaki Rivers (Big and Little Akaki), are the main tributary of Aba Samuel Reservoir that discharges its effluents to the reservoir. The reservoir was rehabilitated in recent years, after long years of closure due to fill-up with water hyacinth debris and silt. There has been no study conducted about water quality status of Ababa Samuel Reservoir using water quality and trophic status indices. This study is the recent one which generated baseline information on the water quality status and ecological condition of Aba Samuel Reservoir. These baseline data can be used to gauge the ecological status of the reservoir and for eco-hydrological applications in conserving and management actions.

1.3. Research Questions

- ➢ What are the physico-chemical and biological parameters in Aba Samuel Reservoir?
- ➢ What is the current ecological condition of Aba Samuel Reservoir based on WQI and TSI?

1.4. Research Objectives

1.4.1. General objective

- ✓ The general objective of this research was to assess ecological condition of Aba Samuel Reservoir using various water quality and trophic status indices.

1.4.2. Specific Objectives

- ✓ To assess current WQI of Aba Samuel Reservoir using major physico-chemical and microbial parameters.
- ✓ To assess current TSI of Aba Samuel Reservoir using TP and Chl *a*.
- ✓ To determine major plankton species composition and abundance and its relationships to physico-chemical parameters in Aba Samuel Reservoir.

1.5. Significance of the study

Aba Samuel Reservoir was rehabilitated in recent years, after long years of closure due to fill-up with water hyacinth debris and silt. Assessing the current ecological condition of the reservoir based on water quality and trophic status indices will be useful to serve as baseline for future monitoring and helps to design the management practices for the sustainability of reservoir. If the reservoir is still undergoing eutrophication, it needs control of nutrient load and other bio-manipulation practices. If water quality of the reservoir has become deteriorated, different mitigating actions such as buffer zone demarcation and waste water treatment plants must be recommended for factories and other users of the reservoir.

1. 6. Limitation of the Study

The present study was done only during the dry months because the road is very difficult to drive for ordinary four wheel drive car during the wet season. The erratic nutrient fluctuations as a result of the variation in the waste discharges and changing water retention time in the reservoir may affect primary production in erratic manner, which may not be captured during the time of sampling.

2. LITERATURE REVIEW

The water quality of any water body (lake, reservoir, river and etc.) determined by its physical, chemical constituents and biological features and their concentration. Hence, water quality assessment involves analysis of physicochemical, biological and microbiological parameters that reflects the biotic and abiotic status of aquatic ecosystems (Suthers and Rissik, 2009, Patil *et al*., 2012, Qureshimatva *et al*., 2015).

The quality of any body of surface or ground water is a function of natural influences and human activities. The scarce supplies of inland fresh-water are aggravated by the rapidly expanding human population, growing the industrial economy and extensive urbanization. These factors severely affect water quality and environmental integrity (Suthers and Rissik, 2009, Patil *et al*., 2012, Saba Kifle, 2017).

2.1. Physico-chemical water quality parameters

Different physicochemical parameters such as: temperature, turbidity, pH, DO, NH_3, used for testing of water quality (Patil, *et al*., 2012).

2.1.1. Secchi Depth

The Secchi disk depth is the measure of water clarity. It indicates the light penetration in the water. Clear water lets light penetrate more deeply and allows photosynthesis to occur and oxygen to be produced in that layer (Voahangiarilala, 2009)

Water transparency (vertical visibility) of Geffersa Reservoir varied from a minimum of 0.20 m in May, 2010 of the minor rainy season to a maximum of 0.66 m in October (Nigatu Ebisa, 2010).

2.1.2. Turbidity

Turbidity indicates the amount of suspended solids in the water, either mineral (such as soil particles) or organic (like algae). The turbidity analysis is a measure of the amount of light scattered in water and more suspended particles cause greater scattering and thus high turbidity value. Turbidity values vary for two main reasons. One reason is physical such as heavy rains and fast-moving water which causes erosion. The other reason is biological due to algae growth and bacterial degradation of organics in the water column (Voahangiarilala, 2009).

A study conducted by Saba Kifle, (2017) in Legedadi Reservoir reported that the mean turbidity value was (471.64 ± 49.01NTU). According to study by Nigatu Ebisa, (2010) on Geffersa Reservoir, The Reservoir exhibited fluctuations in turbidity from 7.2 to 189 NTU, with the minimum and maximum levels occurring in December, 2009 and May, 2010 corresponding to the dry and rainy periods.

2.1.3. pH

pH is a measure of the acidity or alkalinity of water, ranging from acidic (pH less than 7) through to neutral (pH 7) and alkaline (pH greater than 7). One of the reasons of pH change in water is the photosynthesis. This process absorbs carbon dioxide from the water and uses the sun's energy to convert it to simple organic carbon compounds and to produce oxygen. Carbon dioxide in solution has acidizing effect as it reacts with water and form carbonic acid (H_2CO_3). As long as plants and algae remove it, the water becomes more alkaline and the pH increases (Voahangiarilala, 2009).

A study conducted in Legedadi Reservoir reported that mean pH value of the reservoir water was 7.18 ± 0.16 Saba Kifle, (2017). According to Nigatu Ebisa, (2010) reported the pH of Geffersa Reservoir ranged from a minimum of 7.29 in April, 2010 to a maximum of 8.44 in October, 2010.

2.1.4. DO

DO is an important parameter in aquatic environments and an index of physical and biological process going on in water. It determines the ability of aerobic organisms to survive and, in most cases, higher dissolved oxygen is better (Voahangiarilala, 2009, Behera, 2012).

Oxygen enters water body through diffusion across the water's surface, by rapid movement such as waterfalls or riffles in streams (aeration), or as a by-product of photosynthesis. The amount of dissolved oxygen gas depends highly on temperature and somewhat on atmospheric pressure. Salinity also influences dissolved oxygen concentrations, such that oxygen is low in highly saline waters and vice versa. The amount of any gas, including oxygen, dissolved in water is inversely proportional to the temperature of the water; as temperature increases, the amount of dissolved oxygen (gas) decreases (Geneviève and James, 2008, Voahangiarilala, 2009).

Oxygen is required for the metabolism of aerobic organisms and influences chemical reactions. The concentration of oxygen in freshwater has implications for the presence and distribution of organisms, and anoxia can result in the death of aquatic animals. Oxygen is often used as an indicator of water quality such that high concentrations of oxygen usually indicate good water quality. A low DO (less than 5mg L^{-1}) would indicate poor water quality and thus would have difficulty in sustaining many sensitive aquatic lives (Geneviève and James, 2008, Adane Melaku, 2017). According the finding of Saba Kifle (2017), the mean value of DO in Legedadi Reservoir was 6.63 ± 0.38 mg L^{-1}.

2.1.5. Inorganic Nutrients

Phosphorus nutrient is one of the limiting factors in primary production in aquatic ecosystems and therefore excess loads leads to proliferation of algal blooms. Phosphate is important nutrient for the growth of green plants. Phosphates are present in sewage, chemical fertilizers, industrial wastes, storm runoff and in consumer products as detergents, baking powder and etc.

Two common forms of phosphorus are: Total phosphorus (TP) - TP includes dissolved and particulate forms of phosphorus and soluble reactive phosphorus (SRP) – SRP is soluble phosphorus readily usable by algae.

The main pollutants from agricultural activities including nitrogen and phosphorous are nutrients that promote primary productivity and cause eutrophication in the long term (Membrillo-Abad *et al*., 2016). Nitrogen and phosphorus act as fertilizers, stimulating algal blooms and may bring eutrophication of many inland waters. Eutrophication leads to changes in the structure of ecological communities indirectly through oxygen depletion and directly by increasing nutrient concentrations (Israel Deneke, 2006).

NH_4-N concentrations are usually low in oxygenated waters of oligo- to mesotrophic deep water bodies because of utilization by plants in the photic zone and nitrification to N oxidized forms (Quirós, 2003).

2.1.6. Total solids (TS)

TS refer both total suspended solids (TSS) and total dissolved solids (TDS). TSS is the non-filterable residue whereas; TDS refers to the filterable residue. Water with high levels of dissolved solids generally is of inferior palatability and may induce an unfavorable physiological reaction in the transient consumer. WHO (2011)recognized water with a TDS level of less than about 600 mg L^{-1} as good for drinking and it becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mgL^{-1}.

2.2. Biological water quality parameters

The degree of eutrophication is indicated by the quantity of planktonic (phytoplankton, zooplankton) detritus reduced water clarity or transparency (Secchi disc visibility) in the water near the surface (Eshetu Gizaw *et al*., 2004). Chlorophyll is the green molecule in plant cells which carries out the bulk of energy fixation in photosynthesis. Besides, chlorophyll is probably the most-often used estimator of algal biomass in an aquatic system. The concentration of Chl-*a*, therefore, is commonly used as a measure of the density/biomass of the algal population in lakes or reservoirs and an indication of the trophic status of a water body ((Makhlough, 2008).

2.2.1. Microbiological parameters of water quality

Microorganisms such as total coliform and fecal coliform bacteria are among the most important water quality indicators. Total and fecal coliform were determined for water samples from the lake. Coliform bacteria are three different groups; 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 (Feven Solomon, 2007).

Total coliforms (TC) are coliforms, which are common in the environment and are generally harmless. They are able to ferment lactose to acid and gas within 24 h at 35 ± 2°C. Fecal (thermotolerant) coliforms (FC) are a subgroup of TC bacteria. They occur in the intestines and feces of people and animals. The organisms produce acid and gas from lactose at 44 - 45°C. The presence of fecal coliforms in drinking water often indicates recent fecal contaminations (WHO, 2001).

2.2.2. Phytoplankton and Zooplankton

Phytoplankton is the primary producer community and consists mainly of algae such as diatoms, dinoflagellates and a variety of forms from other divisions of the plant kingdom. Phytoplankton constitutes the very basis of nutritional cycles of an aquatic ecosystem. They form a bulk of food for zooplankton, fishes and other aquatic organisms. The phytoplankton composition was influenced by so many factors and they change according to ecological changes. The phytoplankton biomass and community composition is important for the understanding the structure and dynamics of the ecosystem. Phytoplankton as primary producers, form an important source of energy and basis for life in the aquatic environment (Dhanam *et al*., 2016).

The cyanobacteria *Microcystis* and *Anabaena* may produce intracellular toxins and release them into surrounding waters. Zooplankton such as *Daphnia, Copepods* and *Rotifers* are used eco-toxicologically as test organisms to assess the direct and indirect effects of cyanotoxins. High concentrations of cyanotoxins kill zooplankton, including *Daphnia*, while low concentrations of cyanotoxins reduce the growth and reproduction of various zooplanktons (DeMott *et al*., 1991; Gilbert, 1994). Zooplankton such as *Daphnia* can accumulate cyanotoxins in their bodies and may transfer them to higher trophic levels, such as fish (Suthers and Rissik, 2009). Freshwater ostracods are very hardy and are often indicative of stressed environments where most zooplankton has been eliminated (Fernando, 2002). Zooplanktons play a key position in the food web and also influence the functioning and productivity of aquatic ecosystems through their impact on the nutrient dynamics.

2.2.3. Phytoplankton Biomass

Phytoplankton biomass estimated as Chlorophyll *a*. Chlorophyll is the green molecule in plant cells that carries out the bulk of energy fixation in the process of photosynthesis. Besides its importance in photosynthesis, chlorophyll is probably the most-often used estimator of algal biomass in aquatic system. Many types of chlorophyll can be found in plant such as chlorophyll a, b, c, and d, but Chlorophyll *a* is the molecule found in all plant cells and therefore its concentration is what is reported during chlorophyll analysis. It absorbs sunlight and converts it to energy, which is used to produce algae cells during photosynthesis. Its concentration can be an effective measure of the trophic status. Chlorophyll *a* levels may fluctuate over time. They are often higher after rainfall, particularly if the rain has loaded nutrients into the water. Higher concentrations are also observed during the summer months when water temperatures and light increase (Voahangiarilala, 2009).

2.3. Water quality indices

Water quality of any specific area or specific source can be assessed using physical, chemical and biological parameters.

According to Tyagi *et al.*, (2013), there are many types of WQI methods. The most common once are Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI).Water Quality Rating as per different Water Quality Index methods.

National Sanitation Foundation Water Quality Index Rating (NSFWQI) summarizes the data in a single index value in an objective, rapid and reproducible manner. Index value relates to a potential water use; it represents general water quality and does not represent specific use of the water.

Table 1. National Sanitation Foundation Water Quality Index Rating (NSFWQI)

Rating of Water Quality	**WQI Value**
Excellent water quality	91-100
Good water quality	71-90
Medium water quality	51-70
Bad water quality	26-50
Very bad water quality	0-25

2.4. Trophic Status Indices

Trophic-state classification is a useful tool for managing lakes and reservoirs. The quantity of energy captured, stored and potentially used in a freshwater ecosystem (i.e., as reflected by its trophic status) can be estimated relatively simply by applying empirical relationships based on variables such as primary productivity, algal biomass, water transparency and nutrient concentrations. The trophic-state classification of reservoir in a region or in a water management district is useful for establishing lake management strategies and for setting priorities for lake restoration efforts Lind *et al*., (1993). TSI model for tropical/subtropical reservoirs was developed by Lamparelli (2004) and Cunha *et al*., (2013). Trophic State Index (TSI) of Lamparelli (2004) and Cunha *et al.*, (2013) is a trophic state classification method that is based on total phosphorus concentration(TP) and Chlorophyll a (Chl *a*).

Table 2. Lamparelli (2004) and Cunha *et al*., (2013), Trophic Status Index (TSItsr) categories.

