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Health Risk Assessment of Heavy metals, Physicochemical properties and Microbes in Groundwater near Igando Dumpsite in Lagos, Nigeria

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ABSTRACT: The most common and cost-effective waste disposal method is the dumpsite; however, leachate from dumpsites may percolate and compromise groundwater sources. This study evaluated the levels of heavy metals (lead, cadmium, chromium, copper, and arsenic), physicochemical parameters (pH, electrical conductivity, total dissolved solids, hardness, calcium, magnesium, and chloride), and microorganisms in borehole water samples obtained at distances of 50, 100, 200, and 400 meters from the Igando dumpsite in Lagos, Nigeria. The health hazards associated with the heavy metals were also calculated. Physicochemical analysis indicated that the water samples were acidic, with pH values ranging from 4.30±0.01 to 5.21±0.008. They contained levels of calcium (166.73±0.01 - 328.66±0.06 mg/l), magnesium (83.72±0.02 - 119.40±0.17 mg/l), hardness (416.01±0.11 mg/l - 820.00±1.63 mg/l), and chloride (20.07±0.02 - 120.90±0.81 mg/l) that exceeded the limits set by the World Health Organization. Heavy metal analysis showed that, in all locations, lead exceeded the permissible limits, cadmium exceeded the limits except for the 400-m location, and copper, chromium, and arsenic (except for the 50-m location) were within permissible limits. The average daily intake and hazard quotient of the heavy metals were both within recommended limits, but the carcinogenic risks of lead, cadmium, and copper in water collected at a distance of ≤100m exceeded the threshold. Microbiological examinations revealed non-permissible levels of bacteria at all locations, coliforms at the 400-m location, and fungi at the 50-m and 400-m locations. On average, the parameters significantly ($p<0.05$) increased in concentrations as the proximity to the dumpsite decreased. These findings indicate that borehole water is not suitable for drinking without treatment.

KEYWORDS: Bacteria; dumpsites; groundwater; hazard quotient; lead

1. Introduction

Waste generation has been a global issue since the dawn of civilization. Population growth, rapid urbanization, industrial expansion, and economic globalization have amplified waste production [1]. Worldwide, approximately 41.8 million metric tons of waste are generated annually, and this figure is projected to soar to 3.4 billion tons by 2050, given current pollution trends and increased urbanization [2]. The issue of waste generation is of such magnitude that it ranks as a top-priority health concern in Europe [3]. Waste significantly contributes to soil, food, and groundwater contamination, resulting in various diseases. Solid waste, in particular, is a breeding ground for vector-borne diseases and zoonotic diseases, including gastrointestinal, dermatological, respiratory, and genetic diseases, among others [4]. Globally, over 8000 people die daily from diseases related to waste accumulation [5]. The threat posed by waste accumulation is more pronounced in developing nations due to weak economies, inadequate infrastructure, and limited planning.

The most prevalent waste disposal method globally involves the use of dumpsites or landfills and is particularly common in developing nations because of their cost-effectiveness in construction and management [6]. When sited and managed appropriately, dumpsites have a minimal impact on the environment [7]. Unfortunately, dumpsites in developing nations are often poorly managed and have been linked to a multitude of health and environmental issues. Poorly managed dumpsites can cause seepage of leachate into groundwater and contaminate it [8]. Leachates from dumpsites contain heavy metals, microorganisms, and other toxic compounds [9]. Heavy metals are non-biodegradable, persistent, accumulative, and toxic with high molecular weight. Notable heavy metals include nickel (Ni), lead (Pb), chromium (Cr), manganese (Mn), iron (Fe), copper (Cu), and cadmium (Cd), among others. Common environmental microorganisms include bacteria, fungi, viruses, and protozoans. Waste can also compromise the physicochemical properties of water, such as electrical conductivity, pH, hardness, temperature, total dissolved and suspended solids, and nutrient content, among others. This highlights the risk of microbial infections and heavy metal toxicity for people living near dumpsites. High rates of stomach and cervical/uterine cancers in women, as well as stomach, liver, lung, and prostate cancers in men, have been reported among individuals residing in close proximity to dumpsites [10]. This underscores the necessity for regular monitoring of dumpsites in every community.

