Journal of Forestry and Natural Resources
Vol. 3(2), 2024

Research Article

The impact of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) infestation on physiochemical water quality of Lake Ziway, South Central Ethiopia

Mieraf Addisalem[1], Zerihun Girma[2*]

Article Info

[1] Department of General Forestry, College of Agriculture and Natural Resource, Bonga University.
[2] Department of Wildlife and Ecotourism Management, Wondo Genet College of Forestry and Natural Resources, Hawassa University

***Corresponding author**: zed7583@gmail.com

Citation: Mieraf, A., & Zerihun, G. (2024). The impact of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) infestation on physiochemical water quality of Lake Ziway, South Central Ethiopia. *Journal of Forestry and Natural Resources*, 3(2),32-43

Received: 09 August 2024
Accepted: 03 November 2024
Web link: https://journals.hu.edu.et/hu-journals/index.php/jfnr/

OPEN ACCESS

Abstract

Water hyacinth (Eichhornia crassipes) is one of the most invasive weeds in aquatic ecosystems. It has been a serious threat to aquatic biodiversity. This study was conducted to investigate the impact of water hyacinth on the water physicochemical quality of Lake Ziway. Water physicochemical quality samples were taken at four sites in two triplicate and vertically stratified as surface, medium, or deeper, using an FL-2010N Digital multimeter and plastic water sampler. For PO_3 and NO_3 analyses, water samples were collected from the surface, stored in polyethylene bottles, and transported to the laboratory in an icebox. Two samples were taken from areas with dense water hyacinth cover (site 1), less dense (site 2), sparsely infested (site 3), and without water hyacinth (site 4). Furthermore, to investigate the distribution of water hyacinth, key informant interviews were conducted. The results showed that the amount of PO_3 between sites 2 and 3 was significantly different at p ¡ 0.05. The amount of NO_3 at sites 1 and 2 was significantly different from that at site 3, at p ¡ 0.05. There was a significant difference in the pH values among the sites. The pH value at site 1 was significantly different from those at sites 3 and 4 (p ¡ 0.05). The results of the study showed that there was a significant difference in dissolved oxygen (DO) among all sites at p ¡ 0.05. Pearson's correlation coefficient (r) analysis showed that water hyacinth coverage was positively correlated with PO_3 (r = 0.77, N = 4, P ¡ 0.05), NO_3 (r = 0.69, N = 4, P ¡ 0.05), pH (r = 0.16, N = 4, P ¡ 0.05), and temperature (r = 0.78, N = 4, P ¡ 0.05). On the other hand, a negative correlation was observed between DO and water hyacinth percent cover (r = -0.94, N = 4, P = 0.05). This implies that water hyacinth infestation in Lake Ziway adversely affects the water physicochemical quality of the lake. In addition, agrochemical nutrient inputs from the lake shore, intensive irrigation, and floricultural activities have been attributed by key informants to be the main sources of eutrophication in the lake, with consequent expiation of water hyacinth infestation. Therefore, an integrated management approach is urgently needed to control the infestation of water hyacinth and its further expansion into the lake.

Keywords: dissolved oxygen, invasive species, phosphate, nitrate, hydrogen potential (pH), Ethiopia

1 Introduction

Water hyacinth (Eichhornia crassipes (Mart.) Solms) is a free-floating aquatic plant widely regarded by many as one of the most highly invasive weeds in the world (van Wyk and van Wilgen 2002). Water hyacinth has been identified by the International Union for Conservation of Nature and Natural Resources (IUCN) as one of the 100 most aggressive invasive species (Téllez et al. 2008). The success of this invasive species is primarily due to its reproductive output. Water hyacinth flowers throughout the year and releases more than 3000 seeds per year (EEA 2012; Harun et al. 2021). The seeds are long-lived up to 20 years (Harun et al. 2021). It reproduces both sexually and asexually. Water hyacinth grows rapidly, doubling in population within 5–15 days (Craft et al. 2003).

Water hyacinth, due to its extremely rapid growth, has become a major floating water weed in tropical and subtropical regions (Yan and Guo 2017; Harun et al. 2021). It was introduced to Africa from South America in the early 1900s, but since the 1950s, it has become a problematic weed in Southern Africa, the Congo basin, and the Upper Nile (Lubembe et al. 2023). In the East African region, the weed was first noticed almost simultaneously in Uganda, Tanzania, and Kenya in 1987 (Ogwang and Molo 2001; Kiyemba et al. 2023).

Because of their rapid growth, massive biomass, and large surface coverage in natural water ecosystems, water hyacinth blocks sunlight, reducing the photosynthesis rate of aquatic plants (Yan and Guo 2017; Lekamge et al. 2020). Furthermore, water hyacinth has been shown to degrade water quality in lakes and rivers (Tobias et al. 2019), resulting in the loss of aquatic life (Gunaratne et al. 2009). Water hyacinth can reduce water clarity, phytoplankton production, dissolved oxygen, nitrogen, phosphorous, heavy metals, and other pollutants (Villamagna and Murphy 2010). Its rapid growth has clogged major waterways and created problems associated with navigation, national security, irrigation and drainage, water supply, hydroelectricity, and fishing in many countries (Tobias et al. 2019; Lekamge et al. 2020).

In Ethiopia, water hyacinth was officially reported in 1956 from Lake Koka and the Awash River (Stroud 1994). Infestations of water hyacinth in Ethiopia have also been manifested on a large scale in many water bodies of the country, including the Gambella area (Sobat, Baro, Gillo, and Pibor Rivers); Lake Tana, the Abay River just south of Lake Tana, and the Rift Valley (Wondenagegn et al. 2012). In varying magnitudes, it also predominated in most rift valley lakes, canals, reservoirs, and irrigation water supplies (Firehun et al. 2014). In September 2011, water hyacinth was officially recognized as one of the top ten ecologically dangerous and invasive weeds in Ethiopia (Wondie et al. 2012).

A freshwater lake in the central Rift Valley, Lake Ziway, is home to a variety of fish species (Gebremariam 1998) and water birds (Menegesha et al. 2015). Due to extensive irrigation projects brought on by the thriving flower farms in the area, the lake's volume has decreased, and its salinity has slightly increased (Ayenew & Legesse 2007; Benti 2021). Furthermore, evidence indicates that the lake is under severe anthropogenic pressure due to sediment loads from agricultural lands and heavy metal and plastic pollution due to ongoing rapid urbanization (Desta et al. 2015; Benti 2021). It has been noticed that water hyacinth has invaded the irrigation canal leading to water pump stations around Meki town (Benti 2021). In particular, the expansion of the invasive species into the lake suffocates fish and other biodiversity by preventing the penetration of oxygen through its thick mats to the bottom of the water body (King 2013). Deterioration of water quality, invasion of irrigation canals, and hampers fishery and recreational activities, impairing economic activity and aquatic ecosystem health (Desta et al. 2015; Benti 2021). However, little is known about the drivers of infestations and how infestations affect lake water quality and the health of lake ecosystems (Ayenew & Legesse 2007; Wondenagegn et al. 2012; Desta et al. 2015). Water hyacinth infestation is a relatively new phenomenon in Lake Ziway, and it is mainly caused by expansion of irrigation canals (Firhehun et al. 2014; Churko et al. 2023). However, little information exists on how the expansion of the irrigation canal affects the lake's water physiochemical quality, and there is a need for updated information on water hyacinth infestation and its impact on the water physiochemical quality of the lake to take sound management actions. Therefore, this study investigated how the infestation of water hyacinth affects the physiochemical quality of lake water.

