Effects of water hyacinth (*Eichhornia crassipes*) on water quality and composition and abundance of phyto- and zooplankton in the littoral region of Koka Reservoir, Ethiopia

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Abstract

Invasion of aquatic habitats by non-native species is a global environmental challenge with serious ecological, social and economic consequences demanding urgent action. Water hyacinth, Eichhornia crassipes (Martius) Solms, is one of the world's most rampant invasive aquatic plants recognized as one of the top 10 worst weeds in the world. Its appearance in Koka Reservoir was reported in 1965 and has become a threat to the aquatic ecosystem. Although several limnological studies have been made on the reservoir, the effects of water hyacinth on water quality and plankton have not been addressed. Samples were collected monthly from three weed-infested and three non-infested sites from March to July 2018 to assess its effect on water quality, plankton composition and abundance in the reservoir. Potential toxicity of water hyacinth extract was also investigated using white albino mice. During this investigation, the differences between weed-infested and non-infested sites in DO, NO_3-N, NO_2-N, SRP, TP, NH_3, TSS, Turbidity, Silica and Secchi disk depth were significant ($P<0.05$), with lower values in the weed-infested sites except values of TSS, Silica and Turbidity higher in the weed infested sites. The phytoplankton community, which was constituted of 62 species, was dominated by Bacillariophyceae (mainly Aulacoseira granulata) followed by Cyanophyceae (Cylindrospermopsis spp., Microcystis aeruginosa, and Anabaena flos-aquae) and Chlorophyceae in both non-infested and weed-infested sites. The variations in the abundance of phytoplankton and zooplankton between the two sites were significant ($p<0.05$). The phytoplankton species Monorophidium griffithii and Gyrosigma obtusatum and the zooplankton taxa Lecane monostylahomata, Lecane leontita, Trichocerca djurellasejunctipes, Euchlanis menta, and Platyias quadricornis var. bervispinus were found only in the weed-infested sites. Significant differences in Shannon's index (H'), species richness (d) and species evenness (j) of zooplankton and species richness (d) of phytoplankton were also observed between the two sites, with higher mean values in the non-infested sites than in the weed-infested sites ($p<0.05$). Rotifers, followed by Copepods and Cladocerans in the same order, were the most abundant at both sites. The relative density of Rotifers and Cladocerans was higher in the non-infested sites, while that of Copepods was higher next to Rotifesrs in the weed-infested sites. Results of the experimental test on the toxicity of water hyacinth on white albino mice showed unusual changes although the death of the treated mice was not observed suggesting the potential toxic effect of the weed on aquatic biota that would occur with an increase in dose and duration of administration. The existing infestation level of water hyacinth poses a significant effect on water quality, composition and abundance of phytoplankton and zooplankton. The current environmental conditions are favorable for the optimum growth of the weed and further proliferation of the weed and spread to new areas are possible worsening its adverse effect to the ecosystem. Thus, continuous monitoring and development of a sustainable management strategy and regulation of agricultural and urban wastes, have to be addressed.

***Keywords**: Phytoplankton, mice, toxicity test, zooplankton*

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Lists of Abbreviation (Acronyms)

APHA	American Public Health Association
ANOVA	Analysis of variance
AOAC	Association of Official Analytical chemists
CANOCO	Canonical correspondence analysis
DCA	Detrended correspondence analysis
DO	Dissolved oxygen
FAO	Food and Agriculture Organization
PAST	Paleontological Statistics
PCA	Principal Component analysis
RDA	Redundancy Analysis
SPSS	Statistical Package for Social Science
TDS	Total dissolved solids
TSS	Total suspended solids

1. INTRODUCTION

1.1. Background and justification

Invasion of aquatic habitats by non-native species is a global environmental challenge with serious ecological, social and economic consequences demanding urgent action (Williamson, 1999; Xu *et al*., 2012). Aquatic weeds are those unwanted and undesirable aquatic plants, which grow in water and complete at least part of their life cycle in water interfering with the utilization of land and water resources. They are one of the key pressures on world's biodiversity, which alter ecosystem services and processes, reduce native species abundance and richness, and decrease genetic diversity of ecosystems (Hejda *et al*., 2009; Rands *et al*., 2010; Vila *et al*., 2011).

Aquatic ecosystems are threatened by various aquatic weeds all over the globe. Water hyacinth, *Eichhornia crassipes* (Martius) Solms, is one of the world's most rampant invasive aquatic plants recognized as one of the top 10 worst weeds in the world (Mironga, 2014). It spread throughout the world in the late 19th and early 20th century and has invaded freshwater systems in over 60 countries of five continents (Wilson *et al*., 2005). The weed has established in water bodies where hydrological or nutrient conditions have been altered by human activities (Barret, 1989). It is prevalent in tropical and subtropical water bodies where nutrient levels are often high due to agricultural runoff, deforestation, and insufficient wastewater treatment. Nutrients and temperature are considered determinants of overriding importance to the growth and reproduction of water hyacinth (Wilson *et al*., 2007). Its success is also attributed to its ability to outcompete native vegetation and phytoplankton for light and nutrients (Mangas-Ramirez and Elias-Gutierrez, 2004).

Recently, impacts of water hyacinth on the environment and biodiversity of aquatic ecosystems have received due attention in most continents of the world including Asia, Australia, Africa and North America (Dagno *et al*., 2012). The problem has become more severe in Africa especially in Sub-Saharan countries, where new infestations are creating life-threatening situations and environmental and cultural upheaval.

Owing to its unparalleled competitive ability, water hyacinth poses a serious threat to aquatic biodiversity throughout the globe (Pysek and Richardson, 2010; Vila *et al*., 2011; Patel, 2012). Besides suppressing the growth of native plants and negatively affecting microbes, water hyacinth prevents the growth and abundance of phytoplankton and zooplankton under its large mats, ultimately affecting biodiversity, fisheries, and livelihoods (Villamagna and Murphy, 2010; Gichuki *et al*., 2012). Oxygen depletion and reduced water quality also result from the infestation of an area by the weed, with the large water hyacinth mats preventing the transfer of oxygen from the air to the water surface, or decreasing oxygen production by other plants and algae (Villamagna and Murphy, 2010). When the plant dies and sinks to the bottom, its decomposing biomass depletes the oxygen content in a water body resulting in hypoxic condition (EEA, 2012). The infestation also affects the economy through blockage of waterways, hampering agriculture, fisheries, recreation and hydropower (Ndimele *et al*., 2011; Patel, 2012). Floating mats of water hyacinth also support such organisms as pests and vectors detrimental to human health and the environment by providing breeding ground (Minakawa *et al*., 2008).

In Ethiopia, water hyacinth is one of the five invasive alien plants (Taye Tessema *et al*., 2009) and has been recognized as the most damaging aquatic weed since its first appearance in 1956 (Rezene Fessehaie, 2005; Firehun Yiferu *et al*., 2007). The appearance of the weed in Koka Reservoir was first reported in 1965 in the Awash River Basin and it has been invading various water bodies found in different regions of the country (Taye Tessema *et al*., 2009). Lake Tana and some of rift valley lakes are the main water bodies where heavy water hyacinth infestation is observed. Water hyacinth is a constraint to developing country and it has multifaceted problems such as obstructing electricity generation, irrigation, navigation, and fishing, increasing evapotranspiration resulting in water loss, increasing cost of crop production, providing habitat for vectors of malaria and bilharzia, harbors poisonous snakes, causing skin rashes, and hosting agents of amoebic dysentery and typhoid, which have also been documented elsewhere in the world (Taye Tessema *et al*., 2009; Petal, 2012; Mirona, 2014). There are various initiatives to control the expansion of water hyacinth in Lake Tana and but not for Lake Koka, which are losing their biodiversity, socio-economic importance and Bio-reserve value.

Several investigators have monitored the diversity and abundance of phytoplankton and zooplankton under water hyacinth mats in comparison with that of the open water (Chukwuka

and Uka, 2007; Saeed *et al.*, 2013; Wondie Zelalem, 2013; Mironga *et al*., 2014), and observed significant effects of water hyacinth on the composition and abundance of phytoplankton and zooplankton compared to the open water. However, the findings have to be corroborated with the results of studies made along different levels of water hyacinth infestation within the littoral region.

Several studies that investigated the physicochemical limnology, plankton ecology and fish biology and fishery have been documented for Koka Reservoir (Melaku Mesfin, 1988; Elizabeth Kebede and Willen, 1998; Sileshi Mamo 2002; Hadgembes Tesfaye, 2007; Fasil Degefu *et al*., 2011; Seyoum T. Akele, 2011; Lakew Wondimu 2014; Lakew Wondimu, 2015, Yeshiemebet Major, 2016, Mesfin Gebrehiwot, 2017). Even-though the adverse impact of water hyacinth on water quality and biodiversity has been documented elsewhere, none of the studies have looked into the effect of water hyacinth on water quality, phyto and zooplankton abundance, and composition in Koka Reservoir. Therefore, the main objective of the present study was to assess and evaluate the effects of different levels of water hyacinth on water quality and phytoplankton and zooplankton composition and abundance in the littoral region of the reservoir referring to a non-infested (open water) site. Toxicity test was done with extracts from water hyacinth, which were fed orally to mice to understand the potential causes of biodiversity change in the reservoir.

1.2. Hypothesis

It is hypothesized that the littoral region of Koka Reservoir has species composition and abundance of phytoplankton and zooplankton, which differ significantly from those of the non-infested sites (open water sites) due to their infestation by water hyacinth. The tremendous effects of water hyacinth on the composition and abundance of phyto- and zooplankton are associated with its toxicity effect, extensive mat coverage and the consequent reduced light penetration into the water, which reduces photosynthesis by phytoplankton depleting dissolved oxygen and affecting physicochemical parameters of the system that also affect the composition and abundance of zooplankton.

1.3. Research questions

- Does water hyacinth infestation affect water quality in the Koka Reservoir?
- Does water hyacinth infestation affect the composition and abundance of phyto- and zooplankton in Koka Reservoir?
- Does water hyacinth has toxicity effect on plankton?

1.4. Objectives

1.4.1. General objective

The general objective of this research is to investigate the impacts of Water hyacinth (*Eichhornia crassipes*) on water quality, food web and socio-economic impacts of the local region.

1.4.2. Specific objectives

- To determine the effect of water hyacinth infestation on the physicochemical water quality parameters in the littoral region of Koka Reservoir.
- To determine the effect of water hyacinth infestation on phyto- and zooplankton composition and abundance in the littoral region of Koka Reservoir.
- To analyze water hyacinth's potential toxicity effect on mice.

1.5. Significance of the study

Both Phytoplankton and zooplankton constitute major components of food chains, with the former producing the food, and the latter playing an important role in channeling primary production into fish production. Phytoplankton and zooplankton studies are, therefore, necessary since these organisms are playing an important role in the energy transfer from primary producers to organisms of higher trophic levels. Variations in species composition and distribution of phyto- and zooplankton due to the impacts of water hyacinth may, therefore, negatively affect the reproductive biology of the fauna and the functioning of the whole aquatic ecosystem. Thus, the results will update the physicochemical water data and contribute more information on the effect of water hyacinth infestation on plankton. Information on the current

impact of the weed will assist government and non-government bodies in developing strategies of combating water hyacinth in Koka Reservoir and other similar water bodies. The study will also provide baseline data that can be used in monitoring ecological changes and plan further research works.

1.6. Limitation of the study

There is a lack of data on water quality and biodiversity of Koka Reservoir before water hyacinth infestation, which would help to compare with the present findings. However, the reference site (open water) is shallow and has more or less similar conditions with the infested sites.

2. LITERATURE REVIEW

2.1. Aquatic Weeds

Presence of plants in water bodies is essential for the conversion of solar energy into chemical energy for developing aquatic fauna and for continuous addition of oxygen to water during photosynthesis (Sushilklumar, 1996). If water plants due to overgrowth make such water bodies unfit and take the shape of noxious aquatic vegetation, these may be called as aquatic weeds and these aquatic weeds are those unwanted plants growing in water and complete at least a part of their life cycle in water (Bhan and Sushilkumar, 1996). The economic importance of the weeds may accelerate from they polluting drinking water when they day and decay. Besides providing a convenient breeding site for mosquito, snails and other animals of medical and veterinary importance, they may also invade large areas impeding the movement and use of water in irrigation systems and in fish culture.

Invasive aquatic weeds are plants introduced to a new area without the natural checks and balances of their home waters. They can sometimes grow out of control, creating dense monocultures and overwhelming lakes and streams. They are all highly aggressive and create significant ecological and economic damage when they are not controlled. These invasive aquatic plants are called noxious weeds when identified by the Oregon State Noxious Weed Board as having a significant negative impact on the state's natural and economic resources (Sushilklumar, 1996).

2.2. Description, biology, and ecology of water hyacinth

2.2.1. Description

Water hyacinth is a free-floating perennial aquatic plant (or hydrophyte) native to tropical and sub-tropical South America. With broad, thick, glossy, ovate leaves, water hyacinth may rise above the surface of the water as much as one meter in height. The leaves are 10–20 cm across and float above the water surface. They have long, spongy and bulbous stalks. The feathery, freely hanging roots are purple-black. An erect stalk supports a single spike of 8-15 conspicuously attractive flowers, mostly lavender to pink in color with six petals, when not in

bloom, water hyacinth may be mistaken for frog's-bit (*Limnobium spongia*) or Amazon Frogbit (*Limnobium laevigatum*) (Strange *et al*., 2004).

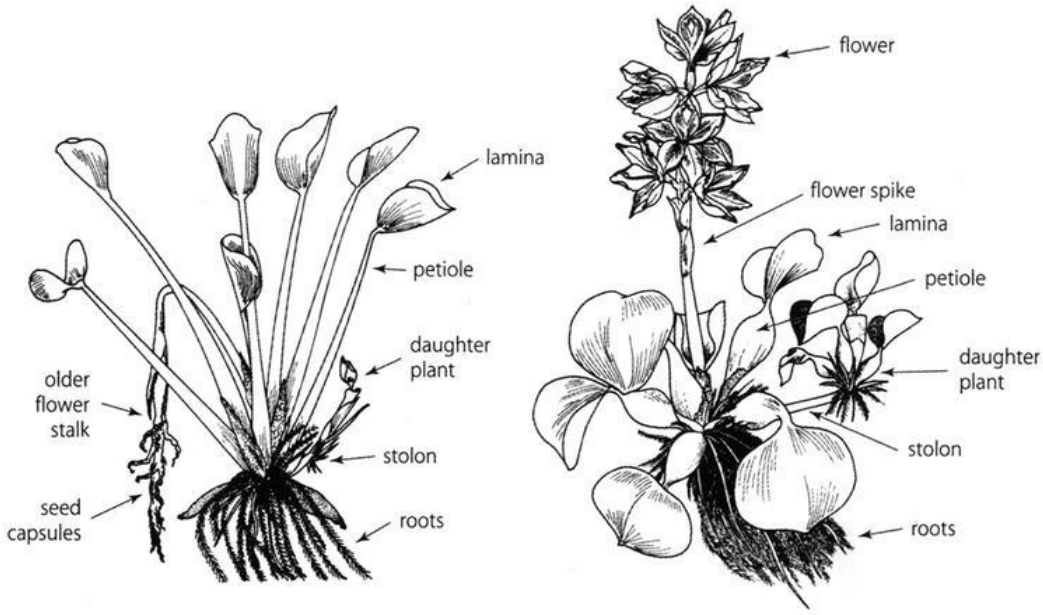


Figure 1. Water hyacinth plant showing different structures/parts

2.2.2. Biology

Under favorable conditions, the population of water hyacinth doubles between 11 – 15 days. Water hyacinth reproduces both by vegetative and sexual reproductive methods and both are characterized by the potential for production of many individuals in a short while (Barrett, 1980b). Seeds are produced in vast quantities, up to 300 seeds per capsule, and are long-lived, remaining viable for 5–20 years (Matthews *et al*., 1977 cited in Gopal, 1987). Seeds sink following release from the seed capsule and may germinate as water level changes (Wright and Purcell, 1995, cited in Julien *et al*., 2001). Dispersal of seed is likely to further contribute to the spread of this weed. Seeds are released directly into the water column, from where they can be carried long distances downstream. The numerous and tiny seeds can also be easily transported by vehicles, boats or pedestrians passing through infested areas (Julien *et al*, 2001).

Although water hyacinth reproduces sexually by producing seeds, seedlings, and fruits (Penfound and Earle, 1948; Barrett, 1980), seeds do not occur in natural populations in some areas of the world (Bock, 1966). This implies that water hyacinth reproduces sexually both in the native and adventive range of its distribution, although, the extent of sexual reproduction and its contribution to the spread of the weed varies greatly in different regions (Gopal, 1987). The quantity of fruits produced and the production of mature capsules varies across different regions (Penfound and Earle, 1948; Barrett, 1980). In terms of several seeds produced per fruit, this is much more variable with those from the tropics having a relatively smaller number of seeds per capsule, but total seed production exceeding that from the temperate population because of a greater proportion of flower producing capsules (Gopal, 1987).

Flowering as well does not occur in all plant populations (Freidel *et al*, 1978). Seed production is affected by humidity and temperature. Low relative humidity results in low fruit setting. Maximum fruiting occurs at a relative humidity greater than 90% and temperatures between 22.5°C and 35.0°C (Gopal, 1987). Although the flowers are attractive and well suited for insect pollination, such rarely occurs in nature (Penfound and Earle, 1948). However, insects have been observed to pollinate in some areas of the world. An insect, Trigona in Indonesia and four groups of bees [Ancyloscelis sp., and Megachilidae and the species of Trigona; Meliponidae and Halictidae were observed to visit flowers in the lower Amazon (Barrette, 1980). Several factors such as climate, the absence of pollinating agents, pollen viability, genetic barriers like self-incompatibility and factors affecting seed germination have been considered responsible for limiting the efficiency of sexual reproduction (Gopal, 1987).

But vegetative reproduction is a common form of propagation in water hyacinth (Julien *et al*, 1999). The daughter plants produced from the horizontal stolons develop roots and eventually separate from the mother plant following decay or breakage of the connecting stolon. These plants are readily distributed by currents, winds, fishing nets and watercraft (Julien *et al*; 1999). Under favorable conditions, a single plant can develop into a substantial infestation in a short time. Doubling days vary from 11 to 15 days (Penfound and Earle, 1948). However, low oxygen tension in the infested area slows down vegetative reproduction (Gopal, 1987).

2.2.3. Ecology

Water hyacinth grows in a variety of freshwater habitats from shallow temporary ponds, marshes and sluggish flowing waters to large lakes, reservoirs, and rivers, which present a broad spectrum of physiochemical environments (Gopal, 1987). Optimum growth of water hyacinth occurs in eutrophic, still or slow-moving fresh water with a pH close to 7, a temperature range between 28°C and 30°C, and abundant nitrogen, phosphorus, and potassium (Reddy *et al*., 1991). Plants will, however, tolerate a wide range of growth conditions and climatic extremes, allowing the weed to infest countries across a wide range of latitudes and climates. Good growth can continue at temperatures ranging from 22°C to 35°C and plants will survive to frost (Wright & Purcell, 1995). Although prolonged cold weather may kill plants, the seeds remain viable (Ueki and Oki, 1979). Plants can infest pristine, relatively low nutrient waterways and can survive for several months in low-moisture substrates. They can tolerate acidic waters but cannot survive in salt or brackish water. Water hyacinth flowers year-round in mild climates, producing abundant seeds in developed mats (Penfound and Earle 1948).

Although water hyacinth forms dense free-floating mats, covering the surface of the water body where it is present, it also grows in association with a variety of plants depending by the world where it is found (Wright and Purcell, 1995).

2.3. Origin and distribution of water hyacinth

2.3.1. Origin

Water hyacinth, *Eichhornia crassipes* (Martius) Solms- Laubach, is fast growing aquatic free floating freshwater plant indigenous to Brazil, Amazon basin and Ecuador region (Gopal, 1987). The first description of water hyacinth was given by the German naturalist von Martius in 1823 while carrying out floral surveys in Brazil. He named it Pontederia crassipes. It was later transferred to the genus *Eichhornia* (in honor of TAF Eichhora, a Russian Minister of Education) by Kuntz in 1843. Solms included it in the *Eichhornia* genus. However, a collector named von Humbolt had collected specimens from Colombia in 1801, with the species *azurea* (Gopal, 1987).

2.3.2. Distribution

2.3.2.1. Worldwide distribution of water hyacinth

The weed is distributed worldwide because of the plant‘s ornamental properties or use as feed (Ding *et al*., 2001). Human mobility and movement of goods due to improvements in communications and infrastructure are crucial drivers in the spread of water hyacinth. Once introduced in an area, people then unknowingly discarded unwanted plant materials into streams, dams, and rivers, which enhance the weed’s dispersal. Connectivity among diverse water bodies has further facilitated the spread of water hyacinth in a region. The dispersal process has also been enhanced by translocation of equipment/machinery, contaminated boats, waterway equipment, and fishing gears. Seeds can be carried by the flowing water current and birds. In the late 19th and early 20th centuries, water hyacinth was introduced in many tropical and subtropical countries. It has invaded over 60 countries (Shanab and Shalaby, 2012). The plant was officially recognized as a serious aquatic pest after the USA Congress passed an act on June 4, 1897, authorizing the Secretary of War to investigate the extent of obstruction to navigation in the waters of Louisiana and Florida. The weed was first introduced into Florida in 1885 by a farmer from Palatka area, who obtained a specimen from World’s Industrial and Cotton Centennial Exposition exhibition held from 1884-1885 in New Orleans, afterward, the weed spread around the USA, and by the end of the nineteenth century, its presence was reported in different countries of Asia, Africa, Australia, South America and North America (Gopal, 1987).

