Article

Phytoremediation capacity of water hyacinth (*Eichhornia crassipes)* as nature-based solution for contaminants and physico-chemical characterization of Lake Water

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Abstract: Water hyacinth (*Eichhornia crassipes*) is a potential accumulator of water pollutants in aquatic ecosystems, and its presence in water systems can affect water quality. This study used different field measurements and laboratory tests of Lake Water to determine the impact of water hyacinth phytoremediation capacity. A total of eight sampling stations used for the two lakes; Lake Koka and Lake Ziway. Sampling stations were selected from sites infested with water hyacinth (low, medium and high) and non-water hyacinth aquatic plants during wet and dry seasons to compare the effects of plants on water quality in the two lakes. All the sampled stations had various human interventions. The water samples were tested for the selected physico-chemical properties namely phosphate, nitrate, pH, electrical conductivity (EC), Biological oxygen demand (BOD_5), temperature, and heavy metals (Chromium (Cr), Lead (Pb), Cadmium (Cd), Zinc (Zn), and Copper (Cu). These water quality variables were compared by means of ANOVA. Despite the COD of Lake Ziway, this study found no significant ($p > 0.05$) variation in the concentrations of Cu, EC, pH and temperature between wet and dry seasons in either lake. Variations in Zn concentration and other physico-chemical parameters (EC, BOD, COD, nitrate, phosphate) between low, medium and high levels of water hyacinth were significant in both lakes ($p<0.05$). Water hyacinth has shown significant phytoremediation nature during wet and dry seasons. The lowest average heavy metal, phosphate, and nitrate concentrations; and significant pH and temperature variations were observed in Lakes Koka and Lake Ziway, among water hyacinth and other grass-infested sites.

Keywords: Heavy metals; water quality; remediation; water security; ecosystem services; spatio-temporal variation; nature-based solution

1. Introduction

Water hyacinth is an invasive alien plant species migrated from South America to different continents in the world [1]–[4]. In 19th century it's invasion spread over Africa and in the mid-19th it dominated many East African rivers and lakes, including Ethiopian fresh water bodies causing economic, social and environmental loss [5], [6]. It is one among the top ten worst weeds in the world, and it is classified as a noxious weed in several African countries [7], [8]. Water hyacinth has proven to be a substantial cause of economic and environmental difficulties in many subtropical and tropical places throughout the world [9], [10]. Ethiopia is part of tropical sub-Saharan Africa where in the country about 35 known invasive alien plant species, including, water hyacinth, currently exist and become one of fresh water bodies impairment source [11]–[14]. Additionally, continued exploitation and unintended contamination of aquatic habitat causing impairment on physical, chemical and biological character of fresh water ecosystem [15], [16].

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At normal circumstance fresh water bodies have a specific premised physico-chemical standard but the invasion of weeds like water hyacinth, triggering significant impacts on deviation of water physico-chemical character from the permission level [17]–[19]. Farmers who cross invaded water bodies to access their farms cannot do so in the presence of the dense mats of the weeds, resulting in high agricultural and economic losses [7], [20]. Smallholder farming was affected by the water hyacinth invasion in a number of ways, including decreased farm output profits, financial difficulty, and the destruction of crops due to the hyacinth's obstruction of water bodies [20]. Water hyacinth influenced crop productivity, fishing, cattle feed, water supply, water transportation, and other economic activities, according to a study conducted on Lake Tana by Enyew *et al*., (2020). As the abundance of water hyacinth increased, the degree of challenge for fishing and fish market activity also increased. The invasion has a number of repercussions on fishing and fish trading, including decreased fish catch, difficulty using fishing gear, decreased profit, and higher fishing costs [7]. These impacts have a significant impact on the long-term viability of fishing and fish trading [7]. In the research communities, the plentiful water hyacinth acts as a habitat for disease-carrying insects such as mosquitoes, which cause malaria and many more vectors carriers a breeding ground. As a result, respondents assessed the water hyacinth invasion to have had a detrimental impact on their health. Despite the fact that many respondent participants perceived malaria infection to be the leading cause of illness in their communities. Prior to the introduction of water hyacinth into the water bodies, the current predominance of the disease in the study communities was widely perceived to be primarily due to the presence of the weed [20], [21]. On the other hand, water hyacinth has remarkable economic advantages. One of the studies conducted on benefits of water hyacinth concluded that after acid pretreatment and post-washing step, the biogas yield increased due to the increased sugar and ethanol yield during saccharification and fermentation of water hyacinth [22]. Different organic acids showed varying yields in ethanol and biogas yield showing different acids affecting the pretreatment efficiency [22]. Despite the widely held belief that the water hyacinth was an invasion, a few fishermen and fish sellers observed that the water hyacinth provided protection for fish [7]. Moreover, water hyacinth was used for compost and bio char [23]. Besides, water hyacinth fast growth and quick expansion related with its high take-up ability for nutrients and minerals found in the aquatic system [24], [25]. It's expansion continued through competing the available nutrients in the aquatic ecosystem and this view supported by the study findings in the lab test conducted under greenhouse conditions [9], [17], [18], [26]. The weeds nature of minerals absorption and nutrients take-up capacity from the soil sustained to dominate native aquatic plant biodiversity [27], [28]. In most cases fresh water body's pollutants are either organic and inorganic compounds, or natural and manmade contaminants, and sometimes heavy metals, or disasters from flood [1], [29]. Consequently, remedial plants studies suggested the water hyacinth has removal efficiency of organic and inorganic contaminants, heavy metals and nutrients form the water habitat [2], [9], [17]. Water hyacinth has been reported as a potential tool for the removal of heavy metals (Pb, Cr, Cd, Zn, and Cu), nutrient contaminant compounds such as (NO_3^-, PO_4^{3-}), adjust pH, and organic and inorganic matters (COD, BOD_5) take up from lake water [18], [30], [31],[32]. Henceforth, in the context of environmental conservation, plants with unique efficiency on chemical removal ability can play a role of phytoremediation [17], [30], [33]–[35]. The plants with phytoremediation capacity remove chemicals from the contaminated sites without disrupting the environments, just applying their inherent capabilities [17], [33]. Currently, seeking an option for cleansing the environment is important research topic for many reasons [18], [30]. Therefore, in this research a comparative study undergone aimed to evaluate nature based solution prospect of water hyacinth on removal of some lake water contaminants and maintaining the standard water physico-chemical character. This study specifically focused on comparison of wet and dry season physico-chemical levels of pollutants in the Lakes; the effect of water hyacinth on the physico-chemical levels of pollutants in the Lakes; and comparison of the physico-chemical levels of pollutants in the Lakes at the lake covered by water hyacinth and any other grasses such as *Aeschynomene elaphroxylon, Echinochloa stagnina (Retz.) and etc*