The Igando dumpsite in Lagos is Nigeria's second-largest dumpsite, covering approximately sixteen hectares of land and receiving about 4000 tons of refuse daily [11]. Regrettably, the dumpsite is poorly managed and emits offensive odors and toxic fumes that pervade the atmosphere. Leachate and debris from the dumpsite have the potential to contaminate the surrounding groundwater. Groundwater serves as the primary water source in the area and Nigeria at large, making periodic groundwater quality assessments in residential areas around the dumpsite a necessity. This study, therefore, evaluated the levels and risks of physicochemical parameters, microbial organisms, and heavy metals in boreholes in residences around the Igando dumpsite, Lagos.

2. Materials and Methods

2.1. Description of the study area.

The Igando dumpsite is situated in the Alimosho local government area of Lagos State, Nigeria (Fig. 1). The dumpsite spans from longitudes 03.173E to 03.175E and latitudes 06.364N to 06.368N [12]. The environment around Lagos features tropical vegetation and is adorned with numerous water bodies, including the Atlantic Ocean, lagoons, rivers, streams, creeks, and estuaries. The area experiences an extended rainy season, typically commencing in March and ending in October, with the remaining months being dry. Lagos shares international borders with the Republic of Benin to the south and west and is bounded by Ogun State to the east and north. Lagos stands as one of the world's most populous cities and Nigeria's most industrialized urban center, making it an economic powerhouse in Africa. The Igando dumpsite ranks among the primary waste disposal sites within Lagos, being the second-largest in the city and across Nigeria, covering an expanse of approximately sixteen hectares of land [11]. Its significance in waste management within the city cannot be overstated. The micro-climate surrounding the dumpsite closely mirrors the overall climate of Lagos. Despite its daily intake of substantial amounts of waste, it suffers from poor management, as evidenced by the persistent odors, fumes, and swarms of flies emanating from the site. The dumpsite's adverse impact on groundwater is evident, necessitating the undertaking of the current study