2.3.2.2. Distribution in Africa

Both intentional introductions (ornamental) and unintentional introductions (rivers flowing from one country to another) of water hyacinth have occurred throughout Africa, since the first intentional introduction into Egypt. The first record of water hyacinth infestation onto the continent was for Egypt in the period 1889– 1892, during the reign of Kheve deTawfiq. It is believed that it has been introduced as an ornamental plant. Water hyacinth occurs throughout the region of the Nile Delta and is believed to spread southwards, due to constructing the Aswan Dam, which has slowed the river down (Gopal, 1987).

The second record for the continent is from South Africa in 1908 (Mendonca 1958). Water hyacinth is believed to have been introduced as an ornamental aquatic plant for garden ponds and aquaria, due to its attractive flowers (Gopal, 1987). With water hyacinth, a warning of what was likely to happen was printed as early as 1913 (Jacot, 1979).

Third, Zimbabwe recorded water hyacinth infestations in 1937. The first record was from the Mukuvisi River in Harare. In the period 1941 to 1960, a further ten African countries recorded water hyacinth infestations, namely: Angola (1942), Benin (1942), Mozambique (1942), Burundi (1957), Congo (1950-1951), the Democratic Republic of Congo (1952), Sudan (1954), Tanzania (1955), Ethiopia (1956), and Rwanda (1957).

2.3.2.3. Distribution in Ethiopia

In Ethiopia the weed was first observed in 1956 in aba Samuel dam, since then, it has been found in different regions of the country, Koka Reservoir, water storage dams and irrigation distribution systems of the Wonji-Shoa and Sugar Estates-its first introduction was from Koka Hydroelectric Power Dam due to the 1996 flood of Awash River into the factory (Tariku Gebeyehu, 2001), Gambella areas (Sobate, Baro, Gillo, and Pibor rivers) and Lake Ellen and neighboring localities in the Rift Valley. Recently, water hyacinth is expanding at an alarming rate in Lake Tana, some of the southern rift valley lakes around Arba Minch. It is a constraint to developing the country (Taye Tessema *et al*., 2004) because of the multifaceted problems associated with its infestation in lakes Tana and Koka. Due to the lack of natural enemies water hyacinth has also become a menace to animals by replacing indigenous grasses in different part of the country (personal observation). There is no clear clue how the introduction of water hyacinth in Ethiopia water bodies took place but its proliferation was fortified due to eutrophication. For example, in Aba Samuel reservoir the effluent discharged from polluted Akaki River caused the weed to proliferate and threaten the lives of aquatic animals and the overall functioning of the reservoir (Ingwani *et al*., 2010). Similarly, in Lake Tana, water hyacinth proliferation has been intensified due to poor watershed management practices because of anthropogenic effects, through pollution by silt load, recession agriculture and water level fluctuation since its first introduction in 2011 (Ayalew Wondie *et al*., 2012). In Lake Koka also an excessive influx of nutrients from surrounding floriculture, agriculture and irrigation

proliferate, the expansion of water hyacinth since its introduction from Aba Samuel reservoir (Rezene Fessehaie, 2005).

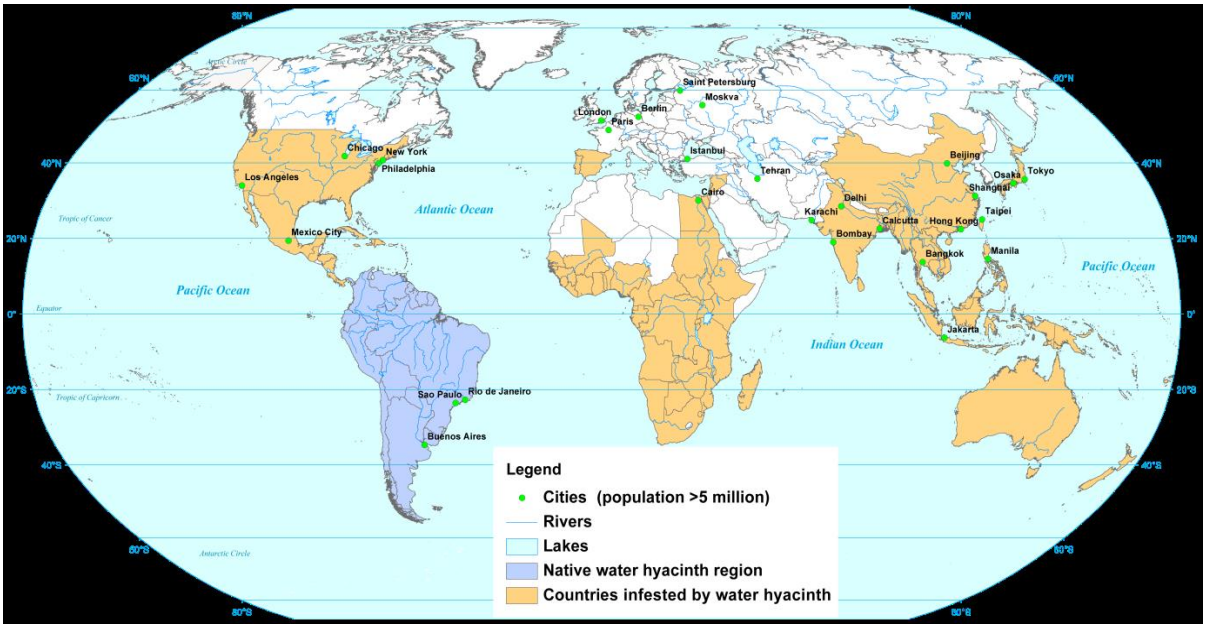


Figure 2. Map showing the global distribution of water hyacinth (Redrawn by UNEP/DEWA from Tellez *et al*., (2008)).

2.4. Chemical composition

Studies have suggested that water hyacinth in its fresh form contains about 90% water and about 15 – 20% solid materials (Ndimele *et al.*, 2011). Generally, the dry weight contains about 25 – 35% protein-related matter, with about 17% amino acids and the rest being amides. Amides are usually toxic; the possible reason water hyacinth is not eaten fresh like other edible vegetables such as lettuce. The carbon content of the dry weed is about 36 – 40% (Edewor, 1988) and direct carbonylation obtained 40 to 60% carbonates and nitrates, respectively in yield ratios. Therefore, water hyacinth has a predominantly cellulosic structure highly impregnated by the amino group directly at the carbonyl structure, hence represented: (Ndimele *et al*., 2011).

Investigations carried out have revealed R to be more of the aliphatic chain. Therefore, the elemental composition of water hyacinth consists of about 12.8% nitrogen, 36 – 40% carbon, 8% hydrogen and about 13-14% oxygen. It also contains heavy metals such as iron, magnesium, and zinc, which justifies its use in phytoremediation. Kumar, undated, revealed that long and dwarf

type water hyacinth contained 14.28% and 11.87% crude protein, 21.79% and 18.22% crude fiber, 2.01% and 1.18% ether extract, 44.49% and 52.85% Nitrogen Free Extract (NFE) and 17.43% and 15.88% total ash respectively (Ndimele *et al*., 2011).

2.5. Impacts of water hyacinth

2.5.1. Impacts on physicochemical parameters

Besides being free from natural enemies, the growth and expansion of water hyacinth are enhanced by the availability of nutrients, high temperature, and water. According to the survey in rift valley water bodies of Ethiopia conducted by Firehun Yirefu *et al*. (2014), significant correlations were observed between water quality parameters and water hyacinth coverage and between climatic factors and water hyacinth coverage. According to the survey, water hyacinth coverage was positively correlated with rainfall (RF), N, P, and temperature (T) and negatively correlated with the depth of the water bodies and altitude. The survey also indicated that both the positive and negative associations between weed infestation, water level and climatic factors were mainly attributed to the nutrient influx (N, P), wave action and depth of the water bodies. Among the water bodies, the strong association between the nutrient influx, wave action and depth of the water bodies was very apparent in Aba-Samuel Dam, Lake Ellen, Lake Elletoke and Koka reservoir.

Saeed *et al.* (2013), who has conducted a research on the impacts of water hyacinth on the physicochemical properties of water and phytoplankton biomass in earthen ponds partitioned into 3 sampling sites, control (0% cover), 5% cover and 10% cover of the water hyacinth, found significant spatial differences in pH. Values for pH were normally highest in control ponds (0 % cover) and lowest in ponds with 5 % and 10 % cover. Saeed *et al.* (2013) suggested that the differences in pH may be related to different rates of removal of carbon dioxide by phytoplankton during photosynthesis as evident from the positive relationship between pH and phytoplankton abundance (McVea and Boyd, 1975; Henry Silva and Camargo, 2008). Dissolved oxygen was also different among treatments being high in control, and low in 10% cover. There was also significant variation in total alkalinity, total dissolved solids, total ammonia and soluble orthophosphate concentration among the three treatments inversely related to the water hyacinth. Wondie Zelalem (2013), who conducted a study on Lake Tana at six sampling sites (weed-

infested and non-infested sites), revealed there was no statistically significant spatial variation in physicochemical parameters. According to Wondie Zelalem (2013), this was most probably due to the short infestation time and weeds biomass reduction due to physical removal, so marked disparity was not observed between the weed-infested and non-infested sites. Significant temporal variations in some physicochemical characteristics of the reservoir like nitrate, phosphate, Secchi depth, and TDS were, however, observed in the study.

According to Mironga *et al*. (2012), who has conducted research on the effects of water hyacinth infestation on physicochemical characteristics of Lake Naivasha, Kenya, water hyacinth exerts various influences on the physicochemical characteristics of the lake. Water temperature values were slightly greater in weed- infested areas than in the non-infested areas because of the dense mat covers of water hyacinth that blocked heat exchanges between the atmosphere and water, although analysis of variance showed there was no significant variation between the weed-infested and non-infested areas. Dissolved oxygen levels were lower in the water hyacinth-infested areas due to the formation of the dense mat of water hyacinth and metabolic activities of epiphytic organisms in the lake. Lower values of pH were in water hyacinth areas than in non-infested areas. There were also higher values of Conductivity and total suspended solids in water hyacinth infested areas than in the non-infested areas.

2.5.2. Impacts on abundance and composition of phytoplankton

Water hyacinth often establishes in areas that lack significant aquatic vegetation, but it can also out-compete submersed vegetation and phytoplankton (Mitchell, 1985). Free-floating plants can monopolize light and absorb nutrients from the water column, preventing phytoplankton and submerged vegetation from obtaining sufficient resources for photosynthesis (McVea & Boyd, 1975). Therefore, free-floating plants can dominate phytoplankton and submerged vegetation when natural controls do not exist outside of the native range (Scheffer *et al*., 2003); hence the presence of water hyacinth in water bodies exerts a tremendous impact on the aquatic ecosystems. Phytoplankton is the foundation of the aquatic food web, the primary producers, feeding everything from microscopic, animal-like zooplankton to multi-ton whales (Aoyagui and Bonecke, 2004). Water hyacinth affects the composition and abundance of phytoplankton both directly and indirectly, in the former case it aggressively competes for nutrients and blocks penetration of light for photosynthesis hence reduces Dissolved oxygen, while in the latter case

decomposition of dead matter consumes more oxygen. Wondie Zelalem (2013) reported that water hyacinth in the lake imposed a shift in the composition and abundance of phytoplankton community as compared to non-infested sites and even lead to deviations from trends reported for the lake by Ayalew Wondie (2006). The researchers also found that the phytoplankton community was constituted by pollution tolerant species (Chlamydomonas) and characterized by lower species diversity in the weed-infested site reflecting influences of water hyacinth on the phytoplankton assemblage. Water hyacinth reduces productivity, abundance, and composition of phytoplankton, suggesting that the water hyacinth is not only a nuisance but that it can also alter the ecology of a lake by changing species composition and biodiversity (Mironga *et al*., 2012). Saeed *et al.* (2013) also noted significant effects of water hyacinth on phytoplankton in the pond.

Water hyacinth infestation in a water body also affects negatively the composition, abundance, and diversity of Macrophytes (Bedlu Bekele *et al*., 2017). Bedlu Bekele *et al*. (2017) reported that water hyacinth affects the composition, diversity, and abundance of macrophytes (sometimes changed the community to nearly monotypic flora), even though some macrophyte species from the Poaceae and Cyperaceae families appeared to coexist with the alien plant.
No one has done a research on the effects of water hyacinth on the composition and abundance of phytoplankton and zooplankton in Lake Koka so far and no one has studied the trends of both phytoplankton and zooplankton either before introducing this alien invasive species to the reservoir.

2.5.3. Impacts on abundance and composition of zooplankton

Zooplanktons are the major grazer in the aquatic food webs, providing the principal pathway for energy from primary producers to the consumers at higher trophic levels, such as fish, marine mammals and turtles (Lampert, 1993). Zooplankton's distribution can be influenced by turbulence, light intensity, temperature, chlorophyll-a, dissolved oxygen (Kiorboe & Saiz, 1995) and food availability (Maceina *et al*., 1992). Changes to zooplankton community diversity and abundance are commonly linked to a shift in the macrophyte community via changes to habitat (Richards *et al*., 1985), but they are also attributed to changes in the density and community composition of zooplankton predators (Meerhoff *et al*., 2003). Reduced phytoplankton productivity can decrease zooplankton abundance by decreasing food availability (Richards *et*

al., 1985; Maceina *et al*., 1992). But the complex structure provided by macrophytes may provide more microhabitats for epiphytic zooplankton, rotifers. Zooplankton response to water hyacinth appears to vary by taxa and geographic location.

Mironga *et al*. (2014), who tried to quantify the impact of water hyacinth on the abundance and composition of zooplankton in Lake Naivasha, Kenya using Shannon-Weiner Diversity Index (H') and Simpson Diversity Index (D), suggested that the weed has reduced the abundance and diversity of zooplankton in the lake. But according to Chukwuka and Uka (2007), the abundance of zooplankton was lower in the weed-infested sites than in non-infested sites. Chukwuka and Uka (2007) argued that the mats of water hyacinth found on the water surface decreased the level of dissolved oxygen affecting the abundance and composition of zooplankton. Dissolved oxygen, pH, conductivity, turbidity and Lake Morphometry have the greatest effect among environmental factors on zooplankton (Aoyagui and Bonecka, 2004).

2.5.4. Toxicity effects of water hyacinth

Water hyacinth is superior to soya bean in terms of production of proteins per hectare (Mitsuda *et al*., 1978). Its leaves typically contain 20–25% protein on a dry matter basis, and it's an essential amino acid pattern is good (Mitsuda *et al*., 1978; Abo-Bakr *et al*., 1984). In addition, the leaves contain plentiful water-soluble vitamins B1, B2, B3, B5, B6 and B12 and fat-soluble vitamins E and A (Monsod and Godofredo, 1981). However, knowledge of its toxicity is much limited. Wu *et al*. (2014), who conducted research on acute toxicity potential of water hyacinth leaves, revealed that water hyacinth leaves are not acutely toxic. The researchers also evaluated the acute toxicity of water hyacinth through an animal feeding test. The concentrations of common toxic metals including cadmium, lead, platinum, palladium, tin, mercury, barium, silver and aluminum in the water hyacinth leaf powder (WHLP) used for the animal feeding test were below their maximum limits for food additives. The results of the hematological analysis, clinical biochemical analysis, histopathological evaluation, general dissection or investigations of internal organs, and observations of appearance and behavior did not, however, indicate any adverse effects from the diet containing WHLP. However, the study conducted by Musfiroh *et al*. (2017) showed that the cross-linked Carboxy-methyl cellulose sodium (Na-CMC) synthesized from water hyacinth cellulose causes liver, kidney, and lung abnormality.

2.5.5. Increased evapotranspiration

Various studies have been carried out to ascertain the relationship between aquatic plants and the rate of evapotranspiration compared with evaporation from an open-surfaced water body. Aquatic plants cause loss of water through evapotranspiration (Akpofure, 2009). This has great implications where water is already scarce. It is estimated that the flow of water in the Nile could be reduced by up to one-tenth due to increased losses in Lake Victoria from water hyacinth. Firehun Yiferu *et al*. (2007) reported that water hyacinth in Wonji-Shoa sugar factory irrigation reservoirs, which was infested with 116.4 ha hyacinth plant, caused annual water loss ranging from 393,660 to 2,945,160 m^3 due to evapotranspiration.

2.6. Some positive sides of water hyacinth

Even though water hyacinth is a notorious world's worst weed, it has different uses in disguise.

2.6.1. Aqua-feeds

Given the current level of per capita consumption of aquatic foods, it is projected that the world will require an additional 23 million tons by 2020 (FAO 2012). Considering that most of the world's major fish stocks are overfished and catches are static or declining, aquaculture could be the only option to increase total fish production. However, aquaculture largely depends on the quality of feeds, the sustainability of which is affected by the supply of animal and plant proteins, oils and carbohydrates. The key aqua-feed ingredients such as fish meal, soybean meal, and various oilseed cakes directly compete with terrestrial animal husbandry (Sumagaysay-Chavoso 2007). In Asia, these ingredients are produced in much lesser quantities than what is being consumed for feed manufacture (De Silva & Hasan 2007). The perennial shortage of this key raw material is highly problematic for feed manufacturers and can affect aquaculture sustainability and profitability. Incorporating plant-based raw materials to satisfy the protein requirement of cultured species is one solution for this problem. One of the untapped resources is aquatic macrophytes which include water hyacinth (*Eichhornia crassipes*), water lettuce (Pistia stratiotes) and duckweed (Lemna spp.) among others.

Hontiveros *et al*. (2015) who have done research on the nutritional value of water hyacinth (*Eichhornia crassipes*) leaf protein concentrate for aqua-feeds indicated that water hyacinth leaf meal concentrate exhibited a considerable potential as an aqua-feed ingredient. The study evaluated the nutritive value of water hyacinth leaf protein concentrate (WHLPC) as a potential feed ingredient for aqua-feeds and measured the Apparent Digestibility of the Ingredient (ADI) for the dry matter in *Oreochromis niloticus* adults. The apparent dry matter digestibility (ADMD) of WHLPC was relatively high at 76.4%. Cadmium, copper, and lead increased after protein concentration but were still considered much lower than the allowable limits set by the European Union for animal feedstuffs.

2.6.2. Biogas production

Biogas is a good quality fuel that can be a replacement for firewood and several other energy sources. The possibility of converting water hyacinth to biogas has been an area of major interest for many years. Conversion of other organic matter, usually animal or human waste, is a well-established small and medium scale technology in several developing countries, notably in China and India. The process is one of anaerobic digestion which takes place in a reactor or digester (an airtight container usually sited below ground) and the usable product is methane gas which can be a fuel for cooking, lighting or for powering an engine to provide shaft power (Calvert, 2002; Ndimele *et al*, 2011; Ojeifo *et al*., 2013). The residue from the digestion process provides a fertilizer rich in nutrients.

A study conducted by Almoustapha *et al. (2008)* shown that discontinuous-type facilities can produce biogas from a mixture of water hyacinth and fresh rumen residue to meet collective needs in cooking energy. The facility's yield, reported in m3 of biogas per m3 of digester per day, has been 0.52 during the warm season and 0.29 during the cool season. Although the yields have been satisfactory, they can be improved by applying the appropriate pretreatments. The facility can save 7.3 tonnes of firewood per year.

2.6.3. Fertilizers

Water hyacinth can be used on the land either as green manure or as compost. As a green manure, it can be plowed into the ground or used as mulch. The plant is ideal for composting. After removing the plant from the water it's left to dry for a few days before being mixed with ash, soil, and some animal manure. Microbial decomposition breaks down the fats, lipids, proteins, sugars, and starches. The mixture can be left in piles to compost, the warmer climate of tropical countries accelerating the process and producing rich pathogen-free compost which can be applied directly to the soil.

The compost increases soil fertility and crop yield and generally improves the quality of the soil. Compost can be made on a large or small scale and is well suited to labor intensive, low capital production. In developing countries, where mineral fertilizer is expensive, it solves the problem of water hyacinth proliferation and also poor soil quality. In Sri Lanka water hyacinth is mixed with organic municipal waste, ash, and soil, composted and sold to local farmers and market gardeners (Jafari, 2010).

2.6.4. Purification

Water hyacinth can aid the process of purification of water either for drinking or for liquid effluent from sewage systems. According to Haider, 1989, water hyacinth has been used in a water treatment plant as part of the pre-treatment purification step, where clean, healthy plants are incorporated into water clarifiers and helped with the removal of small flocs that remain after initial coagulation and floc removal or settling. The result is a significant decrease in turbidity due to the removal of flocs and also a slight reduction in organic matter in the water. Water hyacinth has also been used for the removal or reduction of nutrients, heavy metals, organic compounds and pathogens from water (Gopal, 1987). Water hyacinth can trap pathogens. This makes it suitable to be used to purify drinking water in treatment plants (Vidya and Girish, 2014). Water hyacinth can treat sewage as it can absorb metals such as copper, mercury, and lead (Land Development Department, undated). Papyrus is used for wastewater purification purpose to increase the assimilation capacity of wetlands however water hyacinth can do more on this, but still, we are not planning to use it in wastewater purification purpose.