Trophic Status Classification	**Lamparelli (2004)**	**Cunha *et al*., (2013)**
Ultra-oligotrophic	TSI≤47	≤51.1
Oligotrophic	47<TSI≤52	51.2 – 53.1
Mesotrophic	52<TSI≤59	53.2 – 55.7
Eutrophic	59<TSI≤63	55.8 – 58.1
Super eutrophic	63<TSI≤67	58.2 – 59.0
Hypereutrophic	TSI>67	≥59.1

According to, Lind *et al*., (1993) reported the trophic-state classification of reservoirs is problematic for two primary reasons:

1. An uncertain relationship exists between nutrient supply and primary production in reservoirs. This uncertainty results from:

- Discrepancies between the estimated nutrient supply and the actual nutrient availability for primary production, and
- The influence of other factors (e.g., short water-residence time, limited light availability), unrelated to nutrient availability, on primary productivity.

2. Reservoirs commonly possess a high degree of spatial and temporal heterogeneity in the environmental factors that control primary productivity and, thus, influence trophic status. The spatially heterogeneous and temporally dynamic nature of impoundments makes it difficult to adequately characterize the trophic status of a reservoir.

3. MATERIALS AND METHODS

3.1. Study area Description

Aba Samuel Reservoir is located south west of Addis Ababa city (8^0 47’ 15” to 8^0 60’15’’ N and 38^0 42’ 0” to 38’ 42’ 45” E). It was constructed in 1939 for hydroelectricity power generation purpose and the name of reservoir comes from a nearby church Aba Samuel. Aba Samuel Reservoir is one of the first hydroelectric power generating stations in Ethiopia and it produces 6.6 MW of power capacity per year; However, the reservoir was closed in 1970 due to fill up with water hyacinth debris and silt and rehabilitated in 2014 and is also nowadays used for irrigation. (https://www.industryabout.com/country-territories-3/2550-ethiopia/hydro-energy/39524-aba-samuel-dam/).

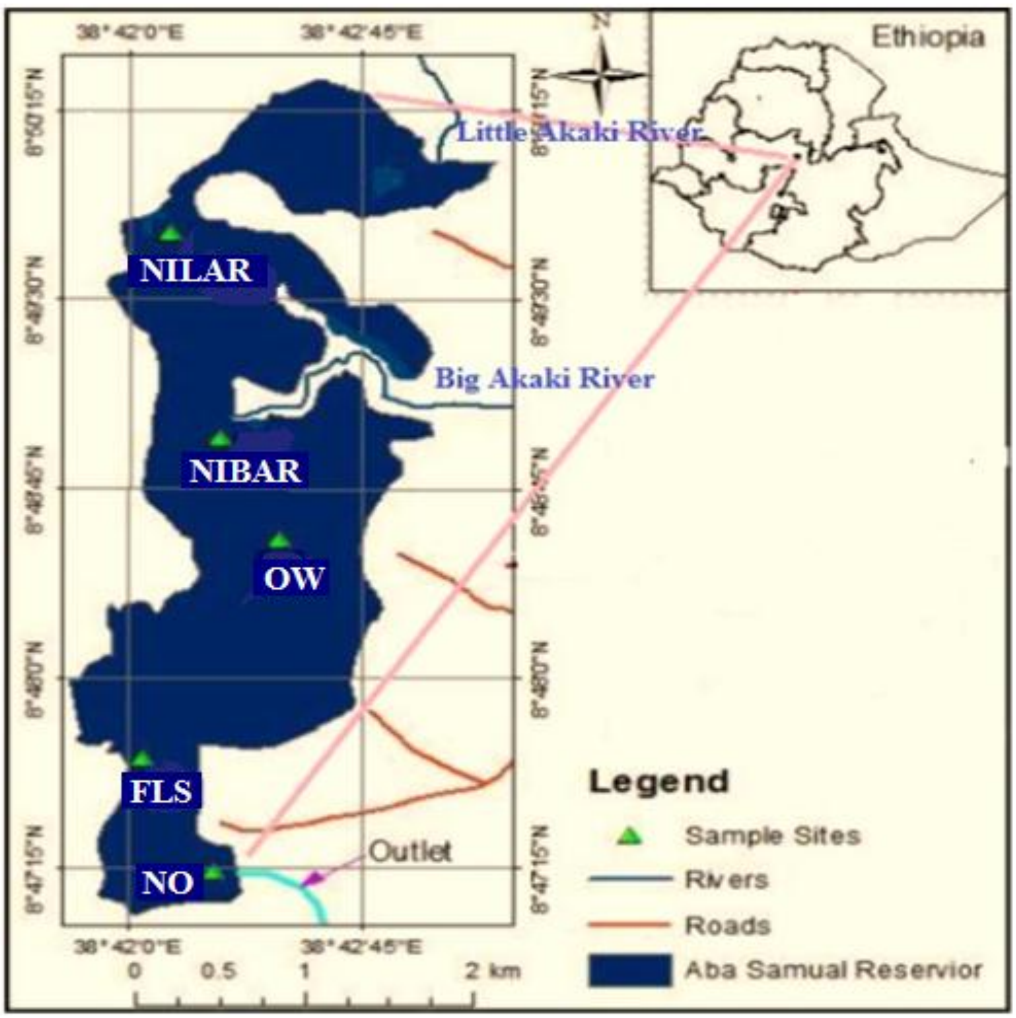

Figure 1. Map of Aba Samuel Reservoir showing sampling points and inflow-outflow.

Aba-Samuel Reservoir has two main tributary rivers Big Akaki and Little Akaki Rivers. The headwaters of the Big Akaki River begin at an elevation of about 3000 maximum above sea level from the Entoto Mountains. The River consists of the tributaries found in the eastern part of Addis Ababa including Abo, Kebena, Ginfle, Bantyketu and Akaki rivers. Big Akaki River flow south wards across the residential and commercial centers of Addis Ababa towards to Aba Samuel Reservoir (Solomon Akalu *et al*., 2011). The western branch of the river, Little Akaki, rise north-west of Addis Ababa on the flanks of Wechacha Mountain and flows for 40 km before it reaches the reservoir (Hamere Yohannes and Eyasu Elias, 2017).

Plate 1. Picture showing Aba Samuel Reservoir and surroundings environment; A: Near outlet waters over flow of the dam, B: Water pump can be used to irrigate crops, C: Pelican (large water birds) mostly that indicate the appearance of fish in reservoir, D: Water hyacinth in the near-shore region of the reservoir.

3.2. Sampling protocol

The study was conducted in Aba Samuel Reservoir between April-July, 2018 and samples of water, phytoplankton and zooplankton were collected from five sites; near inlet Little Akaki River (NILAR), near inlet Big Akaki River (NIBAR), Open water (OW), Fish landing site (FLS) and near outlet (NO) using Kemmerer/ bottle sampler. Composite water samples were collected from various depths using 2L Kemmerer water sampler, well -mixed in a bucket and one-liter composite water sample was taken in polythene bottle for analysis. Samples were put in an ice box and transported to Limnology laboratory of Addis Ababa University.

3.3. Measurements of physico-chemical parameters and nutrient analysis

Temperature, DO, pH, Electrical conductivity (EC) were measured using multi-meter probe (HQ40d) Secchi disc depth (Z_{SD}) or water transparency was measured with a Secchi disc of 20 cm diameter and turbidity was determined using turbidity meter (OAKTON 1T–100). All physico-chemical parameters were measured *on site* during sample collection.

Concentrations of inorganic nutrients were determined in the limnology laboratory of Addis Ababa University following the procedures outlined in (APHA, 1999). All water samples used for nutrient analyses were filtered through glass fiber filters (What man GF/F) except total phosphorus (TP), for which unfiltered water sample was used.

Ammonium ($NH_{4)}$ was analyzed by the phenate method, while nitrate (NO_3-N) was analyzed by sodium-salicylate method APHA (1995), nitrite (NO_2-N) by diazotization with sulphanilamide and coupling with N-1-naphthylethylenediamine di-HCl colorimetric method. Absorbance of NH_4-N, NO_3-N, and NO_2-N were read by JENWAY 6405 spectrophotometer at 640nm, 420nm and 543nm, respectively. Total phosphorus (TP) and soluble reactive phosphorus (SRP) after ammonium persulfate digestion was analyzed by ascorbic acid method (APHA, 1999). Silica (SiO_2) was estimated by molybdo-silicate method. Absorbance of TP, SRP and SiO_2 were read by JENWAY 6405 spectrophotometer at 880nm and 410nm, respectively. All inorganic nutrients absorbance readings were converted to actual concentration using standard curves.

TSS was analyzed by using gravimetric method (APHA, 1999). TSS was analyzed by filtering known volume of water sample using known weight of filter paper (GF/F, 47mm pore size), drying the undissolved material trapped on filter paper at 105°C and measuring the weight of dried filter paper (residue or total suspended particles) using analytical balance and calculated using the following formula (Estefan *et al*., 2013);

$$TSS(\frac{mg}{L}) = \frac{(\mathrm{W2} - \mathrm{W1})\ \mathrm{x}\ 1000}{V}$$

Where:

W1= Weight of dried clean filter paper (in mg)

W2= Weight of dried clean filter paper and seston (in mg)

V= Volume of filtered sample (mL)

3.4. Estimation of Phytoplankton biomass as Chl *a* concentration

Phytoplankton biomass estimated as Chl *a* concentration was determined by the volume of composite samples of particulate material retained on Whatman glass fiber filter papers (GF/F) and pigments of cells retained on filter papers was extracted in 90 % acetone, placed in parafilm covered tube. The extracted pigments were centrifuged at 3000 rpm for 10 minutes. The absorbance of the pigment extract was measured with Jenway 6300 UV-VIS spectrophotometer at 665 and 750 nm before and after acidification with 0.1 mL of 1 N HCl (Wetzel and Likens, 2000). Chl *a* concentration was calculated according to the following equation:

Chl a ($\mu\mathrm{gL}^{-1}$) $= \frac{26.73[(665\mathrm{b}-750\mathrm{b})-(665\mathrm{a}-750\mathrm{a})]\mathrm{x\ Ve}}{\mathrm{VfxZ}}$ Where;

665b and **750b** are absorbance at 665nm and 750nm before acidification respectively.

665a and **750a** are absorbance at 665 and 750 nm after acidification, respectively.

Ve = Volume of extract in ml

Vf = Volume of sample filtered in a liter

Z= Path length of the cuvette (1cm)

3.5. Phytoplankton Species Identification and Abundance

Phytoplankton was sampled with a phytoplankton net with mesh size of 15µm and immediately preserved with Lugol's iodine solution. Samples were used to identify species of phytoplankton and determine their abundance under an inverted microscope. Phytoplankton was identified using appropriate taxonomic literatures on tropical phytoplankton; Komarek and Anagnostidis, (2005), Janse *et al*., (2006), Suthers and Rissik (2009), Bellinger and Sigee, (2010). The abundance of each species was determined using a Sedgewick-Rafter cell under an inverted compound microscope (A. Kruss Optronic, Serial number 32010095, Germany) and calculated according to Hotzel and Croome (1999) formula.

$$Algal\ unit\ mL^{-1} = \frac{Nx\ 1000mm^3}{AxDxF}$$

Where N = number of algal units counted

A = area of field (square) ($1mm^2$)

D = depth of field (square) (Sedgwick-Rafter chamber depth- 1mm)

F = number of fields (squares) counted

3.6. Zooplankton Species Identification and Abundance

Zooplankton samples were collected on a monthly basis using 30 µm mesh size plankton net. Immediately after sampling, zooplankton samples were preserved with 5% formaldehyde in 200 ml plastic bottles. Identification of zooplankton species was done using standard methods and references under an inverted compound microscope in Addis Ababa University, Limnology laboratory Sandercock and Scudder, (1994), Fernando, (2002), Witty, (2004), Glime, (2017). Estimation of zooplankton abundance (No. of individuals per m^3 of reservoir water) were computed for each month using the below formula.

$$Abundance\ (Ind/m^3) = \frac{n\ x\ ssfxGf}{v}$$

n= actual number of individuals counted

ssf= sub sample factor (total sample/sub sample taken)

Gf= Grid factor (number of total grid/number of grid count)

V= volume of water filtered (i.e.$v = \pi r^2 d$); where d is the depth hauled and v is in m^3.

3.7. Microbiological Analysis

Bacteriological parameters including total coliforms and fecal coliforms were analyzed in the Biomedical laboratory at the Department of Molecular, Cellular and Microbial Biology, AAU.

Total coliforms were analyzed by heterotrophic plate count (HPC) using spread plate techniques based on Standard Methods 9215C of (APHA, 1998). One mL of collected samples was serially diluted with distilled water in order to reduce the bacterial density subsequently, and 0.1 mL of the appropriate dilutions was spread directly onto nutrient agar plates. HPC colonies were counted after 24 Hrs. of incubation at 37°C.

Faecal Coliforms were analyzed by Membrane Filtration technique using membrane lauryl sulfate broth (MLS). The water samples were collected in a sterile glass bottle. After sterile absorbent pads were transferred into sterile Petri dishes, 2 ml of sterile membrane lauryl sulfate broth was added to each Petri dish.

The membrane filter forceps were dipped in ethanol, and burned off in the flame of Bunsen burner. Then a sterile membrane filter of 0.45 μm pore size, 44 mm diameter was placed on the membrane filtration unit and a diluted sample was poured and filtered using a manual vacuum pump. The Petri dishes were place upside down in an incubator maintained at 44 $^{\circ}$C ± 0.5 $^{\circ}$C. Finally the number of yellow colonies was counted after 48Hrs. incubation period (APHA, 1998).