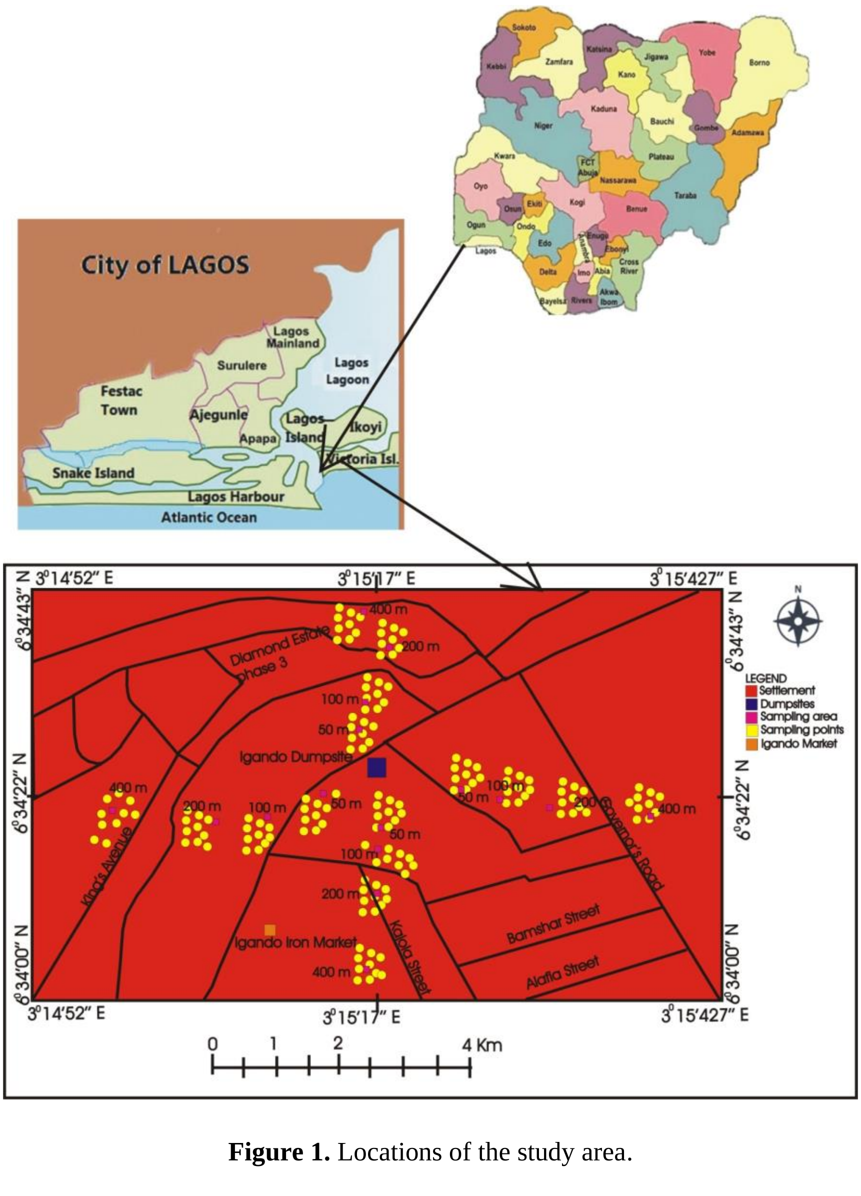

Figure 1. Locations of the study area.

2.2. Sample collection and treatment.

Ten (10) water samples were randomly collected in polyethylene terephthalate plastic bottles at each of the distances: 50, 100, 200, and 400 m from the Igando dumpsite (designated as A, B, C, and D, respectively), resulting in the total collection of 40 samples. The sampling took place during the wet season in May 2022, when leachate seeping into groundwater would be most pronounced [13]. The selection of these sampling locations was based on the research by Igboama et al. [7], which suggests that the most significant groundwater contamination near dumpsites occurs within 200 m. To ensure the integrity of the samples, the sampling bottles were pre-cleaned, sterilized, and rinsed with distilled water before being allowed to air-dry. Prior to actual sampling, the bottles were rinsed twice with each borehole water source to prevent dilution and then appropriately labeled. The collected samples were preserved in the laboratory at 4°C and later analyzed on the following day.

2.3. Determination of physicochemical parameters.

All parameters were measured in accordance with the procedures outlined by [14]. Given that some of the parameters under evaluation are time-sensitive, on-site assessments were performed. The pH levels were determined using the Aquasol digital pH meter (Model No AM-P-AL). Total dissolved solids (TDS) and electrical conductivity (EC) were determined using a portable HM Digital COM-100 TDS Conductivity Meter. Turbidity (NTU) was assessed with the HACH Model DR/2000 Spectrophotometer. Calcium (Ca), chloride (Cl), and total hardness were quantified using the Palin test Photometer 7500.

2.4. Heavy metal analysis.

The procedure outlined by Yahaya et al. [15] was followed in the heavy metal analysis. Each water sample was thoroughly mixed and then digested by transferring 100 ml of it into a previously cleaned 50-ml beaker, which contained 5 ml of concentrated HNO_3. The beaker was heated until the content dried completely, then allowed to cool before an additional 5 ml of concentrated HNO_3 was added. It was heated again until a light-colored residue appeared. To dissolve the residue, 1 ml of HNO_3 was added, and the heating was done at a low temperature. The beaker was rinsed and filled with distilled water up to the meniscus. Subsequently, the digest was analyzed for the presence of Fe, Cu, Mn, Pb, Cr, Ni, and Zn using the UNICAM 969 atomic absorption spectrophotometer. To ensure the accuracy of the analysis, reagents used were formulated from chemicals of analytical grade. Non-metallic materials were used throughout, and they were thoroughly washed with ultrapure water and rinsed with reagent for each container. Blank samples were analyzed concurrently with the water samples to detect any background contamination. Each sample was evaluated three times, and the reproducibility of nearly identical values exceeded 95%.