3. MATERIALS AND METHODS

3.1. Description of the study area

Koka Reservoir, also known as Lake Galilea, is in south-central Ethiopia in the Shewa Zone of the Oromia Region, approximately 100 km Southeast of Addis Ababa. The Lake, with a total water spread area of 180 km^2 (BirdLife International, 2008), is at a geographical position of 08°26` N and 39° 10` E and at an altitude of 1590 m a.s.l.. The sources of water for the reservoir are Awash River (major) and Mojo River (minor). The climate of the study area is characterized by a bimodal rainfall pattern, with a short minor rainy period (Mar-May) and long major rainy period (Jun-Sep) (Fig.2). The mean maximum monthly air temperature varies between 29.5^oC (November & December) and 33.9^oC (May), while the mean minimum monthly air temperature ranges from 10.4^oC (December) to 15.5^oC (May) during years 2000-2015, (Fig.3). Koka Reservoir was reported to have a surface water temperature of 19^oC and a water column that shows no marked thermal stratification.

Koka Reservoir is used for various purposes including hydroelectric power generation, domestic water supply, commercial fishery, recreation, and irrigation. Large commercial agricultural farms present downstream of the Koka dam are irrigated by the regulated flow of the Awash River.

Varieties of wildlife include birds around the lake. The lake also harbors commercially important fish species like *Oreochromis niloticus*, *Cyprinus carpio*, *Clarias gariepinus* and *Labeobarbus intermedius.* It is also infringed with floating macrophytes including water hyacinth (*Eichhornia crassipes*) (LFDP, 1998).

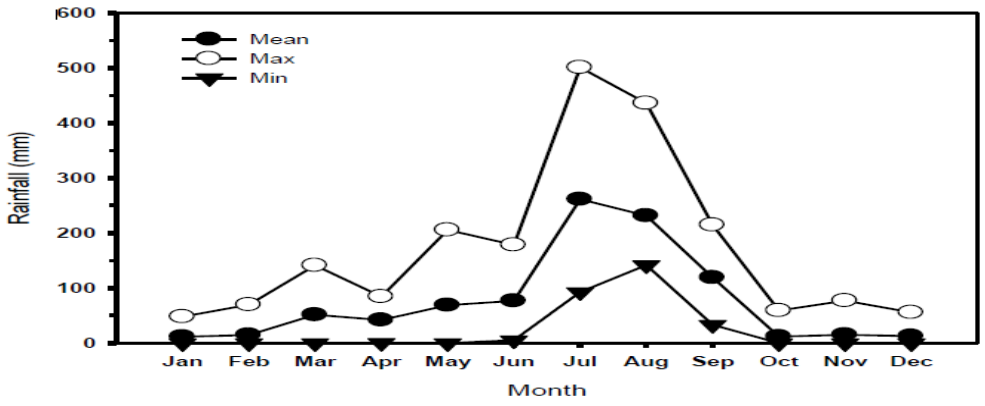


Figure 3. Mean, maximum and minimum monthly rainfall around Koka Reservoir during 2000-2015 (ENMA, 2017).

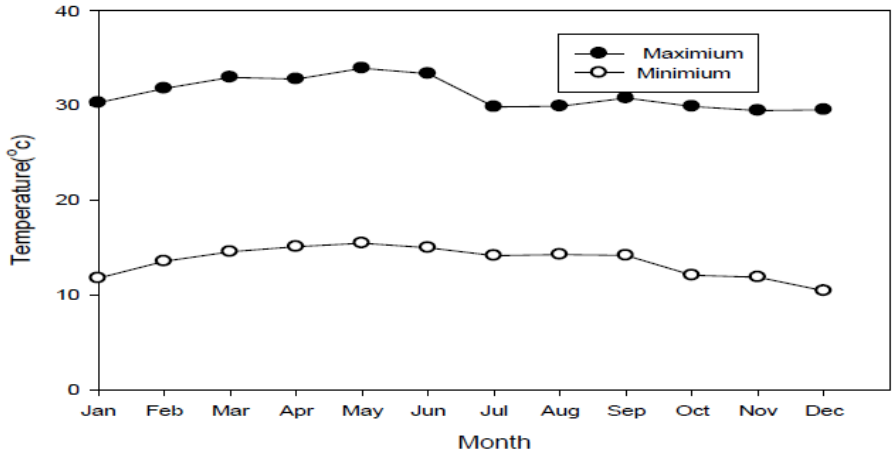


Figure 4. Maximum and minimum monthly air temperature around Koka Reservoir during 2000-2015 (ENMA, 2017)

Koka Reservoir is under a serious threat because of the industrial and intense agricultural activities operating in its catchment. Major sources of wastewater effluents discharged into the reservoir include Shoa and Ethio-tanneries, which discharge their raw effluent directly into the reservoir, Mojo oil mill factory, which drains its effluent into Mojo River, butter houses and poultry farms, which operate in the catchments of the reservoir, release their effluents through Mojo River. Wastewaters discharged into the Akaki River (great and little Akaki), which is one of the main tributaries of Awash River; also eventually find their way into the Koka Reservoir. A large number of floriculture farms located close to the reservoir also release their untreated effluents into its shores. These effluents contain fertilizers and pesticides, which are the sources of heavy metal residues. Besides the above- mentioned pollution sources of anthropogenic origin, sedimentation has become an important concern for the reservoir (Birdlife International, 2008).

3.2. Sampling protocol

The study was conducted for five consecutive months from March to July 2018, representing minor and major rainy periods. Sampling was carried out once a month from weed -infested littoral sites and non-infested open water sites. Three sampling sites were selected for each the littoral and open water regions, (non-infested site 1(NIS1), non-infested site 2 (NIS2), and non-infested site 3 (NIS3)) with six sampling sites. Three sampling sites for weed infested were selected based on the level of infestation of water hyacinth i.e., heavily infested site 4 (HIS4), moderately infested site 5 (MIS5) and low infested site 6 (LIS6) in the littoral region of the reservoir. To determine the level of infestation, three replicates of quadrates (0.5m by 0.5m) were laid across transect and abundance of aboveground of the weed within each quadrate was estimated. Afterward 100, 50 and 10 were counted in the quadrat, thus level of infestation was assigned: 0-40 ind/m^2, low level; 41-200 ind/m^2, moderate level and 201-1000 ind/m^2, heavy level. The length between the Reservoir shore and sampling sites was nearly a Km and the length of the interval among sampling sites was nearly 0.5Km except site 6 nearly 1.5km far.

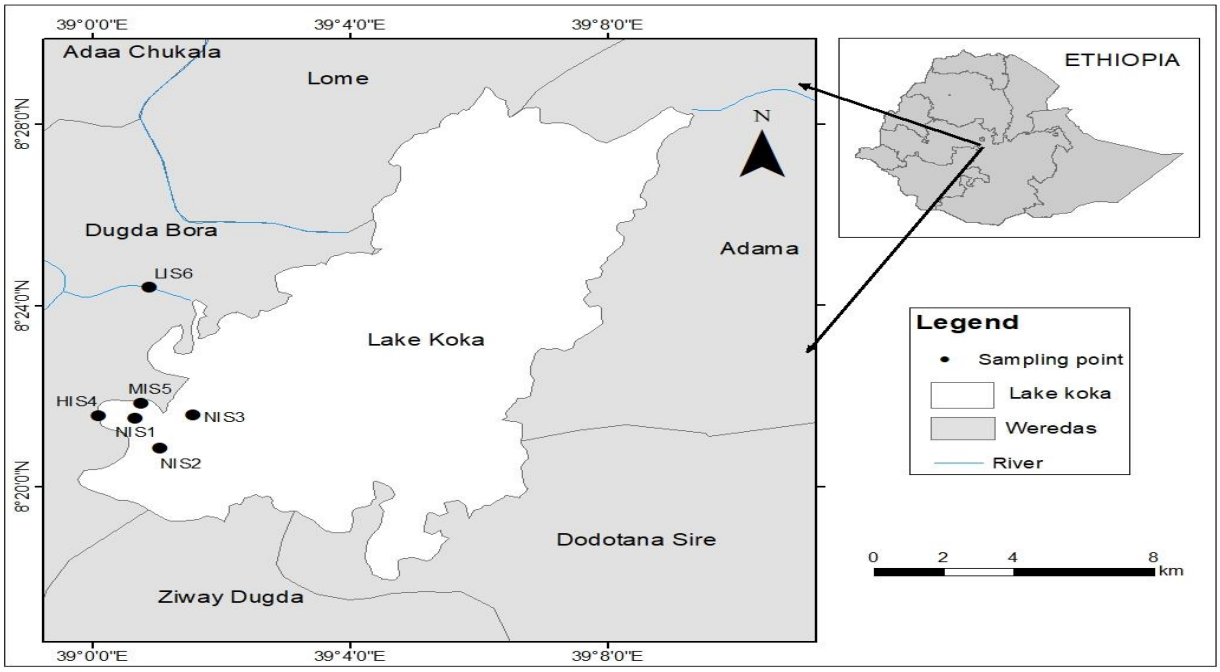


Figure 5. Map of Koka Reservoir with sampling sites. Enset: Location of Koka Reservoir in Ethiopia.

Table 1. Description of sampling sites

Sampling sites	Depth range (m)	Altitude (m) (above sea level)	Coordinates	
			latitude	longitude
Water hyacinth – infested sites				
HIS4	1.5	1585	8^o 21` 32``	39^o 00` 4``
MIS5	0.9	1586	8^o 21` 50``	39^o 00` 21``
LIS6	0.75	1590	8^o 24` 21``	39^o 01` 19``
Non – infested sites (Open water sites)				
NIS1	2.5	1588	8^o 21` 36``	39^o 00` 29``
NIS2	2	1588	8^o 21` 27``	39^o 00` 37``
NIS3	1.9	1587	8^o 21` 36``	39^o 00` 46``

3.3. Measurements of physicochemical parameters

Dissolved Oxygen (DO), pH, specific conductance, and temperature were measured *in situ* using a multi-metric probe (HQ40d), while turbidity was measured using a turbidimeter (OAKTON T-100). Transparency of the reservoir water was measured with a standard Secchi disc following the procedure described in APHA (1999). Samples filtered with glass fiber filters were used for the analysis of all nutrients except total phosphorus. Soluble Reactive Phosphate-phosphorus (SRP, PO4-P), and Total Phosphorus (TP) after per-sulfate digestion were analyzed by the Ascorbic Acid method, while dissolved molybdate reactive silica (SiO_2) was determined by the Molybdosilicate metho (APHA, 1999). Ammonia (NH_3 + NH_4^+-N) was analyzed by the Phenate Method, while Nitrate (NO_3-N) was determined by the Sodium salicylate method (APHA, 1999). Nitrite (NO_2-N) was measured by diazotization with sulphanilamide and coupling with N-1-naphthylethylenediamine di-HCl and subsequent formation of a highly colored azo dye (Wetzel and Likens, 2000). Total dissolved solids (TDS) and Total suspended solids (TSS) were also determined gravimetrically in the laboratory using the following formulae:

$$TDSmg/L = \frac{(\mathrm{A} - \mathrm{B})}{\text{ml Sample}} * 1000$$

Where: A=weight of dried residue + dish, mg

B=weight of the dish, mg

$$TSSmg/L = \frac{\mathrm{A} - \mathrm{B}}{\text{ml Sample}} * 1000$$

Where: A=weight of filter + dried residue, mg

B=weight of the filter, mg

3.4. Collection of biological samples and their analysis

3.4.1. Water hyacinth

Three samples of water hyacinth were collected from sampling points with the quadrate method along with transect. Aboveground biomass of the weed was estimated from the plant material collected from within 0.25m^{2}quadrate. The dry weight of water hyacinth was determined after drying to constant weight at 105°C for 24 hours using an oven (Wetzel and Likens, 1991).

3.4.2. Phytoplankton

Phytoplankton samples were collected from each site using a bucket for weed-infested shallow sites and using bottle sampler (Kemmerer) for open and deep littoral sites. The samples were filtered using a 15µm mesh size net. The collected samples were immediately fixed with Lugol's iodine solution. Concentrated samples were properly mixed and 1 ml sub-samples were taken and transferred to a Sedgewick-Rafter counting chamber. Identification and enumeration (estimation of abundance) were carried out under a binocular inverted biological microscope at a magnification of 40-400x. Phytoplankton species were identified using various identification keys (Gasse 1986; Komarek and Kling 1991; Komarek and Anagnostidis, 2000; and Taylor *et al*. 2007). Enumeration of phytoplankton was made following the procedures outlined in Hötzel and Croome (1999) and abundance of each taxon was estimated using the following formula.

$$C[cells\ /\mathrm{mL}] = \frac{\mathrm{N} * 1000\mathrm{mm3}}{\mathrm{A} * \mathrm{D} * \mathrm{F} * \text{Concentration factor}}$$

Where:

N = number of individual counted A = area of the field (mm2)

D = depth of a field (Sedgwick-Rafter chamber depth) (mm) F = number of fields counted.

$$Concentration\ factor = \frac{\text{volume of lake water filtered (ml)}}{\text{volume of concentrate (ml)}}$$

Figure 6. Pictures illustrating the methods of collection, identification, and enumeration of phytoplankton samples

3.4.2.1. Estimation of phytoplankton biomass as chlorophyll-a

Index of algal biomass, chlorophyll-a concentration, was also estimated. 100ml samples were filtered through Whatman glass microfiber filter papers (GF/F). GF/F containing algal seston was cut into pieces using scissors, 90% cold acetone added and kept in the fridge overnight. Algal seston was homogenized and Chlorophyll a (Chl-a) was extracted using 90% cold acetone. The algal material was centrifuged at 3000rpm for 10 minutes (Wetzel and Likens 2000). The absorbance of the centrifuged extract was measured at 665 and 750 nm using a spectrophotometer (model, Cole-Parmer UV/Visible Spectrophotometer, 115 VAC, 60 Hz). Chl-a concentration was calculated using the following formula (Lorenzen, 1967).

$$chl\ a\ \mu g/L = \frac{\mathrm{K} * \mathrm{F} * (\mathrm{E665b} - \mathrm{E665a}) * \mathrm{Ve}}{Vsf * Z}$$

Where;

E_{665b} = Turbidity-corrected absorption at 665 nm before Acidification= A_{665b}-A_{750b}, where A is absorption value.

E_{665a} = Turbidity-corrected absorption at 665 nm after Acidification= A_{665a}-A_{750a}, where A is absorption value.

K = Absorption coefficient of Chl-a, 11

F = Factor to equate the reduction in absorbance to the initial Concentration of Chl-a, 1.7:0.7= 2.43

R = Maximum ratio of E_{665b}: E_{665a} absent phaeopigments = 1.7

V_E = Volume of extract, in ml

V_{SF}= Volume of sample filtered, in liters

Z = Length of the light path through the cuvette, in cm

3.4.3. Zooplankton

Zooplankton samples were collected from each sampling site using 30µm and 100µm mesh size net vertically from bottom to the surface of and preserved immediately with 4% formalin (Jeje, 1990). A bucket with known volume was used for the weed-infested sites, while nets were employed for the open water sites. The samples collected with a bucket were filtered using plankton nets of 30µm and 100µm mesh size (to collect only large size zooplankton). From the concentrated samples, a sub-sample was eventually poured into a gridded glass counting chamber containing 14 grids. Identification of zooplankton was made using taxonomic keys of Jeje (1990) and Jeje and Fernando (1986). Zooplanktons within 5 grids were also counted under a dissecting microscope at a magnification of 40x and their abundance was follows:

$$ind/L = \frac{\mathrm{N} * \mathrm{SSF} * \mathrm{GF}}{\pi r^2 d}$$

Where N =actual counts of species r=radius of the net GF=grid factor

SSF=sub-sample factor d=depth of the Lake

3.4.4. Toxicity test

To assess the acute toxicity of water hyacinth extract, an experiment was conducted on albino white mice following the procedure in Paulos Getachew *et al*. (2015). The fresh sample was dewatered under shade condition at room temperature, dried at 60 °C for 24 hrs in an oven and then pulverized to particles of the size of 150μm before analyses. The powder was sequentially extracted using Dichloromethane, Ethanol and Distilled water solvents. Dichloro-methane (2000mL) was added to the 200gm powder and shaken for 24hours using a shaker at 160 rpm. Then, filtration with GF/F was made and the crude extract was collected from the filtrate using Rotary-evaporator and the residue was shaken again for 2hours. Finally, the crude extract (sample1) was dried under liquid nitrogen (G 4510E; Domnick Hunter Ltd, Dukesway, England) and kept at -20°c. The residue from the first step was dried in the oven, weighed and the same procedure was repeated using 2000mL Ethanol and crude extract (sample2) was obtained and kept at -20°c. Again the residue from step two was dried, weighed and the same procedure was repeated using 2000mL distilled water and then sample 3 was obtained and kept at -20°c. Mice (8 weeks old) with an average body weight of 28.40 g, which were outbred by the Institute for Cancer Research (ICR), were starved for 6hrs but provided with water *ad libitum*. Extracts (5g in 10ml 5% Tween 80 Kg^{-1}body weight) were prepared and administered orally to mice (n=10 for each extract) with an intra-gastric syringe. The mice were then observed for 3 hours to detect any changes such as abnormal movement, vomiting, sneezing, body change, backward movement, nausea, scaling and death, and the observation was continued for up to 15 days. After 3 hours of observation, the mice were given the usual food for up to 15 days. A group of mice (10) treated with only the usual food served as the control. The mice were treated in compliance with current laws and guiding principles for the care and use of laboratory animals approved by the Animal Ethics Committee of Addis Ababa University. The Ethics Committee approved this study under protocol. Proximate composition of water hyacinth was also done following method in AOAC (2007). Total phenolics content following procedure in Singleton and Rossi (1965) and total flavonoid contents using Aluminum chloride colorimeteric of water hyacinth were also done in the food and nutrition laboratoty of Addis Ababa University.

Figure 7. Water hyacinth (Eichhornia crassipes) extraction and oral administration procedures

3.5. Statistical analysis

Spatial and temporal variations of measured physicochemical parameters were analyzed using one-way Analysis of Variance (ANOVA) at 95 % significance level ($P < 0.05$). Causal relationships (correlation) among physicochemical and biological parameters were assessed and mean numbers and standard errors for each physicochemical parameter were calculated using statistical software (SPSS version 20). Tukey test was employed to see temporal differences in counts of organisms and physicochemical parameters and pair-wise comparisons were made when testing spatial variations between the sites. To see differences among study sites, regarding nutrient levels, Principal Components Analysis (PCA) was employed using PAST software. The relationship between the abundance of taxa of phytoplankton and zooplankton with physicochemical variables was assessed using a multivariate analysis tool, Redundancy Analysis (RDA), using CANOCO for Windows version 4.5. To determine the suitability of RDA in this analysis, Detrended Correspondence Analysis (DCA) was employed. According to Lepš and Šmilauer (1999), if the length of the longest gradient is less than 3, the species data show a linear response to environmental variables. Thus, the linear method of gradient analysis, RDA, is appropriate. Moreover; to describe the diversity and distribution of planktonic community (phytoplankton and zooplankton) the following diversity indices were employed.

Shannon-Weaver index

The Species diversity index (H') (Shannon and Weaver, 1949) of each site was evaluated using the equation:

$$H' = -\sum_{i=1}^{n} \text{piln(pi)}$$

Where; H'=Shannon-Weiner Index, i=counts denoting the i^{th} species ranging from 1 to i., pi=proportion that the i^{th} species represents in terms of several individuals regarding the total of individuals (N) in the sampling space.

Equitability or evenness (j)

Species equitability or evenness (Pielou, 1969) of each sample was evaluated using the equation:

$$j = \frac{\text{H}\prime}{\text{Hmax}}$$

Where; H'=Shannon-Weaver Index, Hmax=antilogarithm of the number of species in the population.

Species richness index (d)

The Species richness index (d) proposed by Margalef (1951) was used to evaluate the community structure of each sample by applying the following equation:

$$d = \frac{\text{S}-1}{lnN}$$

Where; d=Species Richness Index, S=number of species in the population, N=total of individuals in the population.

4. RESULTS

4.1. Physico-chemical features

Physicochemical parameters recorded in this study showed both spatial and temporal variations (Tables 2 and 3). The mean surface water temperatures recorded for the heavily infested site 4 (HIS4, 24.62±0.617), moderately infested site 5 (MIS5, 22.94±0.934) and low infested site 6 (LIS6, 23.86±0.723) sites were slightly higher than those of the non-infested open water sites, Non-infested site 1 (NIS1, 22.52±0.695), Non-infested site 2 (NIS2, 22.84±0.705) and Non-infested site 3 (NIS3, 22.26±0.675). The lowest mean surface water temperature was recorded during March, while the highest was observed during April. There was no significant spatial variation in surface water temperature ($P>0.05$, Table 2, Appendix 1). Significant temporal variation in surface water temperature was, however, observed ($P<0.05$, Appendix 7).

The mean transparency (Secchi depth) value recorded for the two study sites showed statistically significant variation ($P<0.05$, Table 2, Appendix 1). The mean value recorded for the non-infested sites (20.54±3.41cm) was higher than that recorded for the weed-infested sites (14.8±3.56cm). The minimum value was recorded in June at HIS4 of the infested sites (Figure 8). The mean Secchi depth also showed significant temporal variation ($P<0.05$, Appendix 7).

The mean values of pH and Total Dissolved Solids (TDS) recorded in this study were 8.34±0.423 and 676.66±180.49 for the non-infested sites and 8.32±0.092 and 643.33±137.44 for the weed-infested sites, respectively. Statistically, there was no significant spatial difference ($P>0.05$, Table 2 and Appendix 1) between the two sites in the levels of TDS and pH although relatively higher values of TDS and pH were recorded in the non-infested sites. TDS showed significant temporal variation ($P<0.05$, Appendix 7). The minimum and maximum values of TDS (300 mg/L and 1300 mg/L, respectively) were recorded in the non-infested sites.

