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Toxicological Assessment of Borehole Water in Oshodi/Isolo, Lagos, Nigeria: Heavy Metals and Microorganism Contamination Perspectives

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A B S T R A C T

Background: This study focused on the evaluation of the quality of borehole water in Oshodi, Lagos, Nigeria, considering that groundwater serves as the primary source of potable water in the country. However, the vulnerability of groundwater to contamination raises concerns regarding its suitability for consumption.
Methods: Water samples were obtained from Okota, Ayo, Osi, Oke-Afa, Ajao, Oshi, and Iso-Aye Streets in Oshodi and assayed for the presence of heavy metals and microorganisms. The heavy metals analyzed in the samples included zinc (Zn), lead (Pb), chromium (Cr), manganese (Mn), copper (Cu), iron (Fe), and cadmium (Cd). Additionally, the water samples were examined for the presence of bacteria, coliforms, and fungi as representative microorganisms. To evaluate the potential health risks associated with the heavy metals detected, non-carcinogenic risks were assessed. This involved determining parameters such as average daily dermal exposure (ADDE), average daily ingestion (ADI), and hazard quotient (HQ). Further, the carcinogenic risks (CR) of the heavy metals were determined.
Results: The analysis of the water samples revealed that the levels of Pb and Mn, exceeded the recommended limits. However, ADI values for these heavy metals were found to be within permissible limits. The HQ of dermal exposure to Zn, Mn, and Pb during the dry season, as well as for Cr, Mn, Zn, and Pb during the wet season, were higher than recommended limits. The CR (dermal) of Pb and Cr during the wet season and Pb during the dry season were also above recommended limits. In terms of microorganisms, the presence of bacteria, coliforms, and fungi in the water samples was found to be within permissible limits.
Conclusions: Given the identified presence of heavy metals exceeding recommended limits and the potential health risks associated with dermal exposure and ingestion, it is evident that the water from the assessed boreholes in Oshodi poses health hazards to consumers. Therefore, it is imperative to implement decontamination measures to mitigate these risks and ensure the provision of safe and potable water to the community.

1. Introduction

Groundwater such as wells and boreholes is the largest reservoir of freshwater, accounting for over 95% of all available freshwater sources [1]. It is usually cleaner than surface water due to the natural filtration process that occurs

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as it percolates through various rock and sediment layers, effectively removing many contaminants [2]. Therefore, groundwater often contains fewer toxicants compared to surface water, and thus requires fewer purification processes [2]. In developing countries, people prefer groundwater to other sources of drinking water because it is reliable, accessible, and cost-effective [3, 4]. Groundwater supplies ecosystems with water and nutrients and stabilizes temperatures, all of which interact to provide food, energy, health, and recreation for humans [5]. Unfortunately, groundwater sources are increasingly contaminated by natural and anthropogenic activities, which compromises their quality and availability [6]. Among the environmental pollutants, heavy metals are of particular concern due to their high toxicological potential, ability to accumulate in living organisms, widespread distribution, and propensity for biomagnification [7]. Heavy metals are characterized by their high density, and certain ones, such as cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni), cobalt (Co), and lead (Pb), are known to pose potential health hazards [8]. Excessive absorption of these heavy metals, particularly through drinking water, may cause diseases such as cancer, neurotoxicity, immune dysfunction, and other adverse effects [9]. However, some heavy metals, namely Cu, Fe, Mn, and Zn, at low concentrations play a functional role in metabolism [10]. Heavy metal sources include industrial waste, soil erosion, weathering, urban runoff, oil spillage, agrochemicals, atmospheric deposition, mining, and landfills [11]. Groundwater sources can also be contaminated by biological agents, particularly microorganisms, causing disease outbreaks. At least five hundred waterborne pathogens have been reported and are mainly bacterial, viral, parasitic protozoans, and fungal pathogens [12]. High microbial populations are often observed in groundwater located in residential areas, particularly those with a high density of latrines [13]. They are also found in groundwater around farmlands and landfills due to infiltration by leachates [14, 15]. After invading the cells, microorganisms may disrupt the immune mechanism or intoxicate the cell to cause diseases [16]. Examples of waterborne diseases caused by microorganisms include diarrhea, gastrointestinal diseases, and systematic illnesses, among others [17]. Considering the vulnerability of groundwater to heavy metal and microbiological contamination, there is a need to constantly monitor groundwater sources to prevent health hazards. In Isolo/Oshodi, Lagos, residents preferred groundwater because piped water is inadequate, which is symptomatic of developing nations. The area is highly populated with a lot of anthropogenic activities, which can potentially contaminate groundwater. This necessitates a periodic assessment of groundwater quality in the area. However, literature searches show that such an assessment has not been carried out in the area in recent times. This study, therefore, aimed to evaluate the toxicity of borehole water in Oshodi/Isolo, Lagos, Nigeria, with regard to heavy metal and microorganism contamination.

