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The Role of GIS in Monitoring the Impacts of Climate Change and Heavy Metals Contamination on Water Quality in Eleyele Lake, Southwestern Nigeria

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ABSTRACT

A vital source of water, lakes are negatively impacted by pollutants such as heavy metals from industrial, agricultural, and urban processes, as well as the effects of climate change. Potential pollution-related health issues like cancer and infectious diseases may result from this. To assess the degree of pollution on water quality and its impact on human health, this study utilized GIS software, specifically ArcMAP, to analyze the spatial distribution of physical, chemical, and heavy metal concentrations in the water from Eleyele Lake in Ibadan, Nigeria. Using accepted techniques, the physical and chemical characteristics of the lake water, as well as the presence of heavy metals, were assessed at nineteen distinct locations throughout the study area. Water pH ranged from 7.8 to 8.1, while electrical conductivity ranged from 90 to 199 µs/cm3, and total dissolved solids ranged from 57 to 127 mg/L. Nitrate and sulfate ranged from (1.61–47 and 0.1–3.67 mg/L). The concentrations of Cr and Cd range from (0.011-0.09 mg/L) and (0.001-0.019 mg/L), respectively. Zn and Ni ranged from (0.04-2.55 mg/L and 0.03-1.36 mg/L) while Pb concentration ranged from 0.002-0.03 mg/L. All determined physico-chemical parameters were within permissible levels, while 85% of the heavy metals' concentrations were higher than permissible levels. A high concentration of heavy metals poses serious health risks to the population that depends on the lake as a source of domestic water and its aquatic organisms. Some of the heavy metals show a negative correlation with the physico-chemical parameters. This reflects different sources and controlling processes. The results show the water samples from the selected areas within Eleyele Lake were contaminated with heavy metals, with fewer climate change impacts. Efforts are needed to reduce anthropogenic influence on the lake through strict environmental controls. Also, to protect public health and water quality in the area, given the persistent and changing nature of industrial pollution.

Keywords: Heavy Metals; Climate Change; Geographic Information Systems; Contamination; Water Quality; Eleyele Lake; Physico-Chemical Parameters; Spatial Distribution; Public Health; Southwestern Nigeria.

1. Introduction

Water is a vital natural resource that is essential to humans and other living creatures (Atangana and Oberholster, 2021; Aiyelokun et al., 2017; Ravindra, 2022; Edokpayi, 2020). The blue, green, and grey water footprint, as well as the green water footprint, are essential resources utilized for human consumption, agricultural practices, industrial applications, livestock farming, mining activities, and biodiversity sustenance (Carrard et al., 2019; Tortajada, 2018). The main unprecedented pressures on groundwater resources, which can affect water quality, are climate change, rapid population growth, urbanization, agricultural use, Persistent Organic Pollutants (POPs), plastic pollution, industrialization, microbial contamination, heavy metal effluent discharge into nearby reservoirs, solid waste disposal (Akhtar et al., 2021; Atangana and Oberholster, 2021; Zakir, 2020; Olasoji, 2019), biomedical waste discharge, and unsustainable development activities (Ahamad et al., 2021; Kim et al., 2019).

The recent worldwide water crisis has demonstrated that climate change poses a greater threat than we had realized, with significant effects on the water cycle and life and sustainable development (Zhang et al. 2023; Ma, 2020). We are now living in a period of climate anomaly. But this is the new normal. Recent years have seen a rise in water pollution, highlighting the need for tools that can uniquely forecast future trends and potential water quality changes in the face of the continuous threat of climate change. According to previous research, climate change would cause higher local temperatures and more frequent/intense rainfall, which would result in increased nutrient loading and suspended solids discharge into water bodies (Rachmadi et al. 2020; Tonni, 2024; Cardoso, 2020). Climate change impacts on freshwater ecosystems may be brought about by changes in water quality coupled with rising atmospheric temperatures (Amanambu, 2020; Armitage, 2020b). Therefore, anticipated shifts in worldwide rainfall and air temperature may have an impact on river flows, resulting in mobility and dilution of pollutants. Conversely, rising water temperatures can have an impact on the kinetics of chemical reactions, resulting in deterioration in the quality of the water and the condition of the freshwater ecology (Petpongpan, 2020; Caretta, 2022; Abedin, 2019; Khaniya, 2021; Mafimisebi, 2024). Many authors have examined the effects of climate change on environmental chemical pollutants (Salila et al., 2020; IPCC, 2022; Muhammad et al., 2024; Aerts et al., 2020; Bodansky, 2021; De Wit, 2021). In addition to the persistence and movement of chemical contaminants in the environment, climate change variables also affect the responses, fate, and bioaccumulation of environmental pollutants. Rising temperatures may cause toxic chemical pollutants to be released, broken down, transported, and mobilized at a faster rate, which could increase their exposure to the environment and humans (Shiv, 2024; Anetor, 2022; Anik, 2023; Babuji, 2023).