Table 2. Mean ±SE, minimum and maximum values of the physicochemical parameters recorded for the water hyacinth-infested and non-infested sites.

Parameters	Non-infested sites			Weed-infested sites		
	Mean±SE	Min	Max	Mean±SE	Min	Max
T($^{\circ}$C)	22.54±0.37	20.2	24.8	23.8±0.46	21.3	26.3
pH	8.34±0.42	5.56	9.74	8.32±0.09	8	8.86
K_{25}(µScm^{-1})	118.7±5.13	77.2	139.8	138.6±8.58	80.2	210.7
TDS (mg/L)	676.66±180.5	100	1300	643.33±137.4	200	1100
TSS (mg/L)	127±20.73	40	260	258.47±45.85	107	820
DO (mg/L)	6.86±0.21	5.46	8.67	3.77±0.375	1.1	6.46
Secchi depth(cm)	20.54±3.41	10	27	14.8±3.56	5	26
Salinity (mg/L)	89±3.85	57.9	104.85	103.55±6.89	60.15	158
Turbidity (NTU)	98±4.48	50	120	194.8±25	100	380

The mean values of TSS and turbidity recorded in this study were 127±20.74 mg/L and 98±4.48 NTU for the non-infested sites and 258±45.85 mg/L and 194.8±25 NTU for the weed-infested sites, respectively. The boundary values of the ranges of variations in Turbidity and TSS were considerably lower at the non-infested sites (50-120 NTU, 40-260 mg/L) than those recorded for the weed-infested sites(100-380 NTU, 107-820 mg/L). Both TSS and turbidity showed significant spatial variations ($P<0.05$, Table 2 and Appendix 1).

Dissolved oxygen (DO) concentration exhibited a statistically significant spatial variation between the non-infested and infested sites ($P<0.05$, Table 2 and Appendix 1). The mean dissolved oxygen (DO) concentration of the non-infested sites (6.86±0.725 mg/L) was higher than those of HIS4, MIS5 and LIS6 sites (2.88±1.42, 3.61±1.33, and 4.814±1.11mg/L, respectively). The highest value of dissolved oxygen (DO) concentration was recorded at the non-infested sites (8.67 mg/L) while the minimum was observed at the HIS4 site (1.10 mg/L). Statistically significant spatial variation ($P< 0.05$) was also recorded between HIS4 and LIS6 sites.

Though not statistically significant, mean (K_{25}) and salinity showed variations between the two sites (Table 2, Appendix 1). Higher values of Electrical conductivity and salinity were recorded

for the weed-infested sites (210.7 µS cm^{-1} and 158 mg/L, respectively) than for the non-infested sites (139.8µS $cm^{-1}$and 104.63 mg/L, respectively). However, specific conductance and salinity showed statistically significant variations among the sampling months (P<0.05, Appendix 7).

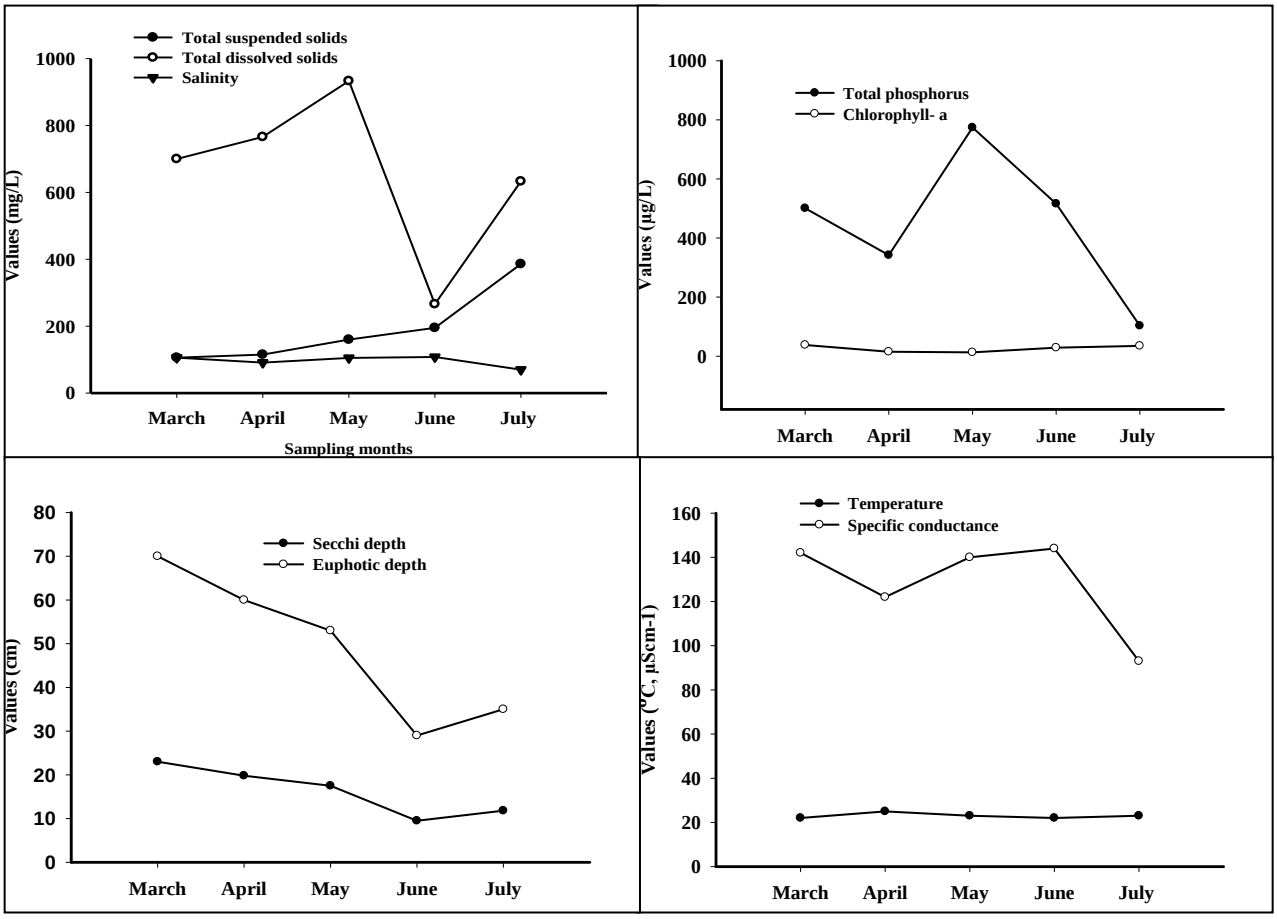


Figure 8. Temporal trends of physicochemical parameters at the study sites.

The concentrations of inorganic nitrogen species, Nitrate, (NO_3-N) and Ammonia (NH_3+ NH_4^+-N)), showed statistically significant variations between the non-infested sites and weed-infested sites (P<0.05, Table 3 and Appendix 1). In the non-infested sites, the mean value of nitrate (211.33±11.36 µg/L) was slightly higher than those of the HIS4 and MIS5 sites (152.±4.89 µg/L, 138±6.78 µg/L, respectively), while it was lower than that of LIS6 site (389±14 µg/L). The mean value of ammonia was slightly higher in the non-infested sites (46.93±7.2 µg/L) than in the HIS4 and MIS5 sites (44.6±7.4 µg/L, 43.2±5.47 µg/L, respectively) although it was lower than that of the low infested site (77.4±0.8 µg/L) (Table 3).

Table 3. Minimum (Min), maximum (Max) and mean concentrations of nutrients recorded for the study sites

Parameter	Non-infested sites			Weed-infested sites			p-value
	Mean±SE	Max	Min	Mean±SE	Max	Min	
NO_3-N(µg L^{-1})	211.33±6.54	260	170	159±4.58	180	140	0.00
NH_3-N(µg L^{-1})	46.93±3.89	75	32	43.9±4.35	65	29	0.07
PO_4-P(µg L^{-1})	168.1±17.78	248.9	53.96	149.8±20.25	258.7	53.9	0.00
SiO_2(mg L^{-1})	5.1±1.6	17.69	1.15	6.60±2.75	24.45	0.02	0.00

Mean concentrations of soluble reactive phosphate-phosphorus (PO_4-P, SRP) and Silica (SiO_2) showed statistically significant variations between the non-infested sites and weed-infested sites ($P<0.05$, Table 3 and Appendix 1). The higher mean value of SRP concentration was recorded for the LIS6 site (683 ± 1.76 µg L-1) than for the non-infested sites (180±31.53 µg L^{-1}). However, during May, when the weed biomass increased, the lower mean value of SRP (84.83 µgL^{-1}) was recorded for the weed-infested sites than for the non-infested sites (153.1 µg L^{-1}). At the weed-infested sites, the highest concentration of SRP was recorded during June for HIS4 and in March for the LIS6, while the lowest occurred during May concomitantly with the increased weed biomass (Fig. 9). In the non- infested sites, the highest SRP concentration was recorded during June, while the lowest was observed during July (Fig. 10).

Mean SiO_2 concentrations recorded for HIS4 and MIS5 (7.1±4.6 and 6.12±3.75) were broadly similar to that observed for - the non-infested sites (6.84±1.94 mg L^{-1}), while the mean silica level determined for LIS6 (28.23±3.83 mg L^{-1}) was about 4 to 4.5 times those of all other sites. In the weed-infested sites, the highest and lowest values of SiO_2 concentration were recorded during May and June at the HIS4 and in May and July at the MIS5 and LIS6 (Figure 10), respectively. In the non-infested sites, however, the lowest SiO_2 concentration was recorded during June, while the highest was observed during May (Fig. 10).

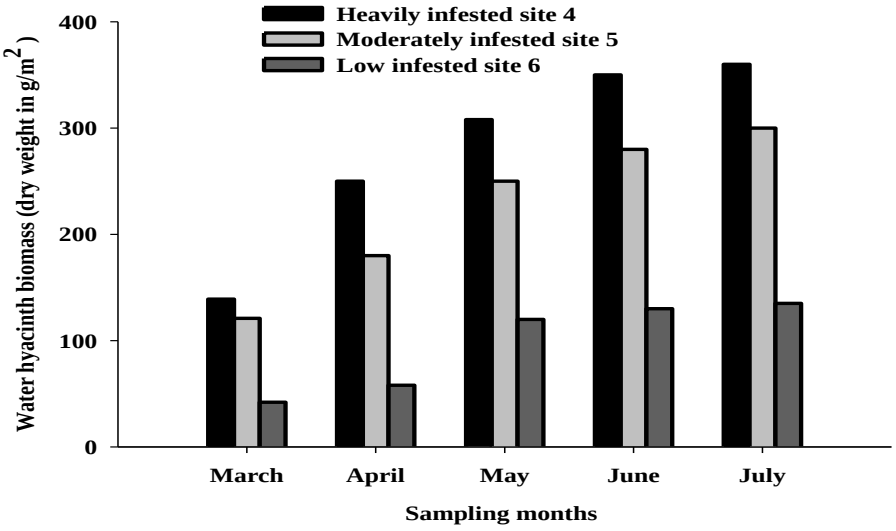
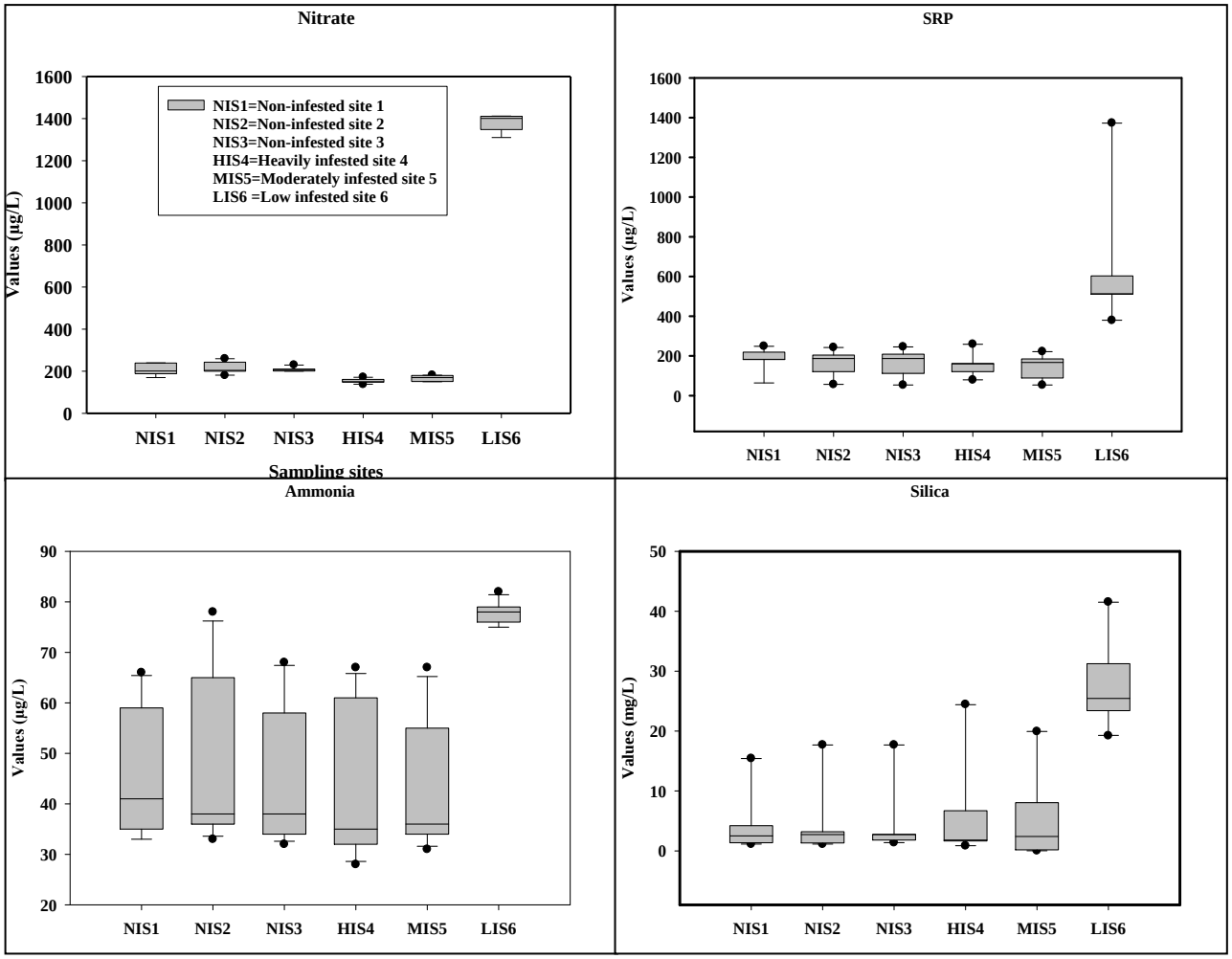


Figure 9. Temporal trends of water hyacinth biomass at the weed-infested sites.



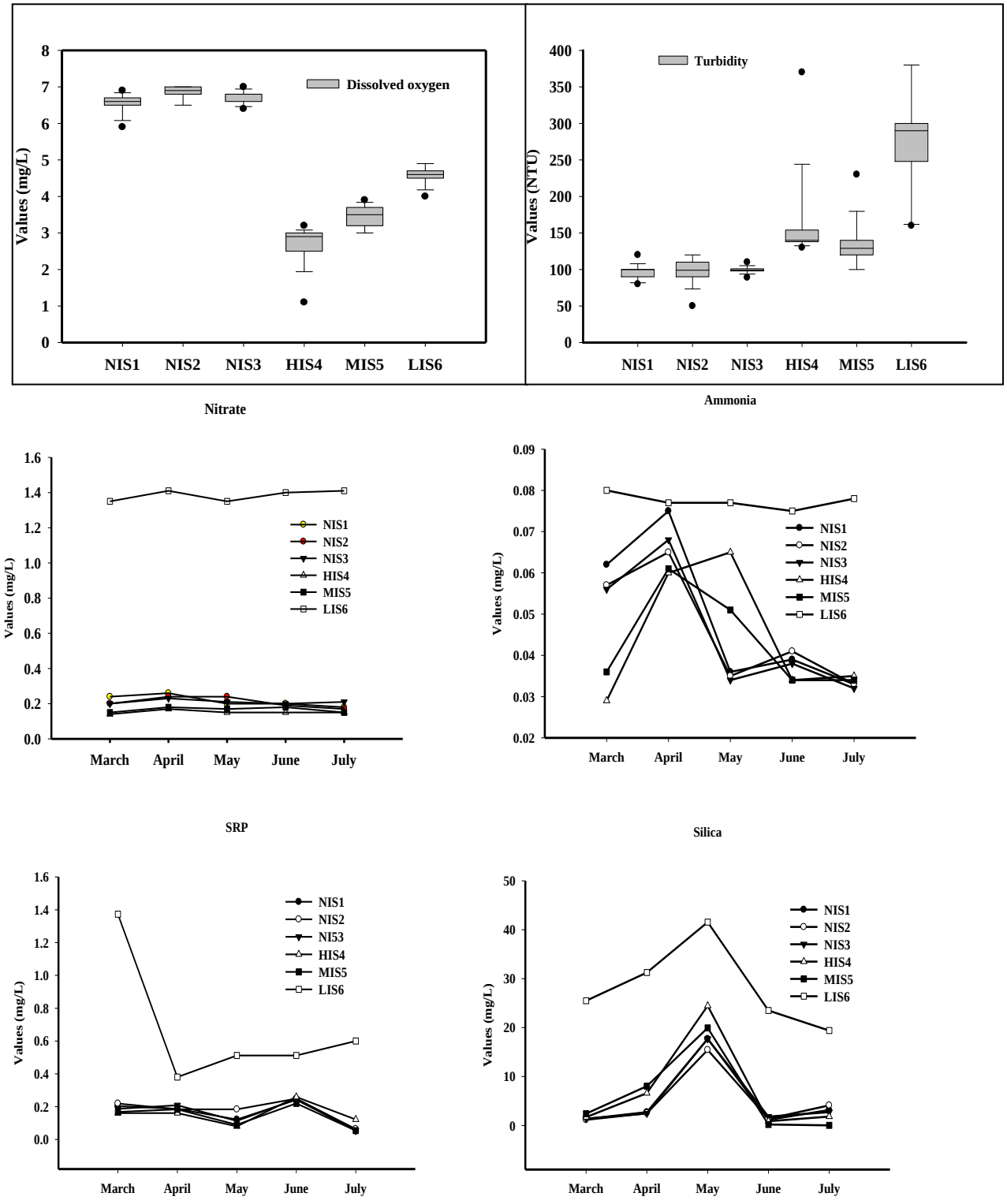


Figure 10. Spatial and temporal trends of nutrient concentrations at the study sites

4.1.1. Ordination of nutrients versus sites

Principal Component Analysis (PCA) (Figure 11) categorized the sampling sites based on the principal nutrient loading. In this analysis, the first two components (Axes) accounted for 87.21% of the total variations. The first component accounted for 66.57%, while the second accounted for 20.64% of the explained variance. Axis 1 was positively correlated with temperature, specific conductivity, salinity, TSS and silica, while it was negatively correlated with nitrate, phosphate, pH, dissolved oxygen and TDS with an eigenvalue of 6.66. Axis 2 was positively correlated with nitrate, temperature, pH, specific conductivity and salinity while it was negatively correlated with phosphate, dissolved oxygen, TDS, TSS and silica with an eigenvalue of 2.06 (Table 4). Results of the PCA showed negative and positive correlations of non-infested sites with Axis 1 and Axis 2, respectively and were discriminated from the weed-infested sites due to high levels of nutrients, dissolved oxygen, pH and TDS. The weed-infested sites showed positive correlations with both axes and were discriminated from the non-infested sites due to high salinity, conductivity, silica, and TSS. This indicates that non-infested sites were discriminated from sites infested with water hyacinth with high concentrations of nutrients and dissolved oxygen as compared to all the weed-infested sites.

Table 4. Correlation coefficients of physic-chemical parameters with the first two principal component axes

Sites	NO3	SRP	T^oc	pH	DO	K_{25}	TDS	Salinity	TSS	Silica
Axis1	-0.38	-0.249	0.31	-0.03	-0.38	0.37	-0.02	0.37	0.36	0.38
Axis2	0.119	-0.072	0.10	0.67	-0.06	0.15	-0.66	0.10	-0.25	-0.07

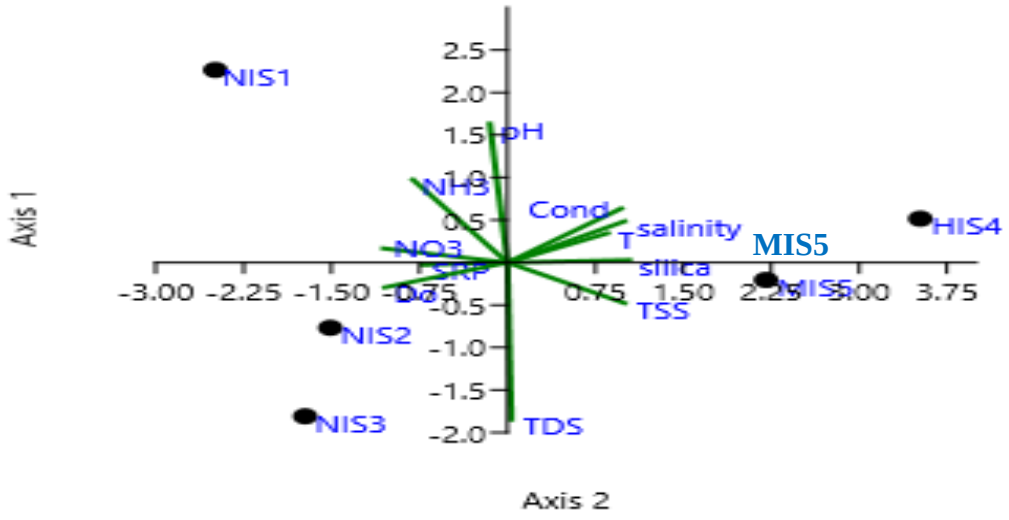


Figure 11. Bi-plot of principal component analysis with ordination of nutrients in relation to sites (Abbreviations: NIS1 = non-infested site 1, NIS2 = non-infested site 2, NIS3 = non-infested site 3, HIS4 = heavily infested site 4 and MIS5 = medium infested site 5).

