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RESEARCH PAPER

Health Risks of Ecosystem Services in Ologe Lagoon, Lagos, Southwest Nigeria

Yahaya Tajudeen[1*], Muhammed Alkali[2], Onyeziri Joy Ada[3], Abdulmalik Abdulazeez[1], Shemishere Ufuoma[4], Bakare Tayo[5], Yusha'u Bello Kalgo[2]

1. Department of Biological Sciences, Federal University Birnin Kebbi, PMB 1157, Kebbi State, Nigeria
2. Department of Pure and Industrial Chemistry, Federal University Birnin Kebbi, Nigeria
3. Department of Environmental Science and Resource Management, National Open University of Nigeria, Lagos
4. Department of Biochemistry and Molecular Biology, Federal University Birnin Kebbi, Nigeria
5. Department of Biochemistry, Osun State University Osogbo, Nigeria

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ABSTRACT
Ologe Lagoon is one of Lagos, Nigeria's five major lagoons, which provide essential ecosystem services such as agriculture, fishing, transportation, salt and sand mining, tourism, and industrial development. There are concerns, however, that the lagoon's water may not be safe for the ecosystem functions it offers. As a result, the physicochemical properties, heavy metal concentrations, and microbial loads of water samples from the lagoon, as well as their health risks, were examined in this study. Physicochemical analysis showed that calcium, chloride, nitrates, sulphate, dissolved oxygen, acidity, alkalinity, total dissolved solid, and total suspended solid were present within the World Health Organization permissible limits, but not so for phosphate and temperature. The heavy metal analysis revealed that the water had non-permissible levels of iron, cadmium, chromium, nickel, manganese, and copper, but lead was normal. The microbiological examination showed abnormal bacteria counts, while coliform and fungus were not detected. The average daily oral and dermal exposure to cadmium, chromium, and nickel were higher than the recommended daily intake, but iron, lead, and copper were within the limits. The hazard quotient of oral and dermal exposure to cadmium, dermal exposure to chromium, and oral exposure to manganese were higher than the recommended limit (> 1). The carcinogenic risks of Cd, Cr, and Ni were also greater than the acceptable limit. The results obtained indicate that Ologe Lagoon's water is unsafe for the lagoon's ecosystem functions. Relevant agencies should ensure that waste is treated before being discharged into the lagoon.
Keywords: bacteria, cadmium, ecosystem services, hazard quotient, phosphate

INTRODUCTION

Lagoons are complex coastal zones that connect the land and the sea. Estuaries, coastal wetlands, seagrass, meadows, coral reefs, mangrove and kelp forests, and upwelling areas are all examples of coastal zones or waters (Femi *et al.*, 2021). Lagoons provide vital ecosystem services that benefit both the economy and ecology of the area (Davies-Vollum *et al.*, 2019). Economic activity in the lagoons includes fishing, shellfish harvesting, salt and sand mining, and maritime transport (Anthony *et al.*, 2009). Agriculture, tourism, recreation, as well as industrial and urban development are some of the economic activities in the areas surrounding the lagoons (El Mahrad *et al.*, 2020). Ecological services delivered by coastal lagoons include

* Corresponding author Email: yahayatajudeen@gmail.com and yahaya.tajudeen@fubk.edu.ng

storm protection, breeding grounds for marine fishes, and ensuring the continuous existence of the marine environment (Femi *et al*., 2021).