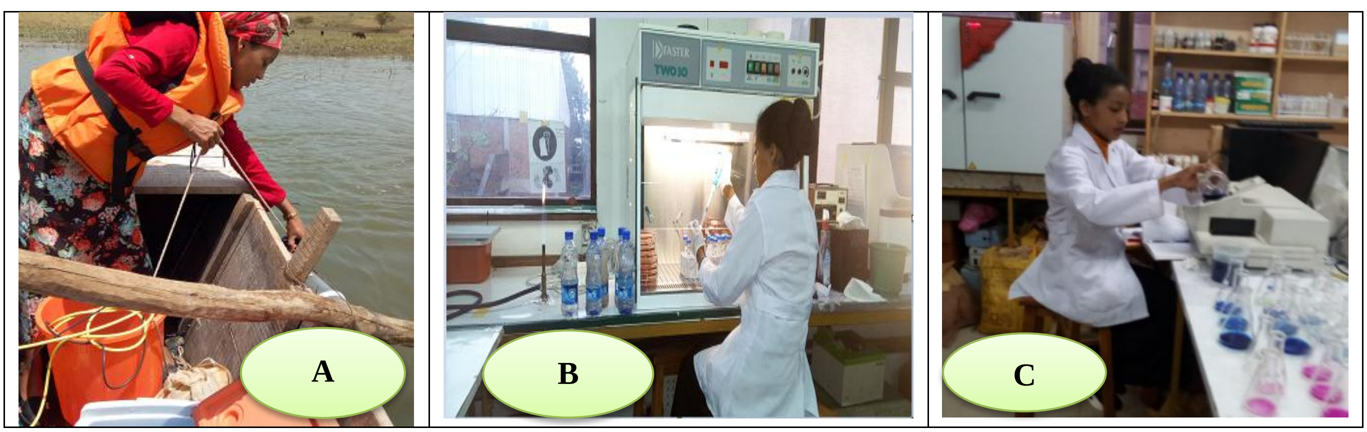

Plate 2. Pictures showing; A: Collecting Samples, B: Microbial analysis in Biomedical laboratory, C: Nutrient analysis in Limnology laboratory.

3.8. Water Quality Indices

One way to evaluate the water quality of a reservoir is through WQI, a number ranging from 0 to 100. A higher number is indicative of better water quality (Hallock, 2002). Water quality calculation is based on 9 parameters, where each parameter has different weights according to their relative importance in the calculation of the index. The parameters are: Water temperature, turbidity, Total Suspended Solids (TSS), DO, pH, NO_3-N, TP and Fecal Coliforms. These parameters are indicative of the water quality and have been established by the National Sanitation Foundation (USA) for the development of an index to classify water quality (Srivastava and Kumar, 2013; Magaly *et al*., 2015).

. The mathematical expression for NSF's WQI is given by;

$$\mathrm{WQI} = \sum_{i=0}^{n} QiWi$$

Where, Qi= sub-index for the ith water quality parameter;

Wi= weight associated with the ith water quality parameter;

n = number of water quality parameters.

3.9. Trophic Status Indices

Most studies published on TSIs refer to temperate environments. Thus, an adaptation of Carlson’s (1977) TSI index for tropical environments proposed by Lamparelli (2004) was used here. The method is still based on the concentrations of TP and Chl a. The formula for reservoir TSIs (Lamparelli 2004) are:

$$\mathrm{TSI\ (Chl\ } a) = \frac{10\ (6 - (0.92 - 0.34 \times \ln\ [chl\ a]))}{\ln 2}$$

$$\mathrm{TSI\ (TP)} = \frac{10\ \ (6 - (1.77 - 0.42 \times \ln\ [\mathrm{TP}]))}{\ln 2}$$

Where; [Chl a] is the chlorophyll a concentration in µg/L,

[TP] is the total phosphorus concentration in µg/L, and ln is the natural logarithm.

The TSI_{Lamp} is the simple arithmetic average of the indices for Chl *a* and TP:

$$\text{TSI Lamp} = \frac{\text{TSI (Chl } a) + \text{TSI (TP)}}{2}$$

TSI was also estimated according to Cunha *et al*., (2013), which developed TSI model for tropical/subtropical reservoirs. TSI for tropical environments by Cunha *et al*., (2013) is based on concentration of total phosphorus (TP) and Chlorophyll a (Chl *a*).

$$\text{TSI (Chl } a) = \frac{10\,(6 - (-0.2512\ln[chl\ a]+0.842257))}{\ln 2}$$

$$\text{TSI (TP)} = \frac{10 \times (6 - (-\ 0.27637\ln[\text{TP}]+1.329766))}{\ln 2}$$

$$\text{TSI}_{\ tsr} = \frac{\text{TSI (Chl } a) + \text{TSI (TP)}}{2}$$

3.10. Data Analysis

All statistical analysis was performed using SPSS software package version 24. The data was analyzed through one-way analysis of variance (ANOVA) at 95% significance level ($P < 0.05$) to compare the spatial and temporal variations of physicochemical parameters and plankton abundance.

The relationships between abundance of phytoplankton taxa, zooplankton taxa and environmental variables were analyzed using multivariate analysis tool, redundancy analysis (RDA) using CANOCO for Windows 4.5. WQI calculator in Excel sheet was also used to calculate the WQI of the reservoirs. Graphs were presented using Sigma-plot version 11.

4. RESULTS

4.1. Physico-chemical parameters of Aba Samuel Reservoir

Data showing the spatial variations of physico-chemical parameters in Aba Samuel Reservoirs during the study period are shown in Table 3. Mean values of DO, %Saturation, K_{25}, NO_2-N, NO_3-N, NH_4, SRP, TP and SiO_2 didn't show statistically significant difference between all the sampling sites (at $p < 0.05$). However, the ANOVA results indicated that, the values of Z_{SD}, Turbidity and TSS recorded in the present study varied significantly among sampling sites (at $P < 0.05$). The water transparency during the study period varied from 0.03 (m) at near inlet little Akaki River in July to 0.9 (m) at near outlet sampling site in April. With mean $\pm$ SE value of Z_{SD} (m) ranged from 0.11 $\pm$ 0.04 at near inlet Little Akaki River to 0.72 $\pm$ 0.09 at near outlet sampling site (Table 3).

Table 3. Spatial variations of physico-chemical parameters recorded for the sampling sites of the present study at Aba Samuel Reservoir (April _ July 2018).

	Sampling Sites (Mean $\pm$ SE, n=5)				
Parameters	**NO**	**FLS**	**OW**	**NIBAR**	**NILAR**
Temp. (°C)	21.44$\pm$0.89	21.35$\pm$ 0.57	22.18$\pm$0.27	21.23$\pm$0.61	23.32 $\pm$0.33
Z_{SD} /Seci. (m)	0.72$\pm$0.09	0.14$\pm$0.03	0.34$\pm$0.07	0.17$\pm$0.06	0.11$\pm$0.04
Turbidity (NTU)	9.67$\pm$1.21	22.03$\pm$3.40	17.62$\pm$2.80	72.48$\pm$10.03	407.9$\pm$99.59
TSS (mg L^{-1})	117.1$\pm$40.20	749.9$\pm$583.7	215.1$\pm$78.25	469.9$\pm$208.7	2169.2$\pm$506.2
K_{25} (µS cm^{-1})	736.1$\pm$19.33	729.9$\pm$38.59	719.5$\pm$29.77	724.5$\pm$36.45	684.0$\pm$26.97
TDS (mgL^{-1})	6973 $\pm$2084	4950 $\pm$2248	4924 $\pm$2147	6384$\pm$1807	5172$\pm$1969
pH	7.86-8.2	7.8-8.16	7.7-8.23	7.69-8.33	7.58-8.41
DO (mg L^{-1})	3.79 $\pm$ 0.61	4.09 $\pm$0.18	3.74 $\pm$0.53	3.55 $\pm$0.65	2.15 $\pm$0.33
% Satur. (mg L^{-1})	53.53$\pm$7.74	61.91$\pm$3.91	55.69$\pm$8.96	53.27$\pm$11.02	31.99$\pm$5.51
NO_2 -N(mg L^{-1})	0.05 $\pm$0.02	0.06 $\pm$0.02	0.06 $\pm$0.02	0.07$\pm$0.02	0.10 $\pm$0.03
NO_3 -N(mg L^{-1})	0.24$\pm$0.04	0.24 $\pm$0.02	0.25 $\pm$0.02	0.23 $\pm$0.05	0.31$\pm$0.03
NH_4 (mg L^{-1})	1.91$\pm$0.28	1.88$\pm$0.24	1.65$\pm$0.51	1.89$\pm$0.30	2.37 $\pm$0.33
SRP (mg L^{-1})	0.012 $\pm$ 0.004	0.015$\pm$ .007	0.017$\pm$ .006	0.018 $\pm$ .006	0.019 $\pm$ .008
TP (mg L^{-1})	0.12 $\pm$ 0.03	0.11 $\pm$ 0.017	0.11 $\pm$ 0.02	0.12 $\pm$ 0.016	0.12 $\pm$ 0.013

SiO_2 (mg L^{-1})	0.25±0.032	0.27±0.026	0.24±0.02	0.24±0.023	0.27±0.04
Chl *a*(μg L^{-1})	15.72±1.54	17.56±1.35	16.27±1.01	15.96±1.47	9.89±2.99

The highest turbidity (703 NTU) was recorded at near inlet Little Akaki River in July, while the lowest (7.14 NTU) was observed in April at near outlet sampling sites (Fig. 2). The values of turbidity recorded varied spatially, with mean ± SE values recorded was ranged from (9.67 ± 1.21) near outlet to (407.9 ± 99.59) NILAR sampling sites (Table 1). The minimum TSS (66.7 mg L^{-1}) was recorded at near outlet in April and maximum (3310 mg L^{-1}) at near inlet Little Akaki River sampling site in July (Fig. 2). The highest peaks of turbidity and TSS values were recorded at near inlet of Little Akaki River at all sampling months.

The highest electrical conductivity (800.26 mg L^{-1}) was observed at near inlet Big Akaki River in April. TDS varied between (400 mg L^{-1}) at fish landing site in May to (11739 mg L^{-1}) at near inlet Big Akaki River in April.

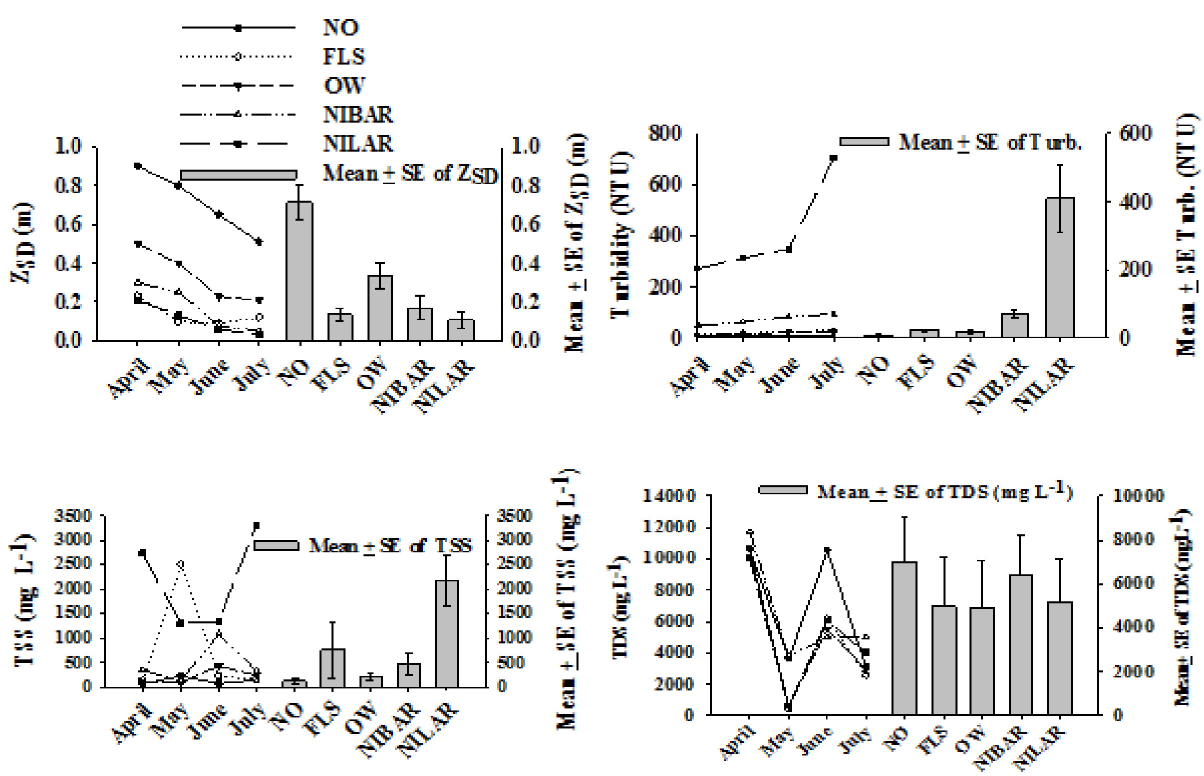

Figure 2. Monthly variations of ZSD, TSS, turbidity and TDS at five sampling sites of Aba Samuel Reservoir (bars indicate means $\pm$ SE). (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

Water temperature recorded for Aba Samuel Reservoir ranged from 19.9 °C at the near outlet sampling site in July to 23.98 °C at near inlet of Little Akaki River sampling site in April. The temperature levels recorded at the near inlet Little Akaki River sampling site were consistently higher than those of other sampling sites (Fig. 3).

