Tropical Aquatic and Soil Pollution

Research Article
Volume 3(1), 2023, 58-68
https://doi.org/10.53623/tasp.v3i1.200

Human Safety Evaluation of Heavy Metals, Physicochemical Parameters, and Microorganisms in Lagoon Water at Ikorodu Lighter Terminal in Lagos, Nigeria

Tajudeen Yahaya[1*], Khadijat Balogun[2], Mohammed Bashar Danlami[3], Ufuoma Shemishere[4], Yunusa Abdulganiyu[5], Olatunji Ola-Buraimo[5]

[1]Department of Biological Sciences, Federal University Birnin Kebbi, PMB 1157, Kebbi State, Nigeria
[2]Department of Environmental Science and Resource Management, National Open University of Nigeria, Lagos, Nigeria
[3]Department of Microbiology, Federal University Birnin Kebbi, Kebbi State, Nigeria
[4]Department of Biochemistry and Molecular Biology, Federal University Birnin Kebbi, Kebbi State, Nigeria
[5]Department of Geology, Federal University Birnin Kebbi, Kebbi State, Nigeria

*Correspondence: yahayatajudeen@gmail.com and yahaya.tajudeen@fubk.edu.ng

SUBMITTED: 5 February 2023; REVISED: 22 March 2023; ACCEPTED: 24 March 2023

ABSTRACT: Ikorodu Lighter Terminal is an important lagoon port in Lagos, Nigeria. However, the intense anthropogenic activities that take place around the port could potentially pollute the water. This study assessed the safety of human exposure to the water around the port. Samples of the water were assayed for physicochemical parameters, namely: electrical conductivity, biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), pH, turbidity, hardness, calcium, chloride, sulphate, nitrite, and phosphate. Moreover, heavy metals, including lead, manganese, copper, cadmium, nickel, and chromium, were analyzed, and their values were used to estimate potential health risks. Also assayed was the presence of microorganisms. The water samples had non-permissible levels of nitrite, oil and grease, and BOD. The concentrations of the heavy metals as well as their average daily ingestion and average daily dermal exposure were within the tolerable limits, except Ni. However, their hazard quotient and carcinogenic risk via ingestion and dermal contact exceeded the tolerable limits. Safe levels of bacteria, coliforms, and fungi were detected in the water. Based on these results, the water may expose users to health hazards. There is a need for policies geared towards the safety of human exposure to the water.

KEYWORDS: Bacteria; biochemical oxygen demand; hazard quotient; nickel; oral ingestion

1. Introduction

Heavy metals and microorganisms occur naturally in aquatic environments through rock weathering and the decomposition of organic matter [1]. They also occur through anthropogenic sources such as mining, industrial and domestic discharges, urban and agricultural runoff, and waste disposal, among others [2]. In recent times, anthropogenic activities have been the main cause of heavy metals and microorganism accumulation in aquatic environments [3]. There are always considerably greater deposits of heavy metals and microorganisms in water bodies that have a distinct anthropogenic origin [4]. Of all anthropogenic sources, industrial activities account for most of the heavy metals in aquatic habitats [2]. The most often detected heavy metals in the environment that cause adverse effects on humans include cadmium (Cd), mercury (Hg), lead (Pb), and arsenic (As) [5]. Others include copper (Cu), zinc (Zn), and selenium (Se), but in trace amounts they perform biological functions in the body [5]. The most often detected water-borne pathogens are diverse enteric and aquatic bacterial species, fungi, protozoans, and enteric viruses [6].

Heavy metals and microorganisms are toxic to aquatic biota, impact water quality, can be incorporated into the food chain, and then potentially impact human health [7, 8]. The spread of "Mina Mata Disease" in Japan, caused by industrial mercury contamination of water and fish in Mina Mata Bay, is a clear example of how heavy metals can harm aquatic environments and people [9]. Heavy metals can build up to toxic levels in aquatic environments unnoticed, making them more dangerous than other pollutants such as oil and solid waste, which accumulate conspicuously in aquatic and terrestrial habitats [9]. This indicates that all bodies of water should be assessed regularly for heavy metal pollution and health risks.

Ikorodu Lighter Terminal in Lagos, Nigeria, is a lagoon port terminal in Ikorodu where goods and people are ferried daily. Anthropogenic activities such as fishing, bathing, and washing also take place at the lagoon end daily. These activities could potentially pollute the water, yet there is no documented study on the pollution index of the water at the terminal. Recent studies conducted in the Lagos Harbour and Epe sections of the lagoon by Basheeru et al. [10] and Yahaya et al. [11], respectively, detected non-permissible levels of heavy metals in the lagoon. To protect people's health, it is important to do similar studies at the Ikorodu Lighter Terminal. In light of the above, this study was proposed to assess the concentrations and potential health risks of heavy metals, physicochemical parameters, and microorganisms in water samples collected from the terminal.