2. Materials and Methods

2.1 Description of the study site

Oshodi-Isolo is a local government in Lagos State, Nigeria (Figure 1). Lagos State is geopolitically located in the southwestern region at longitude 3° 22' 45.1416 "E and latitude 6° 31' 27.7644 "N [18]. The state has an international boundary with the Republic of Benin in its southwestern part and a national border with Ogun State in its northern and southeastern parts. The state's climate is tropical, consisting of a dry season occurring in November through March and a wet season between April and October. Lagos's vegetation is dominantly lowland rainforest and mangrove swamp forest. The state experiences a daily mean temperature of 31 °C and a yearly rainfall of approximately 1540 mm [19]. Oshodi-Isolo Local Government Area (LGA) is located in the northeast of the state. The LGA has a landmass of about 9 km² and a rapidly expanding population of over 1,000,000 people [20]. Oshodi has several industries and hosts one of the most popular and biggest markets in Lagos, with lots of anthropogenic activities. These activities can potentially pollute the environment, particularly groundwater. Thus, the suitability of groundwater in the area needs to be evaluated periodically, which necessitates the current study.

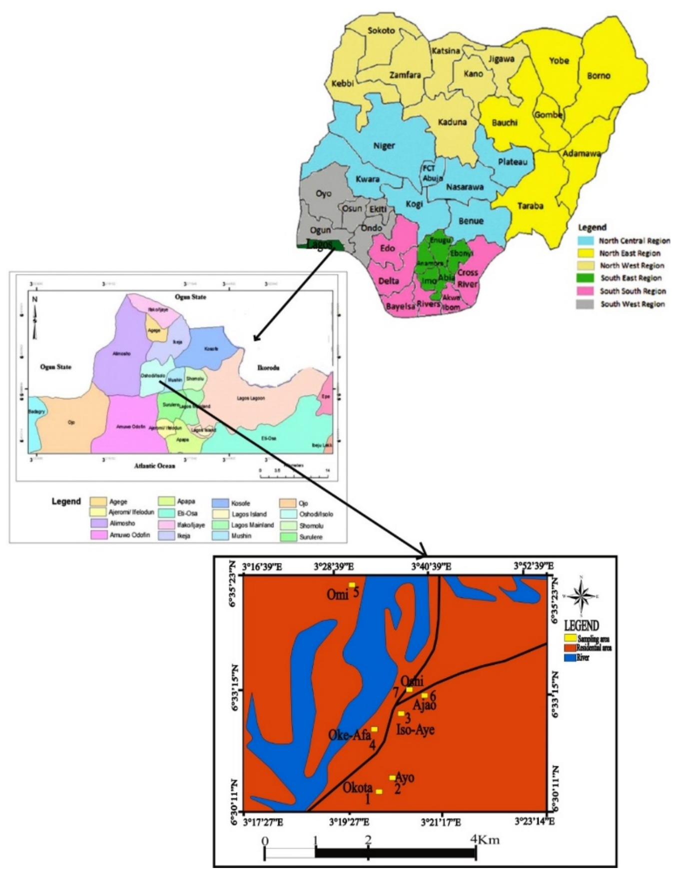

Figure 1. Locations of the study area

2.2 Collection of water samples and preparation

Between January and March 2022 (the dry season), 21 water samples were randomly obtained from boreholes in seven streets (three from each street) in Oshodi. The streets where the sampling took place are Okota, Ayo, Iso Aye, Oke-Alfa, Omi, Ajao, and Oshi. The collection containers were 1000-mL polyethylene terephthalate plastic bottles that had been previously washed and sterilized [4]. The same process was repeated between July and September 2022 (the wet season), bringing the total number of samples collected to 42. The sample containers were covered properly and kept in a refrigerator at about 4 °C in the laboratory.