2.5 Microbial analysis.

The total bacterial count in each water sample was determined by filtering 0.1 ml through a sterile cellulose filter (0.2 µm pore size) and inoculating it onto a nutrient agar plate, following the procedure outlined by Yahaya et al. [15]. The inoculated plates were then incubated for approximately 24 hours at 35 °C. Subsequently, the bacterial colonies that appeared on the plate were counted using a colony counter. Coliforms were assessed by inoculating the filter, which contained bacteria, into lauryl tryptose broth media and incubating it at 35 °C for 2 hours. The filter was then transferred to M-Endo media and incubated at 35 °C for 22 hours. The resulting sheen colonies were observed and counted. Fungal colonies were estimated in a manner similar to the bacteria, with the only difference being the addition of penicillin to the nutrient agar to prevent bacterial growth.

2.6. Health risk assessment.

The health risks associated with the heavy metals in the borehole were calculated using equations 1, 2, and 3 as provided by [16].

$$ADI = \frac{C_x \ X \ I_r \ X \ E_f \ X \ E_d}{B_{wt} \ X \ A_t} \quad (1)$$

$$HQ = \frac{ADI}{RFD} \quad (2)$$

$$CR = ADI / \ CSF \quad (3)$$

In equation 1, Average Daily Intake (ADI) stands for average daily ingestion of a heavy metal per kilogram of body weight, C_x represents the concentration of heavy metals in water, I_r signifies the ingestion rate per unit time, E_f denotes the exposure frequency, E_d represents the exposure duration (which is equal to the life expectancy of a Nigerian resident), B_{wt} stands for body weight, and A_t denotes average time (E_d x E_f). Table 1 shows the standard values and units for these parameters. In equation 2, Hazard Quotient (HQ) stands for the hazard quotient, and RFD indicates the oral reference dose (measured in mg/l/day) of heavy metals. The specific RFD values are as follows: Cu = 40, Pb = 1.4, Cd = 0.5, As = 0.6, and Cr = 3.0. In equation 3, and Carcinogenic Risk (CR) stands for carcinogenic risks, and CSF represents the cancer slope factor (measured in mg/kg/day). The CSF values are as follows: Pb = 0.009, Cr = 0.50, Cd = 6.10, Fe = 0.0, and Cu = 0.0. A CR value exceeding 10^{-6} was considered potentially carcinogenic.

Table 1: Standard values for calculating average daily ingestion of heavy metals [16].

Exposure factor	Unit	Value
Exposure frequency (E_f)	Day/year	365
Ingestion rate (I_r)	l/day	2
Exposure duration (E_d)	Year	55
Average body weight (B_{wt})	kg	65
Average time (A_t)	Day	20075

2.7. Data analysis.

The values were presented as mean ± standard deviation (SD) using the Statistical Package for Social Sciences (SPSS) version 21. Analysis of variance (ANOVA) was employed to determine the significant differences ($p \leq 0.05$) between values at each location. Additionally, the ADI, HQ, CR of the heavy metals were calculated using the software.

3. Results and Discussion

3.1. Physicochemical characteristics of the water samples.

Table 2 presents a comparison of the physicochemical characteristics of water samples collected from boreholes situated at varying distances from the Igando dumpsite. The comparison is made both within the different distances and against the standards set by the Nigerian Industrial Standards (NIS) and the World Health Organization (WHO). The results indicate noteworthy variations ($P \leq 0.05$) in the physicochemical parameters of water samples obtained at distances of 50, 100, 200, and 400 meters from the dumpsite. The water samples demonstrated acidity, with pH values recorded as 4.30±0.01 at 50 m, 4.51±0.02 at 100 m, 4.89±0.02 at 200 m, and 5.21±0.008 at 400 m, falling below the permissible limits outlined by both NIS and WHO. Furthermore, the concentrations of Ca (328.66±0.06 mg/l at 50 m, 267.33±0.05 mg/l at 100 m, 166.73±0.01 mg/l at 200 m, and 230.46±0.04 mg/l at 400 m), Mg (119.40±0.17 mg/l at 50 m, 97.12±0.013 mg/l at 100 m, 60.17±0.061 mg/l at 200 m, and 83.72±0.02 mg/l at 400 m), and water hardness (820.00±1.63 mg/l at 50m, 667.03±0.87 mg/l at 100 m, 416.01±0.11 mg/l at 200 m, and 575.92±1.55 mg/l at 400 m) in all the samples exceeded the permissible limits. However, TDS, EC, and Cl (at 400 m only) levels remained within the acceptable range. Overall, the concentrations of these water parameters increased as the proximity to the dumpsite increased.