4.2. Biological Features

4.2.1. Phytoplankton composition, abundance, and biomass

During the study period, 62 taxa were identified (Table 5). The identified taxa of the present study belonged to six taxonomic classes: Cyanophyceae (blue-green algae, 12), Bacillariophyceae (diatoms, 16), Chlorophyceae (green algae, 27), Euglenophyceae (euglenoids, 5), Cryptophyceae (cryptomonads, 1) and Dinophyceae (dinoflagellates, 1). The species composition and abundance of weed-infested and non-infested sites showed statistically significant differences regarding most taxonomic groups ($p<0.05$, and Appendix 2). Bacillariophyceae, Cyanophyceae, and Chlorophyceae had higher densities in the non-infested sites (190473, 67116 and 48058 Cells mL^{-1}) than at the weed-infested sites (51366, 20900, 14416 Cells mL^{-1}), respectively. Bacillariophyceae was the most dominant group both at the non-infested and weed-infested sites with the maximum density of 190,473 and 51366 Cells mL^{-1} and with percentage contribution of 60% and 52% to the total phytoplankton abundance at the two sites, respectively (Table 5 and Figure 12).

Table 5. Phytoplankton taxa identified during the study period.

	Non-infested sites	Infested sites
Cyanophyceae	*Anabaena flos- aquae* Bréb. *A. philippinensis* Gilbert *A. spiroides* Kleb. *A. torulosa* Bornet & Flahault *Anabaenopsis* spp. *Aphanizomenon gracile* Lemm. *Cylindrospermopsis africana* Kom. and Kling. *C. raciborskii* Wolosz. *Microcystis aeruginosa (*Kütz*)* Kütz. M. *flos-aquae* Kütz. *M. panniformis (Kom) Komárková-Legnerová* *M. wesenbergii* (Kom) Kom.	*Anabaena flos- aquae* Bréb. *Aphanizomenon gracile* Lemm *Cylindrospermopsis africana* Kom. and Kling. *Microcystis aeruginosa (*Kütz*).* Kütz.
Chlorophyceae	*Actinastrum hantzschii* Lagerh. *Ankistrodesmus braunii* Lemmermann *A. convolutus* (Nägeli) Rabenhorst *A. nannoselene* Skuja *Ankyra judai* (G.M.Smith) Fott *Chlorella* sp. *Closterium acutum v.variable* (Lemm.) Krieg. *Closterium dianae* (Ehrenberg) Kuntze *Chlamydomonas ambigua* Ehrenberg *Cosmarium* spp. *Oocystis* spp. *Pediastrum simplex* Meyen. *P. boryanum* (Turp.) Meneghini. *P. duplex* Meyen *P. gracillium* Meyen *Scenedesmus acuminatus var. minor* G.M.Smith *S. granulate* West & G.S.West	*Actinastrum hantzschii* Lagerh. *Ankistrodesmus nannoselene* *Ankyra judai* *Closterium dianae* *Chlamydomonas ambigua* *Cosmarium* spp. *Monoraphidium griffithii* *Oocystis* spp. *Pediastrum duplex* *Scenedesmus acuminatus* *S. angularis* *S. guadricauda* *Staurastrum cingulum var, obesum* *S. upplandich* *Selenastrum* spp.

	*S. quadricauda (*Turp).Breb. *Selenastrum* spp. *Staurastrum cingulum* *S. obesum* *S. upplandich* *Tetraedron* spp.	
Bacillariophyceae	*Aulacoseira granulata* (Ehr.) Simons. *Cyclotella comta* (Ehrenberg) Kützing *C. melosiroids* (Kirchner) Lemmermann *Cymbella* spp. *Diatoma tenuis* C.Agardh *Diploneis ovalis* (Hilse) Cleve *Eunotia zasuminensis* (Cabejszekówna) Körner *Fragilaria construens* (Ehrenberg) Grunow *F. pinnatta* Ehrenberg *F. virescens* Ralfs *Gyrosigma* spp. (Sullivant & Wormley) C.S.Boyer *Melosira ambigua* (Grunow) O.Müller *M. granulata* (Ehrenberg) Ralfs *Navicula* spp. *Nitzschia* spp. *Synedra ulna (Nitzsch.)* Lange Bert.	*Aulacoseira granulata* *Cyclotella comta* *Diatoma tenuis* *Fragilaria construens* *F. pinnatta* *Gyrosigma obtusatum* *Melosira ambigua* *Navicula* spp. *Nitzschia* spp. *Synedra ulna (Nitzsch.)* Lange Bert.
Euglenophyceae	*Euglena acus* (O.F.Müller) Ehrenberg *E. oxyuris* Schmarda *Phacus longicauda* (Ehr.) Duj. *P. tortus* (Lemmermann) Skvortzov *Strombomonas* sp.	*Euglena acus* Eher. *Phacus longicauda* (Ehr.) Duj.
Dinophyceae	*Peridinium inconspicuum* Lemmermann	
Cryptophyceae	*Cryptomonas* spp.	

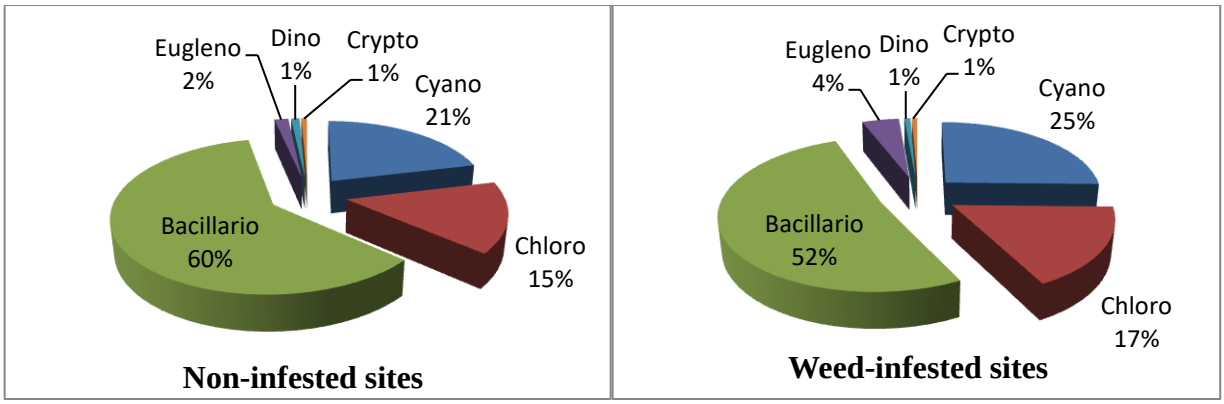


Figure 12. Percentage contribution of phytoplankton classes to the total phytoplankton counts. (Cyano=Cyanophyceae, Chloro= Chlorophyceae, Bacillario= Bacillariophyceae, Eugleno= Euglenophyceae, Dino= Dinophyceae, Crypto= Cryptophyceae).

Aulacoseira granulata, *Cylindrospermopsis* spp., *Microcystis aeruginosa*, *Synedra ulna*, *Anabaena* spp. and *Closterium acutum* were the most common taxa at both sites. The density of the phytoplankton taxa was higher in the non-infested sites than in the weed-infested sites (Table 7). The density of phytoplankton taxa showed statistically significant spatial variations within the weed-infested sites and between the weed-infested and non-infested sites, with much higher abundance at the non-infested sites ($P<0.05$) (Figure 13 and Appendix 2). Species of phytoplankton like *Pediastrum simplex*, *Pediastrum duplex*, *Pediastrum boryanum*, *Cosmarium* spp., *Staurastrum* spp., *Fragilaria pinnate*, *Cymbella* spp., and *Diploneis ovalis* were absent in the HIS4, while *Gyrosigma obtusatum* and *Monoraphidium griffithii* were present only in the weed-infested sites.

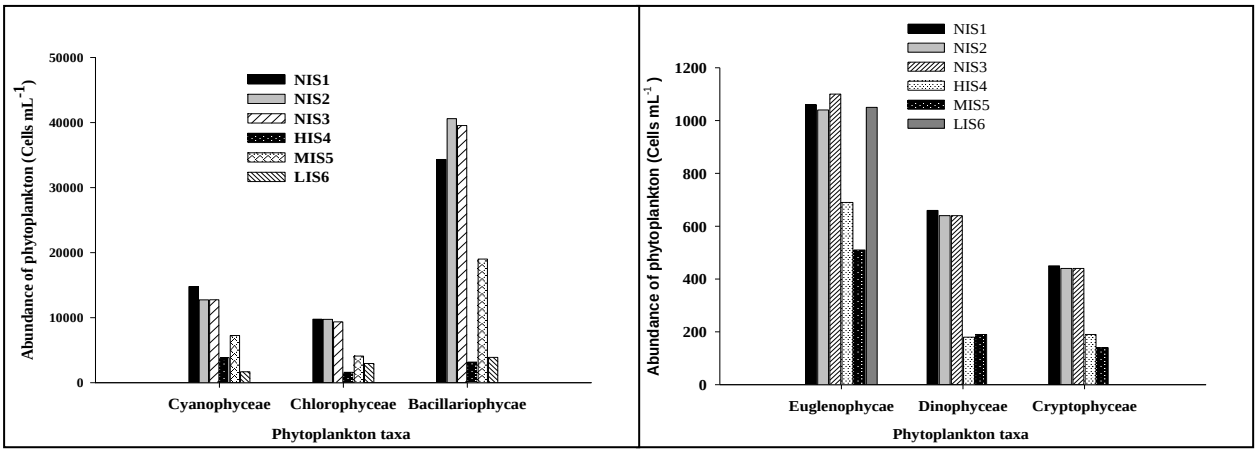


Figure 13. Spatial trends of phytoplankton abundance

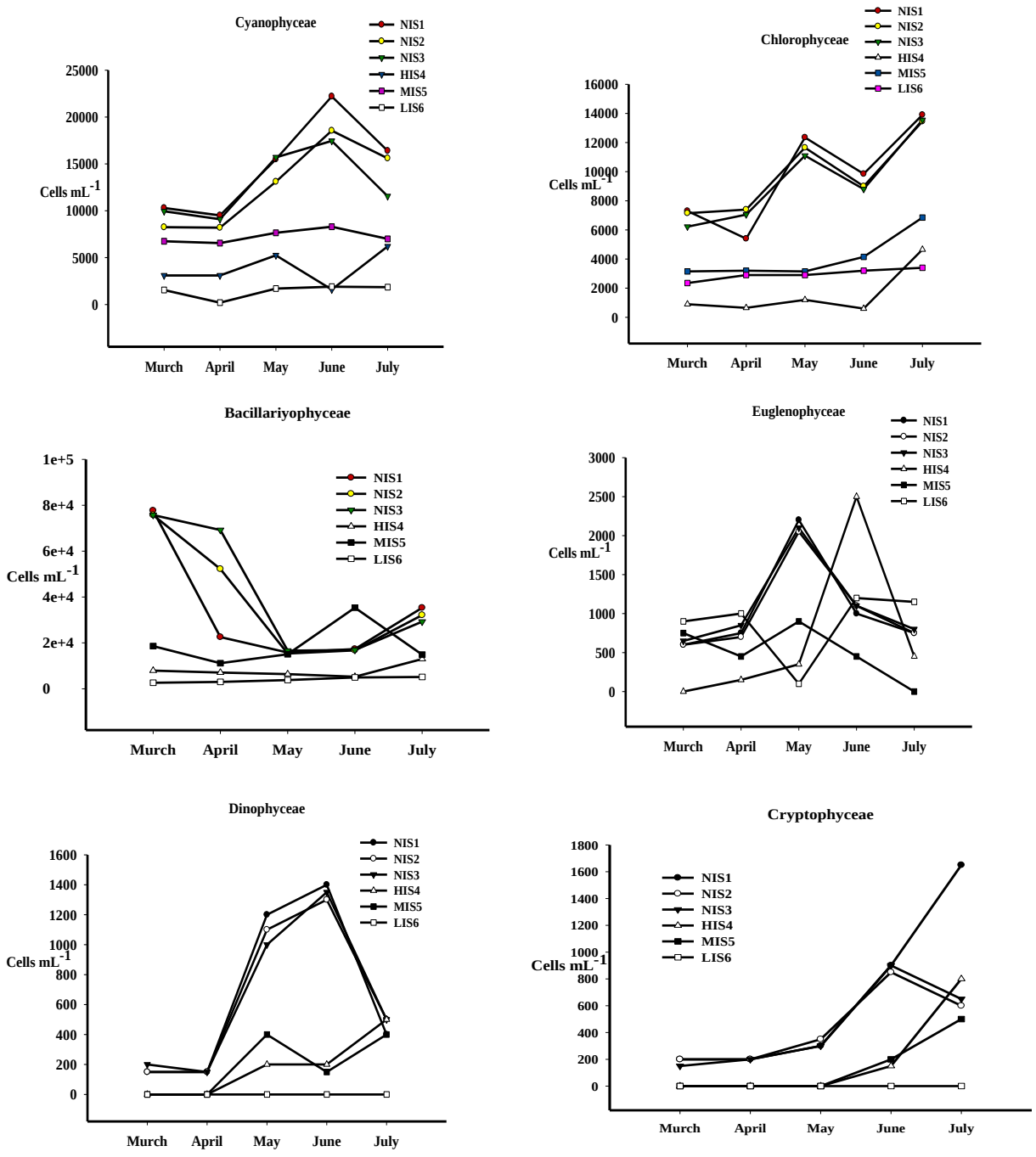


Figure 14. Temporal trends of the abundance of phytoplankton taxa

Higher mean values of Shannon-Weaver's index (H') and species richness (d) of phytoplankton were recorded for the non-infested sites than for the weed-infested sites while the slightly higher mean value of species evenness (j) was recorded in the weed-infested sites (Table 6). The values of Shannon-Weaver's index, species evenness (j) and species richness (d) at both sites were lower in March while they reached their maximum during June. Species richness (d) showed a significant difference between the two sites (Table 6, Appendix 3).

Table 6. Results of diversity indices computed for phytoplankton species.

Diversity indices	Non-infested sites		Weed-infested sites		p-value
	Range	Mean±SE	Range	Mean±SE	
H'	1.12 - 3.1	2.25±0.204	1.43 – 2.49	2.14±0.089	0.137
j	0.34 – 0.91	0.67±0.06	0.55 – 0.97	0.78±0.04	0.165
d	2.35 – 2.62	2.53±0.03	1.11 – 2.5	1.7±0.13	0.00

Chlorophyll-a (Chl-a) concentration ranged from 4.17 to 64.64 μg L^{-1}, with a mean value of 23.16.42±7.68 μg L^{-1} in the weed-infested sites and from 8.34 to 69.5μg L^{-1} with a mean value of 29.97±9.15 μg L^{-1} in the non-infested sites. Besides small spatial variations, there were no significant differences in the concentrations of Chl-a within and between the two sites ($P>0.05$). However, statistically significant temporal variations in Chl-a concentration were observed. In the weed-infested sites, the highest Chl-a concentration was recorded at MIS5 during July. Similarly, in the non-infested sites, the highest value of Chl-a was recorded at NIS1 during March.

Table 7. Phytoplankton composition and their relative abundance (RA (%)) observed at the weed-infested and non-infested sites (mean of the three sites)

Taxa	Non-infested sites		Infested sites	
	Cells mL^{-1} ($*10^2$)	RA%	Cells mL^{-1} ($*10^2$)	RA%
Cyanophyceae	**134.24**	**21**	**42.61**	**25**
Anabaena flos-aquae	18	2.85	5.2	2.83
Anabaena spiroides	12.43	1.96	4.96	2.7
Aphanizomenon gracile	13.9	2.2	9.56	5.2
Cylindrospermopsis spp.	40.63	6.42	10.86	5.9
Microcystis flos-aquae	33.83	5.35	7.8	4.26
Microcystis aeruginosa	15.4	2.43	4.16	2.26
Chlorophyceae	**96.12**	**15**	**28.83**	**17**
Actinastrum hantzschii	10.1	1.59	3.16	1.72
Chlamydomonas spp.	10.6	1.67	4.46	2.43
Closterium acutum	14.13	2.23	4.13	2.25
Cosmarium spp.	4.76	0.75	1.6	0.87
Oocystis spp.	16.65	2.63	6.1	3.32
Pediastrum boryanum	4.36	0.69	0.66	0.36
Pediastrum duplex	4.93	0.78	1.2	0.65
Pediastrum simplex	4.63	0.73	0.96	0.53
Scenedesmus acuminatus	6.96	1.1	2.26	1.23
Scenedesmus quadricauda	6.4	1.01	2.3	1.25
Staurastrum obesum	4.33	0.68	0.83	0.45
Staurastrum upplandich	8.3	1.3	1.13	0.62
Bacillariophyceae	**381.53**	**60**	**86.9**	**52**
Aulacoseira granulata	288.86	45.64	53.66	29.16
Cyclotella cemta	17.23	2.72	4.4	2.39
Fragilaria construes	7.6	1.2	2.2	1.196
Fragilaria pinnatta	6.5	1.02	2.26	1.23
Navicula spp.	6.13	0.97	4.33	2.35
Nitzschia desertorum	4.21	0.66	4.6	2.5
Synedra ulna (Eher.)	50.4	7.96	31.26	16.99
Euglenophyceae	**10.66**	**2**	**7.5**	**4**
Euglena acus	4.5	0.71	3.46	1.88
*Phacus longicauda (*Eher.*)* Duj.	4	0.64	2.6	1.41
*Phacus tortus (*Lemm.) Skv.	2.2	0.34	1.43	0.78
Dinophyceae	**446**	**1**	**1.23**	**1**
Peridinium inconspicuum Lemm.	6.46	1.02	1.23	0.67
Cryptophyceae	**4.43**	**1**	**1.1**	**1**
Cryptomonas spp.	4.43	0.7	1.1	0.59

4.2.2. The relationship between physicochemical variables and density of phytoplankton taxa

In this Redundancy Analysis, the first two axes accounted for 98.5% of the cumulative percentage of variance in species–environmental relationship (Table 8). The first axis accounted for 97.1% of the variance, and showed strong positive correlations with Silica, Specific conductance, Salinity, temperature, and TSS, while negatively correlated with phosphate, TDS, Nitrate, DO and pH concentrations. However axis 2, which accounted for 1.4% of the variance, was positively correlated with silica, TSS, TDS and temperature and negatively correlated with nitrate, phosphate, pH, DO, specific conductance and salinity (Figure 15).

The density of Bacillariophyceae was positively correlated with dissolved oxygen, and nitrate ($r = 0.461$, $p<0.05$, 0.546, $p<0.01$, respectively) and negatively correlated with TSS and temperature ($r=-0.484$ and 0.405, $p<0.05$). Cyanophyceae was also positively correlated with dissolved oxygen and pH ($r=0.725$, $p<0.01$, $r=0.400$, $p<0.05$, respectively) and negatively correlated with temperature ($r=-0.444$, $p<0.05$).Chlorophyceae was positively correlated with dissolved oxygen and nitrate ($r=0.729$, $p<0.01$, $r=0.478$, $p<0.05$, respectively) and negatively correlated with specific conductance and salinity ($r=-0.491$ and $r=0.491$, $p<0.05$). Euglenophyceae was, however, positively correlated with specific conductance and salinity ($r = 0.533$ and 0.533, $p<0.01$). Dinophyceae was positively correlated with dissolved oxygen and pH ($r = 0.506$ and $r=0.423$, $p<0.05$), while Cryptophyceae was positively correlated with dissolved oxygen and TSS ($r = 0.467$ and $r=0.468$, $p<0.05$) and negatively correlated with specific conductance and salinity ($r=-0.467$, and $r=0.467$, $p<0.05$).

Table 8. Results of Redundancy Analysis (RDA) for the relationship between environmental variables and phytoplankton taxa using the first two Axes.