2.3 Heavy metal analysis

100 mL of each sample were placed in a clean digestion flask. Following this, 9 mL of concentrated HNO_3 and 3 mL of concentrated HCl were added. The flask was heated until the observed brownish fumes (nitrogenous compounds) were eliminated and a light-colored, clear solution appeared, indicating the completion of the digestion process. After cooling, the flask was rinsed with distilled water, following which the solution was filtered into a 50 mL volumetric flask, and topped up to the meniscus. Subsequently, an atomic absorption spectrometer manufactured by Buck Scientific with model number 210 VGP was used to determine the levels of Co, Zn, Fe, Cu, Mn, Cr, Pb, and Cd in the solution.

2.4 Health risk assessment of the heavy metals

2.4.1 Non-carcinogenic risk

Four equations, named equations 1 through 4, were used to calculate the non-carcinogenic health risks of heavy metals detected [21].

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

Where ADI represents average daily water ingestion in mg per kg per day, CoH means the concentration of heavy metals (mg/L) in water, IR indicates ingestion rate per unit time, measured in L/day = 2 [21], EF is short for exposure frequency, calculated in days/year = 365 [21], ED is abbreviated for exposure duration, measured in years = 55 [21], ABW represents average body weight in kg = 65 [21], and AT stands for average time, obtained by multiplying Ed and Ef = 20075 [21].

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

Where ADDE means average daily dermal exposure mg per kg per day; ESSA stands for exposed skin surface area (cm^2) = 18,000; AF is the adherence factor ($kg/m^2/day$) = 0.7; *DAF* denotes dermal absorption factor (cm/h) = 0.1 for Cu, 0.14 for Cd, 0.0002 for Cr, 0.006 for Pb, 0.0006 for As, 0.03 for Zn, and 0.001 for Mn [21].

$$HQ \text{ for Oral} = \frac{\text{ADI}}{\text{RFD}} \qquad (3)$$

$$HQ \text{ for Dermal} = \frac{\text{ADDE}}{\text{RFD}} \qquad (4)$$

In equations 3 and 4, HQ stands for hazard quotient, while RFD represents the reference dose in mg/L/day. The *RFD* (oral/dermal) for Pb, Cd, Cr, Cu, Mn, Zn, and Fe is 0.0035/0.000525, 0.0005/0.00001, 0.0003/0.00006, 0.04/0.012, 0.14/0.0018, 0.3/0.00005, and 0.007/0.007 [21]. An HQ greater than 1 was deemed toxic.

2.4.2 Carcinogenic risks

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

$$CR \text{ for Oral} = ADI \times CSF \qquad (5)$$

$$CR \text{ for dermal} = ADDE \times CSF \qquad (6)$$

In equations 5 and 6, CR stands for carcinogenic risk of dermal or oral exposure to heavy metals, and CSF is short for 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 Cr is 0.5. A CR value above 10^{-6} was considered potentially carcinogenic.

2.5 Quality control and assurance

Chemicals of analytical grade were used to formulate all the reagents used. A detergent solution was used to wash all the containers, which was followed by rinsing with distilled water and the reagent to be put in each container. Background contamination during heavy metal analysis was avoided by intermittently analyzing blank samples along with the samples. Furthermore, each heavy metal was evaluated three times, with the results being repeatable with a 95 % confidence level.

2.6 Microbiological analysis

The bacterial count was estimated using the membrane filtration method as conducted by Yahaya *et al.* 2022 [4]. 100 mL of each water sample was filtered with a sterile cellulose filter (pore size of 0.2 µm). The filter was then inoculated onto a nutrient agar plate and incubated at 35 °C for a day. A colony counter was then used to estimate the population of bacteria that grew on the plate. The coliform count was also calculated using the membrane filtration method, but the microbes were grown using the two-step enrichment method. The bacteria-laden filters were inoculated onto an absorbent pad that had been enriched with lauryl tryptose broth and then incubated for 2 h at 35 °C. The filters were later placed on an absorbent pad that had been saturated with M-Endo medium and incubated for 22 h 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 also used to estimate fungi. However, the nutrient agar was supplemented with penicillin to kill bacteria.