2. Materials and Methods

2.1. The study area

The Lakes included in the study are Lake Koka and Lake Ziway. In General, the rift-valley region and in particular the district of Lake Koka and Lake Ziway at upper Awash River Basins of the rift valley shows the two lakes are vulnerable for many natural process and anthropogenic activities [36]–[38] . For instance; at upper Awash River Basins of the rift valley, predominantly, the districts of Lake Koka and Lake Ziway are the center for many agricultural activities, and hydrological features, in Ethiopia [36]. Lake Koka is a man-made lake built in the 1960s to generate hydroelectric power (Figure 1). The lake has a surface area of around 200 km^2, a mean depth of 9 m, and a mean surface water temperature of 19°C. Lake Koka located at the coordinates of longitude 39^0 to altitude $39^010'$E in between $8^02'$ to $8^026'$N latitude. The Awash and Modjo rivers provide inflow to the lake. Agriculture is the main activity in the basin, and Acacia trees are widely scattered. Basically, in Ethiopia, this locations are susceptible for continued exploitation that causes natural biodiversity loss, climate changes, precipitation, etc. Therefore, these activities are major factors for many surface water pollution that conveys climate change impact and invasive alien species infestation.

Lake Ziway located at the coordinates of 8.0074′N, and 38.8416′E (Figure 1). Lake Ziway is the sole freshwater lake among the natural lakes in the middle rift valley basin. It serves as a water supply source for Ziway and its surrounds. Furthermore, more water is being drawn from the lake to irrigate small and large-scale private and state-owned farms. Lake Ziway is located around 165 km south of Addis Ababa, at an elevation of 1638 m above sea level. It has an average depth of 4 m and an area of around 435 km^2. The lake's two main feeder rivers, Meki and Ketar, flow from the eastern and western highlands, respectively [6], [37]. The present study location was at districts of Lake Koka and Lake Ziway of upper Awash River Rift Valley. The two lakes are situated in the rift-valley of upper Awash River Basins in a coordination, found at central Ethiopia. Lake Koka and Lake Ziway are known as the Central Ethiopian largest fresh water lake and there is a road crossing the two lakes that apparently connect the two. Water hyacinth has infiltrated the lakes and established itself along the lake water banks [14], [38].

2.2. Sample sites

In this study physico-chemical characterization of Lake Koka and Lake Ziway water quality was conducted for a period of one year (September 01, 2021- August 30, 2022) considering wet and dry seasons. In order to assess the physico-chemical pollutant concentration in the lakes' water, four water samples from each lake were taken at four different sites purposefully. A total of eight sampling stations were carefully selected for the two lakes. The stations SK_1L, SK_2M, SK_3H, SZ_1L, SZ_2M, and SZ_3H were collected from low infected, medium and high infected sites by the water hyacinth. The stations SK_4G and SZ_4G were collected from others grasses affected sites from Lake Koka and Ziway, respectively. The samples were collected using the dark plastic bottles, temporary stored in sampling box and stored at 4 ^oC prior to samples analysis. The sampling station selection based on human intervention, through industry, city and agricultural actions land graving, and many more related anthropogenic activities.