Because these potential toxicants have wide sources, a very long biological half-life, and are accumulative and indestructible, the presence of heavy metals has become a contemporary global issue (Khatri et al., 2020; Rahman et al., 2020; Ganiyu et al., 2021; Varol et al., 2022). Several self-cleaning methods cannot remove metals from the water system, resulting in geo-accumulation, bioaccumulation, and biomagnification (Anandkuma, 2019; Zhang, 2023; Qin, 2022). Since they significantly affect the quality of water, a few pollutants, including organic, inorganic, heavy metals, POPs, and emerging contaminants, have become a global concern in the last few decades as water use has increased dramatically (Singh et al., 2024; Rahman et al., 2019; Zhang, 2023; America, 2024). Even though heavy metals exist in nature, their excessive use and discharge of raw wastewater from many tanning, leather, and chemical industries have caused serious ecological harm (Kinuthia, 2024; Ternes, 2015; Camilo, 2021). The heavy metals that are released enter aquifers, dissolve in water, and quickly build up in different organs of aquatic species, like fish, crabs, and prawns, before being absorbed by humans, the apex consumers (Hama, 2023; Zaynab, 2022; Sharma, 2023). The buildup of heavy metals in water and food items causes several issues and disrupts their physiological functions (Garai, 2021; Isangedighi, 2019; Sonone, 2020; Sharma, 2025). According to WHO standards (World Health Organization, 2017), Ba, As, Cd, Cr, Co, Pb, Hb, Se, and V are extremely harmful heavy metals that are not absorbed by any organism, even at a microscopic level (Ray, 2024; Emenike, 2022). However, necessary elements like Fe, Cu, Zn, Mg, Mg, and other beneficial metals have positive effects on human health at low concentrations but can be harmful at high concentrations (Saikat, 2022; Balali-Mood, 2021; Achmad, 2017; Jomova, 2025; Angrand, 2022). The severity of metal toxicity results in carcinogenic, teratogenic, genotoxic, and mutagenic consequences in humans, according to Alvarez et al. (2021). In addition, there are over 50 heavy metals that have been classified, but 17 of them are especially worrisome because of their extreme toxicity and availability, even at low amounts (ATSDR, 2023). The spatial interpolation of pollutants has been understood, and contamination hotspots have been mapped thanks to the use of geographic information systems and principal component analysis (Abdur et al., 2025; Kluska et al., 2024; Cukrov, 2024). Even with these advancements, ongoing monitoring and more thorough research are still necessary to protect public health and water quality in the area, given the persistent and changing nature of industrial pollution.

Water bodies, such as lakes, have a significant socio-economic and bio-aesthetic value (Jose, 2020; Sharma, 2023). They are a reservoir of water containing a wide variety of fish food, which are vital resources for supporting the development of any country. Nigeria is one of the tropical nations that is fortunate to have many renewable natural resources, such as freshwater supplies. One of them is the Eleyele reservoir in Southwestern Nigeria. The 100 square kilometer area of the catchment, which includes the reservoir, is a changed form of natural wetland (Tijani, 2010). The Eleyele reservoir, built in 1942, is a crucial component of the natural heritage that has been extensively used by the population of Ibadan and its surrounding area for many years. It is one of the most significant lake systems in Nigeria's Southwest, providing nursery and reproductive habitat for a wide range of fish species (Ayoade, 2022). Additionally, the Oyo State Water Corporation abstracts the reservoir at the Eleyele Treatment Works to process and distribute potable water to the residents of Ibadan (Awomeso, 2014). As a result, the reservoir is mainly used for flood management, household water supply, and fishery development.

Unfortunately, pollution caused by household waste, industrial wastewater, agricultural runoff, and poor fishing practices is quickly destroying the Eleyele reservoir. Ajani et al. (2004) claim that the unrestricted way agricultural, industrial, and domestic effluent is discharged into natural water bodies has led to significant contamination of the reservoir. The Eleyele lake in northwest Ibadan is now thought to be affected by chemical and pesticide runoff from agriculture, effluents from aquaculture, solid waste from residential areas, and artisanal fishermen killing young fish. This issue occurred when Ibadan experienced a population boom that resulted in rapid industrialization and urbanization.

1.1. Study Objectives

This study aims to contribute to the existing knowledge on water quality assessment and provide valuable insights for policymakers, researchers, and stakeholders involved in water resource management and environmental protection.

Thus, the objective of this study is as follows:

1) To examine the heavy metal contamination of Eleyele Lake.
2) To examine if the water from the lake is good for domestic purposes.
3) To analyze high and low polluted areas within the Eleyele Lake through spatial distributions.
4) To evaluate the influence of climate change on the lake through its physical and chemical properties.
5) To assess the importance of GIS in the continuous monitoring of water quality in the study area.