2.7 Data analysis

The levels, as well as the ADI, ADDE, HQ, and CR of the heavy metals, were presented as mean ± standard deviation (SD) using the Microsoft Excel software version 22. The levels of significance among various parameters were tested using the student's t-test, in which $p \leq 0.05$ was taken to be statistically different.

3. Results and Discussion

3.1 Levels of heavy metals in the water samples

Table 1 reveals the levels of heavy metals in the water samples obtained from boreholes in Oshodi. During the wet season, all the heavy metals were within the permissible limits of the World Health Organization [22], except for Pb in the samples obtained from Okota, Ayo, Osi, Oke-Afa, Ajao, and Oshi. Mn was also above the permissible limits at Omi. During the dry season, Mn concentrations were higher than the recommended limits in all the water samples, as were Pb concentrations in Osi. On average, the values of the heavy metals were higher during the wet season than the dry season, which implies that the samples were more contaminated during the wet season. The results show that water from boreholes in the mentioned streets may pose some health risks, particularly Pb and Mn toxicities. Pb, when ingested, may accumulate in the brain, kidneys, liver, and bones, causing multi-organ damage over time [23]. Even at low concentrations, Pb can cause chronic damage to children's mental health and intelligence [24]. In adults, Pb can increase blood pressure and cause kidney, reproductive, and cardiovascular problems [25]. Overexposure to Mn can lead to liver, kidney, neurological, and respiratory disorders, as well as hyperkeratosis, Huntington's disease, pigmentation changes, and type 2 diabetes [26, 27]. In children, overexposure to Mn through drinking water may impair reasoning abilities and adaptive behaviors [28]. Among previous studies, Egbueri and Unigwe (2019) [29] detected non-tolerable levels of just one heavy metal (Cu) in water samples obtained from groundwater in Oshodi, which is slightly consistent with the findings of the current study, which detected non-tolerable levels of just two heavy metals. The result is also in line with Adeniyi *et al.* (2016) [30], who reported that most heavy metals evaluated in groundwater from Oshodi were within the acceptable limits of the WHO. However, the results contradict those of Ogoko (2019) [31], who documented non-tolerable concentrations of several heavy metals in groundwater on Lagos Island. Yahaya *et al.* (2020) [11] also documented abnormal levels of most heavy metals evaluated in groundwater sunk in the Shomolu area of Lagos. The accumulation of heavy metals in groundwater can be influenced by both anthropogenic activity and the special placement of borehole water, even in the same locality. Boreholes sited close to dumpsites, factories, artisanal works, etc. will inevitably contain elevated concentrations of heavy metals. Furthure, the geological characteristics of areas also influences heavy metal accumulations in groundwater.

Table 1. Mean levels (mg/L) of heavy metals in water samples collected from boreholes in Isolo/Oshodi, Lagos

Location	Seasons	Heavy metals							
		Cd	Co	Cu	Zn	Cr	Fe	Mn	Pb
Okota	Dry	BDL	0.001±0.0001	BDL	0.92±0.001	BDL	0.01±0.0	BDL	0.06±0.001
	Wet	BDL	BDL	0.02±0.002	0.01±0.001	0.001±0.001	0.05±0.0	0.08±0.0	0.02±0.00
Ayo	Dry	BDL	BDL	0.02±0.002	0.04±0.003	BDL	0.09±0.003	BDL	0.06±0.002
	Wet	BDL	BDL	0.010±0.001	0.003±0.001	0.001±0.00	0.003±0.00	0.09±0.0	0.003±0.00
Iso-Aye	Dry	BDL	0.001±0.00	0.005±0.002	0.001±0.00	BDL	0.001±0.00	0.02±0.002	0.004±0.001
	Wet	BDL	BDL	0.006±0.001	0.014±0.002	0.001±0.00	0.008±0.00	0.16±0.004	0.005±0.00
Oke Afa	Dry	BDL	0.002±0.0001	0.006±0.002	0.035±0.002	0.0001±0.00	0.008±0.005	0.013±0.00	0.005±0.002
	Wet	BDL	BDL	0.011±0.002	0.004±0.001	0.00014±0.0	0.017±0.001	0.29±0.003	0.001±0.00
Omi	Dry	BDL	BDL	0.003±0.00	0.005±0.001	BDL	0.007±0.001	0.06±0.005	0.001±0.00
	Wet	BDL	BDL	0.017±0.00	0.003±0.00	BDL	0.035±0.004	0.12±0.001	0.006±0.001
Ajao	Dry	BDL	0.006±0.0002	BDL	0.001±0.0001	BDL	0.003±0.001	0.04±0.002	0.007±0.001
	Wet	BDL	BDL	0.063±0.003	0.051±0.002	0.020±0.001	0.017±0.001	0.87±0.005	0.033±0.001
Oshi	Dry	BDL	0.001±0.00	0.002±0.00	0.012±0.001	BDL	0.013±0.001	0.04±0.003	0.048±0.002
	Wet	BDL	BDL	0.083±0.002	0.036±0.001	0.010±0.00	0.263±0.003	0.67±0.002	0.018±0.00
WHO [22]		≤0.02	≤0.05	≤ 5.0	≤ 5.0	≤0.05	≤ 0.3	≤ 0.005	≤ 0.01