2 Materials and methods

2.1 Study area description

The study was conducted at Lake Ziway in the Great Rift Valley zone of Ethiopia. It is situated in the eastern showa zone of the Oromia region, about 160 km from Addis Ababa (Figure 1). Lake Ziway has an open water area of 434 km^2, an average depth of 4 m, and an elevation of 1636 m asl (Zeray et al. 2016). Lake Ziway is located at 7°52' - 8°8' N and 38°40' - 38°56' E, close to Ziway town. The lake encompasses three main rivers; the two main rivers flowing into the lake are Meki and Katar, and the other river (Bulbula) flows out of the lake. Floriculture industries are situated between Lake Ziway and the main highway at altitudes between 1600–1700 m asl and are reported to draw a significant amount of water from the lake and are suspected to discharge industrial influents into the lake (MoWR 2006). The Bulbula River flows out of Lake Ziway to the south and feeds Lake Abijata. Groundwater flows from Lake Ziway toward the North-South gradient feeding Lakes Langano, Abijata, and Shala (Tenalem 2001). All of them lay at lower elevations, with Lake Shala being the final recipient. There is an irrigation canal that draws water from the lake and is used for the production of fruits around the lake, but the canal near the outlet of the lake is highly infested with water hyacinth.

The minimum and maximum annual precipitations are 729.8 mm and 1227.7 mm, respectively, while the mean annual temperature is 18.5 °C (Desta and Lema 2017). Much of the shoreline of Lake Ziway is covered with lush marshy vegetation. The islands have vegetation consisting of different trees and shrubs interspersed with climbers and herbs (Zegegye 2006).

The lake water, its shoreline, riverine woodland, and wet grassland

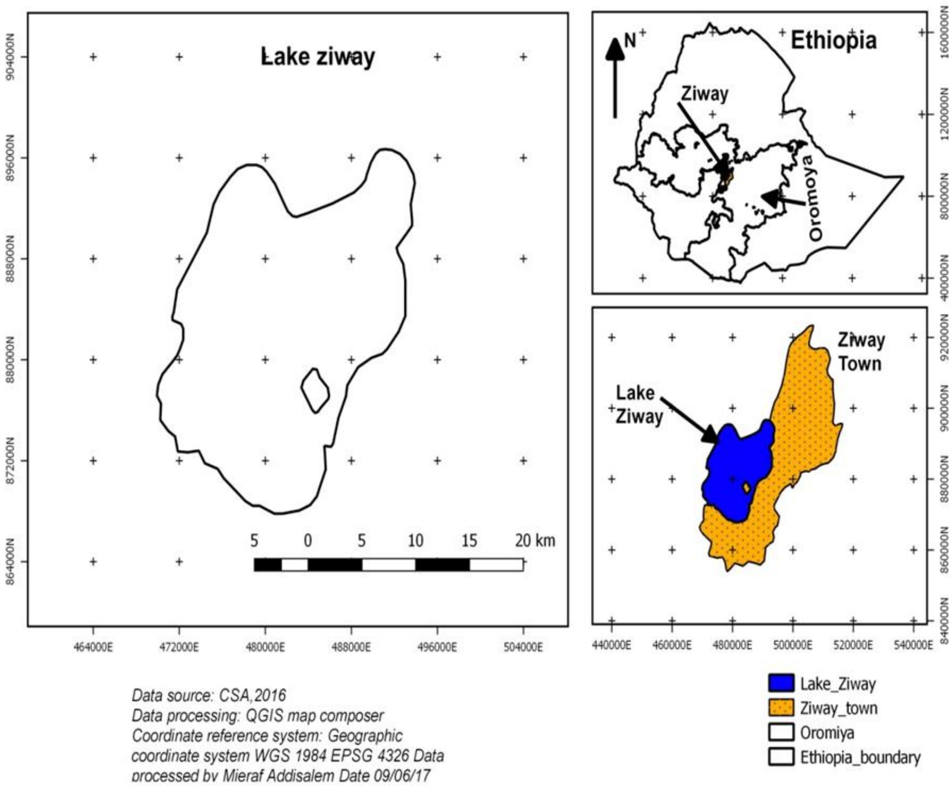

Figure 1: Location Map of Lake Ziway

habitats also serve as roosting and stopover sites for diverse and abundant resident and Palearctic migratory bird species (EWNHS 1996; Mengesha et al. 2015). Tilapia nilotica (Oreochromis niloticus) is the dominant fish species at Lake Ziway, but African catfish (Clarias gariepinus) and Crucian carp (Caracius caracius) are also occasionally encountered (Gebremariam 1998). A study reported that Phragmites australis, Typha latifolia, Cyperus articulates, Echinochloa colona, Cyperus papyrus, Echinochloa stagnina, and Schoenoplectus corymbosus were among the emerging macrophytes in Lake Ziway (Damtew et al. 2021). Furthermore, in some areas of the shoreline, two macrophytes with floating leaves and roots—Nymphaea lotus and Nymphoides indica—were also discovered. Pistia stratiotes and Potamogeton schweinfurthii were macrophytes found in the free lake-floating and submerged, respectively (Damtew et al. 2021). Mixed crop-livestock agriculture is the most significant economic activity in local communities. Rainfall is crucial to agriculture, but Lake Ziway is surrounded by irrigation. Fruits, tomatoes, onions, and maize are the main crops and vegetables grown near Lake Ziway (Desta 2021). Cattle, sheep, goats, horses, mules, and donkeys are among the animals that are raised, and the majority of crops are rain-fed (Desta et al. 2017). Small-scale trading and fishing are two more sources of income. Ziway Town is also an emerging city that is an important source of urban waste, mostly dumped in the lake. Furthermore, floriculture investment around the lake is also considered a source of pollution in the lake (Beneberu and Mengistu 2009).

2.2 Method

A reconnaissance survey was carried out to identify localities infested by water hyacinth. Following the reconnaissance survey, four sites were purposely selected based on the level of infestation. There were four sampling sites, where three had water hyacinth and one did not. Sampling sites were established along the length of the irrigation canal to establish sampling sites at different levels of water hyacinth infestation. Site 1 was a highly infested site, while Site 2 was moderately infested, and Site 3 was sparsely infested. The classifications of high, low, and medium were based on observation, expertise recommendations, and local communities' suggestions (Chruko et al. 2023). Each sampling site had two replicates of samples, making up a total of eight samples (Chruko et al. 2023). The distance between Sites 1 and 2 was 89.73 m, Sites 2 and 3 were 114.13 m and site three and four (control) was 13.4 km. The distance between two replicates of sampling plots ranged from 15.65 m to 24.19 m based on the width of the canal and level of infestation (Table 1). Each sampling plot was stratified vertically into three strata: surface, middle, and deep. The stratification height from sampling point to sampling point varied based on the depth of the water at each sampling site (Table 1). The depth of stratification varied from 0.22 at Site 2 to 1.75 m at the control site (site four) (Table 1).