2. Material and Method

2.1. Description of the Study Area

Lake Eleyele is located in Nigeria's Oyo State, northwest of Ibadan, at a height of 125 meters above sea level and between 7°25'00' and 7°26'30'N latitude and 3°51'00' and 3°52'30'E, as shown in Figure 1. The lake is artificial, created in 1939 by the construction of a dam across the Ona River, which is a component of a vast network of inland waterways that drains south into the Lagos Lagoon. Additionally, the Otaru, Awba, Yemoja, and Alapo streams all empty into it. The reservoir, which serves the city of Ibadan in southwest Nigeria, has a catchment area of approximately 323.8 km^2, an impoundment area of 156.2 hectares, and a storage capacity of 29.5 million liters of water. Ibadan is the largest precolonial metropolis in Nigeria and Sub-Saharan Africa. In Africa, it ranks fourth behind Cairo, Lagos, and Johannesburg. Ibadan had a total population of 1.3 million in 1991 and is expected to grow to 3.649 million by 2025, assuming an 8% annual growth rate. However, the city's growth is primarily due to its long-standing role as a regional administrative center since the colonial period, combined with significant rural-urban migration, and has little to do with industrialization.

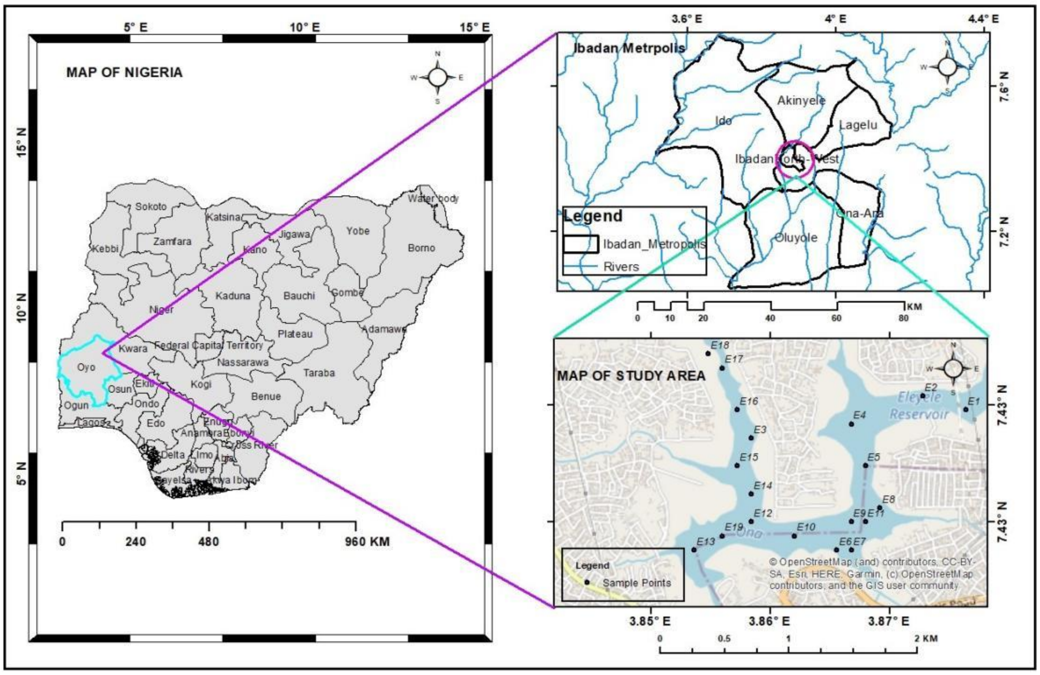

Figure 1. Map showing the sampling points in the study area

2.2. Geology and Geomorphology of the Study Area

The Precambrian basement complex, spanning most of the study area, consists of quartzite, schist, biotite, and biotite-hornblende gneiss (migmatite) (Fig. 2). Most of the visible ridges are significantly worn down, with quartz schist making up around 60% of the research area. Minerals with jointed and fractured structures that have medium to coarse grains include feldspar, quartz, and mica. Tijani et al. (2004) describe Ibadan's hilly landscape as "quartzite ridges and gneiss Inselbergs encircled by adjacent plains." Eleyele Lake, located in southwestern Nigeria, has a peculiar bimodal climate with rainy and dry seasons. The rainy season lasts from March to October, with an average annual rainfall of around 1,250 mm. In contrast, the dry season, known as the harmattan, lasts from November to February and is distinguished by significantly less precipitation. The lake is surrounded by Apete to the north, Olopemewa to the south, and Ijokodo and Awotan to the northwest. It is principally supplied by the Ona and Alapata rivers, which form a dendritic drainage pattern throughout the basin. Geophysical research suggests that the Eleyele area's subsurface is made up of layers of topsoil, laterite, sandy clay, and ancient crystalline bedrock. Despite its geological sturdiness, the basin is increasingly vulnerable to environmental stressors. Numerous litter dumps distributed throughout the catchment region pose a considerable risk, especially during the peak rainy season, as they can leach heavy metals and other contaminants into the lake. Concerns about the lake's

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water quality and quantity are growing due to a variety of issues. These include population growth, rapid urbanization, industrial development, and over-exploitation of water and fish resources. As a rather small reservoir, Eleyele Lake is especially sensitive to anthropogenic stresses, needing immediate attention to sustainable watershed management (Akinyemi et al., 2014).