* Note: BDL stands for below detection levels.

Table 2. Average ingestion of heavy metals per person from borehole water collected during dry and wet seasons

Location	Season	Heavy metals						
		Co	Cu	Zn	Cr	Fe	Mn	Pb
Okota	Dry	0.00004	0.000	0.0037	0.000	0.00035	0.000	0.0021
	Wet	0.000	0.0006	0.00027	0.00004	0.0019	0.0029	0.0019
Ayo	Dry	0.000	0.00023	0.0015	0.00004	0.00035	0.000	0.0022
	Wet	0.000	0.00038	0.00012	0.00001	0.00012	0.0038	0.00012
Iso-Aye	Dry	0.00005	0.00019	0.001	0.000	0.00004	0.0009	0.00015
	Wet	0.000	0.0023	0.00054	0.00004	0.000031	0.000	0.0003
Oke Afa	Dry	0.00008	0.00023	0.0014	0.00004	0.00031	0.0005	0.00017
	Wet	0.000	0.00042	0.00015	0.00001	0.0007	0.29	0.0007
Omi	Dry	0.000	0.00012	0.00019	0.000	0.00027	0.0022	0.00003
	Wet	0.000	0.00065	0.0012	0.000	0.0014	0.0045	0.0002
Ajao	Dry	0.00023	0.000	0.00004	0.000	0.0001	0.002	0.0003
	Wet	0.000	0.0024	0.0019	0.0097	0.003	0.0042	0.001
Oshi	Dry	0.0001	0.0001	0.0005	0.000	0.0005	0.002	0.002
	Wet	0.000	0.0032	0.0014	0.0004	0.010	0.003	0.001
RDI [22]		-	0.90	3.0	0.20	0.30	-	0.21

* Values were expressed in mg/kg; RDI stands for recommended daily intake.

Table 3. Average daily dermal exposure to heavy metals per person from borehole water collected during dry and wet seasons

Location	Seasons	Heavy metals						
		Co	Cu	Zn	Cr	Fe	Mn	Pb
Okota	Dry	0.0003	0.000	8.322	0.000	0.003	0.000	0.109
	Wet	0.000	0.603	0.090	0.0001	0.015	0.024	0.036
Ayo	Dry	0.000	0.181	0.362	0.000	0.271	0.000	0.109
	Wet	0.000	0.302	0.027	0.0001	0.001	0.027	0.005
Iso-Aye	Dry	0.0003	0.151	0.009	0.000	0.0003	0.006	0.007
	Wet	0.000	0.181	0.127	0.0001	0.0024	0.048	0.009
Oke Afa	Dry	0.001	0.181	0.316	0.001	0.002	0.004	0.009
	Wet	0.000	0.322	0.036	0.000	0.005	0.087	0.002
Omi	Dry	0.000	0.006	0.045	0.000	0.002	0.018	0.002
	Wet	0.000	0.058	0.027	0.000	0.011	0.036	0.009
Ajao	Dry	0.018	0.000	0.009	0.000	0.001	0.012	0.013
	Wet	0.000	1.899	0.461	0.001	0.005	0.262	0.059
Oshi	Dry	0.003	0.060	0.155	0.000	0.004	0.012	0.087
	Wet	0.000	2.503	0.326	0.001	0.079	0.202	0.033
RDI [22]		-	0.90	3.0	0.2	0.3	-	0.21

* Values were expressed in mg/kg; RDI stands for recommended daily intake.