The low pH values (acidity) of the water indicate a substantial presence of organic waste at the dumpsite. According to Amano et al. [17], the decomposition of organic waste results in the release of carbon dioxide, which reacts with groundwater to form carbonic acid. The excessive concentrations of cations (Ca, Mg, and Cl) in the water could have been released during the acidic fermentation of organic waste [18], contributing to the water's hardness [19]. These findings raise concerns about the safety of this water for consumption. Acidic water can cause gastrointestinal and eye disorders in sensitive individuals [20]. An overload of Ca in the bloodstream can weaken the bones, lead to kidney stones, and disrupt heart and brain functions [21]. High Mg intake can cause hypermagnesemia, characterized by impaired kidney function, bowel disorders, hypothyroidism, and Addison's disease, with a potential link to cardiovascular disease and cancer [22]. Chloride-rich water may lead to excessive salt intake, resulting in conditions such as edema, obesity, high blood pressure, pulmonary edema, cerebral edema, and gastrointestinal diseases [23]. These results align with previous studies by Osibanjo et al. [24] and Yahaya et al. [25], all of whom detected non-tolerable levels of physicochemical parameters in well and borehole water situated around dumpsites in Lagos. In contrast, Oluseyi et al. [26] and Ameloko and Ayolabi [27] did not detect abnormalities in the physicochemical parameters of borehole water near dumpsites in Lagos. These inconsistencies could be due to the varied volume of pollutants released by the dumpsites, influenced by the type and quantity of waste deposited, the age of the dumpsites, and the climatic conditions around the dumpsites [28].

Table 2. Mean levels of physicochemical characteristics in water samples collected from boreholes in residential areas around the Igando dumpsite in Alimosho, Lagos.

Physicochemical characteristics	Location A (50 m)	Location B (100 m)	Location C (200 m)	Location D (400 m)	Standard limits	
					NIS [29]	WHO [30]
pH	4.30±0.01^{a}	4.51±0.02^{b}	4.89±0.02^{c}	5.21±0.008^{d}	6.0 -9.0	6.5 – 8.5
EC (μS/cm^{3})	120.90±0.08^{d}	100.11±0.09^{c}	79.07±0.29^{a}	90.07±0.03^{b}	1000	300
TDS (mg/l)	106.47±0.05^{d}	44.50±0.371^{c}	56.99±0.013^{b}	41.02±0.06^{a}	500	500 - 1500
Hardness (mg/l)	820.00±1.63^{d}	667.03±0.87^{c}	416.01±0.11^{a}	575.92±1.55^{b}	150	100 - 250
Calcium (mg/l)	328.66±0.06^{d}	267.33±0.05^{c}	166.73±0.01^{a}	230.46±0.04^{b}	65-70	75
Magnesium (mg/l)	119.40±0.17^{d}	97.12±0.013^{c}	60.17±0.061^{a}	83.72±0.02^{b}	20	50
Chloride (mg/l)	120.90±0.81^{d}	100.11±0.03^{c}	79.06±0.02^{b}	20.07±0.02^{a}	250	250

Note: Data were presented as mean ± standard deviation. Data in the same row with different superscript letters (a, b, c, and d) are different significantly ($P \leq 0.05$). NIS stands for Nigerian Industrial Standards and WHO represents World Health Organization.