From each sampling point and vertical strata (surface, middle and deep), an FL-2010N digital multimeter was used to measure pH, dissolved oxygen, and temperature on site. For PO_3 and NO_3 anal-

Table 1: Depth of each stratum at the sampling sites

Sample site	Geographical location	Distance between sampling plots	Sampling point	Depth (cm)		
				Surface	Middle	Deep
1	8°6'57.90"N, 38°4823.80"E					
	8°6'57"N, 38°48'24.26"E	15.65 m	1	0	0.35	0.7
			2	0	0.2	0.4
2	8°6'55.01"N, 38°48'22.96"E					
	8°6'54.95"N, 38°4823.57"E	18.94 m	1	0	0.3	0.6
			2	0	0.11	0.22
3	8°6'51.64"N, 38°48'21.77"E					
	8°6'8.82"N, 38°48'9.91"E	16.51 m	1	0	0.15	0.3
			2	0	0.3	0.6
4	8°6'8.82"N, 38°48'9.91"E	24.19 m	1	0	0.87	1.75

yses, water samples from each sampling point and vertical stratum were collected from the surface, stored in polyethylene bottles, and transported to the laboratory in an icebox. Water samples were collected using 3 mL plastic containers and rinsed with distilled water before use to remove any remaining contaminants. The water samples were temporarily stored in an ice-packed cooler to maintain the physical properties of the water, transported to Hawassa University General Chemistry Laboratory, and stored in a refrigerator at approximately 40 °C prior to analysis (Gangwar et al. 2012). The same sites established for physicochemical analysis were used. A total of 8 plots with a size of 1 m x 1 m ($1m^2$) were used to sample the extent of water hyacinth infestation. In each sampling plot, the percent cover of water hyacinth was estimated using the prepared sampling quadrant, which contains 100 squares; each square is 1 m x 1 m. The coordinates of each sampling plot were recorded using Gramin GPS.

Key informants (KI) from the surrounding kebele and Ziway Fishery research centers were selected based on their knowledge of water hyacinth, as informed by Ziway Agricultural Research Fishery experts, fishing experience, experience of involving in water hyacinth management, and duration of stay in the localities. Since the purpose of the key informant study was to supplement the correlation between water hyacinth infestation and the physiochemical quality of Lake Ziway, due to limitations in time and budget, this study focused on one kebele. Based on the information obtained from Ziway Agricultural Research Fishery experts, one kebele was the most important source of water hyacinth-infested water. The selection of these KIs from the kebele was carried out using the snowball method. Accordingly, six farmers from the kebele were randomly asked to give the name of 4 KIs. Out of the 24 candidate KIs, 10 top rankings were selected. On the other hand, from the Ziway Agricultural Research Fishery Center two experts with experience working on water hyacinth were purposively selected.

The key informant interviews focused on gathering information on the history of the water hyacinth invasion, possible causes of infestation, impacts, and management efforts. The interview also assessed the point and non-point agricultural activities performed by the local community that tend to facilitate water hyacinth infestation and the awareness of the control measures and possible impacts of water hyacinth. Interviews were conducted with pre-prepared questionnaires in English and were translated into Amharic.

2.3 Data analysis

Data were coded and entered a computer using Microsoft Excel 2013 and statistical software. The collected data were analyzed using SPSS (statistical package for social sciences) version 20. One-way ANOVA was used to compare the mean physicochemical parameter values among different sites. Pearson's correlation analysis was used to determine whether a correlation existed between physicochemical parameters and the percentage of water hyacinth cover.

3 Results and Discussion

3.1 Physicochemical parameters

The highest mean concentration (0.41±0.54) of phosphate was recorded at site 2, and the lowest (0.22±0.21) was found at site 3 (Table 2). There was a statistically significant difference (p¡0.05) in the concentration of phosphate between sites two and three. The highest mean concentration (1.76±0.25) of nitrate was found at site 2, and the lowest (1.35±0.29) was recorded at site 3. There was a statistically significant difference (p¡0.05) in the concentration of nitrate between sites two and three and between sites one and three (Table 2). The highest pH and DO were recorded at site 4. There was a statistically significant variation in the DO concentration among all sites (P¡0.05) (Table 2). The highest mean temperature (24.23±0.99) was recorded at Site 1 and the lowest (22.65±1.62) was recorded at Site 3 (Table 2). The differences in the mean concentration of nutrients among the sampling sites could be due to differences in the coverage of water hyacinth, where high water hyacinth abundance reduces the concentration of nutrients in the water.

Water hyacinth has a higher nutrient uptake capacity than other macrophytes (Rodríguez-Gallego et al. 2004). This may have a significant impact on the concentration and turnover rates of nutrients in a lake (Pinto and Greco 1999). The authors also stated that water hyacinth can significantly reduce nutrient concentrations in water bodies depending on the extent of cover. Similarly, Lekamge et al. (2020) reported that the nitrate concentrations in infested areas were significantly lower (p¡0.05) than those on shorelines without water hyacinth. This indicates that water hyacinth took up nitrates from the lake water, which may have a significant impact on the concentrations and turnover rates of nutrients in the Lake. Various studies have indicated that water hyacinth concentrations reduce nitrate concentrations (Rommens et al. 2003; Greenfield et al. 2007; Lekamge et al. 2020).

The highest concentration of NO_3 at Site 2 compared to Sites 1 and 3 could probably be due to the dung from cattle in the catchment, since there is an animal ranch a few meters ahead from the canal. Consequently, livestock were more frequently observed at Site 2. It is believed that cattle fed (locally known as furshka) are mixed with urea, which is rich in nitrogen; thus, when the cattle's waste enters the water level of nitrate, it tends to increase. It has been widely reported that the main nitrate sources are animal waste, commercial fertilizer, and decaying organic matter (Mayer et al. 2002).

The ANOVA results showed that pH was significantly lower in water hyacinth-infested areas compared to shorelines without water hyacinth, and the mean pH of all sites was 7. This is in line with studies conducted by Yan and Guo (2017) and Lekamge et al. (2020), who reported that the optimum growth of water hyacinth occurs in eutrophic, still, or slow-moving fresh water with a pH close to 7. According to Melissa (2017), water hyacinth can tolerate acidic water but cannot survive in salt or brackish water. The lower concentration of dissolved oxygen in areas highly infested by water hyacinth could be due to the presence of water hyacinth affecting the quality of the lake by decreasing the amount of oxygen that is available in infested areas.

Because water hyacinth grows so rapidly, the mats constantly produce detritus, which decomposes and increases the oxygen demand in the water column (Tobias et al. 2019). The mats of the weed could avoid the transport of oxygen; also, decomposed parts of the weed could inhibit the transport of oxygen, which in turn threatens the biodiversity of the lake (Degaga 2018). Likewise, studies have reported lower levels of dissolved oxygen under water hyacinth canopies by average spot measures of below 5 mg/L in water hyacinth (the minimum level for fish survival) (Troutman et al. 2007; Miskella et al. 2021). Therefore, the presence of water hyacinth implies a continued decline in the levels of dissolved oxygen from the control group to highly infested sites (site 1), which threatens the biodiversity of the lake.

Along the depth of the water (surface to deep), the concentration of phosphate tended to slightly decrease (Figure 2), although no significant difference (p¿0.05). The results of the study showed that at the three strata, there is an optimal amount of phosphate for the growth of water hyacinth. Similarly, it has been reported that the half-saturation coefficient for water hyacinth grown under constant conditions ranges from 0.02 to 0.1 mg/L for phosphates (Acero 2019).

Along the depth of the water (surface to deep), the concentration of nitrate tended to increase at most sites but decreased at Site 3 (Figure 3). However, no significant differences were observed among the vertical stratifications of the sites (p¿0.05). The results of this study showed that at the three strata there is an optimal amount of nitrate for the growth of water hyacinth. A previous study pointed out that the half-saturation coefficient for water hyacinth grown under constant conditions ranges from 0.05 to 1 mg/mL for nitrogen (Prasetyol et al. 2021).