3.2 Health risk of heavy metals in the water samples

The non-carcinogenic risks (ADI and ADDE) of the heavy metals were both within the recommended limits (Tables 2 and 3). Furthermore, the HQs of the heavy metals via ADI were within tolerable levels (Figure 2). However, the HQ of Mn, Pb, and Zn during the dry season and Cr, Mn, Pb, and Zn during the wet season via ADDE were higher than the recommended limits (Figure 3). Table 4 reveals the carcinogenic risks of the heavy metals via oral and dermal exposures, in which the risk values for Cr (wet season only) and Pb were higher than acceptable values. These results show that daily oral water ingestion may not cause any significant non-carcinogenic risks, but dermal exposure to the water may cause non-carcinogenic health risks related to Mn, Pb, Zn, and Cr toxicities. Additionally, oral and dermal exposures to the water may cause carcinogenic risks related to Cr and Pb toxicities. Adeniyi *et al.* (2016) [30] noted a significant health risk from prolonged consumption of heavy metals in groundwater samples obtained from Oshodi, which is consistent with the current findings. Emenike *et al.* (2019) [32] also reported non-carcinogenic and carcinogenic risks of heavy metals in groundwater across the Lagos metropolis. However, the results contradict those of Egbueri and Unigwe

(2019) [28], who reported an excellent pollution index in groundwater samples obtained from Oshodi. Yahaya *et al.* (2020) [11] also reported permissible values of ADI and HQ of heavy metals in water samples collected from boreholes in Shomolu, Lagos.

3.3 Microorganisms in the water samples

Table 5 depicts the levels of bacteria, coliforms, and fungi in the water samples. All the microorganisms evaluated were detected within the permissible limits. The detection of permissible counts of bacteria, coliforms, and fungi in the water samples showed that daily consumption of the water may not cause any pathogenic disease, particularly diseases related to the microorganisms evaluated. These results contradict all the retrieved literature with similar objectives. Notably, Yahaya *et al.* (2020) [11] detected non-tolerable counts of microorganisms in borehole water samples collected from Shomolu in Lagos. Emmanuel-Akerele *et al.* (2021) [33] also detected harmful levels of microorganisms in borehole water obtained in Ayobo, Lagos. In addition, Oloruntola *et al.* (2018) [34] reported non-permissible counts of microorganisms across the Lagos metropolis. Anthropogenic activities and sanitary conditions varied across the state, which could influence concentrations of microorganisms in water.