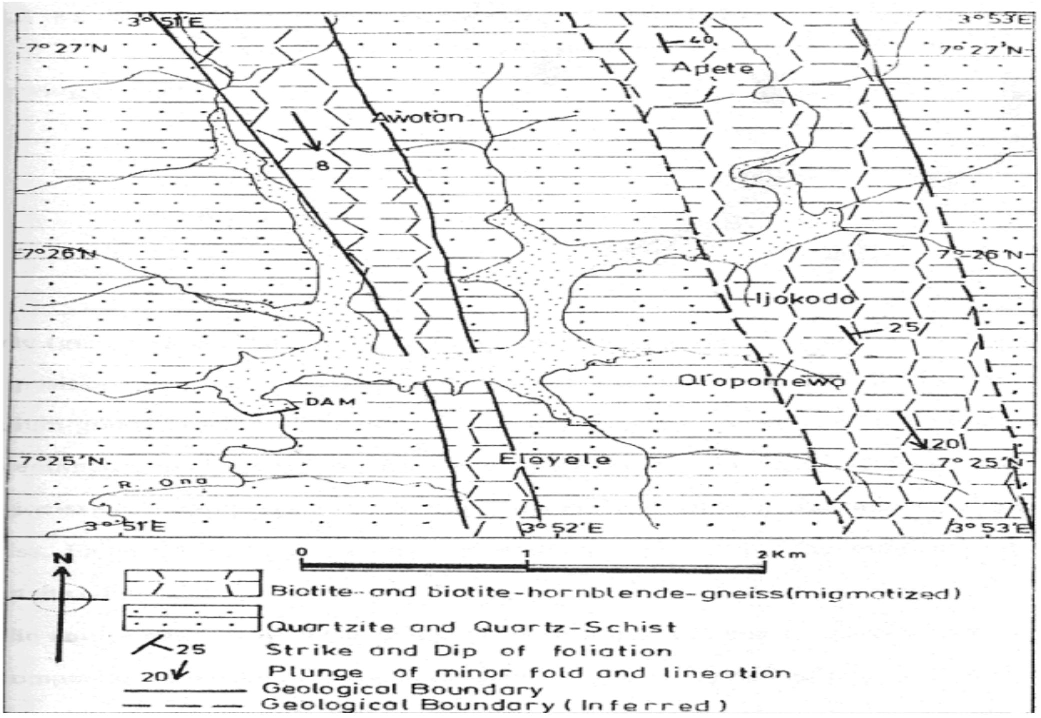

Figure 2. Geological Map of the Study Area

3. Results and Discussion

3.1. Sampling and Analysis

GPS was utilized to gather nineteen (19) water samples from Eleyele Lake. To guarantee an airtight seal and prevent air from becoming trapped in the bottles' tops, each water sample was collected in a new, opaque plastic bottle with a volume of 500 ml and immediately corked. Before sampling, the bottles were thoroughly cleaned with a detergent solution and treated with a 10% v/v nitric acid solution overnight. Following that, the bottles were repeatedly cleaned with deionized water until they were acid-free and air-dried. During sampling, each bottle was cleaned at least four times with sampling water before being collected in pairs and labeled appropriately. The specimens were collected manually in compliance with the American Public Health Association's (APHA 2012) sampling guidelines. Metal analysis samples were promptly acidified with strong nitric acid (1 mL) to prevent metal loss due to precipitation or absorption, whereas physicochemical and anion analysis samples were not acidified. The laboratory received all the samples at once, utilizing an ice transporter. The specimens were stored in the refrigerator at 4°C until analysis. The physicochemical properties of the samples were immediately determined at the collection sites. A calibrated thermometer was used to measure the water temperature. pH, EC, and TDS were measured using a portable Multiparameter meter calibrated with traceable standards (Model: SensionTM156, HACH, USA). The samples for NO_3^- and SO_4^{2-} were analyzed using an Ion Chromatograph (Model: 10 AD, SHIMADZU, Japan).

3.2. Physico-Chemical Properties of Eleyele Lake Water Quality

NO3–Results of the physical properties of groundwater samples are given in Table 1 and Figure 3a. For the water sample, pH, EC, and TDS ranged from 7.8 to 8.1 (Average, 7.93); 90 to 199 µScm-1 (Average, 123.2 µScm-1); 57.6 to 127.4 mgL-1 (Average, 76.71 mgL-1), respectively. For the chemical properties, the concentrations of NO_3^- and SO_4^{2-} in water samples ranged from 1.61 to 47.0 mgL-1 (Average, 7.88 mgL-1), and 0.10 to 3.67 mgL-1 (Average, 0.38 mgL-1), respectively. Physico-Chemical characteristics of all samples revealed that the water of the study area is of good quality for drinking and other domestic purposes.