Along the depth of the water (surface to deep), the temperature concentration tended to slightly decrease at sites two and three (Figure 4). The slight increase in temperature was a result of the dense mats of water hyacinth over the water surface, which blocked the exchange of heat between the lake surface and the atmosphere (Navarro and Phiri 2000). At the same time, the decay of organic matter from water hyacinth results in heat generation and therefore the rise in temperature (Getahun and Kefale 2023). A similar study by Ndimele (2012) also showed that dense mats of water hyacinth over the surface block the exchange of heat between the water column and depth. The results show that all sites are favorable for water hyacinth growth. Similarly, According to Prasetyol et al. (2021), good growth can continue at temperatures ranging from 22°C to 35°C, and plants will survive frosting.

Along the depth of the water (surface to deep), the pH values tended to remain almost constant at all sites (Figure 5). This indicates that the pH value along each stratum is optimal for water hyacinth growth. This could be the reason why water hyacinth can grow over the range of acidity to alkaline. According to Nandiyanto et al. (2024), water hyacinth plants grow over a pH range of 4.0–10.0, and water hyacinth plants growing in either acidic or alkaline media tend to change their pH toward neutrality. However, According to El-Gendy (2004), water hyacinth plants do not survive in water media with pH $\leq$4.

Along the depth of the water (surface to deep), the DO concentration tended to slightly decrease at all sites (Figure 6). The fact that DO levels dropped from surface to depth could be due to the formation of a dense mat of water hyacinth in the infested sites and the metabolic activities of epiphytic organisms in the lake in the control group.

The high DO level near the water surface is probably attributed to the release of oxygen by phytoplankton during photosynthesis. According to Puyate and Rimrukema (2008), the intensity of sunlight in a water body decreases with depth, such that the photosynthetic activities of phytoplanktons decrease with depth. Generally, the DO level in water increases as the pressure in the water increases or as the temperature of the water decreases (Villamagna and Murphy 2010).

The abundance of water hyacinth began in the canal (Figure 7). The canal was located 1.5 km from the open lake, and the abundance was categorized as highly dense, less dense, and sparsely populated. The highly populated started from the beginning of the canal and was sparsely at the shore of the open lake. Based on the percent cover result, site one is found to be a highly infested site (99%), while site two is dense (91%) and three is sparsely allocated (31%). site four (control) had 0% cover infestation (Figure 7).

Table 2: The mean difference (Mean±Sd) values of water quality parameters at the sample sites

Parameters	Site one	Site two	Site three	Site four
PO_3 (mg/l)	$0.28±0.10^{ab}$	$0.41±0.54^{b}$	$0.22±0.21^{a}$	$0.29±0.74^{ab}$
NO_3 (mg/l)	$1.73±0.35^{b}$	$1.76±0.25^{b}$	$1.35±0.29^{a}$	$1.6±0.22^{ab}$
pH	$8.02±0.12^{a}$	$8.08±0.34^{a}$	$8.78±0.20^{b}$	$9.03±0.07^{b}$
DO (mg/l)	$0.46±0.21^{a}$	$3.25±2.06^{b}$	$5.42±1.23^{c}$	$7.43±0.28^{d}$
Temp (°C)	$24.23±0.99^{b}$	$24.08±0.56^{b}$	$22.65±1.62^{a}$	$22.77±0.77^{a}$

Table 3: *

Note: different letters on the mean value within a row indicate significant difference at p¡0.05

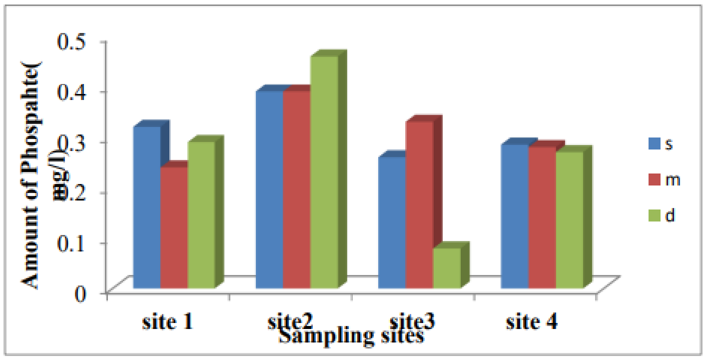

Figure 2: Concentrations of phosphates between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth

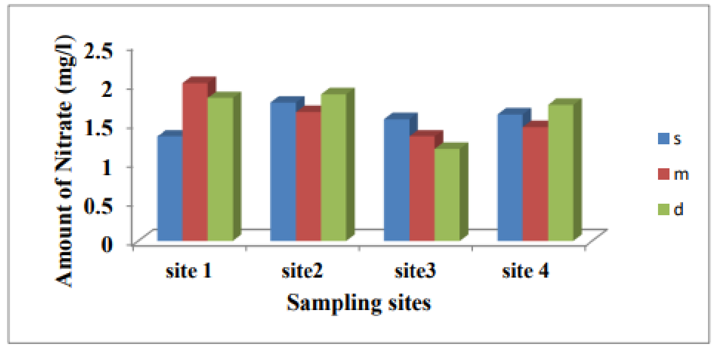

Figure 3: Nitrate concentrations along vertical stratification (surface, middle and depth) between sites at different depths. Note: s = surface, m= middle and d= depth

3.2 Water hyacinth abundance

Water hyacinth abundance (expressed as percent cover) was positively correlated with PO_3 (r = 0.77, N = 4, P ¿ 0.05), NO_3 (r = 0.69, N = 4, P ¿ 0.05), pH (r = 0.16, N = 4, P ¿ 0.05), and T (r = 0.78, N = 4, P ¿ 0.05) (Table 3). However, DO was negatively correlated with water hyacinth abundance (r = -0.94, N = 4, P¡0.05).

The positive correlation of PO_3 with water hyacinth abundance, because water hyacinth requires a sufficient amount of PO_3 for optimum growth. Consequently, if the water has sufficient phosphate, it will enhance the growth and percentage coverage of water hyacinth in the water body. Similar studies have shown that the colonial growth of water hyacinth is correlated with the nutrient levels of water bodies, especially phosphorus (Xie and Yu 2003; Acero 2019).

The positive correlation of NO_3 with water hyacinth abundance could be due to the fact that water hyacinth takes nitrates from the lake and uses them for growth and biomass production (Nandiyanto et al. 2024). Similarly, a study by Aoyama and Nishizaki (1993) revealed that plant nutrient content is a more accurate indicator of plant growth, with a linear relationship between the percentage of nitrogen in leaves and growth rate. Relatively lower pH was recorded in water hyacinth-infested areas. Similarly, Momanyi (2012) reported that pH was significantly lower (P¡0.05) in a water-hyacinth-infested area (6.92±0.04) than in open water (7.71±0.05).

The increase in temperature over areas with thick mats of water hyacinth is mainly attributed to dense mats blocking the exchange of heat between the water column and the atmosphere, thus increasing the water temperature (Prasetyol et al. 2021). Likewise, Bayu et al. (2024) indicated that Lake Tana experienced high temperatures in areas with high levels of water hyacinth infestation.

The negative correlation between DO and water hyacinth abundance could be due to the fact that when the mat of the weed covers the surface of the water body, the transportation of oxygen from the atmosphere to the lake decreases. Thus, the amount of DO inside the mat decreases, and when the large mats of the weed decompose, the amount of DO decreases as the heat generated from the decaying organic matter in water hyacinth increases. Furthermore, increases in temperature could also reduce the amount of oxygen dissolved in water because, in general, warmer water holds less oxygen than cooler water (Villamagna and Murphy, 2010). Similarly, Masifwa and Denny (2001) found an inverse relationship between dissolved oxygen concentrations and water hyacinth abundance in Lake Victoria (Uganda).