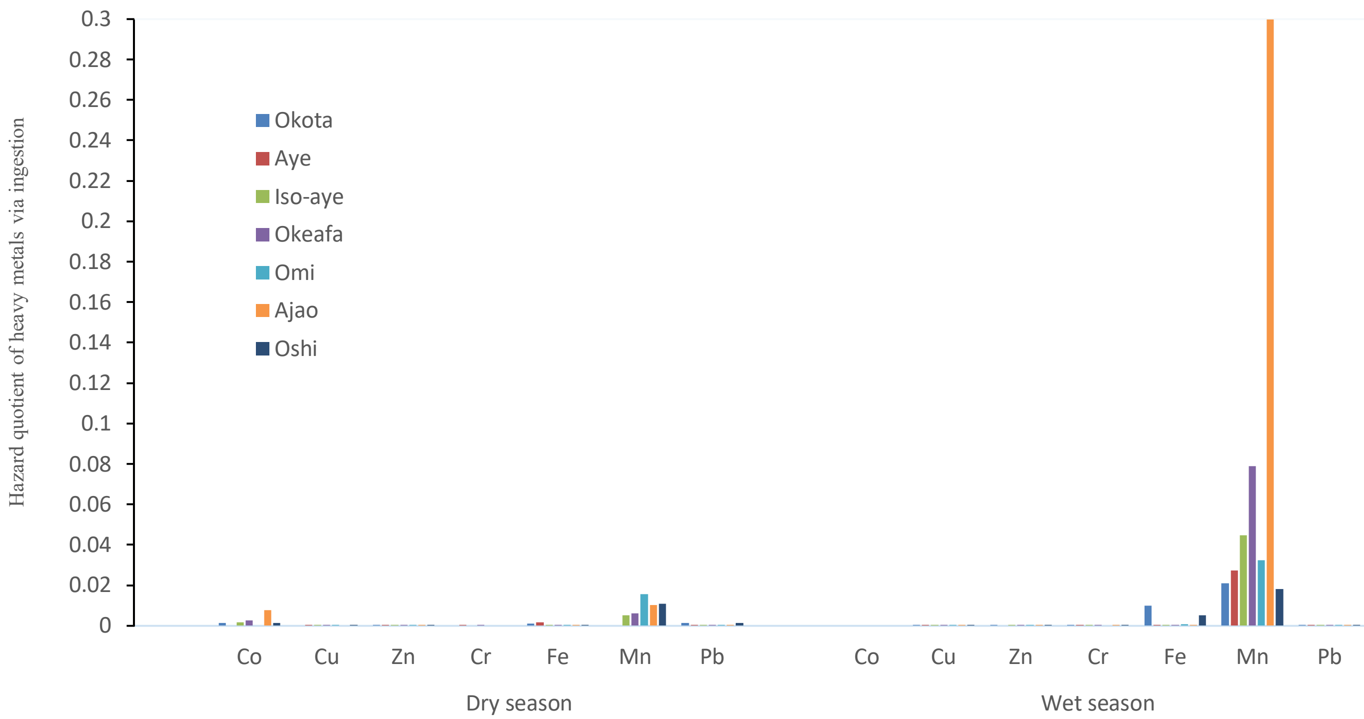

Figure 2. Hazard quotient of heavy metals via ingestion of borehole water collected during dry and wet seasons

Table 4. Carcinogenic risk of heavy metals in borehole water collected during dry and wet seasons

Locations	Season	Pb	Cd	Cr	Cu	Zn	Mn	Fe
Okota	Dry season	0.000019	0.000	0.000	-	-	-	-
	Wet season	0.0000007	0.000	0.000	-	-	-	-
Aye	Dry season	0.000019	0.000	0.000002	-	-	-	-
	Wet season	0.0000010	0.000	0.000002	-	-	-	-
Iso-Aye	Dry season	0.0000013	0.000	0.000	-	-	-	-
	Wet season	0.0000016	0.000	0.0000025	-	-	-	-
Oke Afa	Dry season	0.0000014	0.000	0.000002	-	-	-	-
	Wet season	0.0000003	0.000	0.000019	-	-	-	-
Omi	Dry season	0.0000003	0.000	0.000	-	-	-	-
	Wet season	0.000	0.000	0.0000025	-	-	-	-
Ajao	Dry season	0.000002	0.000	0.000	-	-	-	-
	Wet season	0.0000110	0.000	0.000	-	-	-	-
Oshi	Dry season	0.000002	0.000	0.000	-	-	-	-
	Wet season	0.0000059	0.000	0.00019	-	-	-	-