3.2. Levels of heavy metals in the water samples.

Figure 2 illustrates the concentrations of Pb, As, Cu, Cd, and Cr in the borehole water samples. Across all locations, Pb (0.098±0.002 mg/l at 50 m, 0.079±0.004 mg/l at 100 m, 0.077 ± 0.147 mg/l at 200 m, and 0.077±0.001 mg/l at 400 m) exceeded permissible limits. On the other hand, Cu (0.382±0.001 mg/l at 50 m, 0.389±0.001 mg/l at 100m, 0.387±0.173 mg/l at 200m, and 0.377±0.001 mg/l at 400 m) and Cr (0.040±0.002 mg/l at 50 m, 0.030±0.016 mg/l at 100 m, 0.030±0.010 mg/l at 200 m, and 0.020 ± 0.014 mg/l at 400 m) remained within the acceptable range. As was below detection levels in all locations except for samples collected at a 50m distance from the dumpsite, which recorded 0.008±0.009 mg/l. Cd (0.017±0.006 mg/l at 50 m, 0.020±0.014 mg/l at 100 m, 0.020±0.005 mg/l at 200 m, and 0.002±0.003 mg/l at 400 m) exceeded permissible limits in all locations except for samples collected at 400 m. Overall, the levels of these heavy metals increased as the proximity to the dumpsite increased. The most probable sources of Cd in the water are wastes from phosphate fertilizers, sewage sludge from homes and industries that produce Ni-Cd batteries, iron and steel, pigments, and plastics [31]. Pb is naturally occurring, but high concentrations may suggest waste from homes and industrial products such as paint, ceramics, pipes, cosmetics, plumbing materials, solders, gasoline, and batteries, among others [32]. Cr is also naturally occurring but can be released from iron, steel, and tannery processing [33]. In addition to natural deposits, Cu can be released from industrial and agricultural waste [34].

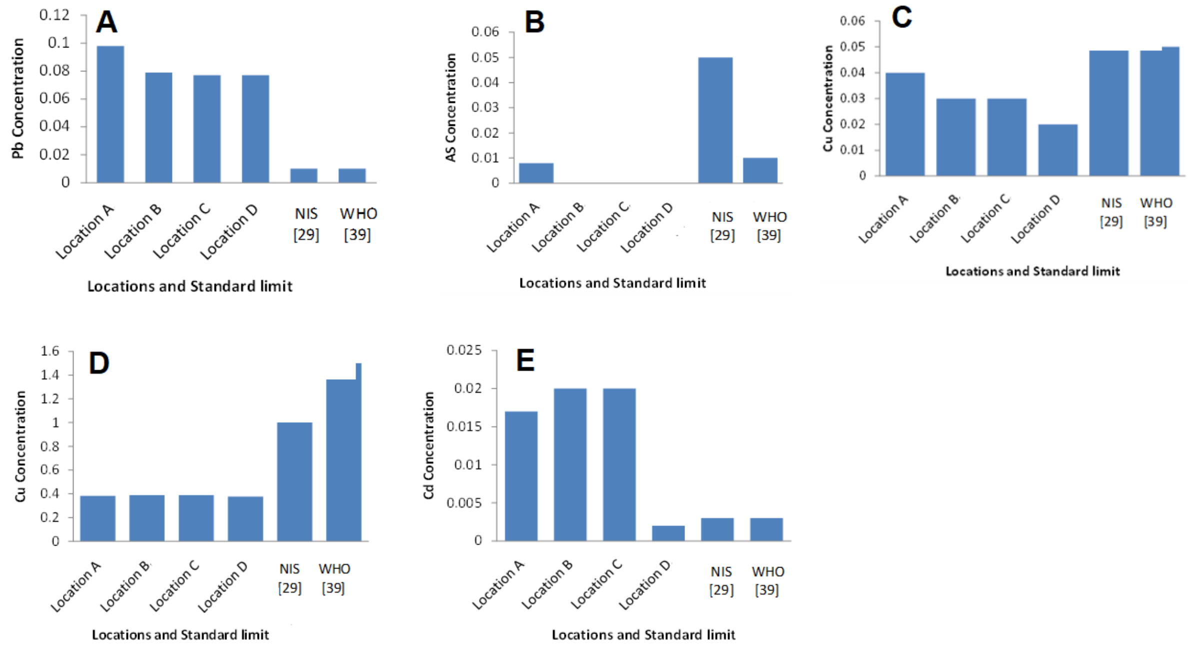

Figure 2. Mean levels of Pb (A), As (B), Cr (C), Cu (D), Cd (E), and in water samples collected from boreholes in residential areas around Igando dumpsite in Alimosho, Lagos. (Note: BDL means below detectable limits, NIS stands for Nigerian Industrial Standards, and WHO represents World Health Organization.