Unfortunately, lagoon ecosystem services are being threatened by environmental pollution. Untreated municipal, agricultural, and industrial wastes are discharged into lagoons, polluting the water. Even when the wastes are treated, the byproducts, which are still potentially harmful to aquatic organisms and humans, are discharged into the lagoons (Kumolu-Johnson and Ndimele, 2012). Pollution affects lagoons' water quality, biodiversity, and ecosystem services provided by lagoons (Gianello *et al*., 2019; El Mahrad *et al*., 2020). Human populations who live near lagoons and rely on them for sustenance are affected by the loss of ecological services such as coastal protection and fisheries (El Mahrad *et al*., 2020). One of the common pollutants in water are heavy metals (Kinuthia *et al*., 2020). A heavy metal is a dense metal that is harmful at low doses (in most cases). The most frequently detected heavy metals in water include arsenic, cadmium, chromium, copper, lead, nickel, and zinc (Yahaya *et al*., 2019; Moruf and Durojaiye, 2020). The lagoon's heavy metal pollution is less obvious and direct than other types of pollutants, yet it has far-reaching consequences for the aquatic environment and humans (Okunade *et al*., 2021). Heavy metal-containing substances can cause a variety of diseases, including respiratory and genetic diseases, blood abnormalities, skin damage, vision problems, and brain damage (Yahaya *et al*., 2011). Another group of pollutants that are often detected in polluted water are microorganisms. Waterborne microorganisms, which include viruses, bacteria, parasitic protozoa, and fungi, number more than 500 and can contaminate drinking water (Soller *et al*., 2010). Overall, this shows that constant monitoring and management of lagoon water quality is necessary to prevent health hazards and ensure continuity of ecosystem services delivered by lagoons.

In Lagos, Nigeria, Ologe Lagoon is one of the five major lagoon complexes that deliver several socio-economic benefits, including aquaculture, fishing, and salt and sand dredging (Edwin *et al*., 2008). Some other services supplied by Ologe Lagoons are drinking water, mat-weaving materials, wood for making canoes, and medicinal plants for managing hypertension, treating malaria, typhoid fever, jaundice, and psychopathic patients (Ndimele, 2019). The lagoon is also used by the inhabitants to transport people and commodities to nearby towns and villages for socioeconomic activities (Ndimele, 2019). However, the lagoon receives freshwater from River Owo, which is laden with poorly treated and untreated effluents from the Agbara industrial estate (Edwin *et al*., 2008). Moreover, harmful municipal and agricultural wastes are dumped directly into the lagoon. Thus, it is important to regularly test the lagoon's water quality in order to protect the health of humans and aquatic life. Additionally, to safeguard the lagoon from adverse effects so that it can continue to provide services. To this end, this study was conceived to determine the physicochemical parameters, heavy metal concentrations, and microbial loads of Ologe Lagoon in Lagos State, Nigeria, and ascertain their health risks.

MATERIALS AND METHODS

This study was carried out at Ologe Lagoon in the Oto-Awori area of Lagos, Nigeria. The lagoon has a surface area of approximately 64.5 km^2 and is brackish in nature (Aderinola *et al*., 2018). It is located between 6°27'N and 6°30'N latitudes and 3°02'E and 3°07'E longitudes. It drains its water into the Atlantic Ocean through two channels: Lagos Harbour and Badagry Creek. The middle of Ologe Lagoon is deep, but the banks are shallow. The Rivers Owo, Ore, and Opomu supply water to the lagoon. The area around Ologe Lagoon has a prolonged rainy season between March and November with an average rainfall of 154 mm

(Adeyemi *et al*., 2019). The vegetation is that of an equatorial rain forest, with a freshwater mangrove swamp as its main feature (Adeyemi *et al*., 2019). Around the lagoon, there is intense fishing, maritime transportation, mat weaving, canoe manufacturing, and industrial development, among other things. Unfortunately, waste water from industries and residential areas, as well as other anthropogenic activities, pollutes the water. Thus, there is a need to constantly monitor the water quality of the lagoon to safeguard human health, protect the environment around it, and ensure that it continues to deliver ecosystem services.