Aba Samuel Reservoir was slightly alkaline with pH ranging from 7.58 at near inlet of Little Akaki River in May to 8.41 at near inlet Little Akaki River sampling site in April. The maximum DO recorded was 5.42 mg L^{-1} (74.8 % saturation) at near outlet sampling site in June and minimum DO 1.56 mg L^{-1} (23.25 % saturation) was observed at near inlet Little Akaki River in July and the mean $\pm$ SE values of DO ranged from 3.79 $\pm$ 0.61 mg L^{-1} at near outlet sampling site to 2.15 $\pm$ 0.33 mg L^{-1} at near inlet little Akaki River with mean value of 3.46 $\pm$ 0.33 mg L^{-1} (Fig. 3).

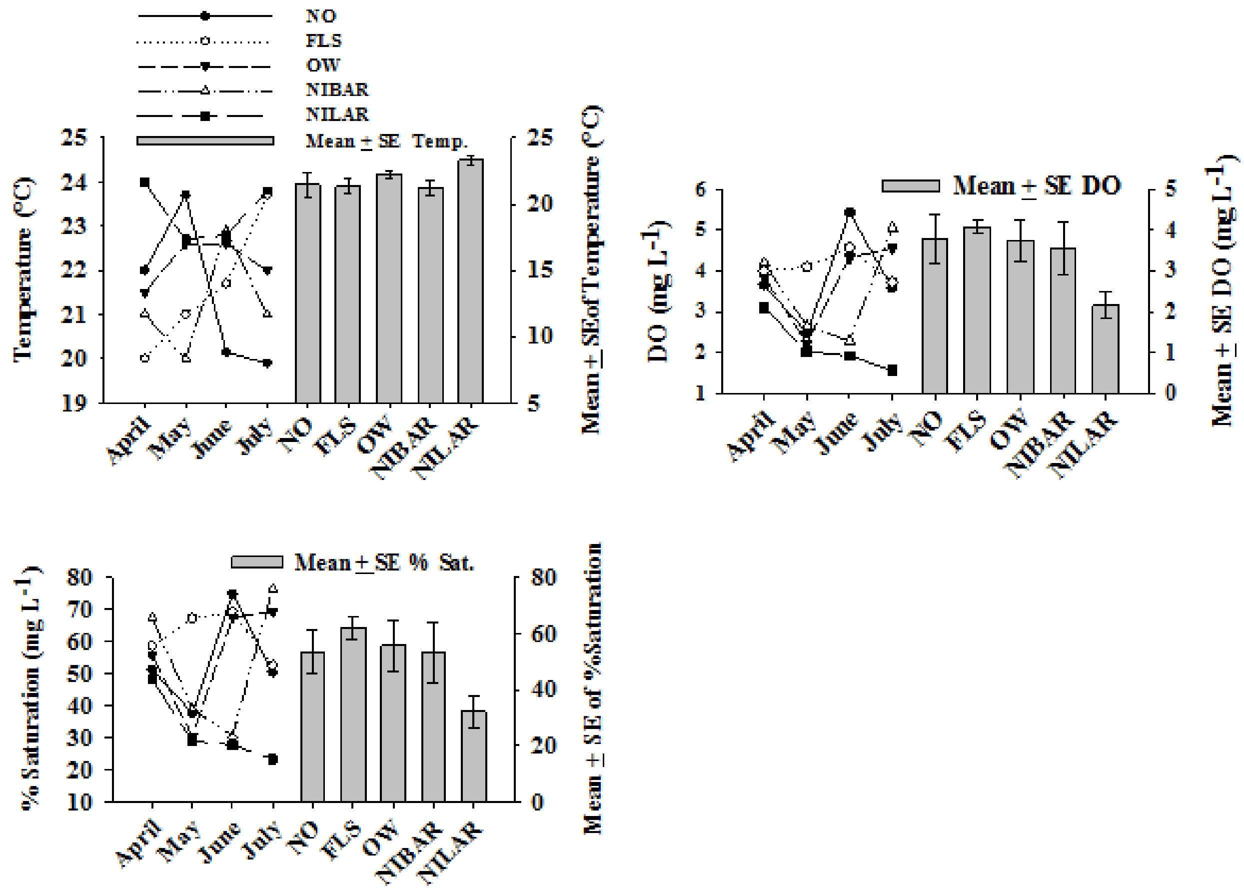

Figure 3. Monthly variations of Temperature, DO and %Saturation at five sampling sites of Aba Samuel Reservoir (bars indicate means ± SE). (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

The concentration of NO_3-N (mg L^{-1}) mean ± SE values ranged from 0.23 ± 0.05 at NIBAR to 0.31± 0.03 at NILAR. The concentration of NH_4–N (mg L^{-1}) mean ± SE values ranged from 1.65 ± 0.51 at open water to 2.37 ± 0.19 at near inlet Little Akaki River sampling sites (Table 1).

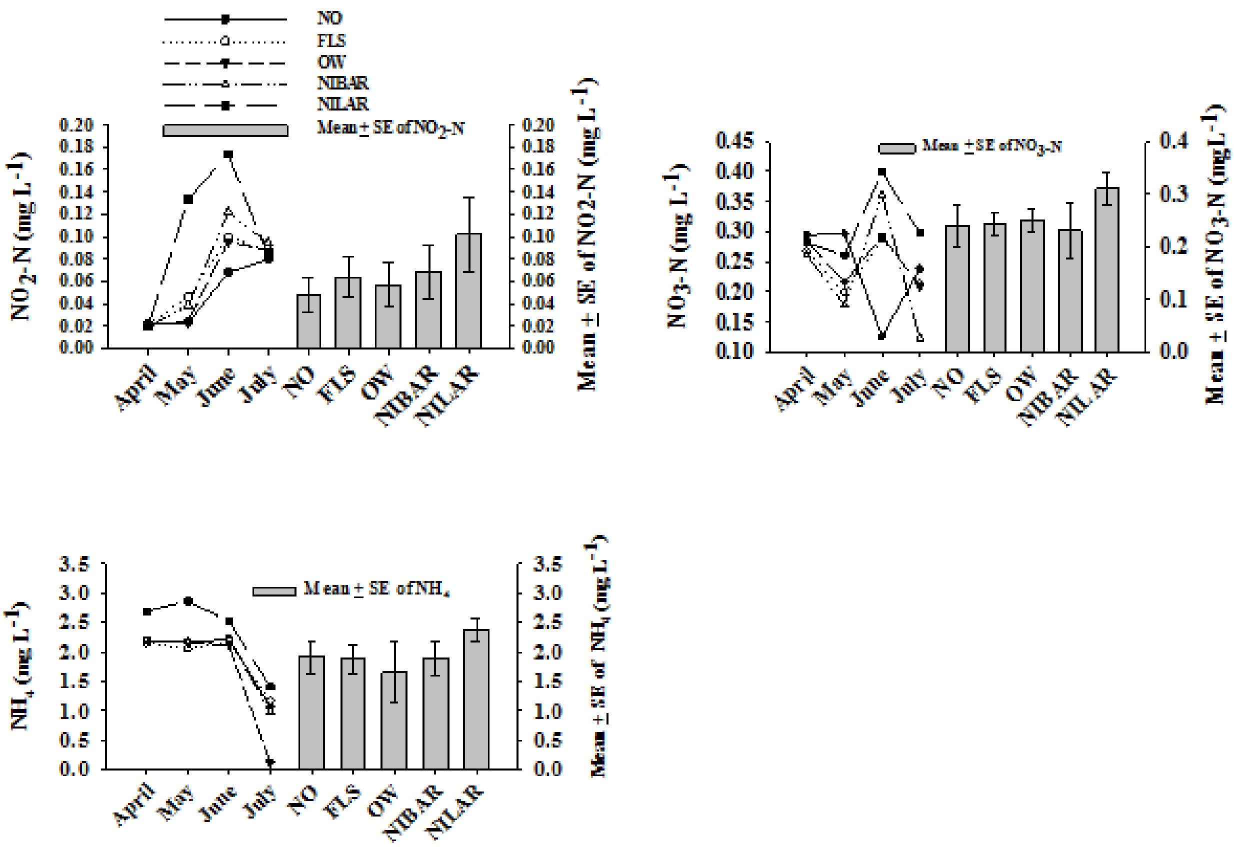

Figure 4. Monthly variations of NO_2-N, NO_3-N and NH_4 at five sampling sites of Aba Samuel Reservoir (bars indicate means $\pm$ SE). (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

TP concentration values varied both spatially and temporally, with the maximum TP (0.197 mg L^{-1}) recorded at NO in July and minimum TP (0.066 mg L^{-1}) recorded at OW sampling site in June. The mean concentration of SRP raged from 0.012 $\pm$ 0.005 at NO to 0.0195 $\pm$ 0.008 (mg L^{-1}) at NILAR sampling site (Table. 1).

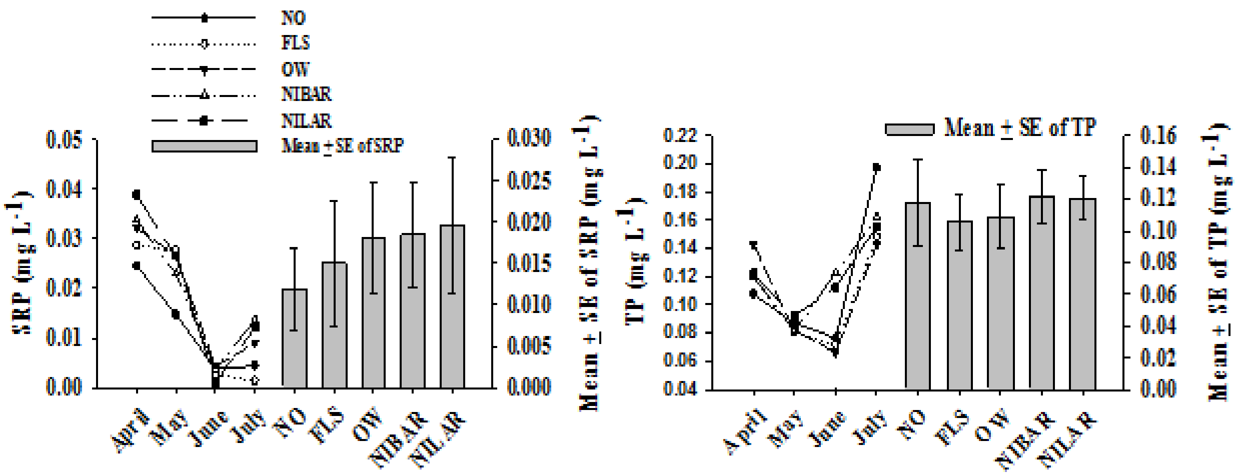

Figure 5. Monthly variations of TP and SRP at five sampling sites of Aba Samuel Reservoir (bars indicate means ± SE). (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

The concentration of SiO_2 (mg L^{-1}) varied from 0.186 to 0.369 with a mean value of 0.24 ± 0.02 at OW to 0.27 ± 0.038 at NILAR sampling site.

4.2. Biological Parameters

4.2.1. Phytoplankton Species Composition and Abundance of Aba Samuel Reservoir

During the study period, a total of 20 species of phytoplankton belonging to four algal classes were identified. The species compositions of the phytoplankton communities at the five sampling sites were similar. The identified species belonged to the algal classes namely Cyanobacteria with 5 species, Bacillariophyta with 6 species, Euglenophyta with 2 species and Chlorophyta with 7 species (Table 4).

Table 4. List of phytoplankton identified during study period in Aba Samuel Reservoir.

Phytoplankton Class	Species
Cyanophyceae (Blue-green algae)	*Anabaena* sp. *Aphanizomenon* sp. *Chroococcus* sp *Microcystis* sp. *Oscillatoria* sp.
Bacillariophyceae (Diatoms)	*Aulacoseira granulatae* *Cyclotella* sp. *Fragilaria* sp. *Navicula* sp. *Nitzschia* sp. *Synedra ulna*
Euglenophyceae (Euglenoids)	*Euglena* sp. *Phacus* sp.
Chlorophyceae (Green algae)	*Coelastrum* sp. *Cosmarium* sp. *Oocystis* sp. *Pediastrum duplex* *Scenedesmus* sp. *Spirogyra* sp. *Volvox* sp.

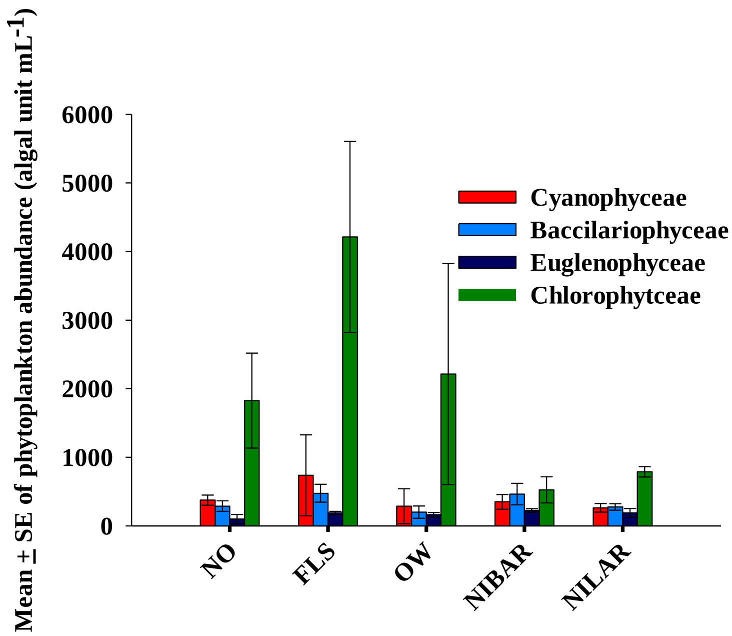

Figure 6. Mean ± SE of phytoplankton abundance from five sampling sites in Aba Samuel Reservoir. (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

4.2.2 Phytoplankton biomass of Aba Samuel Reservoir

Phytoplankton biomass estimated as chlorophyll *a* concentration during study period varied temporally and spatially from (2.67 µg L^{-1}) at near inlet Little Akaki River sampling site in July to (19.87 µg L^{-1}) at near outlet sampling site in June (Fig. 7). Overall mean of phytoplankton biomass (15.08 ± 0.94 µg L^{-1}). However, the variation in the phytoplankton biomass measured as Chl *a* among sites was not statistically significant at p= 0.05 (Table 1). The low Chl *a* during study period at near inlet Little Akaki River sampling site may be affected by high turbidity.