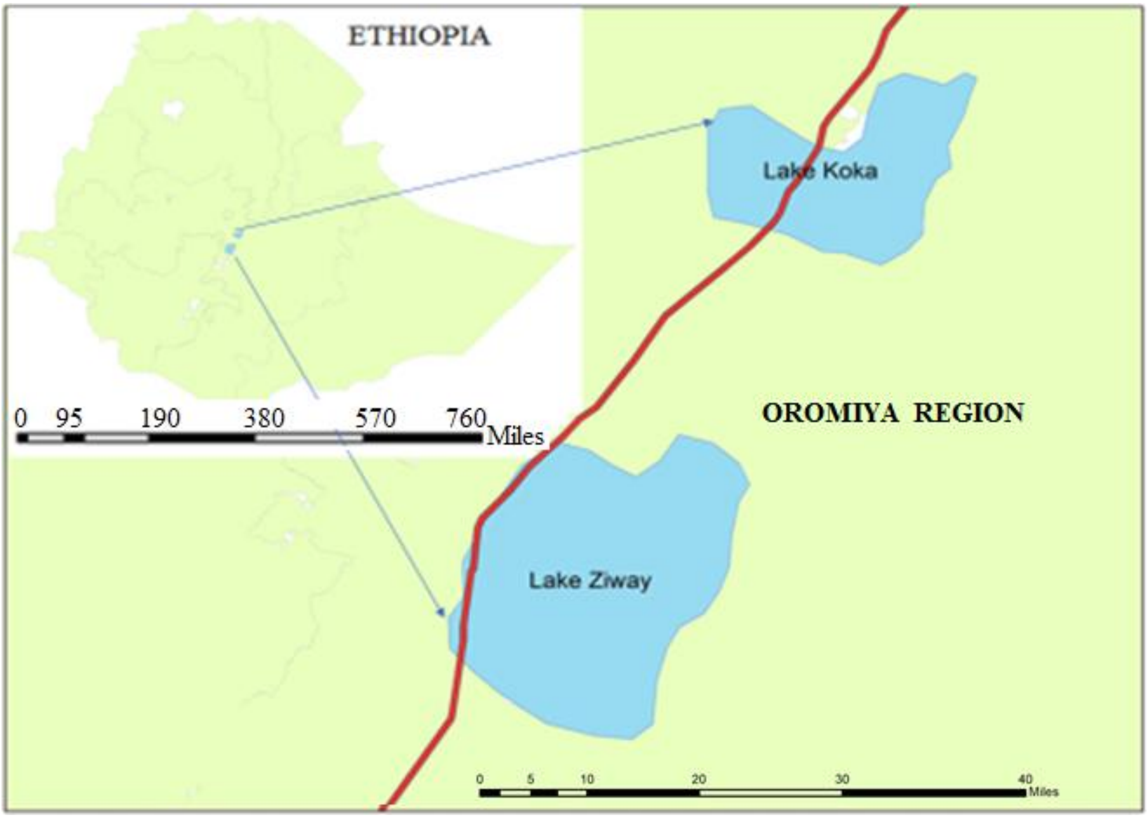

Figure 1| Study area (Lake Koka and Lake Ziway)

Detailed description of water sample habitat by water hyacinth infestation level and site is given in Table 1. At sites SK_1L and SZ_1L there were less human activity but the nearby villagers have been practiced agricultural activities surrounding the lakes. The second sites (SK_2M, SZ_2M) were relatively located at industrial zone, recreation center, or fishing and fish market places with more human activity than the first site. The third sites (SK_3H, SZ_3H) were categorized as the area with the highest industrial influence, agricultural impacts, and heavy human activities carrying zone than both site 1 and 2. The fourth stations (SK_4G, SZ_4G) were the lakes' water body covered by other grasses excluding water hyacinth. The purposes of including the fourth sites in the study were to consider other grasses impact in comparison with the water hyacinth invaded lakes' water.

Table 1. Description of water sample habitat by water hyacinth infestation level and site

Description	**Lakes**							
	Lake Koka				Lake Ziway			
Study sites	Site 1 SK_1	Site 2 SK_2	Site 3 SK_3	Site 4 SK_4	Site1 SZ_1	Site 2 SZ_2	Site 3 SZ_3	Site 4 SZ_4
Water hyacinth invasion or infestation level	Low (L)	Medium (M)	High (H)	Other grasses (G)	Low (L)	Medium (M)	High (H)	Other grasses (G)
Label	SK_1L	SK_2M	SK_3H	SK_4G	SZ_1L	SZ_2M	SZ_3H	SZ_4G

2.3. Lakes' Water Physico-chemical Variables Test

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In this study, two types of lakes' water test namely in-situ and ex-situ water sample test were conducted. The ex-situ test was held for the selected physico-chemical variables in the laboratory, whereas in-situ water sample test was done for unstable physico-chemical variables. In-situ test was conducted at the study sites. As mentioned earlier, one of the water hyacinth studied and reported topic for many researchers was its potential on heavy metals removal, and some nutrients uptake capacity by its root from the water body. Based on this review, in the current study, water hyacinth's heavy metals removal tendency and selected nutrients uptake capacity assessed following the plants level of invasion at different location in the study lakes. In the research, parts of the lake covered by other plant species, rather than water hyacinth, were also assessed to compare the selected heavy metals removal tendency and nutrients uptake performance of those plants with the water hyacinth.