Parameters	Axis 1	Axis 2
Eigenvalues	0.971	0.014
% variance of species-environment relation	97.1	1.4
Nitrate	-0.9394	-0.3318
Phosphate	-0.4777	-0.6728
T°c	0.7387	0.2518
pH	-0.6592	-0.0848
DO	-0.9506	-0.2426
Specific Conductance	0.9898	-0.0888
TDS	-0.2015	0.7555
salinity	0.9981	-0.0260
TSS	0.8887	0.3368
silica	0.9800	0.1562

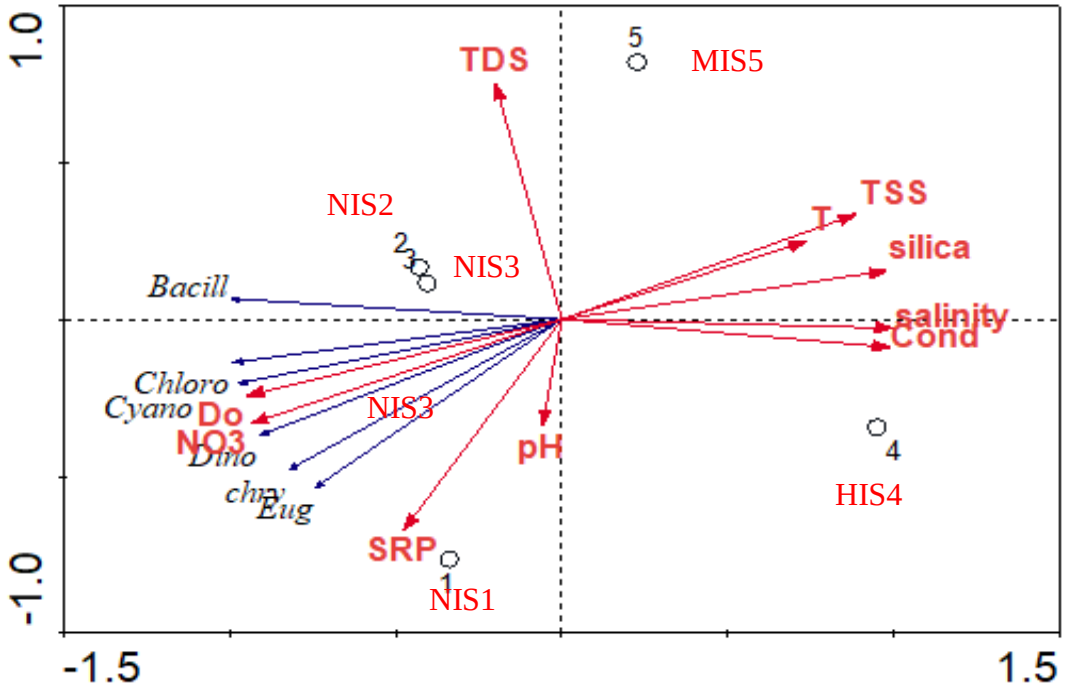


Figure 15. Ordination diagram of Redundancy Analysis (RDA) of the first two ordination axes summarizing the relationship between physicochemical variables and phytoplankton taxa (Abbreviations; TDS=total dissolved solid, TSS= total suspended solid, Cond=specific conductance, NO3= Nitrate, T=temperature, SRP=Soluble reactive phosphate-phosphorus, DO=Dissolved Oxygen, Bacill=Bacillariophyceae, Chloro=Chlorophyceae, Cyano=Cyanophyceae, Dino=Dinophyceae, Chry=Cryptophyceae, Eug=Euglenophyceae).

4.2.3. Zooplankton composition and abundance

List of species identified in this study with their percentage (relative) abundance is presented in Table 10. 38 zooplankton species belonging to three taxonomic groups were recorded in this study (Table 9). Rotifers comprised 24 species (8 genera), Cladocerans, 9 species (6 genera) and Copepods, 5 species (3 genera). Rotifers were the most species-rich and abundant zooplankton taxa at both sites. They accounted for 48% in the weed-infested sites and 53% in the non-infested sites of the total zooplankton abundance (Fig. 16). Their total density ranged from 22,628 to 48,514 ind. /L and from 195 to 17,375 ind. /L, with mean values of 34,017±2760.5 ind. /L and 6247±1417.3 ind. /L in the non-infested and weed-infested sites, respectively. *Brachionus calyciflorus, Keratella tropica,* and *Filinia* spp. were the most prominent species of rotifers, which contributed 27.82% and 24.22% of the total zooplankton density in the non-infested and weed-infested sites, respectively (Table 10). Rotifers reached their peaks of 48,514 ind. /L at the non-infested sites during June, while their peak of 13,373 ind. /L during June, at the weed-infested sites, occurred (Figure 18). The abundance of Rotifers showed significant differences between the two sites ($p<0.05$, Appendix 4).

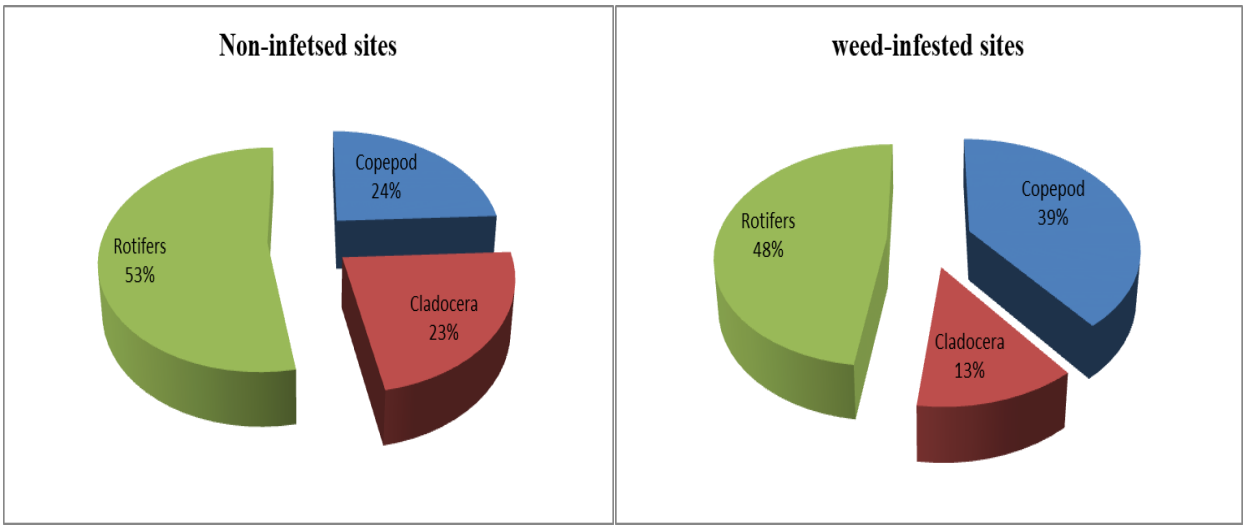


Figure 16. Percentage contributions of different zooplankton taxa to the total zooplankton abundance at the study sites

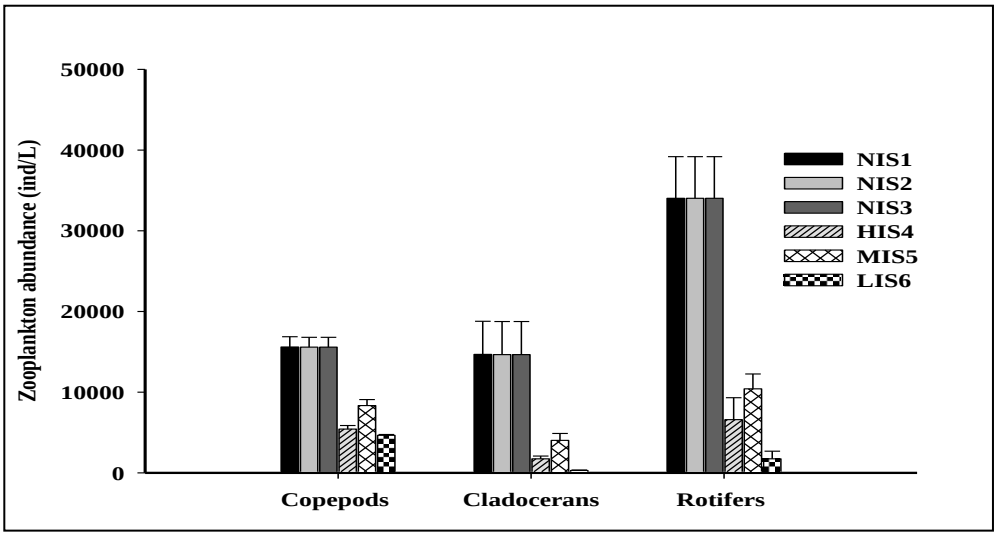


Figure 17. Spatial trends of zooplankton taxa at the study sites.

The density of copepods ranged from 12,609 to 19,034 ind/L, with a mean value of 15,580±661.84 ind. /L at the non-infested sites, while the density at the weed-infested sites varied from 3,905 to 9,566 ind/L, with a mean value of 6134±502.81 ind. /L. Copepods had the second highest density, next to rotifers, both at the weed-infested and non-infested sites, contributing 39% and 24% of the total zooplankton density, respectively. The highest copepods density was recorded at both weed-infested and non-infested sites during June, while their lowest density was recorded during April at the weed-infested and non-infested sites (Fig. 18). The weed-infested and non-infested sites did not differ in the species composition of copepods. *Mesocyclops* sp. was the most abundant species at both sites, followed by Nauplii.

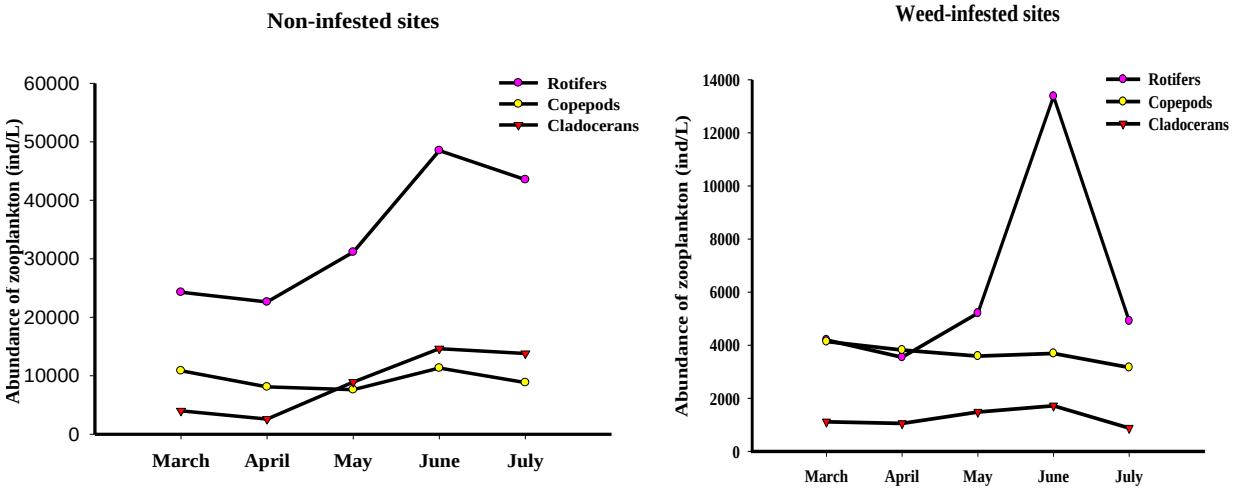


Figure 18. Temporal trends of zooplankton abundance at the study sites.

The density of Cladocerans ranged from 4,337 to 24,402 ind. /L at the non-infested sites with a mean value of 14661±2189.12 ind. /L, while at the weed-infested sites, it varied from 293 to 5661 ind. /L, with a mean value 2,082±481.12 ind. /L. The contribution of Cladocerans to total zooplankton density was 23% at the non-infested sites and 13% at the weed-infested sites. There were significant spatial and temporal differences in Cladocerans density ($P<0.05$ and Appendix 4). Among the Cladocerans, *Ceriodaphnia* spp., *Diaphanosoma* spp., and *Moina micrura* were the dominant species at the non-infested and weed-infested sites, with mean contributions of 6% and 5%, respectively, to the total zooplankton density (Table 10).

Table 9. Zooplankton taxa identified in samples collected from the study sites during the study period.

Non-infested sites		
Copepods	**Cladocerans**	**Rotifers**
Calanoid	*Alona* sp.	*Anuraeopsis fissa*
Cyclopoid	*Bosmina longirostris*	*A. Naviculla*
Harpacticoid	*Ceriodaphnia* spp.	*Asplanchna priodonta*
Mesocyclops	*Daphnia barbata*	*Brachionus angularis*
Nauplii	*D. pulex*	*B. calyciflorus*
	Diaphanosoma spp.	*B. falcatus*
	Moina micurura	*B. forficula*
		B. havanaensis trahea
		B. plicatilis
		B. patulus
		B. quadridentatus
		Filinia grandis
		F. pejleri grandis
		Keratella quadrata dispersa
		K. tecta
		K. tropica
		K. vulga f.heterospina
		Polyarthra remata

		P. vulgaris *Pompholyx sulcata* *Trichocerca elongata* *T. flagellata* *T. pusilla* *T. mus*
Weed-infested sites		
Copepod	**Cladocerans**	**Rotifers**
Calanoid Cyclopoid Harpacticoid Nauplii	*Alona* sp. *Bosmina longirostris* *Ceriodaphnia* spp. *Diaphanosoma* spp. *Moina micurura*	*Anuraeopsis fissa* *Asplanchna priodonta* *A. Naviculla* *Brachionus angularis* *B. bidentata* *B. calyciflorus* *B. caudatus* *B. patulus* *Euchlanis dilatata* *Filinia pejleri* *F. grandis pejleri* *Keratella tropica* *Lecane leontina* *L. monostyla homata* *Polyarthra vulgaris* *Pompholyx sulcata* *Platyias quadricornis var.bervispinus* *Trichocerca djurella sejunctipes* *T. elongata* *T. mus*

Table 10. Zooplankton taxa and their relative abundance [RA (%)], observed in samples collected from the weed-infested and non-infested sites (mean of the three sampling sites)

Taxa	Non-infested sites		Weed-infested sites	
	Ind/L (*10^2)	RA%	Ind/L (*10^2)	RA%
Copepods	**155.8**	**24**	**61.4**	**39**
Calanoid	7.43	1.16	5.12	0.797
Cyclopoid	85.2	12.76	22.98	3.73
Nauplii	62.5	10.01	32.27	5
Cladocerans	**146.6**	**23**	**20.8**	**13**
Bosmina longirostris	12.1	1.87	1.6	0.24
Ceriodaphnia spp.	58.58	9.11	8.72	1.36
Daphnia barbata	3.9	0.6	0	0
Daphnia pulex	4.1	0.64	0	0
Diaphanosoma spp.	29.3	4.56	0.32	0.05
Moina micurura	38.7	6	10.2	1.59
Rotifers	**340.2**	**53**	**62.5**	**48**
Anuraeopsis fissa	12.5	1.94	0	0
Anuraeopsis naviculla	15.6	2.43	7.16	1.11
Asplanchna priodonta	26.6	4.13	9.7	1.51
Brachionus angularis	5.2	0.81	0	0
Brachionus calyciflorus	71.7	11.98	5.2	0.81
Brachionus caudatus	26.04	4	1.8	0.28
Brachionus falcatus	7.3	1.14	0	0
Brachionus falcatus redactus	10	1.55	0	0
Euchlanis dilatata	0	0	1.95	0.3
Filinia pejleri	55.2	8.58	8.33	1.3
Keratella tropica	46.7	7.26	3.19	0.49
Lecane monostyla homata	0	0	7.1	1.1
Platyias quadricornis				
Polyarthra vulgaris	21.95	3.42	4.8	0.74
Pompholyx sulcata	7	1.1	0.39	0.06
Trichocerca spp.	34.3	5.34	9.24	1.44

The mean values of Shannon-Weaver's index, species richness and species evenness were higher in the non-infested sites than in the weed-infested sites (Table 11). The highest values of Shannon-Weaver's diversity, species evenness, and richness indices were recorded during July in the weed-infested sites. In the non-infested sites, the highest values of the Shannon-Weaver's diversity index and species evenness were recorded during June, while that of species richness index was observed during March. Significant spatial differences in Shannon-Weaver's index and richness indices were observed between the two sites ($P<0.05$, Annex 5).

Table 11. Ranges and means of diversity indices of zooplankton species of the two study sites.

Diversity indices	Non-infested sites		Weed-infested sites		p-value
	Range	Mean±SE	Range	Mean±SE	
H'	2.51-2.91	2.68±0.039	1.19-2.57	2.051±0.1084	0.00
j	0.82-0.93	0.885±0.011	0.74-0.93	0.876±0.0132	0.384
d	1.66-1.95	1.796±0.026	0.47-1.58	1.038±0.0893	0.00

4.2.4. The relationship between physicochemical variables and density of zooplankton taxa

Results of the Redundancy Analysis of the relationship between physicochemical variables and density of zooplankton taxa using the first two axes is shown in Figure 19. The two principal components (Axes) accounted for 98.9% of the cumulative percentage variance in species–environmental relationship. Axis 1 accounted for 76.8% of the variance showing a strong positive correlation with T^oc, K_{25}, salinity, Silica, and TSS, and negative correlation with NO_3, SRP, pH, DO and TDS, while axis 2 accounted for 22.1% of the variance showing positive correlation with SRP, DO, TDS, TSS, and silica and negative correlation with salinity, K_{25}, pH, T^Oc and NO_3 (Table 12).

Density of Cladocerans showed positive correlation with dissolved oxygen and pH ($r = 0.625$, $p<0.01$, and $r=0.46$, $p<0.05$, respectively) and negative correlation with TDS and T^oC ($r=-0.54$ and $r=-0.48$, $p<0.05$). Copepods showed positive correlation with dissolved oxygen, NO_3 and TSS ($r = 0.863$, $r=0.639$, $p<0.01$, and $r=0.461$, $p<0.05$, respectively) and negative correlation with T^oC ($r=-0.573$, $p<0.01$). Rotifers also showed positive correlation with DO and NO_3

(r=0.713, p<0.01, and r=0.453, p<0.05, respectively) and negative correlation with T^{o}C (r=0.453, p<0.01). The remaining physico-chemical variables, however, showed weak but positive and negative relationships with zooplankton density.

Table 12. Results of the Redundancy Analysis (RDA) for the relationship between zooplankton taxa and physicochemical variables using the first two Axes.

Parameter	Axis 1	Axis 2
Eigenvalues	0.768	0.221
% variance of species environment relation	76.8	22.1
Nitrate	-0.9865	-0.0605
Soluble reactive phosphorus	-0.6857	0.1693
Temperature	0.7271	-0.5783
pH	-0.0820	-0.6207
Dissolved oxygen	-0.9915	0.1119
Specific conductance	0.9295	-0.1673
TDS	-0.0123	0.6481
Salinity	0.9493	-0.1274
TSS	0.9372	0.2717
Silica	0.9685	0.0020

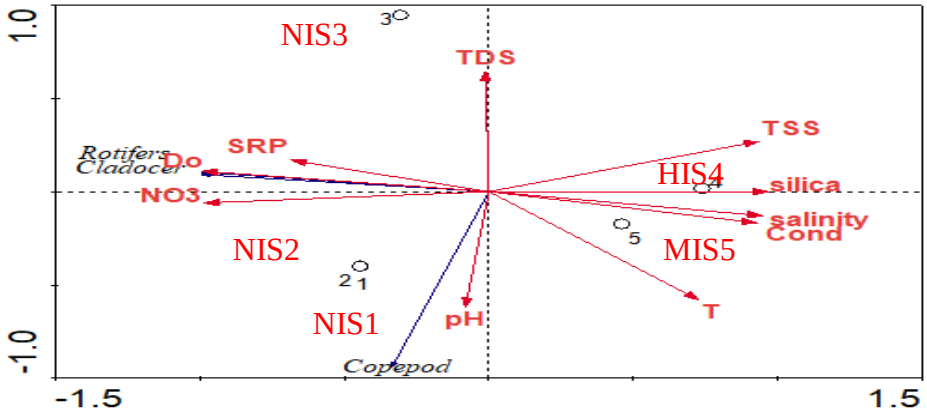


Figure 19. Ordination diagram of Redundancy Analysis (RDA) summarizing the relationship of physicochemical variables and zooplankton taxa using the first two ordination axes (Abbreviations; DO = Dissolved Oxygen, Cond = Specific conductance,

TSS=Total suspended solid, TDS=Total dissolved solid, SRP= Soluble reactive phosphorus, NO3=Nitrate, T=Temperature).

4.2.5. Toxicity effects of water hyacinth (*Eichhornia crassipes*)

4.2.5.1. Proximate composition of water hyacinth *(Eichhornia crassipes)*

In this investigation, the major compositions of water hyacinth were utilizable carbohydrate, crude fiber, and crude ash respectively (Table 13). The water hyacinth of this study had a considerably high amount of fiber (21.16%) (Table13). The crude protein content in the water hyacinth of the present study was 10%.

Table 13. Proximate composition of water hyacinth

Tested parameters	Mean ± SE
The moisture of the dried powder (%)	3.40 ± 0.40
Crude ash (%)	15.00 ± 0.30
Crude fat (%)	1.00 ± 0.50
Crude fiber (%)	21.16 ± 1.05
Crude protein (%)	9.89 ± 0.26
Utilizable carbohydrate (%)	49.55 ± 9.41
Energy kcal per 100gm	246.76 ± 41.08

Data are reported as mean ± SE, all analyses were done in triplicate on Dry Basis (DB)

4.2.5. 2.Total flavonoid and phenolic content of water hyacinth (*Eichhornia crassippes*)

The total flavonoid and phenolic substances content of water hyacinth were determined in this study. As reported in Table 14, water hyacinth had a total flavonoid and phenolic contents of 2.00 mg QE/ g and 1.67 mg GAE/g of the dried sample respectively in the methanol extract.