2. Materials and Methods

2.1. Description of the study area.

The study area, Ikorodu, Lagos State, Nigeria, is located in the southwestern region of the country at latitude 6° 31' 27.7644 "N and longitude 3° 22' 45.1416 "E [12]. Lagos State has an international boundary with the Republic of Benin on its southwestern part and an interstate boundary with Ogun State (Nigeria) on its northern and southeastern parts. The state has a tropical climate with an alternating short dry season (November to March) and long wet season (April to October). Lowland rainforest and mangrove swamp forest dominate Lagos' flora. The state experiences about 1540 millimeters of annual precipitation and an average daily high temperature of 31 °C [13].

Ikorodu is a rapidly expanding city northeast of Lagos and has a border with Ogun State. With more than 1 million inhabitants, Ikorodu currently ranks 12th among the cities in the country. At an annual growth rate of 5.26%, Ikorodu could reach 1.7 million inhabitants by 2035. Some residents of Ikorodu travel by water, mostly through the Ikorodu Lighter Terminal, which, coupled with the fishing, swimming, and trading that take place in and around the port, can potentially pollute the water. Thus, the safety of human exposure to the water in the port needs to be evaluated periodically, which necessitates the current study.

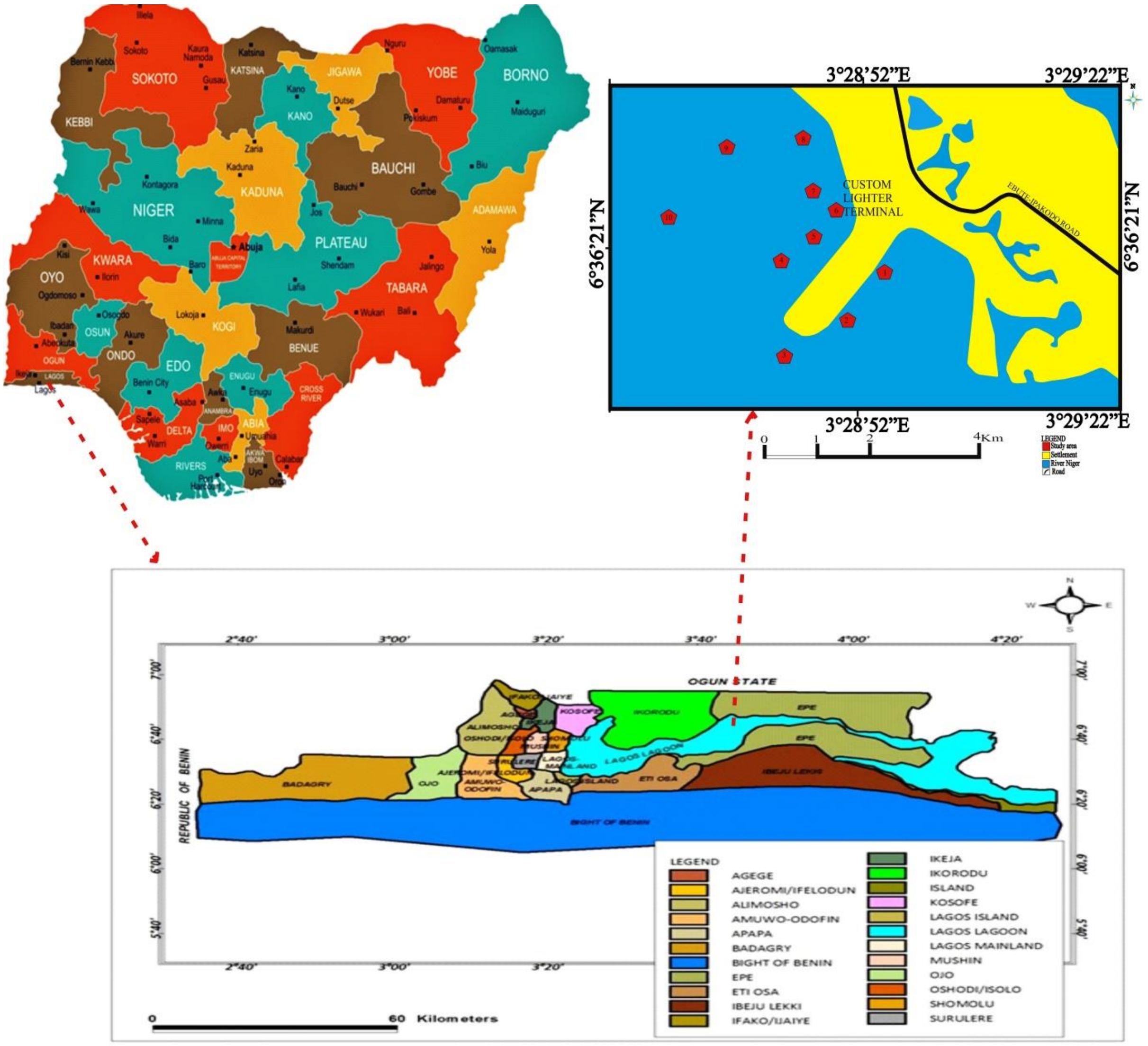

Figure 1. Map of the study area.