3.3. Health risks of heavy metals in the water samples.

The average daily intakes (ADI) of Pb, As, Cu, Cd, and Cr from the borehole water are presented in Table 3. ADI for all the heavy metals fell within the recommended dietary intake (RDI) levels. Similarly, Table 4 illustrates that the hazard quotient (HQ) for each heavy metal in every location remained within the recommended limits (<1). In Table 5, the carcinogenic risks (CR) associated with the heavy metals were presented. Notably, Pb and Cd at a distance of 50 m from the dumpsite, as well as Cu at 50 and 100 m, exceeded the threshold of 10^{-6}. These values suggest that daily consumption of borehole water in the areas studied may not pose a significant non-carcinogenic health risk. However, in strict toxicological terms, there are no safe doses of heavy metals, and heavy metals can interact additively to increase toxicity.

Coming from inorganic sources, heavy metals can accumulate in tissues or organs causing damage. Thus, the presence of appreciable levels of heavy metals in the water raises concern. Contrary to the water's non-carcinogenic health risks, the Pb, Cd, and Cu in the water may pose significant carcinogenic risks, particularly for people consuming water from boreholes situated less than 100m from the dumpsite. Overall, these findings suggest that the water may pose heavy metal-related toxicities. Specifically, exposure to high levels of Pb can result in anemia, fatigue, fetal developmental errors, infertility, and damage to the kidney and brain [35]. Short-term exposure to high levels of Cd can cause flu-like symptoms and lung injury, while chronic exposure can lead to organ damage [36]. Long-term consumption of water containing As can predispose individuals to cardiovascular disease, diabetes mellitus, cancer, mental retardation, and dermatological issues [37]. Hexavalent Cr is a known carcinogen, and some studies suggest that trivalent Cr can rupture cell membranes and cause DNA damage [38]. Ingesting high levels of a Cu compound can cause gastrointestinal disease and, rarely, liver damage [39]. These findings are consistent with those of Kayode et al. [40] and Yahaya et al. [41], all of whom detected non-permissible levels of heavy metals in groundwater near dumpsites in Lagos, Nigeria. However, in a study conducted by Aboyeji and Eigbokhan [42] in Lagos, permissible levels of heavy metals were detected in boreholes near a dumpsite.

Table 3. Average daily intake (ADI) of heavy metals in the water samples collected from boreholes in residential areas around the Igando dumpsite in Alimosho, Lagos.

Heavy metal (mg/L)	Location A (50 m)	Location B (100 m)	Location C (300 m)	Location D (400 m)	Standard Limit WHO [30]
Pb	0.003	0.002	0.002	0.002	0.05
As	0.00	0.00	0.00	0.00	0.05
Cu	0.012	0.012	0.012	0.012	1.00
Cd	0.000	0.000	0.00	0.000	0.005
Cr	0.001	0.000	0.000	0.000	0.100

Table 4. Hazard quotient (HQ) of heavy metals in the water samples collected from boreholes in residential areas around the Igando dumpsite in Alimosho, Lagos.

Heavy Metal (mg/L)	Location A (50m)	Location B (100m)	Location C (200)	Location D (400)
Pb	0.000	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000
Cu	0.024	0.024	0.024	0.023
Cd	0.000	0.000	0.001	0.001
Cr	0.000	0.000	0.000	0.000

Table 5. Carcinogenic risk (CR) of heavy metals in the water samples collected from boreholes in residential areas around the Igando dumpsite in Alimosho, Lagos.