3.3 Drivers of water hyacinth infestation

According to UNEP (2012), the spread of invasive alien species is neither easy to manage nor reverse, and it threatens biodiversity, economic development, and human well-being. As key informants explained the impact of water hyacinth infestation on the social as-

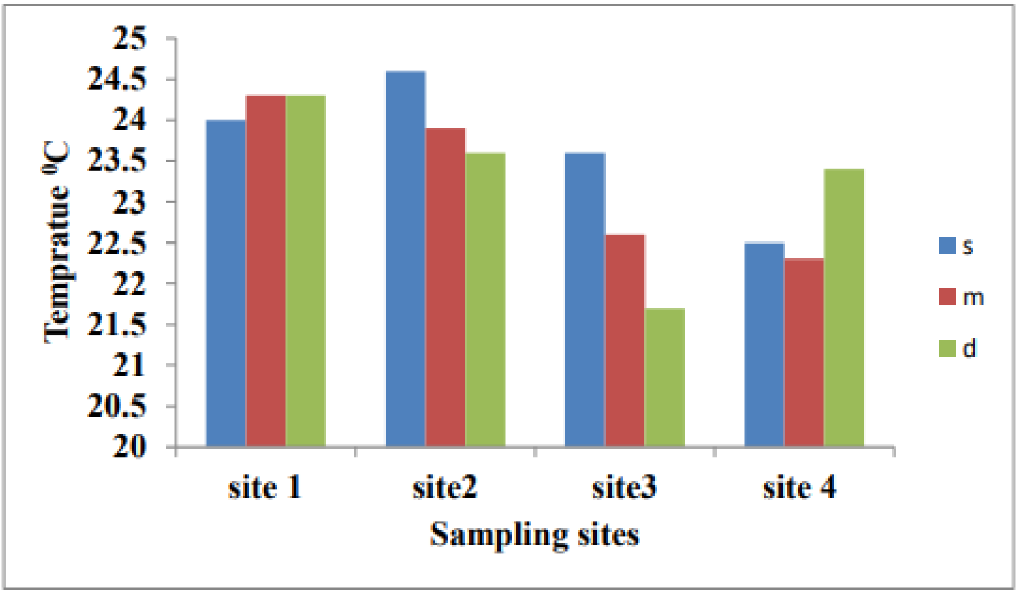

Figure 4: Temperature values between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth

Table 4: Pearson's correlation coefficients (r) for water quality parameters with water hyacinth coverage.

Water quality parameters	Water hyacinth coverage (Percent cover)	p-value
PO_3	0.77	0.232
NO_3	0.69	0.307
pH	0.16	0.837
DO	-0.94	0.059
Temp	0.78	0.222

Table 5: *

Note: PO_3, Phosphate; NO_3, Nitrate; pH Potential of Hydrogen; DO; Dissolved Oxygen; TEMP, Temperature

pects, the communities had a fear that after five years, the lake would be in a dangerous situation. The common social impact of water hyacinth in the study area is expressed as difficulties in boating access, navigability, recreation, and pipe systems for agriculture (Table 4). Similar studies by Ndimele and Jimoh (2011) and Patel (2012) showed that dense mats disrupt socioeconomic and subsistence activities such as ship and boat navigation and restrict access to water for recreation, fisheries, and tourism. If the waterways are blocked, water pipes are clogged. Water hyacinth increases mosquito habitat by providing larval breeding sites that mosquito predators cannot reach, creating microhabitats for the vectors of malaria, encephalitis, and schistosomiasis (Minakawa et al. 2012). From an economic perspective, when the lake is polluted, the amount of water is declining, thus directly decreasing the amount of fishing in cases where people depend on the sale of fish. According to a study conducted in South Africa, the estimated economic costs due to invasive alien species are currently above US700 million (R6.5 billion) per annum (Wilgen and Lange 2011).

Infestations of water hyacinth affect biodiversity. The dense mats of the weed covering the water surface lead to deoxygenation of the water, affecting all aquatic organisms. A dense water hyacinth cover enhances evapotranspiration.

Key informants informed me that from an environmental point of view, the color of the water is dark brown, especially in highly infested areas; this might be due to debris from dead water hyacinth. Similarly, Maliu (2001) stated that the death and decay of water hyacinth vegetation in large masses may create anaerobic conditions and lead to the production of badly smelled or even lethal gases. This is a major problem for the inhabitants since some of them still use this water for bathing and laundry.

Birds that rest on the water before emergence almost do not step on the infested area, and at last, the place is losing its recreational value. In line with this study (Minakawa et al. 2012), even smaller infestations of water hyacinth along shorelines can prevent ducks, turtles, snakes, and frogs from seeking shelter. Aquatic vegetation provides habitats and cover for aquatic invertebrates and fish, providing a prey base for many bird species (Menegesha et al. 2015). A study held in Florida (USA) showed that birds that were seen feeding on water hyacinth mats more frequently found prey around the perimeter of the mats than within the core of the mats (Villamagna and Murphy 2010).

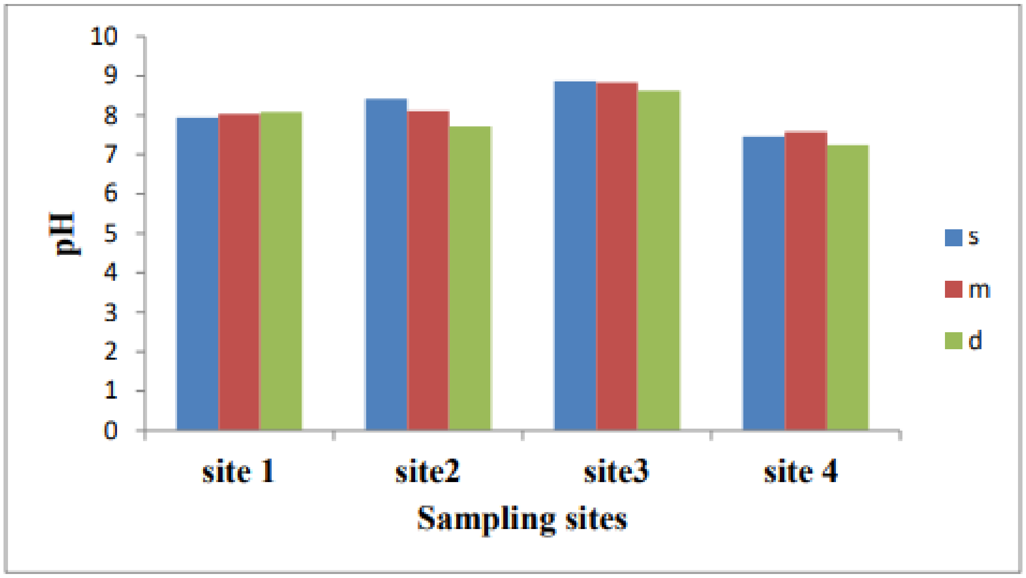

Figure 5: pH value between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth.