2.2. Collection of water samples and preparation.

Triplicate samples of the water in the lagoon were taken at random twice a month for three months, for a total of 18 samples. The water samples were put in 1000-mL polyethylene terephthalate plastic bottles that had already been washed and sterilized. The bottles were tightly sealed and sent to the lab in a sealed polyethylene bag, and then refrigerated at 4 °C.

2.3. Determination of physicochemical parameters.

The water samples were analyzed for physicochemical parameters using the criteria of the APHA [14]. Total dissolved solids (TDS) and pH (as well as alkalinity and acidity) were assessed on-site (for accuracy) with a Pye Unicam pH meter and an HM Digital TDS meter model TDS-4, respectively. A DR 2000 spectrophotometer (Model 50150) was employed to evaluate phosphates, sulphates, calcium, magnesium, and nitrates. An Avial chloride meter (20 x 40 mm) was used to quantify chloride. To determine hardness, a complex metric EDTA titration was used. Turbidity and electrical conductivity were determined by a turbidimeter and an electrical conductivity meter (EC meter), respectively.

2.4. Heavy metal analysis.

The water samples were subjected to heavy metal analysis by flame ionization detection using the Buck Scientific atomic absorption spectrometer Model 210 VGP as described by Yahaya et al. [15]. The heavy metals assayed are cobalt (Co), cadmium (Cd), copper (Cu), chromium (Cr), manganese (Mn), zinc (Zn), iron (Fe), and lead (Pb). One hundred milliliters (100 mL) of each sample were aspirated, aerosolized, mixed with acetylene and air, and then heated between 2100 and 2800 °C. Heating reduced the atoms of each heavy metal to their free and lowest energy states, which absorb light based on the wavelength of the heavy metal. Heavy metal-specific wavelengths were determined by passing a beam of light over the flame from a lamp whose cathode was made of the heavy metal under evaluation. A photomultiplier was used to measure the reduction in the light intensity due to absorption, which is equivalent to the concentration of the heavy metals in the sample. A series of standard solutions for each heavy metal ion was made using deionized distilled water and stock solutions (1000 ppm): 0.00, 0.20, 0.50, 0.60, and 1.00. To get accurate quantitative data, the regression coefficient of the standard calibration curve for each heavy metal was set above 0.9960.

2.5. Quality control and assurance.

Analytical-grade reagents were used throughout. Glass materials were immersed in 10% nitric acid for 24 hours, rinsed with ultrapure water, then treated with a 0.5% (w/v) $KMNO_4$ solution before being rinsed once more with ultrapure water. To assess for background contamination, blank samples were analyzed alongside the test samples. The analysis of the blank samples showed that the evaluation of the heavy metals was done within the certified range of 96–100% recovery. Moreover, each sample was analyzed three times, and 95% accuracy was achieved in the reproducibility of the same values. Also, reference materials were used to ascertain the accuracy and precision of the instrument.

2.6. Health risk assessment.

The non-carcinogenic health risks posed by consumption of the water were estimated using equations 1, 2, 3, and 4 [15].

$$ADI = \frac{CoH \times IR \times ED}{ABW \times AT} \qquad (1)$$

In equation 1 above, ADI stands for average daily oral ingestion of heavy metals in mg/kg/day; CoH indicates concentration (mg/L) of heavy metals in water; IR denotes the ingestion rate of water per unit time (L/day) = 2; EF means exposure frequency (days/year) = 365; ED represents exposure duration (years) = 55 (life expectancy of a resident Nigerian); ABW is the average body weight (kg) = 65; AT is the average time in seconds obtained by multiplying Ed x Ef = 20075.

$$ADDE = \frac{CoH \times ESSA \times AF \times DAF \times EF \times ED}{ABW \times AT} \qquad (2)$$

In equation 2 above, ADDE is the average daily dermal exposure in mg/kg/day; ESSA indicates exposed skin surface area (cm^3) = 28,000; AF represents adherence factor ($kg/m^2/day$) = 0.7; and DAF stands for dermal absorption factor (cm/h) = 0.1 for Cu, 0.14 for Cd, 0.04 for Cr, 0.006 for Pb, 0.0006 for As, 0.02 for Zn, and 0.001 for Mn.

$$HQ \text{ for oral} = \frac{ADI}{RFD} \tag{3}$$

$$HQ \text{ for dermal} = \frac{ADDE}{RFD} \tag{4}$$

In equations 3 and 4, HQ stands for hazard quotient, while RFD represents the reference dose in mg/L/day. The RFD (oral/dermal) of Mn, Pb, Cd, Cr, Cu, Ni, and As are 0.046/0.0018, 0.0035/0.000525, 0.001/0.001, 1.5/0.003, 0.04/0.04, 0.02/0.02, and 0.0003/0.0008, respectively.