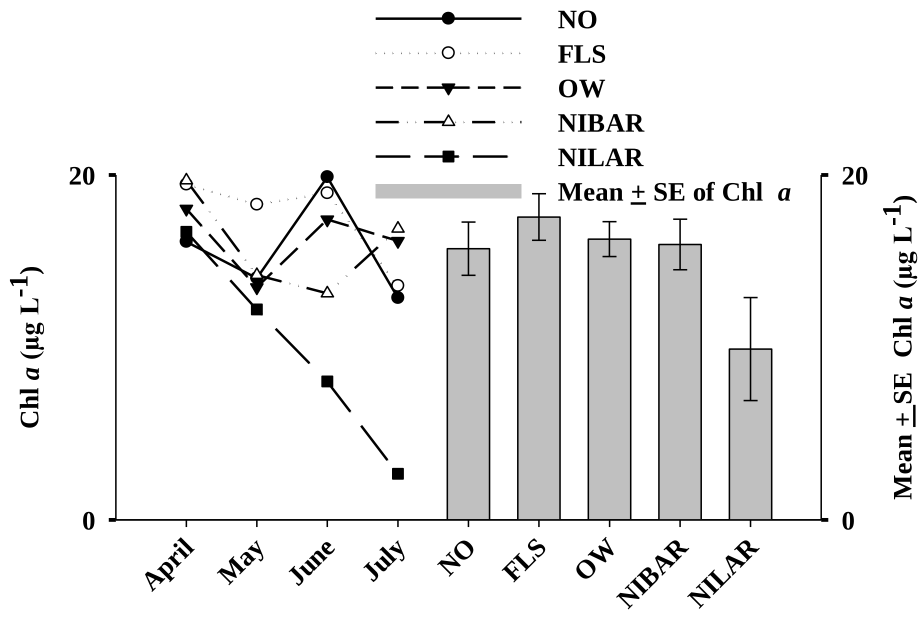

Figure 7. Monthly variations of Chl *a* at five sampling sites of Aba Samuel Reservoir (bars indicate means ± SE). (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

4.2.3. Zooplankton Species Composition and Abundance

A total of 9 species of zooplankton were identified and counted throughout the sampling period. The zooplankton species of all the sampling sites belonged to Order Cyclopoida *(Thermocyclops* and *Mesocyclops*), Cladocera (*Daphnia magna*, *Daphnia barbata)*, Rotifera and Ostracoda.

Table 5. List of Zooplankton identified during study period in Aba Samuel Reservoir.

Taxa	Species
Copepoda	*Thermocyclops sp.*
	Mesocyclops sp.
	Cyclopoid Nauplii.
Cladocera	*Daphnia magna*
	Daphnia barbata

Rotifera	*Branchionus sp.*
	Filina sp.
	Polyarthra sp.
Ostracoda	undetermined sp.

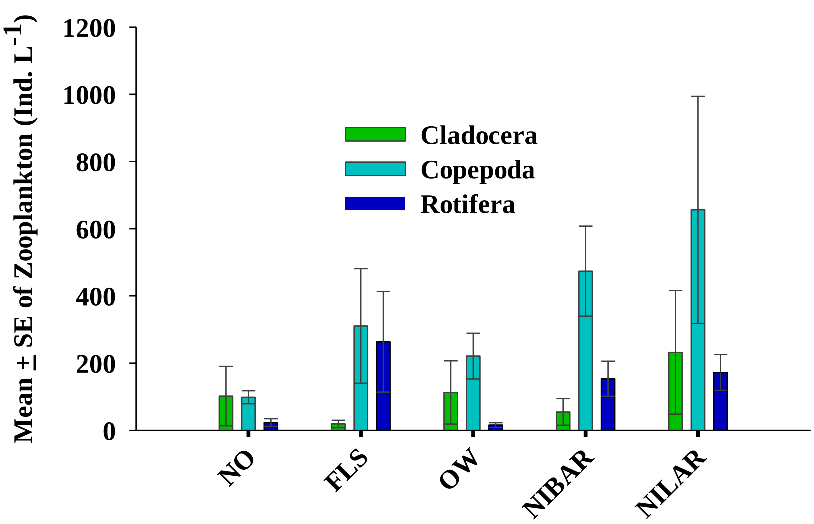

Figure 8. Mean of Zooplankton abundance from five sampling sites in Aba Samuel Reservoir. (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

4.2.4. Microbiological water quality parameters in Aba Samuel Reservoir

The result of analysis for total coliform (TC) bacteria ranged from (30 CFU mL^{-1}) at open water sampling site in April to (21337 CFU mL^{-1}) at fish landing site in July with overall mean $\pm$ SE of (4869 $\pm$ 1508 CFU/ mL^{-1}) and Fecal coliform ranged from (40 CFU $100mL^{-1}$) at near inlet of Big Akaki River in June to (560 CFU $100mL^{-1}$) at fish landing site in May.

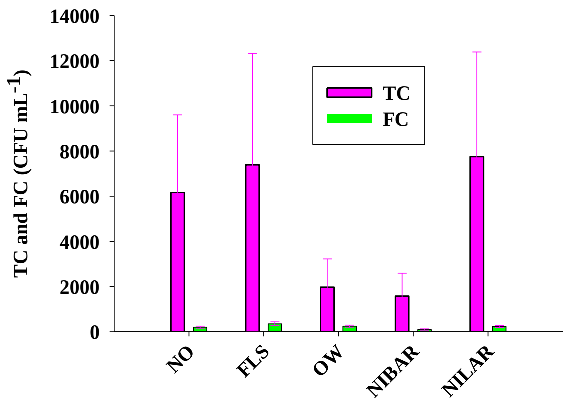

Figure 9. Mean + SE of Total coliform (TC) and Fecal coliform (CFU mL^{-1}) at five sampling sites in Aba Samuel Reservoir. (Acronyms: NO: Near outlet, FLS: Fish landing site, OW: Open water, NIBAR: Near inlet Big Akaki River, NILAR: Near inlet Little Akaki River).

4.3. Water quality Index (WQI) of Aba Samuel Reservoir

Water quality index values calculated using DO (%saturation), FC, pH, temperature, total phosphorus, nitrate, turbidity and total suspended solid data of all sampling sites based on NSFWQI proposed by Brown *et al*. (1970). According to NSFWQI rating, the mean values of water quality index for Aba Samuel Reservoir ranged from 37.10 to 43.69 indicating bad water quality (Table 6).

Table 6. WQI values calculated for Aba Samuel Reservoir and water quality category based on National Sanitation Foundation Water Quality Index (NSFWQI).

Sampling Sites	**WQI values**	**Water quality category**
NO	43.69	Bad
FLS	41.50	Bad
OW	41.86	Bad
NIBAR	40.85	Bad
NILAR	37.10	Bad

4.4. Trophic State Index (TSI) of Aba Samuel Reservoir

Trophic state index values calculated using total phosphorus (TP) and Chl *a* data of all sampling sites based on the models developed for tropical waters are given in table 7.

Table 7. Trophic state indices values of Aba Samuel Reservoir calculated using total phosphorus (TP) and Chl *a* data during study period based on the models developed for Tropical waters. (Note: NO- near outlet, FLS- fish landing site, OW- Open water, NIBAR- near inlet Big Akaki River, NILAR- near inlet Little Akaki River sampling site).

	Sites	**TP(μg L^{-1})**	**Chl *a*(μg L^{-1})**	**TSI(TP)**	**TSI (Chl *a*)**	**TSI of Sampling sites**	**Trophic status**
Lamparelli, (2004)	NO	117.11	15.72	62.53	60.17	61.53	Eutrophic
	FLS	105.42	17.56	62.42	60.73	61.58	Eutrophic
	OW	108.61	16.27	62.53	60.38	61.45	Eutrophic
	NIBAR	121.28	15.96	63.36	60.25	61.80	Eutrophic
	NILAR	120.52	9.89	63.39	57.01	60.29	Eutrophic
Cunha *et al., (*2013)	NO	117.11	15.72	51.83	64.48	58.15	Supereutrophic
	FLS	105.42	17.56	52.50	64.06	58.28	Supereutrophic
	OW	108.61	16.27	52.65	64.32	58.48	Supereutrophic
	NIBAR	121.28	15.96	50.92	64.42	57.67	Eutrophic
	NILAR	120.52	9.89	50.80	62.82	56.81	Eutrophic

The trophic state indices calculated for the Aba Samuel Reservoir water were TSI (Chl *a*) which ranged from (51.55) at near inlet Little Akaki River and open water sampling sites in July to (61.39) at near outlet sampling site in June. TSI (TP) ranged from (59.89 – 66.49) (Appendix 4). The Lamaperlli's average TSI value for the tropical Aba Samuel Reservoir was 62.21 that indicated the Aba Samuel Reservoir is eutrophic status, also according to the average TSI of Cunha *et al*., (2013) TSI_{tsr} of Aba Samuel Reservoir ranged from 56.81 to 58.48 and categorized as eutrophic to Supereutrophic trophic status (Appendix 4).

4.5. Plankton and Physico-chemical parameters Relationships

Canonical redundancy analysis indicated that the first two axes make 98% of the cumulative percentage of variance in plankton species–environmental relationship (Table 8).

Table 8. Result of redundancy analysis (RDA) of plankton biomass/ abundance versus physico-chemical variables relationship including eigenvalues and percentage of variance explained by the first two axes.

Variables	Axis 1	Axis 2
Eigenvalues :	0.770	0.210
Cumulative percentage variance of species-environment relation	77	21
ZSD	0.9064	0.1408
Turbidity	-0.5417	-0.5771
Temp.	-0.2779	-0.3826
pH	0.2968	0.7249
DO	0.3815	0.6933
NO_3-N	-0.4337	-0.3605
NH_4	-0.5513	-0.4773
SRP	-0.5184	-0.5695
TP	0.0393	-0.9275
SiO_2	-0.7877	0.2183

The axis one, which contributed 77% of the variance, was positively correlated with Z_{SD}, pH, DO and TP and axis two 21% with Z_{SD}, pH, DO and $SiO_{2.}$

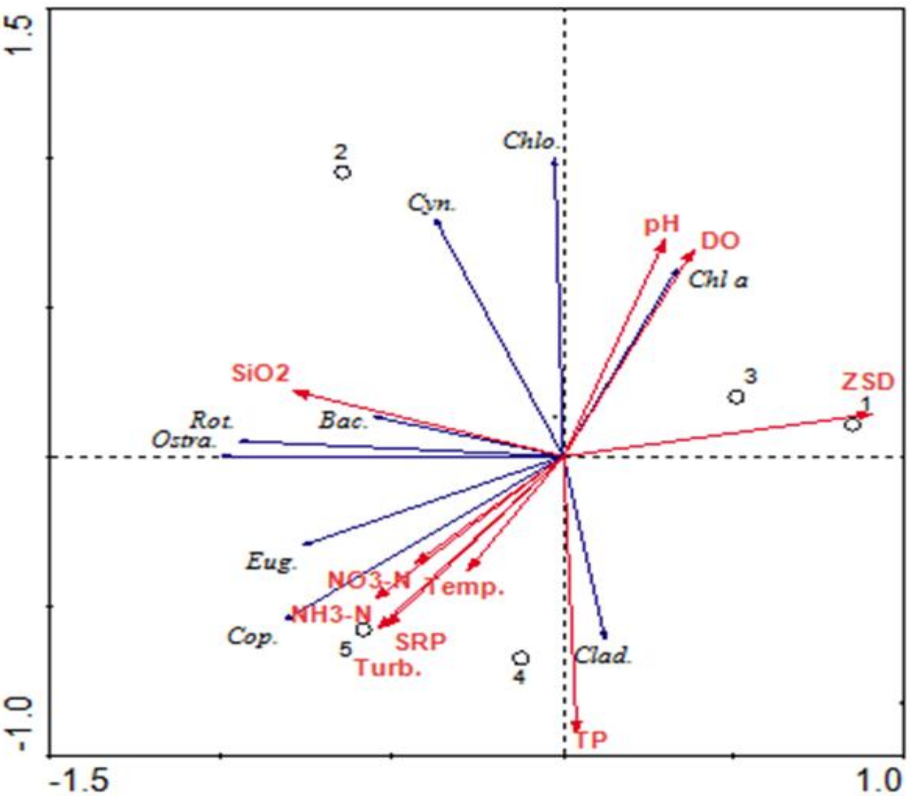

Figure 10. Tri-plot of the redundancy analysis showing the association of plankton genus abundance and environmental variables at five sampling sites; Blue arrows represent plankton genus and red arrows environmental variables and numbers represent sampling sites (Abbreviation: Bac - bacillariophyceae, Chlo - chlorophyceae, Chl *a*- chlorophyll *a*, Cyan-cyanophyceae, Eug- euglenophyceae, Clad- cladocera, Cop- copepods, Rotif- rotifer, Ostra-ostracod; 1- near outlet, 2- fish landing site, 3- Open water, 4- near inlet Big Akaki River, 5- near inlet Little Akaki River sampling site).