2.4. Lakes' Water Quality Measurement by Physico-chemical Character

The lakes' water physico-chemical characters measured were: pH, temperature, electrical conductivity, nutrients, biological oxygen demand (BOD_5), chemical oxygen demand (COD), dissolved oxygen (DO), and heavy metals. The pH and electrical conductivity were analyzed by using pH meter and Electric Conductivity Meter in Siemens per meter ($S \cdot m^{-1}$). Nitrate and phosphate concentration were measured by using the UV-Vis spectrophotometer (Hach DR6000™, LPV441.99.00002, USA). Nitraver®5 and PhosVer®3 reagent powder pillows were used for the analysis of nitrate and phosphate, respectively. The lakes' water sample dissolved oxygen (DO) was measured by Portable Dissolved Oxygen Meter. The biological oxygen demand (BOD_5) of the lakes' water sample was determined using the digital BOD incubator (TS 606/4-i), which operates at 20 ^{o}C. The heavy metals composition of the lakes' water samples were analyzed using Atomic Absorption Spectroscopy. Moreover, the water samples odor was quantitatively stated by observation and on its smell, which noted as weather the water had an objection to the noise or not. Likewise, to consider seasonal variation of the water hyacinth impact, at wet and in dry seasons, the data were collected for selected heavy metals (Pb, Cr, Cd, Zn, and Cu), nutrients (NO_3-, $PO_4$3-), organic and inorganic matters (COD, BOD5), pH, and physico-chemical variable concentration of the lakes' water sample. Any deviation of lake water physico-chemical character from the permitted standard of fresh water bodies due to plant invasion was considered. During the samples analysis, cheek ups and calibration were taken as precautions before and after measuring and registering every data.

2.5. Water Sampling

Water samples were collected from the lakes according to the sampling design. Collections of the samples were done by using 250 mL polyethylene containers pre-cleaned by soaking into nitric acid and chilled. The samples were temporary stored in sampling box followed by storing at 4 ^{o}C before ex-situ analysis in the laboratory. The samples were transferred to the laboratory with 24 hr as recommended by EEPA and WHO. Entire this study, all the water sampling materials and laboratory equipment's were used from Addis Ababa University and Addis Ababa Science and Technology University, which located approximately at 165 km from the field of study.

2.6. Sample Analysis

In this study, water quality variables such as: Cr, Pb, Cd, Zn, Cu, Ca, and PO_4^{3-}, NO_3^-, COD, and BOD_5, temperature and pH were tested, data properly tabulated and statistically analyzed by applying one-way analysis of variance (ANOVA).

3. Results and Discussion

3.1. Comparison of wet and dry season physico-chemical levels of pollutants in the Lakes

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Lake Koka and Lake Ziway, the physico-chemical analysis of the samples observation during the wet season (between July and August 2021) and dry season (between January and February 2022) presented in Table 2 and Table 3. The selected months were purposively chosen considering highest dry and wet seasons of Ethiopian weather and climate nature. As shown in Table 2 and Table 3, Cr and Cd were not detected at both wet and dry season for both Lakes (Lake Koka and Lake Ziway). For both lakes Pb were detected mainly during the dry season. Low concentration of Cu (0.03-0.07 mg/L) was detected in the samples collected from Lake Koka. As indicated Table 2, the variation in the concentration of heavy metals (Pb, Zn), nutrients (PO_4^{3}-P, NO_3-N), and biological organic matter (BOD_5) were significant ($p<0.05$) (Table 4) between the wet and dry seasons in the Lake Koka. For lake Koka, only the concentration of EC, $PO_4$3-P (during the dry season), NO_3-N; and the values of temperature and pH weren't exceeded the WHO standard value. In this regard, Lake Ziway showed similarity except on the concentration of EC, which exceeded the WHO standard value (Table 3).