The carcinogenic risks of the water were calculated from equations 5 and 6 [15].

$$CR \text{ for Oral} = ADI \times CSF \tag{5}$$

$$CR \text{ for dermal} = ADDE \times CSF \tag{6}$$

In equations 5 and 6, CR stands for the carcinogenic risk of oral or dermal exposure to heavy metals in water, and CSF represents the cancer slope factor (mg/kg/day). The *CSF* for Pb is 0.0085, Cd is 6.3, Cr is 0.5, Cu is 0.00, and As is 1.5. A *CR* value greater than 10^{-6} was considered potentially carcinogenic.

2.7. Microbiological analysis.

The membrane filtration method, as outlined by Yahaya et al. [15], was employed to determine the total bacterial counts. In order to do this, 100 mL of each water sample was filtered through a sterile cellulose filter with a pore size of 0.2 µm. The filter was then inoculated onto a nutrient agar plate and incubated at 35 °C for 24 hours. Using a colony counter, the number of bacterial colonies that grew on the plate was estimated. The coliform count was also calculated using the membrane filtration method. However, the two-step enrichment method was used to grow the microbes. The filters containing the bacteria were inoculated onto an absorbent pad that had been saturated with lauryl tryptose broth, and the mixture was then incubated for two hours at 35 °C. The filters were later placed on an absorbent pad that had been saturated with M-Endo medium, where they were incubated for 22 hours at 35 °C. A colony counter was used to estimate the number of sheen colonies observed. The same procedures used to estimate bacterial counts were used to estimate fungi. However, the nutrient agar was supplemented with penicillin to kill bacteria.

2.8. Data analysis.

The Excel software (version 21) was used to present the values of all the analyses carried out in the water samples as mean ± standard deviation (SD). The software was also used to estimate the *ADI*, *ADDE*, *HQ*, and *CR* of the heavy metals. To test the level of significance among various parameters, the student's t-test was used, with $p \leq 0.05$ considered statistically significant.

3. Results and Discussion

3.1. Physicochemical parameters of the water samples.

Table 1 reveals the physicochemical parameters of water samples collected from Ikorodu Lighter Terminal. All of the physicochemical parameters were within the limits allowed by the World Health Organization (WHO) and the National Environmental Standards and Regulations Enforcement Agency (NESREA), except for the nitrite, oil and grease, and BOD. The results suggest that the water may pose some health risks. Elevated levels of nitrite can change the structure of hemoglobin, which leads to decreased oxygen circulation in the body [16]. In addition, nitrite has carcinogenic risks since it can potentially convert into nicosamine, which is carcinogenic [17]. Excessive levels of nitrite could be due to run-off water containing fertilizer, sewage, and mineral deposits, which will eventually increase the BOD level. High BOD levels lower the amount of oxygen available and compromise aquatic habitats and biodiversity [18]. Oil and grease could have emanated from wastewater effluents, accidental spills, or oil or lubricants used by ferries and ships. Oil and grease can cause eutrophication of aquatic systems as well as allergic reactions, cancer, and irritation of the respiratory tract in exposed humans [19]. The result of the current study is consistent with those obtained by Yahaya et al. [20], who reported non-tolerable levels of some physicochemical parameters, including phosphate and temperature, in water samples obtained from Ologe Lagoon in Lagos. It also agrees with the findings of Aina [21], who discovered non-permissible levels of certain physicochemical parameters in lagoon water obtained from selected jetty points along Ikorodu-Lagos Island in Lagos. On the other hand, Oyeleke et al. [22] reported permissible levels of all physicochemical parameters assessed in water samples obtained at certain points along the Lagos Lagoon. Anthropogenic activities varied along the Lagos lagoons, which could explain the discrepancies in the findings of the cited literature.