5. DISCUSSION

5.1. Physico-chemical parameters of Aba Samuel Reservoir

The highest turbidity (703 NTU) was recorded at near inlet Little Akaki River in July, while the lowest (7.14 NTU) was observed at near outlet sampling site in April and the total mean $\pm$ SE value was (105.94 $\pm$ 99.59 NTU). As compared with some reservoirs and rivers found around Addis Ababa city, the value reported in the present study was lower than the value reported by Birhanu Hailu (2017, 255.67 ± 30.52) for Legedadi Reservoir. The present study indicated that the domestic and industrial wastes disposed from Addis Ababa city directly affect the water quality of Addis Ababa Rivers and Aba Samuel Reservoir. The catchment of Akaki River is the site for industrial establishments, which releases their wastewater directly into the river (Kassahun Tessema, 2017). Akaki River (Great and Little Akaki), is the main tributary of Aba Samuel Reservoir that discharges its effluents to Aba Samuel Reservoir.

The highest turbidity at near inlet Little Akaki River site might be due to the river as it is severely polluted by uncontrolled waste disposal from industrial, domestic and municipal of Addis Ababa. High turbidity affects photosynthesis process, visual predations, filter feeder, and recreational purpose. Akaki River is major source of wastewater pollutants for the reservoir. According to Hamere Yohannes and Eyasu Elias (2017), more than 90% of the Addis Ababa industries discharge their waste to nearby river without proper treatment. Some of the wastes contaminated with toxic industrial wastes.

The maximum mean TSS (mg L^{-1}) value was recorded 2169.2 $\pm$ 06.2 at near inlet Little Akaki River, and the minimum mean 117.1 $\pm$ 40.20 at near outlet site. The maximum TSS value at near inlet of Little Akaki River may be due to increased influx of particulate materials. The lowest mean of Secchi depth (m) recorded 0.11 $\pm$ 0.04 at near inlet Little Akaki River. TSS (p=0.007) and Z_{SD} (0.001*) have spatial significant difference, the highest Z_{SD} were recorded at the site were the lowest turbidity and total suspended solid were recorded. This may be because water transparency was affected by concentration of TSS. Adane Melaku (2017) also recorded that, water transparency was primarily controlled by the concentration of suspended sediment particles rather than by phytoplankton. Organic matter and sediment that emanates from the catchment including Addis Ababa could be major sources of TSS.

TSS prevents the penetration of sunlight into the water column and hence has a negative effect on the primary production of phytoplankton by reducing the euphotic depth and making the water turbid (Mwaura, 2003; Liu *et al.*, 2014).

Water temperature recorded for Aba Samuel Reservoir varied from 22.18 $\pm$ 0.27 at the open water sampling site to 23.32 $\pm$ 0.33°C at the near inlet of Little Akaki River sampling site. Surface water temperatures of all sampling sites was comparable to research result reported by Lakew Wondimu (2014; 21- 26 °C) for Koka Reservoir.

Electrical conductivity of Aba Samuel Reservoir during study period ranged from 631.83 – 817.82 µS/cm which is comparable with some rivers and reservoirs around Addis Ababa. The result of the present study is higher than that of Legedadi Reservoir (92 ± 2.27, Birhanu Hailu, 2017), Gilgel Gibe Reservoir (75.3-129.1, Esayas Embaye, 2013) and Geffersa Reservoir (68.1-135.5, Nigatu Ebisa, 2010). However, Feven Solomon (2007) had earlier reported a comparable result (605 – 684) for same reservoir (before rehabilitation).

The pH of Aba Samuel Reservoir was found to be slightly alkaline in nature. In the present study, the pH ranged from 7.58 to 8.41, which is comparable to the result reported by Lakew Wondimu (2014, 6.13 – 8.6 for Koka Reservoir); Amare Shiberu *et al.*, (2017, 7.12 –7.46 for Awash River); Esayas Embaye (2013, 6.5 – 8.7 for Gilgel Gibe Reservoir) and Nigatu Ebisa (2010, 7.29 – 8.4 for Geffersa Reservoir).

According to Voahangiarilala (2009), the reasons of pH change in water is the photosynthesis. This process absorbs carbon dioxide from the water and uses the sun's energy to convert it to simple organic carbon compounds and to produce oxygen. Carbon dioxide in solution has acidizing effect as it reacts with water and forms carbonic acid (H_2CO_3). As long as plants and algae remove it, the water becomes more alkaline and the pH increases.

Dissolved oxygen is an important indicator of water quality, ecological status, productivity and health of a reservoir. The DO (mg L^{-1}) in the present study ranged from 2.15 $\pm$ 0.33 at near inlet little Akaki River to 3.79 $\pm$ 0.61 at near outlet sampling site with mean value of 3.46 $\pm$ 0.33. This finding is closely similar to the values reported for Akaki River (2.73 $\pm$ 2.05 - 3.14 $\pm$ 2.21, Kassahun Ataly, 2017), Awash River (3.13 – 4.92, Amare Shiberu *et al.*, 2017) and lower than Legedadi Reservoir (10 ± 2.25, Birhanu Hailu, 2017).

The lowest DO was recorded at near inlet of Little Akaki River; this may be due to the discharge of untreated wastewater from Addis Ababa city and industries into the river. Eutrophication leads to the production of algal blooms in reservoirs which is responsible for depletion of dissolved oxygen and contributes to serious water quality problems (EPA, 2000). Additionally, microbial activity consumes dissolved oxygen to decompose organic pollutants. A low DO (less than 5mg L^{-1}) would indicate poor water quality and thus would have difficulty in sustaining many sensitive aquatic organisms (Geneviève and James, 2008). For instance, Cladocerans died when dissolve oxygen was depleted in Lake Hayq (Tadesse Fetahi *et al*., 2011).

The mean $\pm$ SE concentration of NO_3-N ranged from (0.23 $\pm$ 0.05 – 0.31 $\pm$ 0.03 mg L^{-1}). The result were similar to the study reported by Kassahun Ataly (2017, 0.22 - 0.31 mg L^{-1} for Akaki River) and lower than the result reported by Birhanu Hailu (2017, 0.46- 0.62 mg L^{-1} for Legedadi Reservoir). In this study the concentration of NO_2-N values was found in small amount in all sampled sites and to increase in the inlet of Little Akaki River (0.10 $\pm$ 0.03). The high concentration at the inlet could be due to organic wastes, agricultural fertilizers, surface runoff and sewage discharge into the reservoir through the river.

The mean $\pm$ SE concentration of NH_4 (mg L^{-1}) ranged from 1.65 $\pm$ 0.51 at open water to 2.37 $\pm$ 0.19 at near inlet Little Akaki River sampling sites. This may be occurring due to industrial, municipal wastewater discharges and human excreta disposed along the course of river. High NH_4 concentration is an indication of toxicity to aquatic biota and downstream users through drinking and fishing (Kassahun Tessema, 2017).

The mean $\pm$ SE concentration of TP (mg L^{-1}) ranged from 0.105 $\pm$ 0.018 at fish landing site to 0.12 $\pm$ 0.016 at near inlet of Big Akaki River sampling site. TP concentration recorded in Aba Samuel Reservoir was lower than the result recorded for same reservoir before the reservoir rehabilitated by Feven Solomon (2017, 0.13-0.71), Legedadi Reservoir (2.9 ± 1.10 mg L^{-1}, Birhanu Hailu, 2017) and Koka Reservoir (0.478 mg L^{-1}, Lakew Wondimu, 2014).

The mean $\pm$ SE SRP concentration (0.017 $\pm$ 0.003 mg L^{-1}) of this study was lower than the study conducted for reservoirs found around Addis Ababa city the study conducted for Geffersa Reservoir (0.029- 0.2 mg L^{-1}, Nigatu Ebisa, 2010) and Legedadi Reservoir, (0.105 - 0.182 mg L^{-1}, Adane Sirage and Demeke Kifle, 2018).

The high levels of inorganic nitrogen and phosphorus sources have resulted from their external loading through terrestrial runoff and influent domestic and industrial wastewaters. Internal loading through water column mixing considering the shallowness and exposure to wind action (Adane Melaku, 2017) could also be important. The high concentration levels of phosphate and nitrate ions from the high pollution river water source could be attributed to the leaching of fertilizer residues from agricultural farms and the use of phosphate additives in detergent formulations, which can be eroded into the river system during the disposal of wastewaters generated municipally, domestically or industrially (Samuel Melaku *et al*., 2007).

Table 9. Physico-chemical values of Aba Samuel Reservoir in comparison to others reservoirs (Akaki River, Kassahun Ataly, 2017; Legedadi Reservoir, Birhanu Hailu , 2017 and Adane Sirage and Demeke Kifle, 2018; Koka Reservoir, Fasil Degefu *et al*., 2011 and Lakew Wondimu 2014 and Geffersa Reservoir, Nigatu Ebisa, 2010).

Parameters	Legedadi Reservoir	Geffersa Reservoir	Koka Reservoir	Akaki River	Aba Samuel Reservoir, 2007	Present study
Temp. (°C)	19.27±2.8	_	21 – 25	20.18-21.32	20.7 – 22.7	21.9±0.29
Z_{SD} /Seci. (m)	_	0.2 - 0.66	0.12	_	_	0.29±0.057
Turbidity (NTU)	255.7 ± 30.5	7.2-18.9	_	228.6-508.4	_	105.9±39.27
TSS (mg L^{-1})	390 ± 45	_	_	580.7-744.8	_	745.7±222.74
K_{25} (µS cm^{-1})	92 ± 2.27	68.1-135.5	203-393	166.92-254	605 - 693	718.8±13.01
TDS (mgL^{-1})	77 ± 1	_	_	1174-1473	_	5680.9±839.8
pH	7.6± 1.3	7.29-8.44	8– 9	7.49-7.89	6.91 -7.3	7.96±0.05
DO (mg L^{-1})	10± 2.25	_	7.40	2.73-3.14	_	3.46±0.25
NO_2 -N(mg L^{-1})	_	_	_	0.2 - 0.53	_	0.07±0.01
NO_3 -N(mg L^{-1})	0.46- 0.62	0.01- 0.3	0.044	0.22-0.31	_	0.25±0.02
NH_3 -N (mg L^{-1})	0.02- 0.083	0.146	0.089	3.91-5.91	_	1.94±0.15
SRP (mg L^{-1})	0.182- 0.105	0.029- 0.2	0.036	10.25-18.55	_	0.02±0.01
TP (mg L^{-1})	_	_	0.478	18.8-36.09	_	0.11±0.01
SiO_2 (mg L^{-1})	17.9-12.7	2.5-13.4	17.7	_	_	0.26±0.01
Chl *a* (µg L^{-1})	_	12.41	214.1	_	_	15.08±0.94

5.2. Biological Parameters

5.2.1. Phytoplankton biomass/ Chl *a* of Aba Samuel Reservoir

Aba Samuel Reservoir has less productive character as the measured phytoplankton biomass. The mean phytoplankton biomass in terms of Chl *a* (15.08 $\pm$ 0.94 µg L^{-1}) recorded in Aba Samuel Reservoir was lower than Koka Reservoir (214.10 µg L^{-1}, Fasil Degefu *et al*., 2011).

Chl *a* is low as compared with nutrient available in the reservoir because most probably due to high turbidity. The high turbidity in the reservoir is attributed to the daily resuspension of the sediments due to the reservoir's shallowness which greatly affects the light regime in this reservoir. The elevated light attenuation in this reservoir makes light being available for photosynthesis within a very narrow band at the upper surface which subsequently affects the productivity and biomass of the reservoir. Additionally, high concentration of non-living particulate materials such as silt results in increasing turbidity, which light-limits photosynthesis and therefore restricts phytoplankton biomass development (Hadgembes Tesfay, 2007).

5.2.2. Phytoplankton and Zooplankton abundance

The observed dominance of phytoplankton communities in Aba Samuel Reservoir by cyanobacteria (Cyanophyceae), green algae (Chlorophyceae) and diatoms Bacillariophyceae) is a common feature of tropical fresh water and has been reported for reservoirs and lake in Ethiopia including Geffersa Reservoir (Nigatu Ebisa, 2010), Koka reservoir (Yeshiemebet Major, 2016) and Lake Tana (Adane Melaku, 2017).

Green algae (Chlorophyceae) (1913 $\pm$ 499 algal unit L^{-1}) were the most dominant species in Aba Samuel Reservoir during study period as compared to the other Phytoplankton species. The predominance of green algae in freshwaters is the result of their structural and physiological adaptations that include their generally small size, deformed shapes and formation of mucilaginous colonies which reduce loss due to sedimentation or grazing by Zooplankton (Graham and Wilcox, 2000). Green algae seem to be favored by nutrient-rich, fairly turbulent low-salinity waters (Graham and Wilcox, 2000).

Cyanobacteria (Cyanophyceae) was (403 $\pm$ 124 algal unit L^{-1}) the second most abundant in Aba Samuel Reservoir. Dominance of Cyanobacteria is regarded as a sign of eutrophic conditions and poor ecological status of reservoirs and lakes (Paerl *et al*., 2011). The dominance of

Cyanobacteria in the present study reservoir may be due to the levels of nitrate, turbidity and TSS.

Bacilarophyceae was (340 $\pm$ 48 algal unit L^{-1}) the third abundant species in Aba Samuel Reservoir. Bacilariophyceae are the fast-growing and thrive under strong water column mixing conditions (Reynolds, 2006). Euglenophyceae were (172.5 $\pm$ 21algal unit L^{-1}) poorly represented phytoplankton community in Aba Samuel Reservoir.