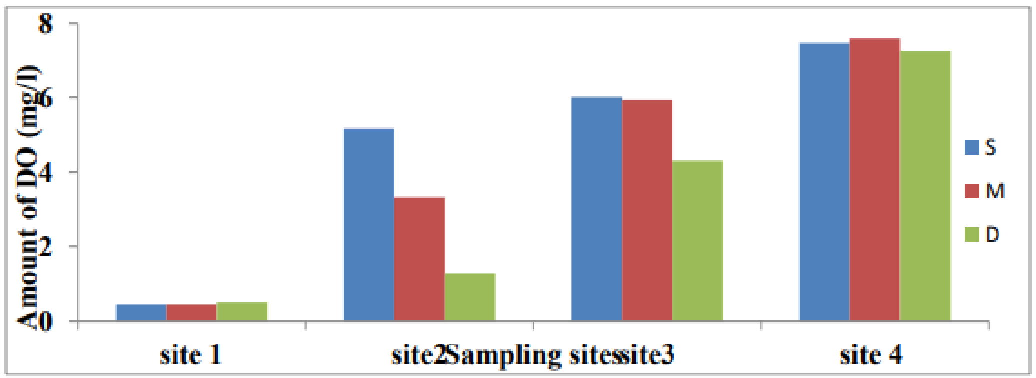

Figure 6: DO values between sites along vertical stratification (surface, middle and depth). Note: s = surface, m= middle and d= depth.

3.4 Conclusions and recommendations

The study revealed that water hyacinth infestation increased the levels of PO_3, NO_3, pH and T^0, whereas declining DO concentrations in Ziway Lake. High oxygen demand or depletion of oxygen due to high organic matter decomposition and low photosynthesis by masked benthic algae may lead to rapid expansion of water hyacinth. Low levels of dissolved oxygen catalyze the release of phosphorus from the sediment, which in turn accelerates eutrophication and can lead to an increase in water hyacinth. Furthermore, agrochemical nutrient inputs from the lake shore, intensive irrigation, and floricultural activities have been attributed by key informants to being the main sources of eutrophication in the lake. Therefore, the presence of water hyacinth implies a continued decline in the levels of dissolved oxygen from the control group to highly infested sites (site 1), which will lead to threats to the biodiversity of the lake.

Finally, an integrated control method for water hyacinth was recommended to stop further expansion of the weed into open lakes. The management of water hyacinth in Lake Ziway should involve a multidisciplinary approach and should be designed in a way that the highest political and administrative levels recognize the potential seriousness of weed infestation. When using water facilities, such as dams, lakes, and rivers, it is recommended that all clothing, boats, trailers, water vessels, and any related equipment be free of plant material before use. This requires better management of urban waste, agricultural productivity inputs, and soil and water conservation practices.

Acknowledgment

We would also like to thank the Ethiopian Ministry of Education for supporting this research project. Family members, field assistants, and friends, especially, deserve special appreciation for their invaluable encouragement and support.

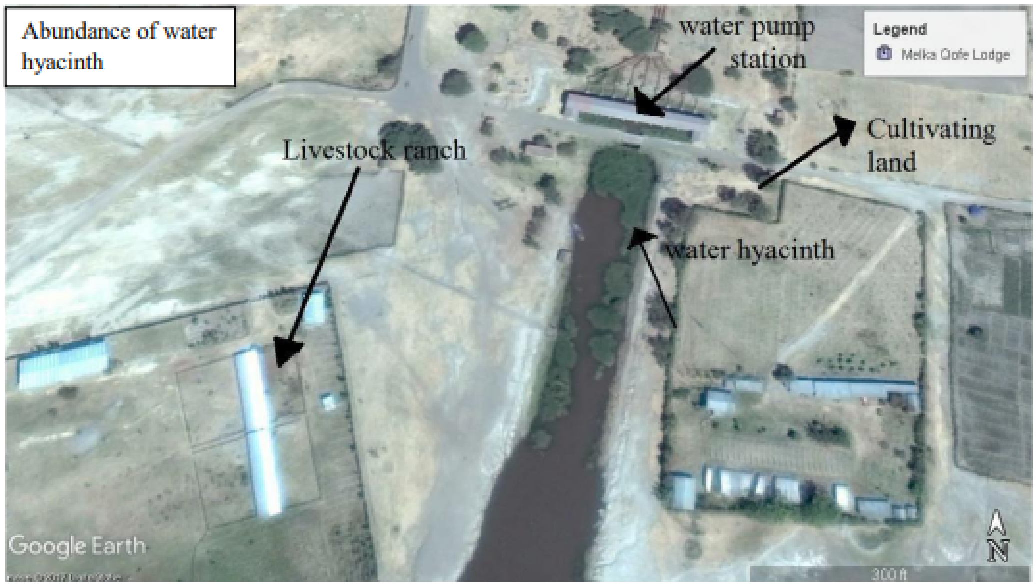

Figure 7: Map showing abundance of water hyacinth along the irrigation canal and the major agricultural drivers of water hyacinth infestation.

Table 6: Key informant interview responses regarding drivers of water hyacinth infestation of Lake Ziway.

	Responses	Yes	No
1	Water hyacinth infested the area in 2008 E.C	11	1
2	An excavator from the Koka Dam brought the invasive species to the irrigation canal	10	2
3	The invasion of water hyacinth has affected fishing	9	3
4	Water hyacinth invasion affected water turbidity	9	3
5	100-kg fertilizer per hectare per year is applied on farm lands around the lake.	8	4
6	Solid and liquid wastes are dumped into the lake or lake's tributaries	7	5
7	Approximately 90% of the farmers used pesticides and herbicides every time they cultivated crops.	11	1
8	We assume that the source of disease-causing organisms infested lakes	11	1
9	The water hyacinth is growing	10	2
10	Water hyacinth appearance affects laundry and bathing around infested areas	11	1
11	Water Hyacinth infestation affected swimming, fishing, and boat movement	12	0
12	Water hyacinth has social, economic, and ecological impacts	12	0

References

[1] Acero, L. (2019). Phytoremediation of phosphorous and ammonia with *Eichhornia crassipes* and *Azolla pinnata* in wastewater from Estero de San Miguel Mendiola. Manila, Philippines. *E3S Web of Conferences, 93*, 02004. https://doi.org/10.1051/e3sconf/20199302004

[2] Aoyama, I., & Nishizaki, H. (1993). Uptake of nitrogen and phosphate and water purification by water hyacinth *Eichhornia crassipes* (Mart.) Solms. *Water Science and Technology, 28*(1), 47–53. https://doi.org/10.2166/wst.1993.0007

[3] Ayenew, T., & Legesse, D. (2007). The changing face of the Ethiopian Rift lakes and their environs: Call of the time. *Lakes & Reservoirs: Research & Management, 12*(3), 149–165. https://doi.org/10.1111/j.1440-1770.2007.00332.x

[4] Bayu, T., Soeprobowati, T. R., Adissu, S., Warsito, B., & Bloor, M. (2024). Effect of climate change on *Eichhornia crassipes* infestation in Lake Tana Sub-Basin, North Western Ethiopia. *Sustainable Environment, 10*(1). https://doi.org/10.1080/27658511.2024.2314399

[5] Beneberu, G., & Mengistu, S. (2009). Oligotrophication trend in Lake Ziway, Ethiopia. *SINET: Ethiopian Journal of Science, 32*(2), 141–148.

[6] Benti, G. (2021). Impacts of anthropogenic activities on the ecology and ecosystem service delivery of Lake Ziway, Ethiopia. *PhD Thesis*, Wageningen University, Wageningen, 294 pages.