Table 2. Average physico-chemical parameters of Lake Koka water during wet and dry season

Lake Ziway	**Season**								**WHO Stand**
	wet				**Dry**				
Parameters	**SZ_1L**	**SZ_2M**	**SZ_3H**	**SZ_4G**	**SZ_1L**	**SZ_2M**	**SZ_3H**	**SZ_4G**	
Cr	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Pb	ND	ND	ND	ND	0.69	0.68	0.69	0.71	0.05
Cd	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Zn	0.05	0.10	0.08	0.04	0.59	0.38	0.57	0.53	0.01
Cu	ND	ND	ND	0.01	ND	ND	ND	ND	2
EC	347.3	315	289	284.4	337.3	306	283.6	280.4	300
PO_4^{3}-P	24.7	17.1	13.1	28.8	0.6	0.60	0.8	0.8	5
NO_3-N	15.3	27.0	36.6	18.2	8.4	9.5	9.6	7.3	50
COD	312	379	344	330.3	260	192	203	229	4.5
BOD_5	6.4	7.8	9.7	11.2	18.3	11.7	15.2	16.7	2
pH	6.5	6.0	6.0	7.8	6.0	5.9	5.5	7.9	6.5-8
T	25.5	25.5	26.5	23	26	28.3	29	23	30

ND-Not detected indicates below the detection level; except pH, physico-chemical parameters are in mg/L

Table 3. Average physico-chemical parameters of Lake Ziway water during wet and dry season

Lake Koka	Season								**WHO Stand**
	Wet				Dry				
Parameters	**SK_1L**	**SK_2M**	**SK_3H**	**SK_4G**	**SK_1L**	**SK_2M**	**SK_3H**	**SK_4G**	
Cr	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Pb	ND	ND	0.08	ND	0.49	0.66	0.56	0.56	0.05
Cd	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Zn	0.18	0.03	0.02	0.19	0.34	0.45	0.37	0.72	0.01
Cu	0.07	0.04	0.03	0.07	ND	ND	ND	ND	2
EC	335.1	309	290.9	276.3	330.1	291	281.9	274.3	300
PO43-P	16.1	16.2	24.8	29.1	3.2	1.5	0.9	4.5	5

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NO3-N	22.2	23.6	14.1	21.1	8.3	10.8	10.6	7.6	50
COD	291.0	263	333.7	323	246	536	264	305	4.5
BOD5	8.4	7.5	9.6	8.1	26.25	37.5	22.5	31.5	2
pH	6.9	5.9	5.1	7.5	6.9	5.5	5.6	7.6	6.5-8
T	28.5	28.5	29.5	25	27	28	29	26	30

ND-Not detected indicates below the detection level; except pH, physico-chemical parameters are in mg/L

As indicated on the results the variation in the concentration of heavy metals Pb, and Zn, nutrients (PO_4^{3}-P, NO_3-N), and biological organic matter (BOD_5) were significant ($p<0.05$) (Table 4) between the wet and dry seasons in the Lake Koka. Considering the heavy metals analyzed, Pb and Zn were detected in all sampling sites, while Cr and Cd were not detected in the two lakes (Table 2 and Table 3). Heavy metals in water bodies are insignificant in non-polluted environments. However, heavy metals major contributor to surface water could be geogenic origin or anthropogenic activities namely industrial, mining, sewage, and agricultural sources [36]. According to Gimeno-García et al., (1996), Pb and Zn were main components of superphosphate fertilizers, and pesticides. The mean level of Pb and Zn (Table 4) in Koka and Ziway were significantly lower compared to the mean Pb levels (0.31–1.36 mg/L) Zn levels (0.46–1.56 mg/L) in Awash river and this similarity reported by Eliku & Leta, (2018). The current mean levels of the heavy metals observed is quite higher than their concentration compared to the nearby Awash river concentration levels as reported by Teklay & Amare, (2015). The variation in the levels of the concentrations may be due to the increment of the economic activities around the two lakes. Agricultural activities and animal manure waste caused the variation of the nutrient (NO_3-N and PO_4^{3}-P) concentration during wet and dry season [41]. In both lakes, Zn mean concentration during the wet and dry season observed exceeding it's the threshold limit concentration in drinking water settled by WHO. As indicated in Table 2 and Table 3, Pb concentration was exceeding the settled standard level during the dry season of the year in both lakes. Moreover, EC, COD and BOD recorded were above the standard level in both lakes. Nitrate, pH, and temperature were within the allowable level by WHO. In both lakes the phosphate above the standard limit were observed during the wet season, which might be due to the application of phosphate based inorganic fertilizers in the agricultural field around these lakes. However, according to Gizaw et al., (2021), phosphate concentration exceeding 0.01 mg/L and nitrate concentration exceeding 10 mg/L could cause eutrophication of lakes. Despite COD in lake Ziway, this study reveals that there were not significant ($p > 0.05$) variation in concentrations of Cu, EC, pH, and temperature between wet and dry seasons in both lakes (Table 4).