The mean abundance of Cyclopoid- Copepoda was 352 $\pm$ 85 ind. L^{-1}, Cladocera 104 $\pm$ 44 ind. L^{-1}, Rotifera 125 $\pm$ 37 ind. L^{-1} and Ostracoda 9143 $\pm$ 1984 ind. L^{-1}. Zooplankton taxa were similar but had lower abundance as compared with the study recorded for Geferssa Reservoir, Gilgel Gibe Reservoir, Lake Hawassa, Lake Hayq. Ostracoda were more abundant than others Zooplankton in Aba Samuel Reservoir. According to Fernando (2002), freshwater ostracods are very hardy and are often indicative of stressed environments (low dissolved oxygen and high turbidity) where most Zooplankton has been eliminated. The DO concentration of the reservoir was very low (Table 3).

5.2.3. Microbiological water quality parameters

The result of analysis for total coliform (TC) bacteria ranges from 6160 $\pm$ 3438 at near outlet to 7750.42 $\pm$ 4630.34 CFU L^{-1} at near inlet Little Akaki River sampling site and fecal coliform (FC) bacteria ranges from 95 $\pm$ 31 CFU 100 ml $^{-1}$ at open water to 350 $\pm$ 88 CFU 100 ml $^{-1}$ at fish landing site; which indicates the presence of high contamination. TC and FC values were higher than the recommended maximum permissible limits of WHO, (2006) and EU, (1998), which states that zero/100 mL for the drinking, irrigation and recreational uses. Aba Samuel Reservoir care is important because water source for local peoples used for drinking, washing, irrigations.

FC bacteria in aquatic environment indicate that the water has been contaminated with the fecal material of man or other animals. FC bacteria can enter water bodies through direct discharge of waste from mammals, from agricultural and from untreated human sewage (WHO, 2011). Point source of pollution on Aba Samuel reservoir comes from construction and industrial in its watershed in and around the city, urban waste, domestic (raw) sewage and factory effluents and contaminants from the tributaries of Akaki River which drain the city of Addis Ababa (Hamere Yohannes and Eyasu Elias, 2017).

5.3. WQI and TSI of Aba Samuel Reservoir

WQI of Aba Samuel Reservoir ranged from 35.25 to 47.97 and is categorized as bad water condition after considering various physico-chemical and biological water quality indices based on NSFWQI standards. The obtained values of NSFWQI at all sampling sites shows that the water quality at all sampling sites are bad. Even after rehabilitation, the water quality and trophic status condition of Aba Samuel Reservoir is still poor and bad due to point and non-point sources wastes, including domestic waste, agricultural, industrial and hospital wastes and the surrounding areas of the reservoir is mostly covered by plastic bottles, glasses wastes and the water has bad odour (Hamere Yohannes and Eyasu Elias, 2017).

Aba Samuel Reservoir can be categorized under eutrophic status according to Lamperlli, (2004) loading with TP and Chl *a*. Eshetu Gizaw *et al*., (2004) and Feven Solomon (2007), reported that the concentration of nutrients in Aba Samuel Reservoir is very high, and this triggers algal bloom and the pollution of the Akaki River was blamed for the emergence of water hyacinth weed in the Aba Samuel Reservoir (Hamere Yohannes and Eyasu Elias, 2017).

Water quality deterioration in reservoirs usually comes from excessive nutrient inputs, heavy metal contamination, organic pollution and obnoxious fishing practices (WHO, 2001, Keke, 2008). According to Subeva *et al*., (2017), nutrient enrichment of water increase production of algae, deterioration of fisheries, deterioration of water quality and other characteristic changes.

WQI of ASR is bad, and the main reason appears to be the waste loading from Addis Ababa city and Akaki catchment.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Currently, Aba Samuel Reservoir water quality is highly polluted based on the physico-chemical and biological water quality index characteristics. This may be due to domestic, industrial, agricultural and other urban wastes from point and non-point sources.

Based on the recommended standard values of WHO and EU, the reservoir water is unsuitable for drinking/domestic uses without treatment. It has high values of turbidity (105.94 NTU) and bacteriological parameters like TC (4969 CFU mL^{-1}) and FC (225 CFU $100mL^{-1}$).

Assessment of water quality and trophic status are an important factor for assessing pollution levels and the productivity of the water body. According to NSFWQI the reservoir water quality indices was categorized as bad water quality and its ecological condition is highly deteriorated and it is not acceptable for drinking, recreational, irrigation and aquatic life uses.

In general, the major problems observed and investigated in the Aba Samuel Reservoir even after rehabilitation indicate that; the water quality and trophic status condition of Aba Samuel Reservoir is still poor and bad due to point and non-point sources wastes. The results; are eutrophication (nutrient pollution), siltation (high rate of sediment deposition) and pollution by inorganic matter.

Despite high nutrient levels, Aba Samuel Reservoir has low plankton diversity and biomass as indicated in the measured phytoplankton abundance and biomass, and zooplankton abundance. The planktons in Aba Samuel Reservoir is very low as compared with other reservoirs found around Addis Ababa and Ethiopian lakes, this situation may be related to different physico-chemical factors, such as high turbidity and TSS, and the low water retention time of the reservoir.

6.2 Recommendation

Water quality of Aba Samuel Reservoir is highly contaminated, so the municipal administration and other service sectors should install wastewater treatment plants; Buffer zone and constructed wetlands in order to reduce the pollutants entering into the reservoir.

Mitigation on point and non-point sources of pollutants is mandatory.

Further research should be conducted in the Aba Samuel Reservoir to investigate the detail water quality status of the reservoir by considering the seasonal/temporal variations of the water quality parameters and heavy metal analysis all over the year.

The Federal and Regional governments should put regulations and legislations in place to improve sanitary facilities to all household and restrict hazardous wastewater generating industries with some buffer zone around Aba Samuel Reservoir.

7. REFERENCES

Abraham Hailemelekot (2009). Determination of Spatio-Temporal Differences of Water Hyacinth and Its Effects Around Lake Aba Samuel, South of Addis Ababa, Ethiopia. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia. 65pp.

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

Adane Sirage and Demeke Kifle (2017). Plant Nutrient and Biological Water Quality of Legedadi Reservoir (Ethiopia): Spatio-temporal Variations. *J. Pollut. Eff. Cont.* **6:** 1- 6.

Adimasu Woldesenbet (2015). Physicochemical and biological water quality assessment of Lake Hawassa for multiple designated water uses. *Journal of Urban and Environmental Engineering* **9**: 146-157.

Amare Shiberu Keraga, Zebene Kifle and Agizew Nigussie (2017). Evaluating water quality of Awash River using water quality index. *Int. J. Water Res. Environ. Engineering* **9**: 243-253.

APHA (American Public Health Association) (1995). Standard methods for the Examination of Water and Wastewater, 19th ed. American Public Health Association, Washington D.C., USA.

APHA (1999). Standard Methods for the Examination of Water and Wastewater, 20th ed. United Book Press, Inc., Baltimore, Maryland, USA.

APHA (1999). Standard Methods for the Examination of Water and Wastewater, 20th ed. United Book Press, Inc., Baltimore, Maryland, USA.

Behera Sh. (2012). *Physiocochemical and Microbial Analysis of Water and Soil Samples in Proposed Coal Mine area at Latehar*. National Institute of Technology, Rourkela. 49pp.

Bellinger, E.G. and Sigee, D.C. (2010). Freshwater algae: identification and use as bio-indicators. Blackwell, UK.243pp.

Birhanu Hailu (2017). Physicochemical and microbial quality of drinking water from source to household taps; the case of Legedadi Reservoir. Addis Ababa, Ethiopia. pp. 1-68.

Brown, R. M., McClelland, N. I., Deininger, R. A. and Tozer, R. G. (1970). A Water Quality Index- Do We Dare.

Carlson, R. E. (1977). Trophic state index for lakes. *Limnology and Oceanography*. **22**: 361-369.

Cunha, D.G., Calijuria, M.C. and Lamparelli, M.C. (2013). A trophic state index for tropical/ subtropical reservoirs (TSItsr). *Ecol. Eng*. **60**: 126 –134.

DeMott ,W. R., Zhang, Q.X. and Carmichael, W.W. (1991). Effects of toxic cyanobacteria and purified toxins on the survival and feeding of a copepod and three species of Daphnia. *Limnology and Oceanography* **36**: 1346–1357.

Dhanam, S., Sathya, A. and Elayara B. (2016). Study of physico-chemical parameters and phytoplankton diversity of Ousteri lake in Puducherry. *World Scientific News* **54**: 153-164.

EELPA. (1987). Aba Samuel Rehabilitation study main report. (Unpublished).

EPA (2002). Onsite wastewater treatment systems manual. EPA/625/R-00/008/2002. Available from http://www.epa.gov/owmitnet/mtbfact.htm. Accessed 10/08/2018.

Esayas Embaye (2013). Composition and Abundance of Crustacean Zooplankton in Relation to Algal Biomass, Fish Predation and Physico-chemical Factors in Gilgel Gibe Reservoir. Jimma, Ethiopia. pp. 1-69.

Estefan G., Sommer R. and Ryan J. (2013). Methods of Soil, Plant, and Water Analysis. In: A manual for the West Asia and North Africa region, pp. 170 -176, (ICARDA, ed). Beirut, Lebanon.

Eshetu Gizaw, Worku Legesse, Alemayehu Haddis, Bishaw Deboch and Birke Wondwossen (2004). Assessment of factors contributing to eutrophication of aba Samuel water Reservoir in Addis Ababa, Ethiopia. *Ethiop J. Health Sci*. **14**: 109–117.

European Union (1998). Council Directive 98y83yEC of 3 November 1998 on the quality of water intended for human consumption. Official Journal of the European Community 1998.p.L330y32 –L330y54.

Fasil Degefu, Kibru Teshome, Gashaw Tesfaye, Fikadu tefera and Aschalew Lakew (2011). Some limnological aspects of Koka reservoir a shallow tropical artificial lake, Ethiopia. *J. Recent Trends Biosci.* **1:** 94-100.

Ferezer Eshetu (2012). Physico-chemical pollution pattern in Akaki River basin, Addis Ababa, Ethiopia. MSc.Thesis, Stockholm University. 30pp.

Fernando, C .H. (2002). *A Guide to Tropical Freshwater Zooplankton*. Backhunys, Leinden.

Feven Solomon (2007). Spatial and temporal water quality trend analysis using sediment cores and water samples from Aba Samuel Lake, south west of Addis Ababa, central Ethiopia. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia. 58 pp.

Geneviève, M. C. and James, P. N. (2008). Water quality for ecosystem and human health. In: International Institute of Polish Academy of Sciences, European Regional Centre for Eco hydrology under the auspices of UNESCO and University of Lodz, pp. 1-154, (Richard, R. and Sabrina, B. eds). United Nations Environment Programme Global Environment Monitoring System (GEMS), New Work.

Getaneh Gebre and Van Rooijen D. (2009). Urban water pollution and irrigated vegetable farming in Addis Ababa. 34 th WEDC International Conference, Addis Ababa, Ethiopia.

Gilbert, J. (1994). Susceptibility of planktonic rotifers to a toxic strain of *Anabaena flos-aquae*. *Limnol. Oceanogy* **39**: 1286- 1297.

Glime, J. M. 2017. Arthropods:Crustacea – Copepoda and Cladocera. Chapt. 10-1. In: Glime, J. M. BryophyteEcology. Volume 2. Bryological Interaction. Ebook sponsored by Michigan Technological University and the International Association of Bryologists. Last updated 21 April 2017 and available at <http://digitalcommons.mtu.edu/bryophyte-ecology2/>.

Graham, L. and Wilcox, L., (2000). Algae. Upper Saddle River: Prentice, Hall, 640 pp.

Habtamu Haile (2007). Suitability of local materials to purify Akaki sub-basin water. PhD dissertation. Karlsruhe University, Thailand.

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

Hallock, D. (2002). A Water Quality Index for Ecology’s Stream Monitoring Program. Washington State.

Hamere Yohannes and Eyasu Elias (2017). Contamination of Rivers and Water Reservoirs in and around Addis Ababa city and actions to combat it. *Environ. Pollut. Climate Change* **1**: 1‒12.

Hotzel, G. and Croome, R. (1999). A phytoplankton counting methods manual for Australian freshwaters. Land and Water Resource Research Development Corporation Canberra, 51pp.

Https://www.industryabout.com/country-territories-3/2550-ethiopia/hydro-energy/39524-aba-samuel-dam/ accessed date 11/10/2018.

Israel Deneke (2006). Assessment of Drinking Water Quality and Pollution. M.Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia. 68pp.

Janse van Vuuren, S., Taylor, J., Gerber, A. and Van Ginkel, C. (2006). Easy identifiacation of the most common freshwater algae. North-West University, South Africa.

Kassahun Atalay (2017). Water Quality of Akaki Rivers and its impact on irrigated vegetable farms. M.Sc. Thesis. Addis Ababa, Ethiopia.

Kassahun Tessema (2017). Heavy Metals in Lake Koka Food Chain: Potential Health Risk Implications. M.Sc. Thesis. Addis Ababa, Ethiopia.

Keke, M. (2008). Assessment of the water quality of Oyun Reservoir, Offa, Nigeria, using selected physico-chemical parameters. *Turkish Journal of Fisheries and Aquatic Sciences* **8**: 309-319.

Komarek, J. and Anagnostidis, K. (2005). Cyanoprokaryota: sub wasser flora von Mitteleuropa. Spektrum Akademischer Verlag, Berlin. **2**: 1_720.