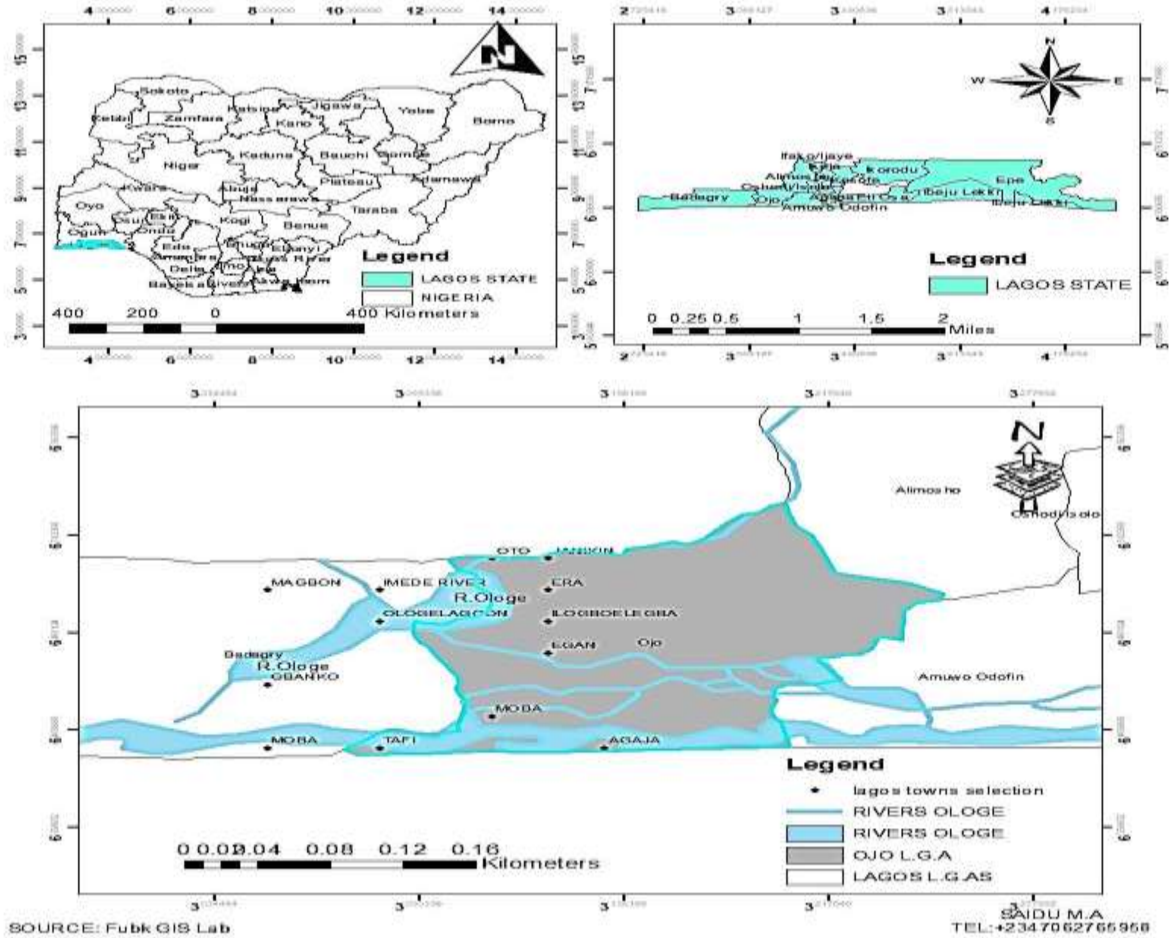

Fig 1: Map showing the location of Ologe Lagoon in Lagos

Water samples were collected from Ologe Lagoon between November 2020 and May 2021 (spanning the dry and wet seasons). The sampling was done at random on the lagoon's bottom and surface in the middle and bank areas. The samples were collected in clean, pre-sterilized plastic containers, sealed, and transferred to the laboratory, where they were kept in desiccators before being subjected to physicochemical, heavy metal, and microbiological analyses.