Table 4. ANOVA relation of physico-chemical parameters of Lake Koka and Ziway water during wet and dry season

Lakes	Parameters	Wet		Dry		ANOVA
		Mean	**SD**	**Mean**	**SD**	**Seasonal**
Koka	Cr	NA	NA	NA	NA	NA
	Pb	0.02	0.045	0.567	0.071	*0.000
	Cd	NA	NA	NA	NA	NA
	Zn	0.105	0.095	0.47	0.173	*0.01
	Cu	0.07	0.077	0	0.000	0.132
	EC	302.85	25.319	294.35	24.791	0.648
	PO_4^{3}-P	21.55	6.478	2.52	1.637	*0.001
	NO_3-N	20.25	4.226	9.32	1.616	*0.003
	COD	302.67	32.073	337.75	134.453	0.630

	BOD_5	8.4	0.883	29.44	6.520	*0.001
	pH	6.35	1.063	6.4	1.025	0.948
	T	27.87	1.97	27.5	1.29	0.761
Ziway	Cr	NA	NA	NA	NA	NA
	Pb	0	0	0.69	0.01	*0.000
	Cd	NA	NA	NA	NA	NA
	Zn	0.067	0.032	0.52	0.095	*0.000
	Cu	0.01	0.020	0	0	0.356
	EC	308.92	28.91	301.85	26.23	0.729
	PO_4^{3}-P	20.925	7.121	0.7	0.114	*0.001
	NO_3-N	24.275	9.605	8.7	1.080	*0.018
	COD	341.32	28.33	221	30.28	*0.001
	BOD_5	8.77	2.11	15.47	2.82	*0.01
	pH	6.57	0.85	6.32	1.07	0.727
	T	25.12	1.49	26.32	2.53	0.45

NA-Not analyzed, SD-standard deviation, *$p < 0.05$-significant

3.2 The effect of water hyacinth on the physico-chemical levels of pollutants in the Lakes

As depicted in Table 5 and Table 6, the variation of Zn concentration between low, medium and high level water hyacinth infested were significant (p<0.05) in both lakes. Other heavy metals namely Cr, Pb, Cd and Cu were not detected in the presence of water hyacinth despite the concentration of Pb, Cd and Cu in some sites of the two lakes (Table 5, and Table 6). This observation demonstrated that water hyacinth has significant effect in removing heavy metals from water during wet and dry seasons. Many researchers reported that water hyacinth has the capacity to take up heavy metals (Pb, Cr, Cd, Zn, and Cu) nutrient (NO_3^-, PO_4^{3-}), pH, organic and inorganic matters (COD, BOD_5) from lake water. For instance, Liao & Chang, (2004) looked at the water hyacinth's capacity to absorb and transport the heavy metals Cd, Pb, Cu, Zn, and Ni in the order of Cu>Zn>Ni>Pb>Cd. Phyto-remedial capability of water hyacinth for heavy metals namely Pb, Cd, Hg and Zn scavenging also demonstrated by Sasidharan et al., (2013). similar results also reported by Kumar et al.,(2021). Moreover, the ANOVA values for physico-chemical levels of EC, BOD, COD, nitrate and phosphate were found to be significant (p<0.05) for the different water hyacinth levels in the lake. This also demonstrated the capacity of water hyacinth towards the absorbance of aforementioned pollutants [44]. Quite similar result with present observation was reported by treating wastewater from mining using water hyacinth constructed wetland and reported water hyacinth as the most efficient plant at removing phosphorus, COD, and EC with removal rates of 97.3 %, 70.5 %, and 22.2 %, respectively [46]. Despite lake Ziway, significant variation (p<0.05) in pH was observed for lake Koka. Moreover, the variation of temperature at different levels of water hyacinth was observed statistically significant (p<0.05) in lake Ziway. This might be due to the shading of the water hyacinth biomass from the direct sunlight during dry season, which causes to raise surface water temperature.

Table 5. ANOVA the effect of water hyacinth on the physico-chemical levels of pollutants during wet and dry season at Lake Koka

Lake	Parameter	SK_1L		SK_2M		SK_3H		ANOVA
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	spatial
Koka	Cr^W	NA	NA	NA	NA	NA	NA	NA

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Cr^D	NA	NA	NA	NA	NA	NA	NA
Pb^W	0	0	0	0	0.083	0.101	0.211
Pb^D	0.497	0.108	0.66	0.044	0.56	0.036	0.075
Cd^W	NA	NA	NA	NA	NA	NA	NA
Cd^D	NA	NA	NA	NA	NA	NA	NA
Zn^W	0.173	0.006	0.02	0.000	0.027	0.006	*0.000
Zn^D	0.347	0.006	0.457	0.012	0.37	0.030	*0.001
Cu^W	0.04	0.010	0.037	0.006	0.04	0.000	0.786
Cu^D	NA	NA	NA	NA	NA	NA	NA
EC^W	335.00	4.58	309.00	3.61	291.00	2.000	*0.000
EC^D	330.00	3.46	291.00	1.73	282.00	1.000	*0.000
$PO_4^{3-}\text{-}P^W$	3.17	0.18	0.93	0.01	1.47	0.017	*0.000
$PO_4^{3-}\text{-}P^D$	16.13	0.06	16.20	0.17	24.73	0.058	*0.000
$NO_3\text{-}N^W$	22.17	0.15	23.60	0.20	14.13	0.404	*0.000
$NO_3\text{-}N^D$	8.30	0.20	10.80	0.00	10.57	0.058	*0.000
COD^W	291.00	2.00	263.00	1.00	333.67	3.215	*0.000
COD^D	246.00	0.00	535.67	0.58	263.67	0.577	*0.000
BOD_5^W	8.33	0.15	7.50	0.10	9.60	0.361	*0.0001
BOD_5^D	26.25	0.25	37.50	0.10	22.50	0.100	*0.000
pH^W	6.43	0.40	5.87	0.12	5.10	0.100	*0.002
pH^D	6.83	0.06	5.37	0.15	5.40	0.346	*0.0002
T^W	28	1.000	28.5	0.500	29.33	0.577	0.155
T^D	27	1.000	28	0.000	28.67	1.155	0.145