Heavy metal (mg/L)	Location A (50m)	Location B (100m)	Location C (200m)	Location D (400m)
Pb	0.075	0.000	0.000	0.000
As	0.000	0.000	0.000	0.000
Cu	0.074	0.025	0.000	0.000
Cd	0.073	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000

3.4. Levels of microorganisms in the water samples.

Table 6 presents the levels of bacteria, coliforms, and fungi in the water samples. All the water samples exceeded the permissible bacteria levels (1100000±1500 CFU/ml at 50 m, 1000000±2100 CFU/ml at 100 m, 100000±1600 CFU/ml at 200 m, and 1000000±2500 CFU/ml at 400 m). Furthermore, the water samples collected at 400m from the dumpsite exhibited non-tolerable levels of coliforms, registering at 110±40 CFU/ml, while fungi exceeded permissible limits at both 50m (200±60 CFU/ml) and 400 m (500±100 CFU/ml) from the dumpsite. These results further corroborate the unsuitability of the water for drinking. Infectious bacteria such as Streptococcus and Staphylococcus multiply rapidly in the body and produce toxins that damage tissues and organs [43]. Certain bacteria, such as Acinetobacter, Pseudomonas, and Enterobacteriaceae, can cause life-threatening infections such as bloodstream infections and pneumonia [44]. The presence of coliforms in drinking water indicates fecal contamination [15]. The most common fecal coliform is E. coli, and while most variants are nonpathogenic, some can release toxins and cause life-threatening diseases, including haemolyticuraemic syndrome [45]. Fungi can cause allergic reactions, skin irritation, immune system dysfunction, as well as produce toxins such as mycotoxins that cause severe health hazards [46]. Similar to the current study, previous research by Oluseyi et al. [26] and Yahaya et al. [38] detected non-permissible levels of microorganisms in groundwater near dumpsites in Lagos. However, Emmanuel-Akerele and Peter [47] did not find non-tolerable levels of microorganisms in groundwater around boreholes in Lagos. The high levels of microorganisms in the water suggest significant nutrient loads from organic wastes in the dumpsites, particularly sewage and food scraps from homes, eateries, and agricultural sources, among others.

Table 6. Mean counts of microorganisms in the water samples collected from boreholes in residential areas around the Igando dumpsite in Alimosho, Lagos.

Microbial count (CFU/mL)	Location A (50 m)	Location B (100 m)	Location C (200 m)	Location D (400 m)	Standard limits	
					NSDWQ [48]	WHO [30]
Total bacteria	1100000±1500	1000000±2100	100000±1600	1000000± 2500	100	100
Total coliform	0.00	0.00	0.00	110 ± 40	10	0
Total fungi	200 ± 60	0.00	0.00	500 ± 100	10	10

4. Conclusions

The results reveal that borehole water near the Igando dumpsite in Alimosho, Lagos, is acidic, hard, and contains non-tolerable levels of cations, including Ca, Mg, and Cl. Furthermore, the water contains non-permissible levels of heavy metals, such as Pb and Cd, along with appreciable levels of Cu and Cr. Borehole water samples collected at a distance of less than or equal to 200 m from the dumpsite were the most affected. While the ADI) and HQ of the heavy metals were within the recommended limits, Pb, Cd, and Cu in water samples collected at or less than 100 m posed carcinogenic risks. Moreover, the water samples had non-tolerable levels of microorganisms, mainly bacterial colonies. Overall, the results suggest that the water is unsuitable for consumption. Based on the findings of this study, we recommend that adequate treatment of water from boreholes located near the dumpsite before consumption is essential. Boreholes should not be situated less than 400 m from the dumpsite. Environmental and health agencies in the area should ensure that the dumpsite is remediated of toxic metals and maintained in hygienic conditions. Public awareness in the area is needed to inform residents about the dangers posed by the dumpsite in terms of physicochemical, heavy metal, and microbial pollution of groundwater. Regular studies, similar to the current one, should be conducted periodically on the dumpsite and its surrounding environment.

Acknowledgments

Not applicable.

Competing Interest

All authors have no competing interest to declare.

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