Table 1. Mean physicochemical parameters of water samples collected from Ikorodu Lighter Terminal

Parameters	Unit	Concentration	Limit [23]
Appearance		cloudy liquid with particles	
pH	-	6.78±0.78	6.5 - 8.5
Color	-	10.00±0.00	50
Odor	-	unobjectionable	-
Electrical conductivity	μS/cm^3	236.67±5.77	≤1000
Total solid	mg/L	247.33±2.52	500
TSS	mg/L	214.06±5.64	≤0.75
Turbidity	NTU	0.10±0.00	<1
TDS	mg/L	130.00±3.46	≤1000
Alkalinity	mg/L	50.08±0.10	≤200
Acidity	mg/L	2.03±0.02	≤200
Hardness	mg/L	50.84±0.58	≤200
Calcium	mg/L	20.38±0.24	≤200
Magnesium	mg/L	3.07±0.02	≤40
Chloride	mg/L	29.33±0.23	≤250
Nitrite	mg/L	0.10±0.00	≤0.08
Sulphate	mg/L	28.11±0.01	≤ 750
Nitrate	mg/L	3.20±0.05	≤ 50
Oil & grease	mg/L	1.67±0.16	≤0.1
BOD	mg/L	9.94±0.06	≤6.0
Dissolved oxygen	mg/L	7.07±0.01	6.5-8

Values were expressed as mean ± SD; TSS= Total Suspended Solid; TDS = Total Dissolved Solid; BOD = Biological Oxygen Demand

3.2. Levels and health risks of heavy metals in the water samples.

Table 2 shows the levels of heavy metals (Pb, Ni, Cu, Cd, Zn, Mn, and Cr) in the water samples. All of the heavy metals were within the WHO's recommended limits, with the exception of Ni. Mn had the highest concentrations in the water, followed by Cr, Ni, and Zn, respectively.

Table 2. Mean levels of heavy metals in water samples collected from Ikorodu Lighter Terminal.

Heavy metal	Concentration	Limit [23]
Pb	0.0020±0.00	≤0.01
Ni	0.018±0.00	≤0.01
Cu	0.0093±0.0002	≤0.05
Cd	0.003±0.0002	≤0.003
Cr	0.036±0.0012	≤0.05
Zn	0.0128±0.0003	≤5.0
Mn	0.0447±0.0002	≤0.05

Values were expressed as Mean ± SD

The average daily oral ingestion (ADI) and average daily dermal exposure (ADDE) to all the heavy metals assessed were within the permissible limits, except for the ADDE of Ni and Cd (Tables 3 and 4).

Table 3. Average daily oral ingestion (ADI) and average daily dermal exposure (ADDE) to heavy metals in the water samples obtained from Ikorodu Lighter Terminal.

	Exposure route (mg/day/person)		
Heavy metal	Oral	Dermal	RDI [23]
Pb	0.00006	0.0036	0.214
Ni	0.00055	1.90	0.1
Cu	0.00029	0.280	0.900
Cd	0.00009	0.127	0.06
Cr	0.0011	0.0022	0.05
Zn	0.00039	0.116	3.0
Mn	0.0014	0.0135	-

Table 4. Hazard quotient (HQ) of heavy metals via oral ingestion (ADI) and dermal exposure (ADDE) to water samples obtained from Ikorodu Lighter Terminal.

Heavy metal	Oral	Dermal
Pb	0.0171	0.114
Ni	0.0275	95
Cu	0.00725	7
Cd	0.09	127
Cr	0.0073	0.73
Zn	0.0013	0.39
Mn	0.0304	7.5

Meanwhile, the hazard quotient (HQ) and carcinogenic risk (CR) of oral and dermal exposure to all the heavy metals were greater than the threshold of 10^{-6} (Table 5). These results shows that acute exposure may not cause any problems, but prolonged exposure to the water may cause both carcinogenic and non-carcinogenic risks. Heavy metals cause toxicity by inducing oxidative stress, DNA damage, and cell death [24]. Overexposure to Pb can cause high blood pressure and kidney damage [25]. Cd exposure may cause cancer, osteoporosis, and liver and kidney damage [26]. At a very high concentration, Cr compounds can initiate carcinogenesis [27]. Long-term Cu exposure causes blood and liver problems, as well as neurological damage [28]. High Ni exposure can cause allergic reactions, skin and organ damage, and immune dysfunction [29]. Excess Mn exposure is neurotoxic, can disrupt iron metabolism, and damage the kidneys [30]. The findings of the current study are in line with the results of previous studies with similar objectives. Notably, Adeyemi et al. [31] and Yahaya et al. [20] found non-permissible levels of heavy metals in water samples collected from Ologe Lagoon in Lagos. Bawa-Allah et al. [32] and Basheeru et al. [10] also reported non-permissible levels as well as carcinogenic and non-carcinogenic health risks of some heavy metals in water samples obtained in the Lagos Lagoon. This consistency suggests that long-term exposure to water from lagoons in Lagos may cause health hazards.

Table 5. Carcinogenic risks of oral ingestion (ADI) and dermal exposure (ADDE) to heavy metals in water samples obtained from Ikorodu Lighter Terminal.