[7] Churko, E. E., Nhamo, L., & Chitakira, M. (2023). Phytoremediation capacity of water hyacinth (*Eichhornia crassipes*) as a nature-based solution for contaminants and physicochemical characterization of lake water. *Water, 15*(14), 25–40. https://doi.org/10.3390/w15142540

[8] Craft, C. P., Megonigal, S., Broome, J., Stevenson, R., Freese, J., Cornell, L., Zheng, S., & Sacco, J. (2003). The pace of ecosys-

tem development in constructed *Spartina alterniflora* marshes. *Applied Ecology, 13*(5), 1417–1432. https://doi.org/10.1890/02-5226

[9] Damtew, Y. T., Verbeiren, B., Awoke, A., & Triest, L. (2021). Satellite imagery and field data from macrophytes reveal a regime shift of a tropical lake (Lake Ziway, Ethiopia). *Water, 13*(4), 396. https://doi.org/10.3390/w13040396

[10] Degaga, A. H. (2018). Water hyacinth (*Eichhornia crassipes*) biology and its impacts on ecosystems, biodiversity, economy, and human wellbeing. *Journal of Life Sciences and Biomedicine, 8*(6), 94–100.

[11] Desta, H. (2021). Local perceptions of ecosystem services and human-induced degradation of Lake Ziway in the Rift Valley region of Ethiopia. *Ecological Indicators, 127*, 107786. https://doi.org/10.1016/j.ecolind.2021.107786

[12] Desta, H., Lemma, B., Albert, G., & Stellmacher, T. (2015). Degradation of Lake Ziway, Ethiopia: A study of the environmental perceptions of school students. *Lakes and Reservoirs: Research and Management, 20*(4), 243–255. https://doi.org/10.1111/lre.12108

[13] Desta, H., & Lemma, B. (2017). SWAT based hydrological assessment and characterization of Lake Ziway sub-watersheds, Ethiopia. *Journal of Hydrology: Regional Studies, 13*, 122–137. https://doi.org/10.1016/j.ejrh.2017.08.002

[14] European Environment Agency (EEA). (2012). Water resources in Europe in the context of vulnerability: EEA 2012 state of water assessment. *EEA Report, 11*(2012). Copenhagen, Denmark: EEA.

[15] El-Gendy, A. S., Biswas, N., & Bewtra, J. K. (2004). Growth of water hyacinth in municipal landfill leachate with different pH. *Environmental Technology, 25*(7), 833–840. https://doi.org/10.1080/09593330.2004.9619375

[16] Ethiopian Wildlife and Natural History Society (EWNHS). (1996). Important bird areas of Ethiopia: A first inventory. Addis Ababa, Ethiopia: EWNHS.

[17] Firehun, Y., Struik, P., Lantinga, E., & Taye, T. (2014). Water hyacinth in the Rift Valley water bodies of Ethiopia: Distribution, socio-economic importance and management. *Journal of Aquatic Plant Management, 52*, 51–58.

[18] Gangwar, R. K., Khare, P., Singh, J., & Singh, A. P. (2012). Assessment of physicochemical properties of water: River Ramganga at Bareilly, UP. *Journal of Chemical and Pharmaceutical Research, 4*(9), 4231–4234.

[19] Gebremariam, Z. (1998). Human interactions and water quality in the Horn of Africa. Retrieved from https://www.web.archive.org

[20] Getahun, S., & Kefale, H. (2023). Problem of water hyacinth (*Eichhornia crassipes* (Mart.)) in Lake Tana (Ethiopia): Ecological, economic, and social implications and management options. *International Journal of Ecology, 2023*, Article ID 4618069. https://doi.org/10.1155/2023/4618069

[21] Greenfield, B. K., Siemering, G. S., Andrews, J. C., Rajan, M., Andrews, S. P., & Spencer, D. F. (2007). Mechanical shredding of water hyacinth (*Eichhornia crassipes*): Effects on water quality in the Sacramento-San Joaquin River Delta, California. *Ecological Engineering, 30*(3), 627–640. https://doi.org/10.1016/j.ecoleng.2007.01.007

[22] Gunaratne, A. M., Jayakody, S., & Bambaradeniya, C. N. (2009). Spatial distribution of aquatic birds in the Anavilundawa Ramsar wetland sanctuary in Sri Lanka. *Biological Invasions, 11*(4), 951–958. https://doi.org/10.1007/s10530-008-9304-4

[23] Harun, I., Pushiri, H., Amirul-Aiman, A. J., & Zulkeflee, Z. (2021). Invasive water hyacinth: Ecology, impact, and prospects for the rural economy. *Plants, 10*(8), 1613. https://doi.org/10.3390/plants10081613

[24] King, M. (2013). *Fisheries biology, assessment and management*. John Wiley & Sons.

[25] Kiyemba, H., Barasa, B., Asaba, J., Gudoyi, P., & Akello, G. (2023). Water hyacinth extent and implications for water quality in Lake Victoria, Uganda. *Scientific World Journal, 2023*, Article ID 4947272. https://doi.org/10.1155/2023/4947272

[26] Lekamge, M. D., Wijeyaratne, M. J. S., & Dahanayaka, G. L. (2020). Water quality parameters contributing to the invasion of water hyacinth (*Eichhornia crassipes*) by Anavilundawa reservoir in Sri Lanka. *Sri Lanka Journal of Aquatic Sciences, 25*(1), 9–17. https://doi.org/10.4038/sljas.v25i1.7572

[27] Lubembe, S. I., Okoth, S., Turyasingura, B., Oyugi, T., Ibarasa, H., Moenga, K., Chavula, P., & Tumushabe, J. T. (2023). Water hyacinth is an invasive species in Africa: A literature review. *East African Journal of Environment and Natural Resources, 6*(1), 243–261. https://doi.org/10.37284/eajenr.6.1.1293

[28] Mailu, A. (2001). Preliminary assessment of the social, economic, and environmental impacts of water hyacinth in the Lake Victoria basin and its status of control. In *Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes* (pp. 130–139). ACIAR Proceedings No. 102.

[29] Masifwa, T., Twongo, T., & Denny, P. (2001). Impact of water hyacinth, *Eichhornia crassipes* (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. *Hydrobiologia, 452*, 79–88. https://doi.org/10.1023/A:1011979226089

[30] Mayer, B., Boyer, E. W., Goodale, C., Jaworski, N. A., Breemen, N. V., & Howarth, R. W. (2002). Nitrate sources in rivers draining sixteen watersheds in the northeastern U.S.: Isotopic constraints. *Biogeochemistry, 57*(1), 171–197. https://doi.org/10.1023/A:1015744002496

[31] Melissa, L. K. (2017). The ability of an aquatic invader to uptake nutrients in an upstream estuarine environment: Implications for reducing the intensity and frequency of massive fish kills in Florida. *USF Tampa Graduate Theses and Dissertations*, University of South Florida, Florida.

[32] Mengesha, G., Elphick, C. S., Field, C. R., Bekele, A., & Mamo, Y. (2015). Abundance and temporal patterns in wetland birds in and around Lake Zeway, Ethiopia. *Journal of Biodiversity Management & Forestry, 4*(1). https://doi.org/10.4172/2327-4417.1000135

[33] Minakawa, N., Dida, G. O., Sonye, G. O., Futami, K., & Njenga, S. M. (2012). Malaria vectors in Lake Victoria and adjacent habitats in western Kenya. *PLoS One, 7*(3), e32725. https://doi.org/10.1371/journal.pone.0032725

[34] Mironga, J. M., Mathooko, J. M., & Onywere, S. M. (2012). Effects of water hyacinth infestation on the physicochemical characteristics of Lake Naivasha. *International Journal of Humanities and Social Science, 2*(7), 103–113.