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

Lamparelli, M.C. (2004). Trophic state in Sao Paulo water bodies: evaluation of monitoring methods. Dissertation [Sao Paulo (Brazil)]: University of Sao Paulo.

Lind, O. T., Terrell, T.T., and Kimme, B.L. (1993). Problems in reservoir trophic-state classification and implications for reservoir management. Washington, D.C, USA. 57–67pp.

Liu, G., Bakker, G., Li, S., Vreeburg, J., Verberk, J., Medema, G., Liu, W. & Van Dijk, J. (2014). Pyrosequencing reveals bacterial communities in unchlorinated drinking water distribution system: an integral study of bulk water, suspended solids, loose deposits, and pipe wall biofilm. *Environmental science & technology* **48**: 5467-5476.

Magaly, M. H., Eduardo da, F. F. and Fernando, L. C. (2015) Water quality and trophic state of a tropical urban reservoir for drinking water supply (Juiz de Fora, Brazil). *Lake and Reservoir Management* **31**:134–144.

Makhlough, A. (2008). Water Quality Characteristics of Mengkuang Reservoir based on Phytoplankton Community Structure and Physico- Chemical Analysis. MSc. Thesis, University Sains Malaysia, Iranian. 24 pp.

Marselina, M. and Burhanudin, M. (2017). Trophic Status Assessment of Saguling Reservoir, Upper Citarum Basin, Indonesia. *Air, Soil and Water Research* **10**: 1–8.

Membrillo-Abad, A., Torres-Vera, M., Alcocer, J., Prol-Ledesma, R., Oseguera, L and Ruiz-Armenta, J. (2016). Trophic State Index Estimation from Remote Sensing of Lake Chapala, México. *Revista Mexicana de Ciencias Geológicas* **33**: 183-191.

Mwaura, F. (2003). The spatiotemporal characteristics of water transparency and temperature in shallow reservoirs in Kenya. *Lakes & Reservoirs: Research & Management* **8**: 259-268.

Nigatu Ebisa (2010). Water Quality and Phytoplankton Dynamics in Geffersa Reservoir/ Ethiopia. M.Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia. 56 pp.

Paerl, H. W., Hall, N. S., & Calandrino, E. S. (2011). Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic and climatic-induced change. *Sci. Total Environ.* **409**: 1739-1745.

Patil, P. N., Sawant, D.V. and Deshmukh, R. N. (2012). Physico-chemical parameters for testing of water – A review. *International Journal of Environmental Sciences* **3**: 1194 – 1199.

Quirós, R. (2003). The relationship between nitrate and ammonia concentrations in the pelagic zone of lakes. *Limnetica* **22**: 37-50.

Qureshimatva, U., Maurya, R., Gamit, S., Patel, R. and Solanki, H. (2015) Determination of Physico-Chemical Parameters and Water Quality Index (Wqi) of Chandlodia Lake, Ahmedabad, Gujarat, India. *J. Environ. Anal. Toxicol.* **5**: 1–4.

Rubio-Arias, H., Contreras-Caraveo, M., Manuel Q, R., Alfonso R. S., and Pinales-Munguia, A. (2012). An Overall Water Quality Index (WQI) for a Man-Made Aquatic Reservoir in Mexico. *Int. J. Environ. Res. Public Health* **9**: 1687-1698.

Saba Kifle (2017). Eutrophication Status of Legedadi Reservior. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia. pp 85.

Samuel Melaku, Taddese Wondimu, Richard Dams and Luc Moens (2007). Pollution Status of Tinishu Akaki River and Its Tributaries (Ethiopia) Evaluated using Physico-Chemical Parameters, Major Ions, and Nutrients. *Bull. Chem. Soc. Ethiop*. **21**: 13-22.

Sandercock, G., A. and Scudder, G., G., E. (1994). An Introduction And Key To The Freshwater Calanoid Copepods (Crustacea) Of British Columbia. University of British Columbia. pp 86.

Shaka Nugusu (2015). Assessment of Surface Water Quality in Upper Awash River Basin. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia. 77pp.

Solomon Akalu , Seyoum Mengistou and Seyoum Leta (2011). Assessing Human Impacts on the Greater Akaki River, Ethiopia Using Macroinvertebrates. *Ethiop. J. Sci.*, **34**:89–98

Srivastava, G. and Kumar, P. (2013). Water quality index with missing parameters. *International Journal of Research in Engineering and Technology* **2**: 609–613.

Stednick, J. and Hall, E. (2001). Applicability of Trophic Status Indicators to Colorado Plains Reservoirs. Colorado State University. 77pp.

Strickland, J. and Parsons, T. (1972). A practical handbook of sea water analysis. *Fish. Res. Board Can. Bull.* **169**:1–310.

Subeva, M., Kenderov, L. and Evtimova, V. (2017). Trophic status and ecological potential of Reservoirs in Bulgaria based on selected parameters. **102**: 218- 232.

Suthers I. and Rissik D. (2009). Plankton: A guide to their ecology and monitoring for water quality. National Library of Australia Cataloguing, CSIRO Publishing.

Tadesse Fetahi, Seyoum Mengistou and Schagerl M. (2010). Zooplankton community structure and ecology of the tropical-highland Lake Hayq, Ethiopia. *Limnologica* 41: 389 –397.

Tesfaye Delelegne (2006). Seasonal and spatial variations of zooplankton in relation to physico-chemical variables and phytoplankton production in Lake Beseka (Metehara). M.Sc. Thesis. Addis Ababa, Ethiopia.

Tyagi, Sh., Sharma, B., Singh, P., and Dobhal, R. (2013). Water Quality Assessment in Terms of Water Quality Index. *American Journal of Water Resources* **3**: 34–38.

UN-Water (2016). Worldwide Assessment of Freshwater Quality. UN-Water. 35 pp.

Voahangiarilala, L. (2009). Characterization of Ranomafana Lake Water Quality –Antsirabe Madagascar. M.Sc. Thesis, University of Stavanger.48pp.

Wetzel, R.., G. and Likens, G., E. (2000). *Limnological Analyses*. 3rd edn. Verlag, Inc. N.Y., New York, 360pp.

WHO (2001). Guidelines, Standards and Health: Assessment of risk and risk management for water-related infectious disease. London, UK. 8pp.

WHO (2006). Guidelines for safe recreational water environments. Swimming pools and similar environments. Geneva.Ethiopia. 89 pp.

Witty, L., M. (2004). Practical Guide to Identifying Freshwater Crustacean Zooplankton, Laurentian University, Canada. 49pp.

Yeshiemebet Major (2016). Plankton community structure and interactions in cyanobacteria-dominated tropical reservoir (Koka, Ethiopia. Ph.D. Thesis Addis Ababa University, Addis Ababa. 163 pp.

8. APPENDICES

Appendix 1. Physical parameters measured during study period at the sampling sites of the present study in Aba Samuel Reservoir.

Months	Sites	Seci(m)	Turbidity	TSS(mg/L)	Cond.	TDS(mg/L)	Temp°	pH	DO(mg/l)	% Satur.
April	S1	0.9	7.14	66.7	780.1242	10620	22	8.2	3.66	51.23
	S2	0.23	14.31	126.67	817.8231	10660	20	8.16	3.99	58.55
	S3	0.5	10.29	100	793.9174	10619	21.5	8.23	3.85	55.57
	S4	0.3	49.3	340	800.2575	11739	21	8.33	4.2	67.3
	S5	0.21	270	2733.33	702.7982	10020	23.98	8.41	3.11	48.1
May	S1	0.8	8.9	220	721.4962	3600	23.7	7.86	2.48	37.7
	S2	0.1	18.7	2500	750.3153	400	21	8.09	4.09	67.3
	S3	0.4	16.2	93.33	737.0251	600	22.6	7.7	2.22	30.4
	S4	0.25	63.6	133.3	773.3987	3800	20	7.69	2.65	38.9
	S5	0.13	312.4	1293.33	751.4725	600	22.7	7.58	2.02	28.9
June	S1	0.65	9.73	71.33	752.2297	10540	20.15	7.98	5.42	74.8
	S2	0.09	25.7	220	719.6568	6200	21.7	7.8	4.56	69.29
	S3	0.23	21.7	426.7	690.3775	5520	22.6	7.89	4.33	67.5
	S4	0.08	82.3	1080	657.0103	4999	22.9	7.84	2.28	30.49
	S5	0.06	346.2	1340	648.3153	6060	22.8	7.81	1.92	27.71
July	S1	0.51	12.9	139.99	690.6002	3133	19.9	7.95	3.58	50.4
	S2	0.12	29.4	153.3	631.8345	2540	22.7	7.98	3.71	52.5
	S3	0.21	22.3	239.99	656.7376	2959	22	8	4.55	69.3
	S4	0.05	94.7	326.66	667.407	5000	21	7.99	5.05	76.4
	S5	0.03	703	3310	633.5302	4010	23.8	7.8	1.56	23.25

Note: S1: near outlet, S2: fish landing site, S3: open water, S4: near inlet Big Akaki River, S5: near inlet Little Akaki River sampling sites.

Appendix 2. Chemical parameters (mg L^{-1}) measured during study period at the sampling sites of the present study in Aba Samuel Reservoir.

Month	Sites	NO2-N	NO3-N	NH4-N	SRP	TP	Silica	Chla(µg-L)
April	S1	0.021	0.295	2.190	0.024	0.108	0.324	16.123
	S2	0.022	0.268	2.146	0.029	0.121	0.262	19.435
	S3	0.021	0.283	2.196	0.032	0.143	0.258	18.033
	S4	0.020	0.261	2.196	0.034	0.120	0.303	19.669
	S5	0.020	0.282	2.696	0.039	0.122	0.290	16.699
May	S1	0.023	0.297	2.162	0.015	0.087	0.272	14.010
	S2	0.046	0.199	2.051	0.028	0.081	0.276	18.277
	S3	0.024	0.216	2.162	0.027	0.082	0.279	13.475
	S4	0.039	0.178	2.162	0.023	0.081	0.241	14.186
	S5	0.134	0.261	2.862	0.027	0.092	0.369	12.204
June	S1	0.068	0.126	2.215	0.004	0.077	0.209	19.875
	S2	0.099	0.288	2.160	0.003	0.072	0.208	18.940
	S3	0.096	0.293	2.108	0.004	0.066	0.186	17.406
	S4	0.122	0.360	2.215	0.004	0.123	0.188	13.117
	S5	0.174	0.399	2.515	0.001	0.112	0.193	8.019
July	S1	0.080	0.239	1.060	0.004	0.197	0.183	12.869
	S2	0.088	0.214	1.171	0.001	0.148	0.335	13.569
	S3	0.088	0.210	0.115	0.009	0.143	0.248	16.167
	S4	0.094	0.124	0.985	0.014	0.162	0.238	16.871
	S5	0.082	0.298	1.408	0.012	0.155	0.241	2.673

Appendix 3. Phytoplankton taxa abundance (cell's L^{-1}) measured during study period at the sampling sites of the present study in Aba Samuel Reservoir.

Month	Sites	Cyanophyta	Bacillariophyta	Egulenophyta	Chlorophyta	phyto
April	S1	300	200	300	650	1450
	S2	100	250	150	300	800
	S3	50	0	150	350	550
	S4	350	750	250	150	1500
	S5	250	150	50	650	1100
May	S1	300	150	50	700	1200
	S2	300	700	200	4150	5350
	S3	50	350	250	50	700
	S4	250	50	250	300	850
	S5	100	250	100	1000	1450
June	S1	300	500	0	2500	3300
	S2	50	700	150	6400	7300
	S3	0	350	150	6950	7450
	S4	150	650	150	650	1600
	S5	400	350	300	750	1800
July	S1	600	300	50	3450	4400
	S2	2500	250	250	6000	9000
	S3	1050	100	100	1500	2750
	S4	650	400	250	1000	2300
	S5	300	350	300	750	1700

Appendix 4. TSI values calculated for Aba Samuel Reservoir

		Lamparelli, (2004)			Cunha *et al*., (2013)		
Month	Sampling sites	TSI(TP)	TSI (Chl a)	TSI	TSI TP	TSI Chla	TSI
April	NO	58.84	68.18	63.51	51.33	64.33	57.83
	FLS	60.17	67.23	63.70	50.46	63.66	57.06
	OW	61.83	68.82	65.33	49.37	63.93	56.65
	NIBAR	60.03	69.25	64.64	50.55	63.61	57.08
	NILAR	60.25	66.56	63.41	50.41	64.21	57.31
May	NO	56.05	64.83	60.44	53.18	64.84	59.01
	FLS	54.88	65.15	60.02	53.94	63.88	58.91
	OW	55.09	64.13	59.61	53.80	64.98	59.39
	NIBAR	54.99	68.40	61.69	53.87	64.80	59.33
	NILAR	56.87	60.34	58.60	52.63	65.34	58.99

June	NO	52.79	64.13	58.46	55.32	63.58	59.45
	FLS	51.06	63.31	57.19	56.46	63.75	60.10
	OW	48.62	62.33	55.48	58.06	64.06	61.06
	NIBAR	59.91	67.72	63.81	50.63	65.08	57.86
	NILAR	58.90	56.94	57.92	51.30	66.87	59.08
July	NO	64.67	58.35	61.51	47.50	65.15	56.33
	FLS	62.18	58.35	60.27	49.14	64.96	57.05
	OW	61.86	51.55	56.70	49.35	64.32	56.84
	NIBAR	62.96	61.10	62.03	48.62	64.17	56.40
	NILAR	62.62	51.55	57.08	48.85	70.85	59.85
	Over all TSI	**59.47**	**64.95**	**62.21**	**50.93**	**64.58**	**57.75**