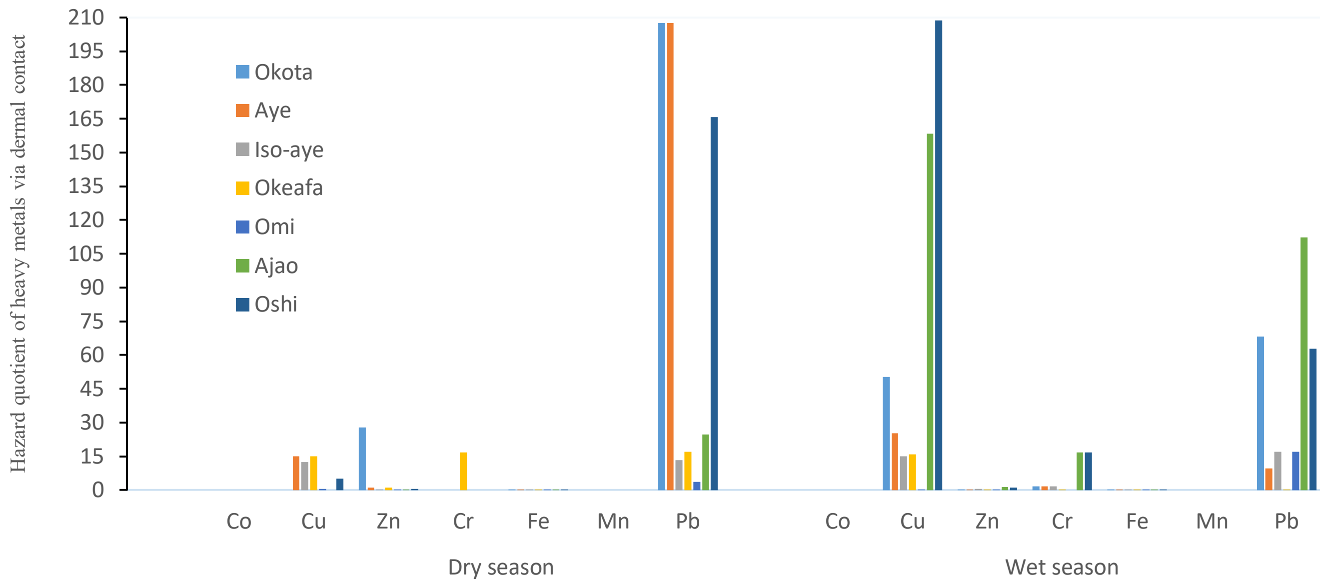

Figure 3. Hazard quotient of heavy metals via dermal exposure to borehole water collected during dry and wet seasons

Table 5. Bacterial, fungal, and coliform counts of borehole water collected during wet and dry seasons

Locations	Season	Total bacterial count	Total fungi count	Total fecal coliform count
Okota	Dry season	55±6.16	16±3.3	ND
	Wet season	45±6.16	13±3.33	ND
Aye	Dry season	47±8.033	ND	ND
	Wet season	57±8.033	ND	ND
Iso-Aye	Dry season	34±5.00	ND	ND
	Wet season	44±5.00	15±4.33	ND
Oke Afa	Dry season	75±8.64	14±3.33	ND
	Wet season	85±8.64	11±3.33	ND
Omi	Dry season	71±5.00	ND	ND
	Wet season	61±5.00	ND	ND
Ajao	Dry season	74±11.33	ND	ND
	Wet season	74±11.33	ND	ND
Oshi	Dry season	12±2.33	16±3.33	ND
	Wet season	22±2.33	17±3.33	ND
[23]		≤100 CFU/mL	≤50 CFU/mL	0 CFU/100 mL

* Values were expressed as mean ± S.D. in CFU/mL; ND indicates not detected.

4. Conclusion

The results showed that borehole water samples from Okota, Ayo, Osi, Oke-Afa, Ajao, Oshi, and Iso-Aye streets, all in Oshodi/Isolo, Lagos, contained non-acceptable concentrations of Pb and Mn during the wet and dry seasons. The daily oral ingestion of the water may not trigger non-carcinogenic health risks; however, dermal exposure to the water may cause toxicities related to Mn, Pb, and Zn during the dry season and Cr, Mn, Pb, and Zn during the wet season. Furthermore, both oral and dermal exposure to the water may cause carcinogenic risks related to Pb and Cr during the wet season and Pb during the dry season. The daily consumption of water may not cause any pathogenic diseases, particularly those borne by coliforms, bacteria, and fungi. Based on the findings of this study, consumers of borehole water in these areas need to treat the water before consumption. Policies aimed at decontaminating the environment need to be put in place in these areas. Efficient pollution control strategies should be put in place at sources of environmental pollution such as dumpsites, factories, artisan shops, sewage, municipal waste, and vehicular emissions.

Authors' Contributions

Tajudeen Olanrewaju Yahaya: Conceptualization; Methodology; Writing-original draft. Nwabudike Hillary Nwabuaku: Data curation. Yunusa Abdulganiyu: Formal analysis. Oluwatoyin Ologe: Investigation; Writing-review and editing.

Lukman Abdullahi: Investigation; Software. Hamdalat Sheu: Data curation; Validation.

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Conflicts of Interest

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Ethical considerations

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