The physicochemical parameters of the water samples were determined according to the American Public Health Association's (APHA, 2012) criteria. A DR 2000 spectrophotometer (Model 50150) was used to measure nitrates, sulfates, and phosphates; a Vial Chloride Meter (20 X 40mm) was used to determine chloride; and a Pye Unicam pH meter was used to evaluate alkalinity and acidity. 5500 Clark DO Sensors were used to measure dissolved oxygen; an HM Digital TDS meter (model TDS-4) was used to assess total dissolved solids and total suspended solids. A complex metric EDTA titration was used to determine hardness.

The heavy metal content of the water samples was analyzed as conducted by Yahaya *et al*. (2012). The samples were digested by taking about 100 ml of each sample in a beaker and adding 5 ml of concentrated HNO_3. The mixture was heated slowly until it evaporated to about 20 ml. The heating was continued with the addition of concentrated HNO_3 until a clear, light-colored solution was observed. The content was filtered into a 100-ml volumetric flask, allowed to cool, and then filled with distilled water to the mark. The concentrations of copper (Cu), lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), magnesium (Mg), iron (Fe), and manganese (Mn) in the water samples were then determined using the UNICAM atomic absorption spectrophotometer (model: 969).

The microbial content of the samples were analyzed following the procedures of Yahaya *et al*. (2020). Bacterial loads were estimated by plating out and filtering 0.1 ml of each water sample on a nutrient agar plate and incubating it at 37 °C for 24 hours. The colonies that developed thereafter were counted with a colony counter. The coliform loads were quantified by filtering each sample on a Mac Conkey agar plate and incubating it at 37 °C for 24 hours. Fungal colonies were determined as described for bacteria, but an antibiotic was added to the nutrient to prevent bacterial growth.

The average daily oral exposure (*ADOE*) and average daily dermal exposure (*ADDE*) to the heavy metals in the water, as well as their hazard quotient (*HQ*), were used to compute the non-carcinogenic risk of the water samples. Equations 1, 2, and 3 were used to calculate these figures (USEPA, 2004).

$$\boldsymbol{ADOE} = \frac{CoH\ x\ IR\ x\ EF\ x\ ED}{ABW\ x\ AT} \tag{1}$$

According to Yahaya *et al*. (2020), the full meaning and standard values of the variables in equation 1 are as follow: *CoH* is the concentration of heavy metals in water (mg/L), *IR* denotes the ingestion rate per unit time (L/day) = 2, *EF* means exposure frequency (days/year) = 365, *ED* stands for exposure duration (years) = 55 (life expectancy of a resident Nigerian), *ABW* indicates average body weight (kg) = 65, and *AT* is the average time (*Ed* x *Ef*) = 20075.

$$\boldsymbol{ADDE} = \frac{CoH\ x\ SSA\ x\ DPC\ x\ ET\ x\ EF\ x\ ED}{ABW\ x\ AT} \tag{2}$$

From eq. 2, *SSA* = 28,000, *DPC* = 0.0002 for Ni, 0.001 for Cd, Cu, Fe, and Mn, 0.002 for Cr, and 0.004 for Pb, where *SSA* stands for skin surface area (cm^3) and *DPC* denotes dermal permeability constant (cm/h) (Yahaya *et al*., 2020).

$$\boldsymbol{HQ} = \frac{ADOE/ADDE}{RFD} \tag{3}$$

In equation 3, *RFD* represents the oral/dermal reference dose (mg/L/day). According to Yahaya *et al*. (2020), *RFD* (oral and dermal) for Pb = 1.4, 0.42; Ni = 20, 5.40; Cd = 0.5, 0.005; Cr = 3.0, 0.015; Zn = 0.3, 0.3; Cu = 40, 12; Zn = 300, 60; As = 0.3, 0.8; Mn = 0.14, - not found; Fe = 0.700, - not found; Mg = not found, not found.

The carcinogenic risk (*CR*) of the heavy metals in the water was calculated using equation 4 (Wongsasuluk *et al.*, 2014).

$$CR = ADOE\ \ x\ CSF \tag{4}$$

From equation 4, *CSF* is the cancer slop factor (mg/kg/day). According to Alsafran *et al.* (2021), the *CSF* for Pb is 0.009, Cr is 0.500, Cd is 6.100, and Ni is 1.700. The permissible limit for a single carcinogenic element is 10^{-6}, while multi-elements is $<10^{-4}$ (Li *et al.*, 2017).