[35] Miskella, J. D., Madsen, A., Llaban, E., & Hard, E. (2021). Dissolved oxygen in water hyacinth following herbicide application. *Journal of Aquatic Plant Management, 59*, 82–89.

[36] Momanyi, J. M., Mathooko, J. M., & Onywere, S. (2012). Effect of water hyacinth infestation on the physicochemical characteristics of Lake Naivasha. *International Journal of Humanities and Social Science, 103*(2), 103–113.

[37] Ministry of Water Resources (MoWR). (2006). Temporal and spatial variation of Cu, Zn, Mn, and Fe contents in soils treated with long-term trace fertilizer application on the Loess Plateau. *Plant Nutrition and Fertilizer Science*, MoWR, Addis Ababa.

[38] Nandiyanto, A. B., Ragadhita, R., Hofffah, S. N., & et al. (2024). Progress in the utilization of water hyacinth as an effective biomass material. *Environmental Development and Sustainability, 26*, 24521–24568. https://doi.org/10.1007/s10668-023-03655

[39] Navarro, L., & Phiri, G. (2000). Water hyacinth in Africa and the Middle East: A survey of problems and solutions. International Development Research Center, Canada.

[40] Ndimele, P. E. (2012). Effects of water hyacinth (*Eichhornia crassipes* [Mart.] Solms) infestation on the physicochemical, nutrient, and heavy metal contents of Badagry Creek and Ologe Lagoon, Lagos, Nigeria. *Journal of Environmental Science and Technology, 5*(2), 128–136. https://doi.org/10.3923/jest.2012.128.136

[41] Ndimele, P. E., & Jimoh, A. (2011). Water hyacinth (*Eichhornia crassipes* [Mart.] Solms.) in phytoremediation of heavy metal polluted water of Ologe lagoon, Lagos, Nigeria. *Research Journal of Environmental Sciences, 5*(5), 424–433. https://doi.org/10.3923/rjes.2011.424.433

[42] Ogwang, J. A., & Molo, R. (2001). Impact studies on *Neochetina bruchi* and *Neochetina eichhorniae* in Lake Kyoga, Uganda. *Proceedings of the 1st IOBC Water Hyacinth Workshop Group, 10-13*, 370–373.

[43] Patel, S. (2012). Threats, management, and expected utilization of aquatic weed *Eichhornia crassipes*: An overview. *Reviews in Environmental Science and Biotechnology, 11*(3), 249–259. https://doi.org/10.1007/s11157-012-9289-4

[44] Pinto, R. M., & Greco, M. K. B. (1999). The contribution of water hyacinth (*Eichhornia crassipes*) and zooplankton to the internal cycling of phosphorus in the eutrophic Pampulha Reservoir, Brazil. *Hydrobiologia, 411*, 115–127. https://doi.org/10.1023/A:1003859405147

[45] Prasetyo, S., Anggoro, S., & Soeprobowati, T. R. (2021). The growth rate of water hyacinth (*Eichhornia crassipes* [Mart.] Solms) in Rawapening Lake, Central Java. *Journal of Ecological Engineering, 22*(6), 222–231. https://doi.org/10.12911/22998993/135286

[46] Puyate, Y. T., & Rimrukeh, A. (2008). Variability with depth of some physico-chemical and biological parameters of Atlantic Ocean water in part of the coastal area of Nigeria. *Journal of Applied Sciences and Environmental Management, 12*(1), 87–91. https://doi.org/10.4314/jasem.v12i1.55555

[47] Rodríguez-Gallego, L. R., Mazzeo, N., Gorga, J., Meerhoff, M., Clemente, J., Kruk, C. F. S., Lacerot, G., García, J., & Quintans, F. (2004). Effects of an artificial wetland dominated by free-floating plants on the restoration of a subtropical, hypertrophic lake. *Lakes and Reservoirs, 9*, 203-215.

[48] Rommens, W., Maes, J., Dekeza, N., Inghelbrecht, P., Nhiwatiwa, T., Holsters, E., Ollevier, F., Marshall, B., & Brendonck, L. (2003). Impact of water hyacinth (*Eichhornia crassipes*) in an eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). I. Water quality. *Archiv Für Hydrobiologie, 158*, 373–388.

[49] Stroud, A. (1994). Water hyacinth (*Eichhornia crassipes* [Mart.] Solms) is found in Ethiopia. In 9th Annual Conference of the Ethiopian Weed Science Committee, Addis Abeba (Ethiopia), 9-10 Apr 1991. *EWSC*.

[50] Téllez, T., López, E., Granado, G., Pérez, E., López, R., & Guzmán, J. (2008). The water hyacinth, *Eichhornia crassipes*: An invasive plant in the Guadiana River Basin (Spain). *Aquatic Invasions, 3*, 42-53.

[51] Tenalem, A. (2001). Numerical groundwater flow modeling of the Central Main Ethiopian Rift lakes basin. *SINET: Ethiopian Journal of Science, 24*(2), 167-184.

[52] Tobias, V. D., Conrad, J. L., Mahardja, B., & Khanna, S. (2019). Impacts of water hyacinth treatment on water quality in a tidal estuarine environment. *Biological Invasions, 21*(12), 3479-3490.

[53] Troutman, D. A., Rutherford, W. E., & Kelso, W. E. (2007). Patterns of habitat use among vegetation-dwelling littoral fish in the Atchafalaya River Basin, Louisiana. *Transactions of the American Fisheries Society, 136*(4), 1063-1075.

[54] UNEP. (2012). Fifth Global Environment Outlook (GEO5): The future we want. United Nations Environment Program, Nairobi.

[55] Van Wyk, & van Wilgen, B. W. (2002). Cost of water hyacinth control in South Africa: A case study of three options. *African Journal of Aquatic Science, 27*, 141-149.

[56] Villamagna, A. M., & Murphy, B. R. (2010). Ecological and socioeconomic impacts of invasive water hyacinth (*Eichhornia crassipes*): A review. *Freshwater Biology, 55*(2), 282-298.

[57] Wilgen, B., & Lange, W. (2011). The costs and benefits of biological control of invasive alien plants in South Africa. *African Entomology, 19*(2), 504–514.

[58] Wondmagegne, T., Wondie, A., & Mingist, M. (2012). Seasonality in abundance, biomass, and production of phytoplankton of Welala and Shesher wetlands in Lake Tana sub-basin (Ethiopia). *Journal of Water Resource Protection, 4*(10), 877.

[59] Xie, Y. H., & Yu, D. (2003). The significance of lateral roots in phosphorus (P) acquisition of water hyacinth (*Eichhornia crassipes*). *Aquatic Botany, 75*, 311-321.

[60] Yan, S., & Guo, J. Y. (2017). *Water Hyacinth: Environmental Challenges, Management and Use*. CRC Press, Florida.

[61] Zegeye, H., Teketay, D., & Kelbessa, E. (2006). Diversity, regeneration status, and socio-economic importance of the vegetation in the islands of Lake Ziway, south-central Ethiopia. *Flora: Morphology, Distribution, Functional Ecology, 201*(6), 483-498.

[62] Zeray, L., Roehrig, J., & Chekol, D. A. (2006). Impact of climate change on Lake Ziway watershed water availability, Ethiopia. *Proceedings of the Conference on International Agricultural Research for Development*, 18-23.