Table 6. ANOVA the effect of water hyacinth on the physico-chemical levels of pollutants during wet and dry season at Lake Ziway

Parameter	SZ_1L		SZ_2M		SZ_3H		ANOVA spatial
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Cr^W	NA	NA	NA	NA	NA	NA	NA
Cr^D	NA	NA	NA	NA	NA	NA	NA
Pb^W	NA	NA	NA	NA	NA	NA	NA
Pb^D	0.693	0.067	0.687	0.045	0.697	0.025	0.968
Cd^W	NA	NA	NA	NA	NA	NA	NA
Cd^D	NA	NA	NA	NA	NA	NA	NA
Zn^W	0.05	0.000	0.107	0.001	0.07	2E-02	*0.0017
Zn^D	0.59	0.000	0.377	0.001	0.57	2E-02	*0.000
Cu^W	NA	NA	NA	NA	NA	NA	NA
Cu^D	NA	NA	NA	NA	NA	NA	NA
EC^W	347.33	4.16	315.33	4.04	289.00	1.000	*0.000

EC^D	337.33	4.16	306.33	5.51	283.67	5.508	*0.000
PO_4^{3-}-P^W	0.64	0.02	0.60	0.01	0.79	0.020	*0.000
PO_4^{3-}-P^D	24.73	0.06	17.10	0.00	13.13	0.058	*0.000
NO_3-N^W	15.27	0.38	26.97	0.35	36.63	1.159	*0.000
NO_3-N^D	8.40	0.20	9.53	0.06	9.60	0.000	*0.000
COD^W	312.33	1.16	378.67	2.52	344.00	53.703	0.102
COD^D	260.00	2.65	192.00	2.00	203.00	0.000	*0.000
BOD_5^W	6.40	0.46	7.87	0.15	9.70	0.100	*0.000
BOD_5^D	18.30	0.20	11.70	0.00	15.13	0.058	*0.000
pH^W	6.83	0.29	6.00	0.50	6.00	0.866	0.226
pH^D	6.07	0.31	5.87	0.12	5.33	0.416	0.061
T^W	25.33	0.29	25.33	1.16	26.67	0.289	0.096
T^D	25.50	0.50	27.33	0.58	28.83	0.764	*0.002

NA-Not analyzed, SD-standard deviation, *$p < 0.05$-significant, ^{W}-wet, ^{D}-dry

3.3 Comparison of the physico-chemical levels of pollutants in the Lakes at the lake covered by water hyacinth and any other native grasses

As indicated in Table 7, Cr and Cd were not detected in both lakes infested by water hyacinth and other grasses. Regardless of water hyacinth and other grasses, Cu was also not detected in Lake Koka during dry season and both during wet and dry seasons in Lake Ziway. Lowest mean Zn concentration (0.39 mg/L) was recorded during the dry season for samples collected from water hyacinth infested compared to the samples collected from the other grasses infested sites (0.72 mg/L) in Lake Koka. Moreover, lower mean phosphate concentration during wet and dry season and lower mean nitrate concentration only at dry season were observed and their variation significance were supported ANOVA value indicated in Table 5 and Table 6. Lowest mean heavy metal, phosphate and concentration nitrate concentration implies that water hyacinth infested lake absorbs more heavy metal like Zn and nutrients (phosphate and nitrate) compared to other grasses infested sites in Lake Koka. In Lake Koka significant pH and temperature variation were significantly observed between water hyacinth and other grasses infested sites. Despite Zn, and BOD_5 concentration, shown trend for the Lake Ziway and the were reported by reported by Sidek et al., (2018) and Getnet et al., (2020).