All the reagents used in this study were made from high-grade chemicals. Each reagent's container was washed in a detergent solution and rinsed thoroughly with water and the reagent. To ensure the accuracy of the heavy metal analysis, the background contamination of the samples was examined. After five samples, blank samples were tested, and all results were reproduced three times. At the 95% confidence level, the values were confirmed to be reproducible. As a result, for further interpretations, the mean value of each heavy metal was employed. The precision and accuracy of the analyzed heavy metals were checked against standard reference materials for every heavy metal.

Data were compiled as mean ± standard deviation (SD) using the Excel software. The Student's *t*-test was used to compare the differences between the test and control groups in which $P \leq 0.05$ was considered a significant difference.

RESULTS AND DISCUSSION

The physicochemical properties of the water samples collected from Ologe Lagoon in Lagos are shown in Table 1. With the exception of phosphate and temperature, the values of all of the properties tested were within the World Health Organization's (WHO) acceptable levels. This result suggests that the water could cause environmental and health risks due to high temperatures and phosphate toxicity. In humans, high phosphate levels can induce digestive disorders (Kumar and Puri, 2012). In the aquatic environment, phosphate overloads can cause algal blooms that block sunlight from reaching photosynthetic plants, resulting in stunted growth or death (Yahaya *et al*., 2021). It may also reduce the amount of dissolved oxygen in the water, suffocating aquatic fauna. High temperatures increase the rate of chemical reactions, which affects biological activity, ultimately resulting in a decreased species population (Jain *et al*., 2013). Moreover, high temperatures increase the toxicity of some compounds in water. The current findings are consistent with those of Jimoh *et al*. (2019) and Bassey *et al*. (2019), who detected normal levels of the majority of physicochemical parameters in Ologe Lagoon water samples. However, the findings contrast with those of Yakub *et al*. (2018) and Okunade *et al*. (2021), who both found abnormal levels of the majority of physicochemical parameters in water samples from Ologe Lagoon.

Table 1: Physiochemical properties of the water samples obtained from Ologe Lagoon, Lagos

Parameter	**Concentration (mg/L)**		**Limit (WHO, 2017)**
	Dry season		**Wet season**
Temperature (^{o}C)	30.60±1.10^{a}	29.50±2.10^{a}	≤25
Ca	160.32±10.20^{a}	159.88±9.50^{a}	≤200
Chloride	70.90±3.90^{a}	70.22±4.11^{a}	≤250
Nitrates	5.79±0.41^{a}	5.03±0.27^{a}	≤ 50
Phosphate	20.04±2.22^{a}	20.02±1.95^{a}	≤ 0.1
Sulphate	25.46±3.77^{a}	24.60±2.46^{a}	≤ 750
BOD	6.50±1.00^{a}	6.30±2.00^{a}	≥ 1.0
Acidity	60.00±2.00^{a}	60.07±2.00^{a}	≤ 200
Alkalinity	40.00±8.660^{a}	39.71±8.66^{a}	≤ 200
TDS	214.00±4.76^{a}	212.88±4.50^{a}	≤ 1000
TSS	20.05±0.58^{a}	20.01±0.51^{a}	≤ 500

Values were expressed as mean ± SD; Values in the same row and with the same superscript are not significantly different at $p \geq 0.05$ (Student's-*t*-test); WHO = World Health Organization; BOD = Biochemical Oxygen Demand; TDS = Total Dissolved Solids; TSS = Total Suspended Solids.