Table 1. Summary of physico-chemical characteristics of the study area water samples

Sample No.	Lat	Long	pH	EC (µScm)	TDS (mg\L)	NO_3^- (mg\L)	SO_4^{2-} (mg\L)
E1	7.433	3.872	8.1	114	72.9	2.83	0.23
E2	7.434	3.869	8	121	77.4	1.61	0.34
E3	7.431	3.857	7.9	118	75.5	14.2	0.1
E4	7.432	3.864	7.9	90	57.6	5.03	0.1
E5	7.429	3.865	7.9	110	70.4	10.8	0.1
E6	7.423	3.863	7.8	114	73	8.66	0.1
E7	7.423	3.864	7.8	156	99.8	11.2	0.1
E8	7.426	3.866	7.8	199	127.4	21.3	0.1
E9	7.425	3.864	8.1	117	74.9	2.43	0.25
E10	7.424	3.86	8	112	71.7	5.98	0.1
E11	7.425	3.865	8	106	67.8	4.56	0.55
E12	7.425	3.857	8	107	68.5	1.94	0.1
E13	7.423	3.853	7.9	97	62.1	10.2	0.2
E14	7.427	3.857	7.9	97	88.3	3.85	0.3
E15	7.429	3.856	8	105	67.2	5.7	0.4
E16	7.433	3.856	8	154	98.7	2.39	0.13
E17	7.436	3.855	7.9	102	65.3	47	3.67
E18	7.437	3.854	7.8	122	78.1	4.67	0.1
E19	7.424	3.855	7.8	158	101.1	5.56	0.1
Min	-	-	7.8	90	57.6	1.61	0.10
Max	-	-	8.1	199	127.4	47.00	3.67
Average	-	-	7.93	120.33	76.71	7.88	0.38
WHO limit	-	-	6.5-8.0	1500	1000	50	250

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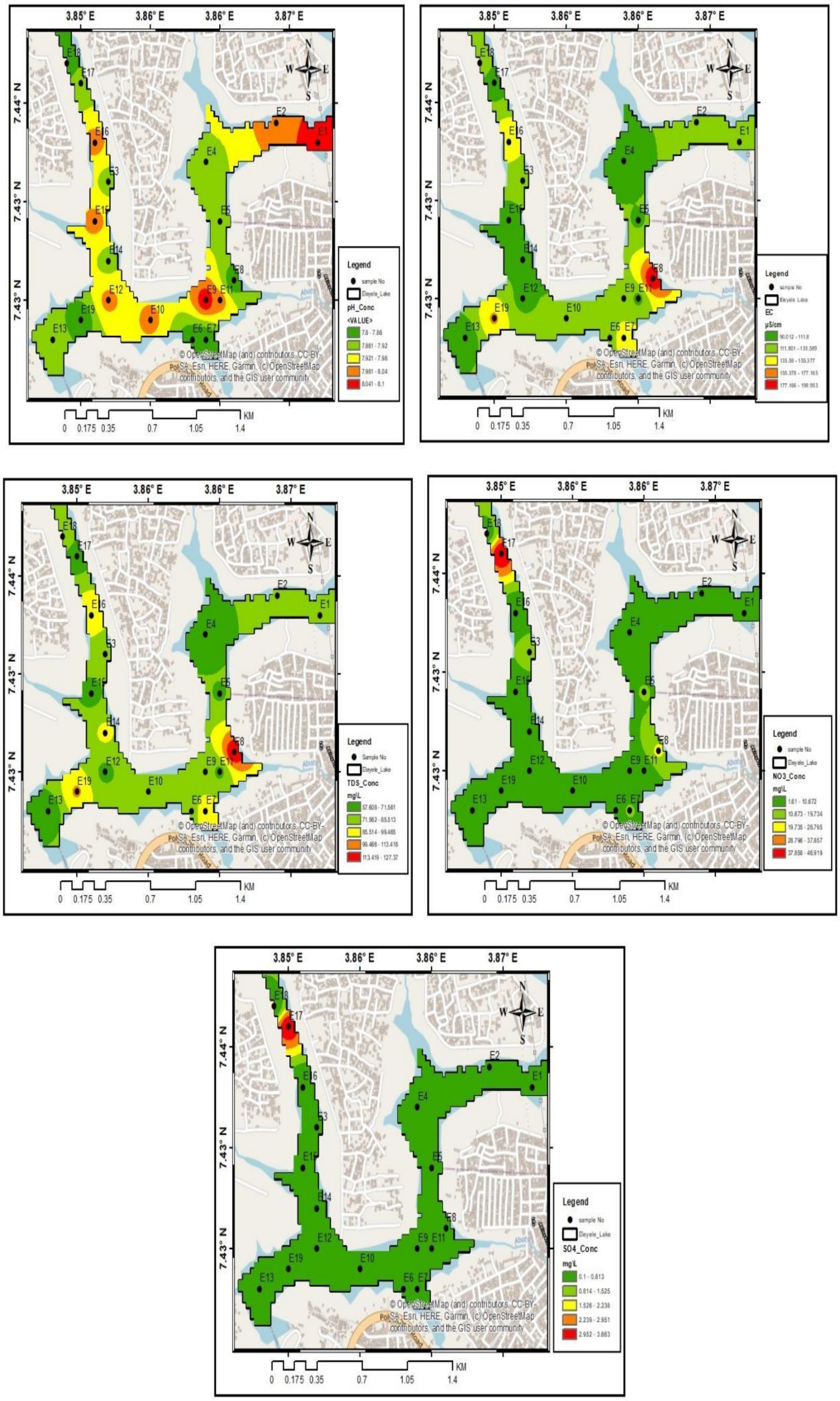