Table 7. ANOVA for the comparison of the physico-chemical levels of pollutants in the Lakes at the lake covered by water hyacinth and other grasses

Lake	Parameter	Hyacinth infested		Other native grasses covered the lake		ANOVA
		Mean	SD	Mean	SD	
Koka	Cr^W	NA	NA	NA	NA	NA
	Cr^D	NA	NA	NA	NA	NA
	Pb^W	NA	NA	NA	NA	NA
	Pb^D	0.57	0.1	0.54	0	0.586
	Cd^W	NA	NA	NA	NA	NA
	Cd^D	NA	NA	NA	NA	NA
	Zn^W	0.08	0.1	0.19	0	0.094
	Zn^D	0.39	0	0.72	0	*0.001
	Cu^W	0.05	0	0.07	0	0.099

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	Cu^D	NA	NA	NA	NA	NA
	EC^W	311.67	22.12	276.33	NA	0.054
	EC^D	301.00	25.51	274.33	3.51	0.147
	PO_4^{3}-P^W	1.87	1.19	4.51	0.14	*0.019
	PO_4^{3}-P^D	19.03	4.99	29.13	0.00	*0.025
	NO_3-N^W	19.93	5.19	21.07	0.30	0.725
	NO_3-N^D	9.90	1.39	7.60	0.00	*0.046
	COD^W	295.67	35.23	323.33	1.15	0.246
	COD^D	348.67	162.48	303.33	3.05	0.654
	BOD_5^W	8.50	1.05	8.13	0.00	0.580
	BOD_5^D	28.73	7.81	31.47	0.00	0.577
	pH^W	5.97	0.90	7.43	0.00	*0.048
	pH^D	6	0.78	7.4	0.20	*0.040
	T^W	28.83	0.57	25.00	1.00	*0.005
	T^D	28.00	1.00	25.67	0.57	*0.025
Ziway	Cr^W	NA	NA	NA	NA	NA
	Cr^D	NA	NA	NA	NA	NA
	Pb^W	NA	NA	NA	NA	NA
	Pb^D	0.69	0	0.71	0	0.101
	Cd^W	NA	NA	NA	NA	NA
	Cd^D	NA	NA	NA	NA	NA
	Zn^W	0.077	0.031	0.043	0	0.089
	Zn^D	0.513	0.114	0.507	0	0.926
	Cu^W	NA	NA	NA	NA	NA
	Cu^D	NA	NA	NA	NA	NA
	EC^W	317.00	29.05	284.33	0.57	0.123
	EC^D	309.00	26.63	280.33	0.57	0.136
	PO_4^{3}-P^W	0.667	0.11	0.770	0.00	0.200
	PO_4^{3}-P^D	18.30	5.89	28.77	0.00	*0.037
	NO_3-N^W	26.3	10.67	18.2	0.30	0.259
	NO_3-N^D	9.17	0.66	7.30	0.10	*0.009
	COD^W	345.00	33.51	330.33	1.53	0.491
	COD^D	218.33	36.50	229.00	0.00	0.639
	BOD_5^W	7.97	1.66	11.20	0.10	*0.028
	BOD_5^D	15.07	3.30	16.67	0.00	0.449
	pH^W	6.17	0.28	7.73	0.14	*0.001
	pH^D	5.80	0.26	7.90	0.00	*0.000
	T^W	25.83	0.57	22.67	0.57	*0.003
	T^D	27.43	1.50	23.00	1.00	*0.013

NA-Not analyzed, SD-standard deviation, *$p < 0.05$-significant, ^{W}-wet, ^{D}-dry

4. Conclusion

Despite seasonal fluctuations, significant variations in pollutant physicochemical levels were found in both lakes. Cr and Cd were not detected at both wet and dry season for both lakes. For both lakes Pb were detected mainly during the dry season. Low concentration of Cu (0.03-0.07 mg/L) was detected in the samples collected from Lake Koka. For Lake Koka, only the concentration of EC, PO_4^{3-} (during the dry season), NO_3; and the values of temperature and pH were not exceeded the WHO standard value. In that respect, the concentrations of EC which exceeded WHO standard values were found to be similar in Lake Ziway. In both lakes, the threshold limits concentrations of Zn in drinking water set by WHO were exceeded during the wet and dry seasons. Despite COD in Lake Ziway, this study shows no significant ($p > 0.05$) variation in Cu, EC, pH and temperature between wet and dry seasons in either lake. This observation demonstrated that water hyacinth has significant effect in removing heavy metals from water during wet and dry seasons. Moreover, the ANOVA values for physico-chemical levels of EC, BOD, COD, nitrate and phosphate were found to be significant ($p<0.05$) for the different water hyacinth levels in the lake. This also demonstrated the capacity of water hyacinth towards the absorbance of water pollutants. Lowest mean heavy metal, phosphate and concentration nitrate concentration implies that water hyacinth infested lake absorbs more heavy metals and nutrients (phosphate and nitrate) compared to other grasses infested sites in Lake Koka and Lake Ziway. In both the wet and dry seasons, it was found that the water hyacinth had a substantial impact on the physicochemical levels of pollutants in the lakes.

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Conflict of interest
There is no conflict of interest related to this work.

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