Table 2 reveals the levels of Mg, Fe, Cd, Cr, Pb, Ni, Mn, and Cu in the water samples. Fe, Cd, Cr, Ni, Mn, and Cu were detected above the permissible limits, but not so for Pb. This result implies that the lagoon's ecosystem services may pose health and environmental risks. Hemochromatosis and tissue damage can be caused by too much Fe (Arko *et al*., 2019). Cu poisoning can lead to gastrointestinal problems and liver damage (Taylor *et al*., 2020). Chronic Cd exposure causes renal tubular injury (Chen *et al*., 2006). Multi-organ damage and dopaminergic dysfunction are linked to Mn poisoning (O'Neal and Zheng, 2015). Chronic Ni exposure can lead to heart and kidney problems, as well as lung and nasal cancer (Genchi *et al.,* 2020). Hexavalent (VI) chromium is an established carcinogen that generates reactive oxygen species that damage DNA (Tripathi *et al*., 2018). According to Nickens *et al*. (2010), Fang *et al*. (2014), and Wang *et al*. (2017), Cr (III) complexes cannot easily pass through cell membranes, but they can accumulate around cells to cause cell-surface morphological changes, cell-membrane lipid injuries via disruption of cellular functions and integrity, and finally DNA damage.

Table 2: Levels of heavy metals in the water samples obtained from Ologe Lagoon, Lagos

Heavy metal	Concentration (mg/L)		Recommended
	Dry season	**Wet season**	**(WHO, 2017)**
Mg	58.24±3.40[a]	57.87±3.21[a]	150.0
Fe	2.25±0.03[a]	2.13±0.04[a]	0.10
Cd	32.041±4.21[a]	32.01±3.97[a]	0.003
Cr	30.02±3.11[a]	30.05±4.00[a]	0.05
Pb	BDL	BDL	0.01
Ni	43.79±2.07[a]	42.25±2.10[a]	0.02
Mn	7.05±0.05[a]	6.90±0.05[a]	0.05
Cu	10.12±0.00[a]	10.21±0.01[a]	0.05

Values were expressed as mean ± SD; Values in the same row and with the same superscript are not significantly different at p > 0.05 (student-*t*-test); BDL = Below Detection Limit; WHO = World Health Organization

Table 3: Average daily oral exposure and average daily dermal exposure to heavy metals in the water samples obtained from Ologe Lagoon, Lagos

Heavy metal	Exposure route (mg/day/person)		
	Oral	**Dermal**	***RDI* (Atique *et al.*, 2017)**
Mg	-	-	-
Fe	0.07	0.58	10.0
Cd	0.98	1.38	0.06
Cr	0.92	2.59	0.20
Pb	-	-	0.21
Ni	1.35	0.38	0.500
Mn	0.22	0.22	-
Cu	0.31	0.44	0.900

RDI= recommended daily intake

The aforementioned health hazards are confirmed in Table 3, which shows that human oral and dermal exposure to Ni, Cr, and Cd were beyond the recommended limit (> 1). Furthermore, the hazard quotient (*HQ*) of oral exposure to Cd and Mn as well as dermal exposure to Cr and Cd were beyond the recommended limit (Table 4). The carcinogenic risks (*CR*) of Cd, Cr, and Ni were also greater than the acceptable limit (Table 4). The results of the current study are consistent with those of Adeyemi *et al*. (2019), Okunade *et al.* (2021), and Uaboi *et al.* (2010), all of whom detected abnormal levels of some heavy metals in water samples obtained from Ologe Lagoon.

Table 4: Hazard quotient and carcinogenic risk of heavy metals in the water samples obtained from Ologe Lagoon, Lagos

Heavy metal	Hazard quotient		Cancer risk
	Oral		Dermal
Mg	-	-	-
Fe	-	-	-
Cd	1.97	1.66	5.97
Cr	0.31	1.03	0.46
Pb	-	-	-
Ni	0.067	0.42	2.29
Mn	1.57	-	-
Cu	0.009	0.22	-
Permissible limits	≤ 1	≤ 1	$\leq 10^{-6}$