	Exposure route (mg/day/person)	
Heavy metal	**Oral**	**Dermal**
Pb	0.00000051	0.00306
Ni	-	-
Cu	-	-
Cd	0.000567	0.8001
Cr	0.00055	0.0011
Zn	-	-
Mn	-	-

3.3 Microorganisms in the water samples

Table 6 shows the levels of microorganisms detected in the water samples. The water contained permissible levels of total coliform, bacteria, and fungi. This result is consistent with those obtained by Yahaya et al. [20], who did not detect non-tolerable levels of bacteria and fungi in water samples collected in Ologe Lagoon, Lagos. Obi et al. [33] also reported a reduced microbial diversity and population in certain sections of the Lagos Lagoon. Contrarily, Nandita et al. [34] detected non-tolerable levels of bacteria and coliform in water samples collected at some sampling points along the Lagos Lagoon. Additionally, Obiakara-Amaechi et al. [35] detected non-permissible levels of microorganisms in water samples collected at the Makoko axis of Lagos Lagoon. The low level of microorganisms in the current study could be attributed to high osmotic stress in the water, which causes the cell to be unable to take up water and become dormant [36]. The heavy metals detected in the water, as well as non-evaluated contaminants such as polycyclic aromatic hydrocarbons and polychlorinated biphenyls, may have also reduced the microbial population of the water [33].

Table 6. Levels of microorganisms in the water samples obtained from Ikorodu Lighter Terminal.

Microorganisms (CFU/mL	**Levels**	**Limit [23]**
Total bacteria	50.20±2.00	≤100
Total coliform	40±0.00	≤50
Fungi	BDL	≤50

Values were expressed as mean ± SD; BDL= Below detection levels.

4. Conclusions

The results showed that the levels of some physicochemical parameters in the lagoon water, namely nitrites, oil and grease, and BOD, were higher than the tolerable limits. Although the levels as well as oral and dermal exposure to heavy metals (Pb, Cd, Cr, Cu, Zn, Mn, and Ni) in the water were within the acceptable limits, the hazard quotient (HQ) and carcinogenic risk (CR) of oral and dermal exposure to the heavy metals exceeded the allowable limits. This suggests that acute exposure to the water may not cause any serious problems, but prolonged exposure may be detrimental. The microbiological populations in the water, namely bacteria, coliforms, and fungi, were within permissible limits, suggesting that exposure to the water may not cause bacterial and fungal infections. Based on these results, sources of water pollution at the lagoon axis, such as industrial and municipal discharges, farming, bathing, and washing, should be discouraged. Health and environmental agencies in the area should work together to ensure the lagoon's water is safe for use.

Acknowledgments

Not applicable.

Competing Interest

Authors have no competing interest to disclose.

References

[1] Yahaya, T.; Doherty, V.F.; Akinola, O.S.; Shamsudeen, A. (2019). Heavy Metal Profile and Microbial Counts of Selected Sachet Water Brands in Birnin Kebbi. *Ife Journal of Science*, *21*, 229-234. https://doi.org/10.4314/ijs.v21i1.20.

[2] Haghnazar, H.; Belmont, P.; Johannesson, K.H.; Aghayani, E.; Mehraein, M. (2023). Human-induced pollution and toxicity of river sediment by potentially toxic elements (PTEs) and accumulation in a paddy soil-rice system: A comprehensive watershed-scale assessment. *Chemosphere*, *311*, 136842. https://doi.org/10.1016/j.chemosphere.2022.136842.

[3] Briffa, J.; Sinagra, E.; Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, *6*, e04691. https://doi.org/10.1016/j.heliyon.2020.e04691.

[4] Vareda, J.P.; Valente, A.J.M.; Durães, L. (2019). Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. *Journal of Environmental Management*, *246*, 101-118. https://doi.org/10.1016/j.jenvman.2019.05.126.

[5] Ngoc, N.T.M.; Chuyen, N.V.; Thao, N.T.T. (2020). Chromium, Cadmium, Lead, and Arsenic Concentrations in Water, Vegetables, and Seafood Consumed in a Coastal Area in Northern Vietnam. *Environmental Health Insights*, *2020*, 14. https://doi.org/10.1177/1178630220921410.

[6] Some, S.; Mondal, R.; Mitra, D.; Jain, D.; Verma, D.; Das, S. (2021). Microbial pollution of water with special reference to coliform bacteria and their nexus with environment. *Energy Nexus*, *1*, 100008. https://doi.org/10.1016/j.nexus.2021.100008.