Table 14. Total flavonoid and phenolic contents of methanol extract of water hyacinth

Extract type	Total flavonoid concentration (mg QE/g sample)	Total flavonoid concentration (mg QE/g extract)	Total phenolics concentration (mg GAE/g sample)	Total phenolics concentration (mg GAE/g extract)
Methanol extract of water hyacinth	2.00 ± 0.01	17.23 ± 0.09	1.67 ± 0.04	14.42 ± 0.35

Data are reported as mean ± SE, all analyses are done in triplicate on Dry Basis (DB), GAE-Gallic Acid Equivalent, and QE-Quercetin

4.2.5.3. Acute mice toxicity test of water hyacinth (*Eichhornia crassipes*) extracts

Sequential extracts of dichloromethane (DCM) (highly non-polar), ethanol (medium polar) and water (highly polar) were prepared from water hyacinth with a yield of 45g, 18g, and 10g respectively. DCM extraction was found to give high yield water hyacinth extracts (45g) followed by ethanol extraction while low yield was obtained from water extraction. The color of the extract changed from brownish (DCM extract) to slightly brown (ethanol and water extractions).

The three extracts of water hyacinth (5 g kg^{-1} body weight) were orally administered to the experimental Mice (n=10 for each extract). Within three hours of oral administration of the extracts, toxic responses except mortality were observed. When the mice were given the DCM extract, all immediately reacted by jumping, sleeping and displaying dizziness for about three hours. Similarly, when the ethanol extract was administered to the mice, all mice immediately reacted by jumping, sleeping and displaying dizziness for about three hours. However, five of ten mice treated with water extracts showed none of the behavioral changes.

5. DISCUSSION

5.1. Physico-chemical parameters

There were significant spatial and temporal variations in most of the physicochemical parameters measured during this study (Table 2, 3 and Annex 1). The mean minimum and maximum surface water temperatures observed in this study occurred during March and April, respectively. The absence of spatial significant variation in water temperature at the non-infested sites may be attributable to the polymictic nature of the reservoir, while at the weed-infested sites, it seems associated with the presence of water hyacinth, which may deter the heat transfer between surface water and the atmosphere, minimizing temperature variation at the weed-infested sites. Similar results were reported by Schreiner (1980) and Mironga, *et al*. (2012) in their study on South Georgia Pond and Lake Naivasha, Kenya, respectively. Mehra *et al*. (1999) have also reported a profound influence of floating water hyacinth mats on diurnal temperature fluctuation. The surface water temperatures of Koka Reservoir is closer to those measured in other Ethiopian Rift Valley and crater lakes (18-27^{o}C, Elizabeth Kebede, 1996), but lower than those reported by Ganf and Horne (1975) for the East African lakes, Lake George, Uganda (26-36 ^{o}C), Lake Turkana (27.5-32.5 ^{o}C) and even water hyacinth supporting Lake Naivasha (27 ^{o}C, Mironga *et al*. 2012).

The lowest mean Secchi depth recorded for the weed-infested sites seems to reflect water hyacinth's effect associated with its capacity to reduce wind mixing due to the complex structure of its leaf and root, which make suspended particles including phytoplankton stay suspended in the water column reducing water transparency (Chukwuka and Uka 2008; Mironga, *et al*., 2012). The high concentration of dissolved solids and suspended particulate matter, which enters the reservoir through its feeder rivers, may have also contributed to the lowest Secchi depth recorded for the weed-infested sites during the study period. Turbulence due to wind-induced mixing, water input through tributary rivers from the catchment area and relatively higher phytoplankton density seem to be the main factors responsible for the low water transparency during the pre-rainy and rainy months. The mean value of Secchi depth of this study is higher than that of Mesfin Degefu *et al*. (2011, 12cm), closer to those recorded by Yeshiemebet Major (2016, 15cm) and Mesfin Gebrehiwot (2017, 19cm) for the open water of the same reservoir. The variation of

the Secchi depth of the present study from those reported by other investigators might also be due to the varied time of sampling and sampling sites. Generally, Secchi depth (cm) of Koka Reservoir is less than those of the Ethiopian rift valley lakes (Beseka, 41; Ziway, 35; Langano, 25-35; Abijata, 65; Shalla, 125; Chitu, 43; Hawassa, 70-80; Abaya, 43; Chamo, 65cm; Elizabeth Kebede and Amha Belay, 1994).

The mean value of TSS from non-infested sites (Table 2) in this study is closer to those values recorded by Yeshiemebet Major (2016; 113mg/L) and Mesfin Gebrehiwot, 2017 (165mg/L) for the open water of the same reservoir; However, the mean value of TSS of the weed-infested sites was higher than those recorded by Yeshiemebet Major (2016) and Mesfin Gebrehiwot (2017). Even though the mean value of turbidity of the open water in the present study is closer to the value recorded by Mesfin Gebrehiwot, (2017), the mean value of the weed-infested sites is still higher. The higher mean value of TSS recorded for the weed-infested site of this study follows the results of the study documented by Mironga *et al*. (2012). Higher values of TSS and Turbidity of the weed-infested sites may be an indication of the effect of water hyacinth on the water quality of the reservoir. The highest values of TSS and turbidity recorded at both sites in June and July respectively are attributable to the disturbance of the reservoir by runoff from the surrounding catchment and feeder rivers.

Although not statistically significant, the relatively lower pH values recorded at the weed-infested sites, when algal biomass was lower and when weed biomass was higher, may have resulted from the CO_2 contributed by incoming water from agricultural areas through runoff and decomposition of organic matter by bacteria. pH of both sites showed significant differences between June and the other sampling months within the range, which was optimum for the growth of water hyacinth and any another organism that lives in the lake (Weiner, 2007; Ndinwa *et al*., 2012). The pH values of the present study are closer to those reported by Elizabeth Kebede and Willn(1998, 8.3), HadgembesTesfaye (2007, 8.11-8.6), and Fasil Degefu *et al*. (2011, 9) for the open sites of the same reservoir. The pH values are also closer to those of other Ethiopian rift valley lakes including Ziwai, Awassa, Abaya, Chamo and Langeno (8.20-8.95), while they are still lower than those of the rest of the rift valley lakes, Metahara, Shalla, Abijata, and Chitu (9.40-10.20; Elizabeth Kebede and Amha Belay, 1994). But the present pH values are higher than those recorded in water hyacinth supporting lakes, Lake Tana (7.97; Wonde Zelalem, 2013) and Lake Naivasha (6.92-7.72; Mironga *et al*., 2012). The relatively high pH values of the non-

infested sites, particularly those recorded during May, coincident with high phytoplankton densities; seem associated with the removal of carbon dioxide by algal communities through their intense photosynthetic activities with the consequent increase in pH (Atobatele and Ugwumba, 2008).

The relatively low mean TDS value recorded for the weed-infested sites seems to reflect the accumulation effect of Water hyacinth by its complex root structure because water hyacinth has substantial capacity to remove TDS from the water surface through accumulation (Borges *et al*., 2008; Gamage and Yapa 2001). The lower mean value of TDS recorded at the weed-infested sites also follows the results of studies documented by Chukwuka and Uka (2007), Borges *et al*. (2008) and Wondie Zelalem (2013) which attributed the decrease in this chemical parameter to the assimilation of substances by water hyacinth.

During this investigation, considerably lower dissolved oxygen concentration was observed at the weed-infested sites, which was markedly lower at the highly weed-infested site (1.1 mg/L) than that recorded for the non-infested sites (8.67mg/L). The present cover of the large water hyacinth mat seems to have contributed to the notable decrease in dissolved oxygen concentration as its mat causes blockage of sunlight from the atmosphere, extra consumption of dissolved oxygen during decomposition of organic matter that emanated from its biomass and the relatively higher temperature coupled with the presence of water hyacinth, which obviously hindered gaseous exchange between the atmosphere and the surface water. The results of the present study are in line with the finding of the different studies documented by some investigators (McVea and Boyd, 1975; Rommens *et al*., 2003; Chukwuka *et al.,* 2008; Mironga *et al*., 2012). The highest oxygen concentration recorded in June (8.67mg/L) for the non-infested sites may be associated with phytoplankton blooming dominated by the cyanobacterial genus *Microcystis* (Fig.16).

Different studies have traced the blooming of water hyacinth populations in a water body to nutrient enrichment (Barret, 1989; Bartodziej and Leslie, 1998; Wilson *et al*., 2005). The weed also grows well in waters polluted with organic contaminants and high concentrations of plant nutrients (Chunkao *et al*., 2012; Ndimele, 2012). Depending on the level of infestation, water hyacinth has the potential to reduce nutrient concentrations, especially during rapid growth through assimilation (McVea and Boyd, 1975; Schreiner, 1980; Pinto and Greco, 1999; Mironga *et al*., 2012).

The observed lower concentration of SRP and nitrate at the weed-infested sites is in line with the contention that water hyacinth assimilates large quantities of nutrients affecting nutrient availability in the water column, which may stress the growth of other plants and algae ((McVea and Boyd, 1975; Schreiner, 1980; Pinto and Greco, 1999). Water hyacinth, compared to other macrophytes, has high nutrient uptake rate and the ability to accumulate vast amounts of nutrients in its tissue (Rezania *et al*., 2013). This property of the weed may have a significant effect on the concentrations and turnover rates of nutrients in the lake (Pinto and Greco, 1999). Similar results were observed by Marshall (1997) in Lake Chivero (Uganda) and Mironga *et al.* (2012) in Lake Naivasha (Kenya). The mean value of nutrients recorded for the weed-infested sites is not low and this seems associated with LIS6, which is at the mouth of Awash River (inlet to Koka Reservoir) and receives inputs from agricultural run-off and effluents of floriculture. There were thus higher levels of nutrients at the non-infested sites than at the heavily and moderately (medium) infested sites. However, a higher concentration of silica was observed at the weed-infested sites, which may have resulted from the low abundance of diatoms (Bacillariophyceae) and input of the nutrient from different sources through LIS6 (an inlet of Awash River).

As the present results indicate, nitrate concentrations in Koka Reservoir are often high (140 to 1410μg l-1) compared to those of most of other Ethiopian rift valley lakes, although they are still lower than those recorded for Legedadi Reservoir (240 to 1850 μg l-1, Adane Sirage, 2006). The observed high nitrate levels in Koka Reservoir (particularly those of LIS6-Awash river mouth) seem to result from inputs from the floriculture and surrounding agricultural lands on which fertilizers are commonly applied to boost crop yield. During periods of rainfall, nutrients may be washed into the reservoir through runoff and may also be introduced through Awash River from the upper catchment areas. The lowest concentration of nitrate was recorded during July (Figure 10) coincident with the highest chlorophyll-a concentration at the study sites suggesting its efficient removal by phytoplankton at least during this month. Although weak, the correlation between nitrate and phytoplankton biomass was also negative ($r = -0.146$).

The mean SRP concentration recorded in this study from the open water is closer to that reported by Hadgembes Tesfaye (2007, 194μg/L), while it is higher than those reported by Elizabeth Kebede and Amha Belay, (1994, 9.5 μg/L), Mesfin Degefu *et al*. (2011, 36.1 μg/L) and Mesfin Gebrehiwot (2017, 4-100 μg/L. The present concentration of SRP is also higher than those

reported for Ethiopian rift valley lakes except lakes Metahara, Shalla and Chitu (Elizabeth Kebede and Amha Belay, 1994). The lowest values of SRP in July at the non-infested sites and moderately (medium) infested sites coincided with the seasonal maxima in phytoplankton biomass. This suggests that phytoplankton growth had a depressing effect on phosphate concentration.

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In the present study, the SiO_2concentration of the non-infested sites was higher than that (2.5 mg/L) recorded by Elizabeth Kebede and Amha Belay (1994), but closer to those recorded by Hadgembes Tesfaye (2007, 15.35mg/L), Fasil Degefu *et al*. (2011, 17.7mg/L) and Yeshiemebet Major (2016, 14.1mg/L) for non-infested sites of the same reservoir. Values recorded for the weed-infested sites, which seem to have been influenced by inputs through LIS6 are, however, much higher than those recorded results. The peak in SiO_2 concentration was observed during May for both non-infested and weed-infested sites, while the lowest was observed in March (Fig.10) coincident with the greater abundance of diatoms (Fig. 14).

In the present study, the concentrations of nitrate, SRP and, silica were always over their limiting levels, [i.e. <20µg/L for nitrogen (Ryding and Rast, 1994), <0.5 mg/L for silica (Reynolds, 1984; Wetzel and Likens, 1991) and <5 µg/L for Orthophosphate (Ryding and Rast, 1994)]. The absence of notable nutrient depletion in Koka Reservoir during the study period may be due to the replenishment from the sediments by mixing as Koka Reservoir is polymictic (Elizabeth Kebede, 1996), which is enhanced by the feeding habit of *Cyprinus carpio* (common carp), and through input from the feeder river (Awash River) and from the surrounding agricultural lands through runoff during the wet months. Nicole (2002) also suggested that wind-induced vertical mixing and increased freshwater input are the causes of elevated concentrations of macronutrients in the water column of inland waters.

5.2. Phytoplankton composition and abundance

Even though no one has studied the composition and abundance of planktons before introducing water hyacinth into the reservoir, different studies have documented the physicochemical limnology, plankton ecology and fish biology and fishery of the Reservoir (Melaku Mesfin, 1988; Elizabeth Kebede and Willen, 1998; Sileshi Mamo 2002; Hadgembes Tesfaye, 2007; Fasil Degefu *et al*., 2011; Seyoum Akele, 2011; Lakew Wondimu 2014 and 2015, Yeshiemebet Major,

2016), after introducing the weed. The detailed taxonomic work by Elizabeth Kebede and Willen (1998) using a single sample from the same Reservoir resulted in the identification of 72 species, while the other work conducted by Yeshiemebet Major (2016) resulted in 89 species. HadgembesTesfay (2007) also documented 24 major taxa. According to HadgembesTesfay (2007), blue-green algae (Cyanophyceae) especially *Microcystis* spp. was dominant throughout his sampling time. Fasil Degefu *et al*. (2011) also documented that cyanobacteria especially (*Anabaena* and *Microcystis* spp.) were the dominant taxa. In the present study, however, Bacillariophyceae especially *Aulacoseira granulata* and *Synedra ulna* were the most dominant taxa during the study period. Particularly *Aulacoseira granulata* accounted for 45.64% and 29.16% of the total phytoplankton abundance at the non-infested and weed-infested sites, respectively. This finding follows the results of the research work done by Elizabeth Kebede and Willen (1998). *Aulacoseira granulata* is a rapidly sinking planktonic diatom (Reynolds, 1994) known for its wide distribution. It is the most common diatom species in shallow mixing lakes and in deeper lakes during high turbulence (Kilham and Kilham, 1975; Hecky and Kling, 1987). The frequently turbulent water column conditions of Koka Reservoir and its adaptation to low light conditions (Reynolds, 1994) seem to favor its persistence and abundance at both sites of the reservoir even though there was variation in the abundance of the diatom between the two sites.

Cyanophyceae, especially *Microcystis* and *Anabaena spp.*, was the second dominant taxa at both sites. Its dominance may be associated with several environmental factors such as low light (Smith, 1986), high temperature (Shapiro, 1990), low carbon dioxide or high pH (Caraco and Muler, 1998) and high total phosphate (Watson *et al.*, 1997). Considerable levels of toxic cyanobacteria is a serious threat to public health and life of domestic and wild animals (Yeshiemebet Major *et al*., 2018).

The third dominant group of phytoplankton at both sites was Chlorophyceae, which was constituted largely by *Oocystis* sp., *Closterium acutum*, *Actinastrum hantzshii*, and *Chlamydomonas* spp. The dominance of Bacillariophyceae and Cyanophyceae might have suppressed the abundance of Chlorophyceae at both sites. Both Chlorophyceae and Cyanophyceae were relatively more abundant at the weed-infested sites than the non-infested sites.

The presence and subsequent collapse or senesce of water hyacinth had a negative effect on the aquatic environment through degrading environmental quality (John-Stephen *et al*., 2009). The

composition and abundance of phytoplankton community could also change due to the nutrients released from the decomposed water hyacinth plant. In this study, the higher relative abundance of pollution-tolerant *Chlamydomonas* species, *Anabaena* species, *Closterium acutum, Actinastrum hantizshii,* and *Synedra ulna* under water hyacinth mat also suggests the prevalence of saprobic conditions at the sites as they are indicator species for such conditions (Jindal and Sharma, 2011).

Unlike weed-infested sites, non-infested sites had higher phytoplankton diversity and higher taxa richness. This disparity could be attributed to the allelopathic effect of water hyacinth on some algal species besides competition for nutrients and light (Gross, 2003). The existence of high diversity of species, usually represented by fewer individuals, is characteristic of a stable ecosystem (Türkmen and Kazanci, 2010). However, a few species with a high number may occur when habitats or niches are constrained by physical or chemical factors. Similarly, the observed higher density of few phytoplankton species such as *Aphanizomenon electus, Anabaena* spp., *Scenedesmus* spp., *Oocystis* spp., *Closterium acutum, Actinastrum hantzshii, Synedra ulna and Chlamydomonas* at the weed-infested sites also indicates perturbation of the sites.

Water hyacinth infestation in a water body also affects negatively the composition, abundance, and diversity of Macrophytes (Bedlu Bekele *et al*., 2017). Bedlu Bekele *et al*. (2017) reported that water hyacinth affects the composition, diversity, and abundance of macrophytes (sometimes changed the community to nearly monotypic flora), even though some macrophyte species from the Poaceae and Cyperaceae families appeared to coexist with the alien plant.

5.3. Zooplankton composition and abundance

Most species observed in this study were reported by an earlier study made on the reservoir (Fasil Degefu *et al*., 2011). However, the number of zooplankton species recorded in the present study can be considered the highest when compared with those of the previous reports on the Reservoir. The sites from which samples were collected and the smaller mesh size (30μm) used could be the possible reasons for the higher number of species (particularly Rotifers) recorded in this study.

The high diversity and dominance of rotifers observed in the reservoir during this study is a finding also reported by Fasil Degefu *et al*. (2011). The species richness and diversity of these zooplankton groups at both weed-infested and non-infested sites may be explained by their

ability to feed on suspended matters, organic detritus and bacteria as predators (Muhammad and Ali, 2013), and their less sensitivity to high concentration of suspended clay particles and turbidity (Rocha and Sendacz 1995). The present very poor positive correlation of rotifer density with Secchi depth (inverse of turbidity) also corroborates the above argument. Rotifers dominance in a reservoir can also be related to their opportunist characteristic (rapid population growth during short favorable seasons), which allows them to succeed in more unstable and dynamic environments (Matsumura-Tundisi*et al.*, 1990). These characteristics, combined with low predation pressure due to their small size, give them a competitive advantage over the other groups (Dumont, 1977). Rotifers are richer than Cladocerans and copepods in tropical water bodies (Rocha and Sendacz 1995). In samples collected from the non-infested sites, their relative densities were higher than those in samples from the weed-infested sites, similar to the spatial pattern reported by Mironga *et al*. (2014). The abundance and species diversity of zooplankton at the weed-infested sites, constituted largely by Rotifers, probably reflect the availability of food, small the temperature fluctuations and the higher ability of rotifers to cope up with the turbid conditions under water hyacinth mats. The abundance of rotifers reached its peak in June both at non-infested sites and weed-infested sites when the nutrient concentrations were higher.

Copepods, represented by Cyclopoids and a Calanoid, were the second most abundant zooplankton group at both non-infested and weed-infested sites. This observation also follows the results reported by Fasil Degefu *et al*. (2011) for open water sites. The greater abundance of Cyclopoid (*Mesocyclops*) and *nauplii* both at the non-infested and weed-infested sites are attributable to the availability of animal food including insect larvae, rotifers, protozoans, Cladocerans and juveniles of Cyclopoids themselves.

Temporal pattern of copepod density was apparent with a higher peak during March and July following the higher density of phytoplankton at both non-infested sites and weed-infested sites. The strong positive correlation of copepod density with other zooplankton groups and the weak and negative relationship with most physicochemical factors seem to indicate the overriding importance of food availability to copepod density in the reservoir. Similarly, the higher Cladocerans density at the non-infested sites than at the weed-infested sites was probably associated with the greater availability of food at the non-infested sites and the dense water hyacinth mat at the weed-infested sites, which affects water transparency and light, temperature,

dissolved oxygen and availability of phytoplankton and food resources (Villmagna and Murphy, 2010).

Changes in species composition of zooplankton assemblages are reflexes of the aquatic ecosystem to environmental stress (Schindler, 1987). Besides the significant variation between the two sites, higher mean values of Shannon-Weaver's index, species richness, and evenness were recorded for the non-infested sites than the weed-infested sites (Appendix 5). This suggests that the existing density of water hyacinth affected the distribution and abundance of the zooplankton community, as high species richness for a area is an indication of relative ecosystem stability (Türkmen and Kazanci, 2010).

Despite water hyacinth's notable negative effects on abundance and composition of zooplankton, some taxa were observed only at the weed-infested sites or non-infested sites during the study period. *Lecane monostylahomata, Lecane leontita, Trichocerca djurellasejunctipes, Euchlanis menta* and *Platyias quadricornis var. bervispinus* were among those taxa observed at the weed-infested sites only, while *Diaphanosoma* spp*., Daphnia barbata, Daphnia pulex, Anuraeopsis fissa, Brachionus falcatus, Brachionus falcatus redactus, Brachionus angularis* and *Ceriodaphnia* spp. were species of zooplankton observed only at the non-infested sites during the study period since they are filter feeders and don't tolerate low dissolved oxygen.