Figure 3a. Spatial distribution of the phyisco-chemical properties in Eleyele lake water samples

3.3. Heavy Metals Concentration in Eleyele Lake Water Quality

The concentrations of heavy metals analyzed in water are shown in Table 2 and Figure 3b. Chromium (Cr^{2+}) concentration was highest in E17 (0.09 mg/L) and lowest in E18 (0.011 mg/L), with an average of 0.046 mg/L. The consumption of contaminated water with chromium causes respiratory problems, skin irritation, and an increased risk of certain cancers, as reported by Georgaki et al. (2023). The highest concentration of cadmium (Cd) was recorded in E15 (0.019 mg/L) and E2 & E12 (0.001 mg/L), with an average of 0.007 mg/L. Water resources with polluted cadmium cause health issues such as kidney damage, bone problems, and increased cancer risk. Christophe et al. (2021) reported that Cd in large concentrations may affect the digestive, immune, and reproductive systems of fish. The average concentration of Cd was higher than the WHO permissible limit of 0.003 mgL-1. Concentration of zinc (Zn) has its highest value in E18 (2.55 mg/L) and lowest in E9 (0.04 mg/L) in the Eleyele lake with an average of 1.062 mg/L. Health issues such as gastrointestinal distress, cardiovascular issues are associated with the intake of zinc-contaminated water reported in the findings of Khan et al. (2023). In the lake of the study area, nickel (Ni), the highest concentration was recorded in E5 (0.03 mg\L) and the lowest in E19 (0.03 mg\L) with an average value of 0.672 mg\L, allergic reactions, skin irritation, and respiratory issues like asthma health issues affect human beings when contaminated water with Ni is consumed (Ali, 2021). There were seasonal variations in lead, with the highest in E17 (0.03 mg/L) and the least in E12 (0.002 mg/L), with an average value of 0.012 mg/L. Water contaminated with lead affects children's development and causes cardiovascular problems in adults (Peter, 2021). The highest concentration of arsenic (Ar) was observed in E10 (0.323 mg/L) and the lowest in E2 (0.005 mg/L). Health challenges such as cancers, skin lesions, cardiovascular issues, and neurological damage usually affect humans when contaminated water with arsenic is consumed (John, 2022). The heavy metals concentration analysis vindicates that both the upstream and downstream of the Eleyele lake are polluted and not safe for human consumption without proper treatment.

Table 2. Summary of heavy metals concentration of the study area water samples

Sample No	Lat	Long	Cr	Cd	Zn	Ni	Pb	Ar
E1	7.433	3.872	0.06	0.005	0.06	0.04	0.005	0.247
E2	7.434	3.869	0.018	0.001	1.73	0.16	0.015	0.005
E3	7.431	3.857	0.052	0.012	0.94	1.03	0.008	0.15
E4	7.432	3.864	0.031	0.011	0.27	0.93	0.02	0.026
E5	7.429	3.865	0.045	0.015	0.13	1.35	0.009	0.1
E6	7.423	3.863	0.03	0.006	0.28	1.07	0.025	0.025
E7	7.423	3.864	0.04	0.002	0.74	0.53	0.012	0.03
E8	7.426	3.866	0.053	0.005	2.55	0.85	0.003	0.042
E9	7.425	3.864	0.03	0.003	0.04	0.36	0.007	0.1
E10	7.424	3.86	0.02	0.011	1.44	1.26	0.013	0.323
E11	7.425	3.865	0.046	0.002	1.01	0.91	0.01	0.118
E12	7.425	3.857	0.02	0.001	1.49	0.84	0.002	0.061
E13	7.423	3.853	0.06	0.016	0.11	1.35	0.018	0.005
E14	7.427	3.857	0.07	0.013	1.44	0.56	0.009	0.134
E15	7.429	3.856	0.06	0.019	0.31	0.74	0.007	0.055
E16	7.433	3.856	0.08	0.005	2.11	0.07	0.015	0.044
E17	7.436	3.855	0.09	0.003	1.58	0.07	0.03	0.005
E18	7.437	3.854	0.011	0.004	2.15	0.081	0.012	0.014

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E19	7.424	3.855	0.059	0.005	0.99	0.03	0.019	0.01
Min	-	-	0.011	0.001	0.04	0.03	0.002	0.005
Max	-	-	0.09	0.019	2.55	1.35	0.03	0.323
Average	-	-	0.046	0.007	1.062	0.672	0.012	0.082
WHO limit			0.05	0.003	3.00	0.07	0.01	0.01