[7] Sehnal, L.; Brammer-Robbins, E.; Wormington, A.M.; Blaha, L.; Bisesi, J.; Larkin, I.; Martyniuk, C.J.; Simonin, M.; Adamovsky, O. (2021). Microbiome Composition and Function in Aquatic Vertebrates: Small Organisms Making Big Impacts on Aquatic Animal Health. *Frontiers in Microbiology*, *12*, 567408. https://doi.org/10.3389/fmicb.2021.567408.

[8] Mitra, S.; Chakraborty, A.J.; Tareq, A.M.; Emran, T.B.; Nainu, F.; Khusro, A.; Idris, A.M.; Khandaker, M.U.; Osman, H.; Alhumaydhi, F.A.; Simal-Gandara, J. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University - Science*, *34*, 101865. https://doi.org/10.1016/j.jksus.2022.101865.

[9] Abui, Y.M.; Ezra, V.; Bonet, R.A.; Amos, B. (2017). Assessment of Heavy Metals Level of River Kaduna at Kaduna Metropolis, Nigeria. *Journal of Applied Science and Environmental Management*, *21*, 347-352. https://doi.org/10.4314/jasem.v21i2.16.

[10] Basheeru, K.A.; Adekola, F.A.; Abdus-Salam, N. (2022). Spatio-temporal monitoring of potentially toxic elements in Lagos harbour water and its health risk implications. *SN Applied Science*, *4*, 298. https://doi.org/10.1007/s42452-022-05186-7.

[11] Yahaya, T.O.; Illo, Z.Z.; Abdulgafar, I.B.; Salihu, M.G.; Gomo, C.B.; Abdulrahim, A.; Abdulkadi, A. (2022). Concentrations and Health Risk Parameters of Heavy Metals in Water

Samples from Epe Lagoon in Lagos State, Nigeria. *Dutse Journal of Pure and Applied Sciences*, *8*, 149-157. https://doi.org/10.4314/dujopas.v8i2b.15.

[12] GPS Coordinate of Lagos Nigeria. (accessed 26 December 2022). Available online: https://www.countrycoordinate.com/city-lagos-nigeria/.

[13] Climate in Lagos (Nigeria). (accessed 5 December 2022). Available online: https://www.worlddata.info/africa/nigeria/climate-lagos.php.

[14] APHA (American Public Health Association) (2019). Drinking Water and Public Health in the nited States. (accessed 12 January 2022).Available online: https://www.apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2020/01/13/drinking-water-and-public-health-in-the-united-states.

[15] Yahaya, T.; Ologe, O.; Yaro, C.; Abdullahi, L.; Abubakar, H.; Gazal, A.; Abubakar, J. (2022). Quality and Safety Assessment of Water Samples Collected from Wells in Four Emirate Zones of Kebbi State, Nigeria. *Iranian (Iranica) Journal of Energy and Environment*, *13*, 79-86. https://doi.org/10.5829/ijee.2022.13.01.09.

[16] Health Problems Caused by Lead. (Accessed 17 December 2022) Available online: https://www.cdc.gov/niosh/topics/lead/health.html#.

[17] Karwowska, M.; Kononiuk, A. (2020). Nitrates/Nitrites in Food-Risk for Nitrosative Stress and Benefits. *Antioxidants*, *9*, 241. https://doi.org/10.3390/antiox9030241.

[18] Vigiak, O.; Grizzetti, B.; Udias-Moinelo, A.; Zanni, M.; Dorati, C.; Bouraoui, F.; Pistocchi, A. (2019). Predicting biochemical oxygen demand in European freshwater bodies. *Science of the Total Environment*, *666*, 1089–1105. https://doi.org/10.1016/j.scitotenv.2019.02.252.

[19] Nowak, P.; Kucharska, K.; Kamiński, M. (2019). Ecological and Health Effects of Lubricant Oils Emitted into the Environment. *International Journal of Environmental Research and Public Health*, *16*, 3002. https://doi.org/10.3390/ijerph16163002.

[20] Yahaya, T.; Muhammad, A.; Onyeziri, J.; Abdulazeez, M.; Ufuoma, S.; Tayo, B.; Yusha'u, B.K. (2022). Health risks of ecosystem services in Ologe Lagoon, Lagos, Southwest Nigeria. *Pollution*, *8*, 681–692. https://doi.org/10.22059/POLL.2021.333654.1265.

[21] Aina, A.T. (2017). Physicochemical characteristics of marine water at jetty points Along Ikorodu-Lagos Island, Lagos State, South-West Nigeria. *Global Journal of Pure and Applied Sciences*, *23*, 193-197. https://doi.org/10.4314/gjpas.v23i1.20.

[22] Oyeleke, P.O.; Popoola, S.O.; Abiodun, O.A. (2019). Assessment of Some Physico-Chemical Parameters of Lagos Lagoon, Southwestern Nigeria. *Academic Journal of Chemistry*, *4*, 9-11. https://doi.org/10.32861/ajc.43.09.11.