Table 5 reveals the levels of bacteria, coliform, and fungi in the water samples. The total bacteria were detected at levels above the WHO permissible ranges, while fungi and coliform were not detected. Bacteria can cause gastrointestinal diseases, such as diarrhea and cholera, as well as fever in people who drink contaminated water (Pramod *et al*., 2014). The bacterial proliferation could have been triggered by high phosphate levels in the water (Singh, 2013). It could have also been triggered by an iron overload in the water (Sawyerr *et al*., 2017). Obi *et al*. (2016) found predominantly bacterial species in soil sediments from the Ologe Lagoon, which is consistent with the findings of the current study. According to Obi and colleagues, there were marine oil spills in the lagoon and the bacteria species found were resistant to degradation by high hydrocarbon concentrations in the water. This shows that the non-detection of coliform and fungal populations in this study despite feaces and sewage overflow might be because of their inability to tolerate hydrocarbon degradation. Furthermore, the lagoon's water is acidic (Table 1), and according to Wahyuni (2015), many coliform species grow poorly in acidic mediums. Many fungal species are sensitive to temperature and grow well between 15 °C and 25 °C as opposed to the 29 °C (wet season) and 30 °C (dry season) of the lagoon under study (Novak Babič *et al*., 2017). Agwu and Oluwagunke (2014), on the other hand, identified several coliform species across sampling points in the Ologe Lagoon, although the microbial counts were significantly lower than those of another lagoon assessed in the study.

Table 5: Levels of microorganisms in the water samples obtained from Ologe Lagoon, Lagos

Microorganism	Level (CFU/mL)		Limit (WHO, 2008)
	Dry Season		Wet Season
Total bacterial	400000±1000[a]	900000±2000[b]	≤100
Total coliform	ND	ND	0
Total fungi/yeast	ND	ND	0

Values were expressed as mean ± SD; ND= not detected; Values in the same row with different superscripts are significantly different at P ≤ 0.05 (student-*t*-test); WHO = World Health Organization

There were no significant differences (p ≥ 0.05) between the dry and wet seasons with regards to the physicochemical parameters and heavy metal concentrations of Ologe Lagoon

(Tables 1 and 2). However, bacterial populations in the water samples during the wet season were significantly ($p \leq 0.05$) higher than those in the dry season (Table 5). Okunade *et al*. (2021) did not find seasonal variations in the physicochemical properties and heavy metal concentrations of Ologe Lagoon. In contrast, Kumolu-Johnson and Ndimele (2012) and Yahaya *et al*. (2021) reported seasonal concentration variations in some heavy metals and physicochemical parameters of Ologe and Lagos Lagoon water, respectively. Furthermore, Akoachere *et al*. (2008) and Islam *et al*. (2017) reported higher concentrations of total bacteria in lagoon and river water during the rainy season than during the dry season. This may be due to higher organic matter and bacterial-laden runoffs into lagoons during the wet season than during the dry season (Islam *et al*., 2017).

CONCLUSION

The findings revealed that the Ologe Lagoon's water is contaminated with bacterial species, implying that it can induce or spread bacterial diseases. Heavy metals, such as Fe, Cd, Cr, Ni, Mn, and Cu, are also present in the lagoon water. This suggests that the lagoon water may induce heavy metal toxicities, especially those related to Ni, Cr, Mn, and Cd because their daily human exposure, hazard quotient, and carcinogenic risk exceeded the recommended limit. Overall, the findings show that the Ologe Lagoon water is unsafe for the lagoon's ecosystem functions.

Based on the findings of the study, the following are recommended:

- Companies that discharge wastewater into the lagoon should be compelled to treat wastewater before being discharged.
- Residents should consider water treatment before use.
- There is a need for public enlightenment among people residing around Ologe Lagoon regarding the health consequences of using contaminated water from the lagoon.
- Efficient waste management and environmental sanitation should be put in place around Ologe Lagoon.
- Similar studies like the current study should be carried out periodically around Ologe Lagoon.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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