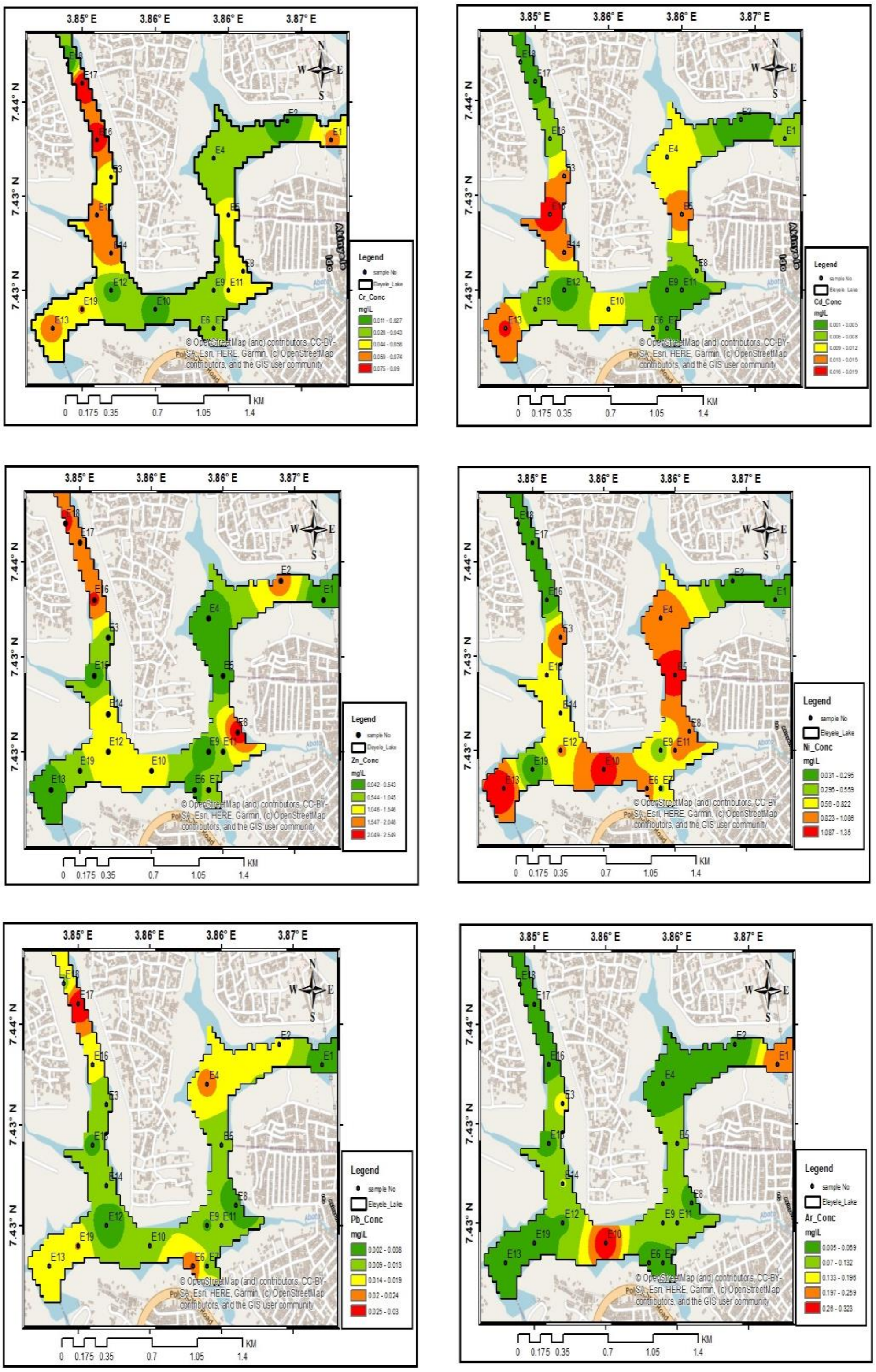

Figure 3b. Spatial distribution of heavy metals concentration in the study area water samples

3.4. Water Correlation

Further to the discussion of the results, the coefficients of correlation were estimated to determine the relationship between the metals and physico-chemical parameters of the water samples. The correlation coefficient values are presented in Table 3. The pH had a positive significant relationship with arsenic (r=0.508). It, however, showed a negative significant correlation with EC (r=-0.386), TDS (r=-0.415), nitrate (r=-0.339), zinc (r=-0.248), nickel (r=-0.119), and lead (r=-0.365). Electrical conductivity revealed a negative significant association with sulfate (r=-0.221), cadmium (r=-0.373), nickel (r=-0.275), lead (r=-0.207), arsenic (r=-0.197), and a very weak correlation with nitrate (r=0.091) and chromium (r=1.00). There exists a positive and significant connection between TDS and zinc (r=0.939; r=0.507), respectively.