[23] Guidelines for drinking-water quality. (accessed 18 December 2022) Available online: https://www.who.int/publications-detail-redirect/9789241549950.

[24] Balali-Mood, M.; Naseri, K.; Tahergorabi, Z.; Khazdair, M.R.; Sadeghi, M. (2021). Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. *Frontiers in Pharmacology*, *12*, 643972. https://doi.org/10.3389/fphar.2021.643972.

[25] Yu, Y.L.; Yang, W.Y.; Hara, A. (2022). Public and occupational health risks related to lead exposure updated according to present-day blood lead levels. *Hypertension Research*, *46*, 395-407. https://doi.org/10.1038/s41440-022-01069-x.

[26] Genchi, G.; Sinicropi, M.S.; Lauria, G.; Carocci, A.; Catalano, A. (2020). The Effects of Cadmium Toxicity. *International Journal of Environmental Research and Public Health*, *17*, 3782. https://doi.org/10.3390/ijerph17113782.

[27] Achmad, R.; B., Auerkari, E. (2017). Effects of Chromium on Human Body. *Annual Research & Review in Biology*, *17*, 1-8. https://doi.org/10.9734/ARRB/2017/33462.

[28] Karim, N. (2018). Copper and Human Health- A Review. *Journal of Bahria University Medical and Dental College*, *8*, 117–122. https://doi.org/10.51985/JBUMDC2018046.

[29] Nannan, Z.; Ming, C.; Jun, L.; Ying, D.; Sheng-li, L.; Yi-xiong, G.; Nana, L.; Yuan, L.; Ping, Y.; Zhen, L.; Jun, Z. (2019). Metal nickel exposure increase the risk of congenital heart defects occurrence in offspring: A case-control study in China. *Medicine*, *98*, e15352. https://doi.org/10.1097/MD.0000000000015352.

[30] Harischandra, D.S.; Ghaisas, S.; Zenitsky, G.; Jin, H.; Kanthasamy, A.; Anantharam, V.; Kanthasamy, A.G. (2019) Manganese-Induced Neurotoxicity: New Insights in to the Triad of Protein Misfolding, Mitochondrial Impairment, and Neuroinflammation. *Frontiers in Neuroscience*, *13*, 654. https://doi.org/10.3389/fnins.2019.00654.

[31] Adeyemi, M.; Olusola, J.; Akpobasah, O.; Adidi, N.; Shelle, R. (2019) Assessment of Heavy Metals Pollution in Sediments from Ologe Lagoon, Agbara, Lagos, Nigeria. *Journal of Geoscience and Environment Protection*, *7*, 61-73. https://doi.org/10.4236/gep.2019.77006.

[32] Bawa-Allah, K.A.; Saliu, J.K.; Otitoloju AA. (2018). Heavy Metal Pollution Monitoring in Vulnerable Ecosystems: A Case Study of the Lagos Lagoon, Nigeria. *Bulletin of Environmental Contamination Toxicology*, *100*, 609-613. https://doi.org/10.1007/s00128-018-2314-8.

[33] Obi, C.C.; Adebusoye, S.A.; Ugoji, E.O.; Ilori, M.O.; Amund, O.O.; Hickey, W.J. (2016). Microbial Communities in Sediments of Lagos Lagoon, Nigeria: Elucidation of Community Structure and Potential Impacts of Contamination by Municipal and Industrial Wastes. *Frontiers in Microbiology*, *7*, 1213. https://doi.org/10.3389/fmicb.2016.01213.

[34] Nandita, D.E.; Ezenwa, U.S.; Adesina, T.D. (2015). Physiochemical and microbiological assessment of Lagos lagoon water, Lagos, Nigeria. *IOSR Journal of Pharmacy and Biological Sciences*, *10,* 78-84. https://doi.org/10.9790/3008-10247884.

[35] Obiakara-Amaechi, A.I.; Iyiola, D.O.; Oyem, I.M.; Moruf, R.O.; Chukwu, L.O. (2022). Bacterial Indicators of Contamination in Highly Impacted Segment of Tropical Lagoon, Southwest Nigeria. *Journal of Applied Science and Environmental Management*, *26*, 705-710. https://doi.org/10.4314/jasem.v26i4.21.

[36] Liu, Y.; Gong, X.; Li, M.; Si, H.; Zhou, Q.; Liu, X.; Fan, Y.; Zhang, X.; Han, J.; Gu, S.; Dong, J. (2021). Effect of Osmotic Stress on the Growth, Development and Pathogenicity of *Setosphaeria turcica*. *Frontiers in Microbiology*, *12*, 706349. https://doi.org/10.3389/fmicb.2021.706349.