5.4. Toxicity effects of water hyacinth (*Eichhornia crassipes*)

5.4.1. Proximate composition of water hyacinth (Eichhornia crassipes)

The original water content of 90% obtained for freshwater hyacinth sample collected from $0.25m^2$ is similar to the results documented in a previous report (Ndimele *et al.*, 2011) indicating that freshwater hyacinth, on average, contains about 90% water and about 15-20% solid materials. Among the major constituents of water hyacinth analyzed in this study, crude ash was found at concentration levels similar to those reported by Okoye *et al*. (2002) in water hyacinth whole plant and leaves (19.01% and 16.79%, respectively) and Hossain *et al*. (2015) in water hyacinth stalks and leaves (12.40%). The high ash content indicates that water hyacinth may contain important minerals. It may also signify the plant's bioremediation capacity. Thus, further study on the mineral content of the plant is highly recommended.

The water hyacinth in this study had a considerably high amount of fiber (Table 13). Similarly, Okoye *et al*. (2002) reported 21.97% fiber content in water hyacinth. In the stalks and leaves of

water hyacinth, 26.90% of fiber was reported by Hossain *et al*. (2015). Dietary fiber plays vital roles in reducing cholesterol level, and prevention of constipation and may serve as a prebiotic for healthy gut micro-flora, etc. Hence, details on the fiber in water hyacinth should be investigated. The crude protein content in the water hyacinth of the present study was 10%. This is a high value compared to those of most Ethiopian cereals including Teff. Hence, further study on the amino acid composition is important to consider the plant at least as fish feed, animal feed and so on. Generally, 100 gm of the dried water hyacinth can provide total energy of 245 Kcal (Table 13).

5.4.2. Total flavonoid and phenolic content of water hyacinth (Eichhornia crassipes)

Freshwater and marine plants are very known sources of polyphenolic substances. With this regard, the total flavonoid and phenolic substances content of water hyacinth were determined in this study (Table 14). Total flavonoid and phenolic contents of water hyacinth recorded in this study seem high compared to those reported in other studies. A lower total flavonoid concentration of 0.48, 0.27 and 0.39 mg QE/g were reported in the leaves, petioles, and roots of water hyacinth, respectively (Tulika *et al*., 2017). The total phenolic substances content in the methanol extract of water hyacinth in the present study was 1.67 mg QE/g. Tulika *et al*. (2017) reported total phenolic content of 0.22, 0.18 and 0.19 mg QE/g in leaves, petioles, and roots of water hyacinth. Jayanthi *et al*. (2011) demonstrated flavonoids, alkaloids, sterols, and proteins in the aqueous extract and anthraquinones, and phenolics in the ethyl acetate extract of water hyacinth. Presence of flavonoids, anthraquinones, anthocyanins, and carbohydrates in methanol fractionate of water hyacinth was also revealed by Jayanthi and Lalitha, (2011). These metabolites are generally used in various pharmaceutical and cosmetic preparations.

5.4.3. Acute mice toxicity test of water hyacinth (Eichhornia crassipes) extracts

In this study, an attempt has been made to determine, which fraction of the organic constituents of water hyacinth (polar or non-polar) is responsible for its toxicity. Results from dichloromethane (DCM) (highly non-polar) administration indicate that non-polar part of water hyacinth is more toxic than the polar one. The way the mice behaved after the first day of administration, like the way they did before the administration of the extracts, indicates that the

dose, and the duration of administration, has to be increased. But, from those observed changes it is possible to conclude that water hyacinth has potential toxicity effects, remembering the necessity of further study to document the acute and chronic toxicity effect of water hyacinth. Several investigators have conducted studies on the toxicity effects of water hyacinth on mice and obtained different results.

Wu *et al*. (2014) reported no acute toxic responses of water hyacinth leaves on mice. In their study they orally administered 4, 8, 12 and 16 g kg^{-1} bodyweight WHLP (water hyacinth leaf powder). The cross-linked Sodium Carboxy-Methyl Cellulose (Na-CMC) synthesized from water hyacinth cellulose applied on rats caused liver, kidney, and lung abnormality (Musfiroh *et al*., 2017). In the present study, 5g in 10ml 5% Tween (80 Kg body weight)$^{-1}$ of each extract were orally administered to white albino mice (n=10). With this concentration only in the DCM and ethanol extract, the toxic responses mentioned above were observed. In the water extract, however, five of ten treated mice didn't show acute toxic response. The DCM and ethanol extracts might be considered slightly toxic (5-15 g/Kg, if extract/feed induces acute toxic response (Loomis, 1996). Yet, this needs further investigation with more mice being tested. This study indicated the potential of water hyacinth as a good source of macronutrients and phenolic compounds. Further detailed studies on the sub-lethal and chronic toxicity of the extracts are strongly recommended.

6. CONCLUSIONS and RECOMMENDATIONS

6.1. Conclusions

Water hyacinth biomass in Koka reservoir varied both spatially and temporally with the highest weed biomass during the rainy months (June and July). Due to the lack of control or absence of intervention measures, its density was increasing throughout the sampling period (March-July). The prevailing weed biomass perturbed physicochemical conditions of the water column.

In this study, statistically significant spatial differences in most physicochemical characteristics of the reservoir were observed between the non-infested and weed-infested sites, although some of the temporal variations were not statistically significant. The observed marked effect of the weed on the reservoir's water quality was due to its high density, extensive mat coverage, lack of control intervention campaign and extent of accumulation of its detritus. The older the mat, the more the quantity of detritus that can be accumulated at a site and the more the impact imposed on the aquatic environment (Schreiner, 1980). A statistically significant effect of water hyacinth on most physicochemical parameters of the reservoir was manifested. For instance; nitrate, dissolved oxygen, SRP, TP, and ammonia concentrations, and Secchi depth were higher in the non-infested sites than in the weed-infested sites. But turbidity, TSS and silica were statistically higher in the weed-infested sites than in the non-infested sites.

One limitation of this study was lack of previous plankton record compiled before introducing the weed into the reservoir. As a consequence, it is almost impossible to determine whether water hyacinth in the reservoir has caused a major long-term shift in the composition of the planktons community as compared to what was observed at the non-infested sites. However, there was a statistically significant difference in the abundance of both phytoplankton and zooplankton between the non-infested sites and weed-infested sites, with higher abundance in the non-infested sites. Presence of pollution tolerant species along with low species diversity in the weed-infested sites reflects the influence of water hyacinth on phytoplankton assemblage. Even though not as much as those in the non-infested sites, the dominance of *Aphanizomenon electus*, *Anabaena* spp., *Scenedesmus* spp., *Oocystis* sp., *Closterium acutum*, *Actinastrum hantzshii*, *Synedra ulna and Chlamydomonas* species, which probably could modulate nutrient uptake and

photosynthetic activity depending on environmental conditions (Grossman, 2000) and presence of *Monoraphidium griffithii* and *Gyrosigma obtusatum* only in the weed-infested sites, were favored by water hyacinth.

The effects of water hyacinth on the abundance and composition of zooplankton were also manifested with a lower number of zooplankton and pollution-tolerant species in the weed-infested sites. Presence of some taxa including *Lecane monostylahomata, Lecane leontita, Trichocerca djurellasejunctipes, Euchlanis dilatata,* and *Platyias quadricornis var. bervispinus* only in the weed-infested sites seem to suggest that water hyacinth mats in the reservoir did not hurt them. Availability of more and diverse food, diverse niche and refugees associated with the presence of the weed might have resulted in their abundance and diversity.

A single dose toxicity test of the weed on white female albino mice revealed that water hyacinth has potential toxicity effect on the plankton. Even though no death was recorded, some changes were observed in the experimental mice. If the dose was increased, there would probably be an indication that the observed changes could transform themselves into serious cases.

The existing infestation level of water hyacinth poses a significant effect on water quality, composition, and abundance of phytoplankton and zooplankton. Environmental conditions like nutrients are favorable for its optimum growth. Further proliferation will continue to occur and the weed may even spread to new areas and worsen its effect.

6.2. Recommendations

- This study provided information on the extent of water hyacinth effect on the Reservoir ecosystem. Further research is recommended to see the effect of the weed on the reservoir ecosystem through different experimental studies that involve different aquatic organisms.
- Although in much less number than that in the non-infested sites, phytoplankton and zooplankton in the water hyacinth-infested sites might be favorable for the growth and production of planktivorous fish species. However, water hyacinth may also have an indirect adverse effect on fish production by blocking migration for spawning reducing the breeding grounds. Therefore, further research is needed to clearly understand the effect of water hyacinth on fish production and hence on its socio-economic effect on the local community.
- Although the treatment of mice with the weed extract led to different behavioral changes, toxicity test of the weed didn't show death in the treated groups. Therefore, further study has to be done by increasing the dose and duration of administration to clearly understand the extent of toxicity of the weed.
- Nutrients from floriculture, feeder rivers, and surrounding catchments are the root causes for the proliferation of water hyacinth (*Eichhornia crassipes)* in the reservoir. Therefore, proper management has to be planned, which integrates the efforts of local inhabitants, farmers, investors, and any other stakeholders.
- There are different methods of controlling water hyacinth proliferation. Integrated management approach is the most preferred by different scientists. However, for the immediate control of the proliferation of the weed, physical removal is an advisable solution even though it is labor-intensive and time-consuming. Koka Reservoir needs an urgent management action, i.e., physical removal as an immediate solution and proper planning for an integrated approach to this problem, which includes the use of biological agents.
- The situation also points out the need for development of sustainable management of agricultural and industrial wastes.

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8. APPENDICES

Appendix 1. One-way ANOVA test results of spatial variations in physicochemical features.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Nitrate	Between Groups	5953266.667	5	1190653.333	2023.773	.000
	Within Groups	14120.000	24	588.333		
	Total	5967386.667	29			
Nitrite	Between Groups	14887.767	5	2977.553	6.512	.001
	Within Groups	10973.200	24	457.217		
	Total	25860.967	29			
Ammonia	Between Groups	4274.800	5	854.960	4.216	.007
	Within Groups	4867.200	24	202.800		
	Total	9142.000	29			
Soluble reactive phosphorus	Between Groups	1140018.128	5	228003.626	7.557	.000
	Within Groups	724150.327	24	30172.930		
	Total	1864168.455	29			
Total phosphorus	Between Groups	1895231.006	5	379046.201	2.934	.033
	Within Groups	3100569.296	24	129190.387		
	Total	4995800.303	29			
Silica	Between Groups	2130.513	5	426.103	6.775	.000
	Within Groups	1509.462	24	62.894		
	Total	3639.975	29			
Total suspended solid	Between Groups	230042.667	5	46008.533	2.560	.034
	Within Groups	431347.200	24	17972.800		
	Total	661389.867	29			
Total dissolved solid	Between Groups	309000.000	5	61800.000	.473	.793
	Within Groups	3138000.000	24	130750.000		
	Total	3447000.000	29			
Temperature	Between Groups	19.955	5	3.991	1.457	.240
	Within Groups	65.724	24	2.739		
	Total	85.679	29			
Dissolved oxygen	Between Groups	81.800	5	16.360	13.689	.000
	Within Groups	28.682	24	1.195		
	Total	110.482	29			
pH	Between Groups	.954	5	.191	.337	.886
	Within Groups	13.603	24	.567		
	Total	14.556	29			

	Between Groups	4441.448	5	888.290	1.092	.390
Specific conductance	Within Groups	19522.163	24	813.423		
	Total	23963.611	29			
	Between Groups	133387.031	5	26677.406	8.830	.000
Turbidity	Within Groups	72512.312	24	3021.346		
	Total	205899.343	29			
	Between Groups	338.000	5	67.600	1.640	.006
Secci Depth	Within Groups	989.200	24	41.217		
	Total	1327.200	29			
	Between Groups	2498.655	5	499.731	1.092	.390
Salinity	Within Groups	10981.895	24	457.579		
	Total	13480.550	29			

Appendix 2. Phytoplankton density differences between infested and non-infested sites.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Cyanophyceae	Between Groups	7.224E8	5	1.445E8	13.425	.000
	Within Groups	2.583E8	24	1.076E7		
	Total	9.807E8	29			
Chlorophyceae	Between Groups	3.557E8	5	7.114E7	12.392	.000
	Within Groups	1.378E8	24	5741062.500		
	Total	4.935E8	29			
Bacillariophyceae	Between Groups	6.549E9	5	1.310E9	3.522	.016
	Within Groups	8.926E9	24	3.719E8		
	Total	1.548E10	29			
Euglenophyceae	Between Groups	1517416.667	5	303483.333	.789	.568
	Within Groups	9233000.000	24	384708.333		
	Total	1.075E7	29			
Dinophyceae	Between Groups	2169750.000	5	433950.000	2.610	.051
	Within Groups	3991000.000	24	166291.667		
	Total	6160750.000	29			
Chryptophyceae	Between Groups	930666.667	5	186133.333	2.485	.060
	Within Groups	1798000.000	24	74916.667		
	Total	2728666.667	29			

Appendix 3. One-way ANOVA test results of indices for phytoplankton species

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
H	Between Groups	.196	5	.039	.092	.993
	Within Groups	10.252	24	.427		
	Total	10.448	29			
j	Between Groups	.300	5	.060	1.694	.174
	Within Groups	.850	24	.035		
	Total	1.151	29			
d	Between Groups	7.639	5	1.528	27.589	.000
	Within Groups	1.329	24	.055		
	Total	8.968	29			

Appendix 4. Zooplankton density differences between infested and non-infested sites

ANOVA

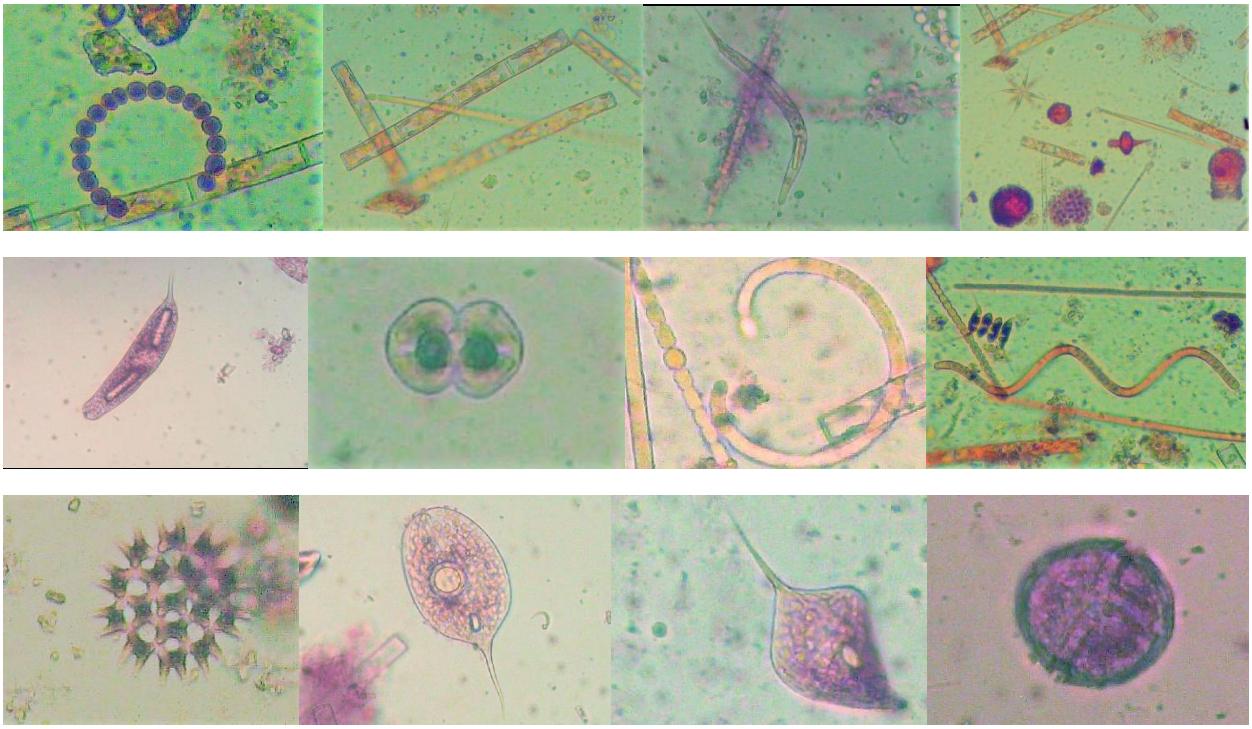
		Sum of Squares	df	Mean Square	F	Sig.
Copepod	Between Groups	7.070E8	5	1.414E8	31.649	.000
	Within Groups	1.072E8	24	4467672.732		
	Total	8.142E8	29			
cladocer	Between Groups	1.219E9	5	2.438E8	5.716	.001
	Within Groups	1.023E9	24	4.264E7		
	Total	2.242E9	29			
Rotifers	Between Groups	5.973E9	5	1.195E9	15.638	.000
	Within Groups	1.833E9	24	7.639E7		
	Total	7.806E9	29			

Appendix 5. One-way ANOVA test results of indices for zooplankton species

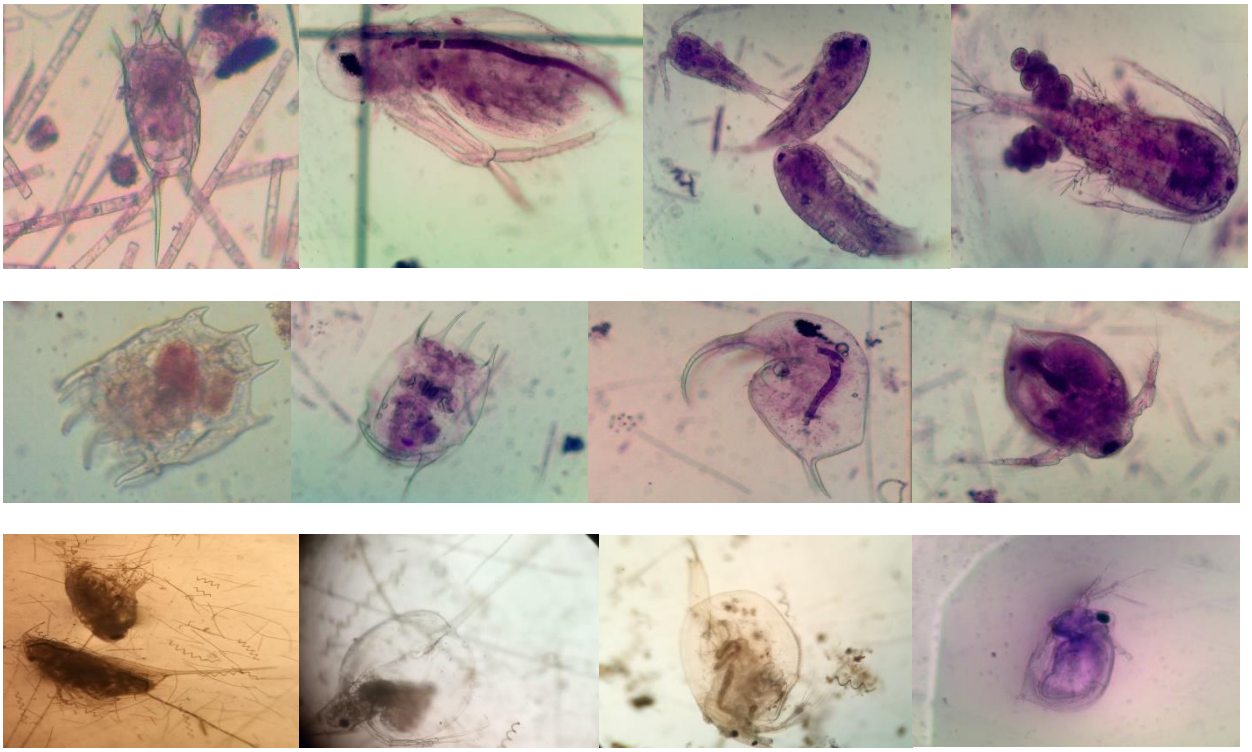
ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
H	Between Groups	4.585	5	.917	18.246	.000
	Within Groups	1.206	24	.050		
	Total	5.791	29			
j	Between Groups	.011	5	.002	1.105	.384
	Within Groups	.049	24	.002		
	Total	.061	29			
d	Between Groups	5.440	5	1.088	37.666	.000
	Within Groups	.693	24	.029		
	Total	6.133	29			

Appendix 6. A plate of major phytoplankton and zooplankton taxa identified in this study.



Phytoplankton



Zooplankton

Appendix 7. One-way ANOVA test results of temporal variations in physicochemical features

ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
chlorophylla	Between Groups	(Combined)	3033.367	4	758.342	5.193	.003
			25.441	1	25.441	.174	
			3007.926	3	1002.642	6.866	
			3651.012	25	146.040		
			6684.379	29			
total dissolved solid	Between Groups	(Combined)	1458666.667	4	364666.667	4.585	.006
			240666.667	1	240666.667	3.026	
			1218000.000	3	406000.000	5.105	
			1988333.333	25	79533.333		
			3447000.000	29			
temperature	Between Groups	(Combined)	40.875	4	10.219	5.702	.002
			.280	1	.280	.156	
			40.595	3	13.532	7.551	
			44.803	25	1.792		
			85.679	29			
specific conductivity	Between Groups	(Combined)	10947.044	4	2736.761	5.256	.003
			3293.745	1	3293.745	6.326	
			7653.298	3	2551.099	4.900	
			13016.567	25	520.663		
			23963.611	29			
salinity	Between Groups	(Combined)	6158.216	4	1539.554	5.256	.003
			1852.926	1	1852.926	6.326	
			4305.289	3	1435.096	4.900	
			7322.335	25	292.893		
			13480.550	29			
secci	Between Groups	(Combined)	777.200	4	194.300	8.832	.000
			666.667	1	666.667	30.303	
			110.533	3	36.844	1.675	
			550.000	25	22.000		
			1327.200	29			