Nitrate showed a negative significance with arsenic (r=-0.226), positive significance with sulfate (r=0.841), chromium (r=0.498), zinc (r=0.202), and significant positive correlation with lead (r=0.460). Cadmium (r=-0.051) and nickel (r=-0.039) are weakly associated with nitrate. Sulfate showed a strong positive significance with chromium (r=0.504), and lead (r=0.542). It, however, indicated negative significance for cadmium (r=-0.182), nickel (r=-0.306), and arsenic (r=-0.192). Chromium showed a significant positive correlation between cadmium and lead (r=0.238; r=0.223), respectively, while a positive correlation occurred with zinc (r=0.014). However, a strong negative correlation occurred with nickel (r=-0.229). There exists a positive significant relationship between cadmium and nickel (r=0.571), with arsenic (r=0.192) showing a positive correlation, but showing significant and weak negative correlation with zinc (r=-0.412) and lead (r=-0.049), respectively.

A strong negative correlation was observed between zinc and nickel (r=-0.339), while a negative correlation was observed with lead and arsenic (r=-0.066; r=-0.138). Nickel is positively correlated with arsenic (r=0.231), while it is negatively correlated with lead (r=-0.124). The lead was only negatively associated with arsenic (r=-0.410).

Table 3. Correlation matrix of physio-chemical parameters and heavy metals of Eleyele Lake

Variables	**pH**	**EC**	**TDS**	**NO_3^-**	**SO_4^{2-}**	**Cr**	**Cd**	**Zn**	**Ni**	**Pb**	**Ar**
pH	1	-	-	-	-	-	-	-	-	-	-
EC	-0.386	1	-	-	-	-	-	-	-	-	-
TDS	-0.415	0.939	1	-	-	-	-	-	-	-	-
NO_3^-	-0.339	0.091	0.051	1	-	-	-	-	-	-	-
SO_4^{2-}	0.015	-0.221	-0.231	0.841	1	-	-	-	-	-	-
Cr	0.002	0.100	0.195	0.498	0.504	1	-	-	-	-	-
Cd	-0.036	-0.373	-0.292	-0.051	-0.182	0.238	1	-	-	-	-
Zn	-0.248	0.507	0.560	0.202	0.147	0.014	-0.412	1	-	-	-
Ni	-0.119	-0.275	-0.294	-0.039	-0.306	-0.229	0.571	-0.339	1	-	-
Pb	-0.365	-0.207	-0.251	0.460	0.542	0.223	-0.049	-0.066	-0.124	1	-
Ar	0.508	-0.197	-0.146	-0.226	-0.192	-0.082	0.192	-0.138	0.231	-0.410	1

4. Conclusion

The elevated levels of heavy metals observed in the water from Eleyele Lake may pose a danger to the local population who consume water from the lake. Also, the physico-chemical parameters of Eleyele Lake showed distinct, temporal, and spatial variations throughout the study period. Lake water quality parameters undergo seasonal changes, and values are generally higher during the wet season. The necessary stakeholders must provide a health advisory for the consumption of water and control the increasing encroachment of farming and building activities around the Eleyele Lake area.

We recommend the adoption of an Integrated Water Resources and Environmental Management plan to ensure the overall quality of the ecosystem in the area and safeguard the health of the people. Additional research should be conducted on affected fish tissues, and further studies are needed to assess the effectiveness of drinking water treatment plants that supply drinking water to the public. The results obtained from the present study shall be useful in the future management of Eleyele Lake.

5. Future Recommendations

The following recommendations need to be considered for future purposes:

1) Enforce environmental regulations to control industrial, agricultural, and urban discharges contributing to heavy metal pollution in Eleyele Lake.

2) Issue public health advisories regarding the safety of using water from the lake for domestic purposes, especially in areas with high contamination.

3) Implement spatially guided monitoring by means of GIS tools to identify and manage highly polluted zones within the lake.

4) Regulate land-use activities such as farming and construction around the lake to reduce seasonal pollutant influx and preserve water quality.

5) Promote continuous research and monitoring of both water quality and aquatic organisms, along with regular evaluation of treatment plants supplying drinking water from the lake.

6) Encourage the integration of GIS-based water quality monitoring into regional environmental policy for effective long-term water resource management.

7) Support community education and stakeholder involvement in environmental protection efforts to reduce local sources of pollution and improve conservation awareness.

Further research is needed to deepen the understanding of heavy metal contamination in Eleyele Lake and its broader environmental and health implications. While this study has highlighted the spatial distribution of contaminants and revealed concentrations of heavy metals exceeding permissible limits, the full impact on aquatic life, especially fish species consumed by residents, remains underexplored. Detailed toxicological studies on bioaccumulation in fish tissues would provide insight into the potential for long-term health risks from the food chain.

In addition, future studies should investigate the effectiveness and resilience of existing drinking water treatment facilities, particularly during peak pollution periods such as the wet season when runoff intensifies. Understanding the capacity of these systems to remove or reduce heavy metal concentrations will inform decisions about public water supply safety.

Declarations

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Competing Interests Statement

The author declares no competing financial, professional, or personal interests.

Consent for publication

The author declares that he consented to the publication of this study.

Authors' contributions

Author’s independent contribution.

Availability of data and materials

Supplementary information is available from the author upon reasonable request.

Informed Consent

Not applicable for this study.

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