Fountain Journal of Basic Medical and Health Sciences, 1 (2), 77-89.

Evaluation of Ecological and Health Risks of Heavy Metals in Selected Hand-Dug Wells around Ido-Osun Landfill Site in Osogbo, Osun State, Nigeria

Oladeji F.O.[1*], Adewoye S.O.[2], Opasola A.O.[3], & Yusuf B.A.[3]

[1]*Department of Environmental Health Science, Fountain University, Osogbo, Osun State, Nigeria;*
[2]*Department of Environmental Biology, Ladoke Akintola University, Ogbomoso, Oyo State, Nigeria;*
[3]*Department of Environmental Health Science, Kwara State University, Malate, Nigeria.*

**Corresponding Author: fooladeji@fuo.edu.ng, +2348035612220.*

Abstract

Background: Groundwater is a vital source of drinking water, especially in developing regions. However, its quality is increasingly compromised by contamination from nearby landfill sites. **Objective:** This study assessed the physicochemical characteristics and heavy metal concentrations in groundwater around the Ido-Osun landfill, located in Osogbo Local Government Area, Osun State, Nigeria. **Methodology:** Groundwater samples were collected and analysed using standard procedures. Physicochemical parameters were measured, and heavy metals were quantified using Atomic Absorption Spectrophotometry after acid digestion. Results were compared against World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) guidelines. The Water Quality Index (WQI) was computed to provide an integrated assessment of water safety. **Results:** While most physicochemical parameters fell within acceptable limits, elevated levels of total dissolved solids (TDS: 429.8 mg/L) and nitrate (NO_3^-: 37.46 mg/L) were recorded in some samples. Heavy metal analysis revealed concerning concentrations of lead (Pb: 0.03 mg/L), chromium (Cr: 0.24 mg/L), and copper (Cu: 0.16 mg/L). The calculated WQI was **358.84**, placing the groundwater in the **"extremely poor"** category. This classification indicates that the water is **unfit for drinking without significant treatment**, posing immediate health risks. The WQI integrates various water quality parameters into a single value, and such a high score signals serious contamination affecting the overall usability of the water source. The health risk assessment further revealed a high non-carcinogenic hazard index (HI: 29.88), driven mainly by lead exposure (HQ: 29.25), far surpassing the safety threshold of 1. Carcinogenic risk values for lead (0.00057) and chromium (0.00027) also exceeded the USEPA's acceptable range (1.0×10^{-6} to 1.0×10^{-4}), indicating a potential lifetime cancer risk. **Conclusion:** The presence of elevated lead and chromium, along with a critically high WQI, underscores the urgent threat posed by the landfill to groundwater quality and public health. Immediate remediation strategies, consistent groundwater monitoring, and improved waste management practices are essential to prevent long-term health consequences for nearby communities.

Keywords: Groundwater contamination, landfill leachate, health risk assessment.

Introduction

Groundwater constitutes approximately 98% of the world's available freshwater and is relatively well distributed across different regions of the globe. It is generally regarded as a consistently reliable and naturally replenishing water source due to its protected subsurface location, making it less vulnerable to short-term depletion or immediate pollution compared to surface water (Mishra, 2023; World Bank, 2022). The quality of groundwater is of paramount importance for its suitability in industrial, agricultural, and especially domestic applications (RamyaPriya & Elango, 2022). The hydrochemical composition of both surface and groundwater is influenced by multiple natural and anthropogenic factors, including geological formations, topography, seasonal variations in runoff, land use patterns, and proximity to pollution sources (Adeoye *et al*., 2021; RamyaPriya & Elango, 2022). Changes in rainfall, evaporation rates, and groundwater recharge affect the spatial and temporal distribution of contaminants, particularly in tropical climates such as that of southwestern Nigeria. In Nigeria, especially in Osun State, groundwater is the predominant source of potable water for the majority of the population, particularly in peri-urban and rural areas where access to treated municipal water remains limited or erratic (Akinlolu *et al.,* 2023; Ige *et al.,* 2020). This dependence on groundwater has increased significantly due to the failure of public water supply schemes to meet rising domestic and commercial demands. However, this critical water resource is increasingly under threat from a wide range of pollution sources, notably uncontrolled solid waste disposal practices. In many urban centers across Nigeria, including Osogbo, the capital of Osun State, open dumpsites are commonly located near residential areas and water sources without consideration of environmental safety standards (Ganiyu *et al*., 2017; Afolabi *et al.,* 2021). Leachate from decomposing waste contains a complex mixture of organic and inorganic pollutants including nitrates, phosphates, heavy metals such as lead (Pb), chromium (Cr), cadmium (Cd), and copper (Cu), and pathogenic organisms (Ogundele *et al*., 2022). These contaminants percolate through the unsaturated zone into the aquifer, causing physicochemical and microbiological deterioration of groundwater (Adesakin et al., 2022). For instance, a recent study in Ido-Osun, Osun State, reported high concentrations of lead and chromium in groundwater samples taken near landfill sites, exceeding both WHO and Nigerian Standards for Drinking Water Quality (NSDWQ) guidelines (Oladeji *et al.,* 2024). Prolonged consumption of such contaminated water can lead to serious health implications, including neurological disorders, kidney damage, developmental delays in children, and increased lifetime cancer risks (USEPA, 2023). Despite the increasing health risks, routine groundwater monitoring is still lacking in many parts of Nigeria, and public health responses to groundwater contamination are often reactive rather than preventive. This highlights the urgent need to assess the current state of groundwater quality in areas surrounding active or abandoned landfill sites, such as the Ido-Osun dumpsite in Osogbo Local Government Area.

Methodology

Study Area

Osogbo, the capital city of Osun State in southwestern Nigeria, covers an area of about 47 square kilometers. The headquarters of Olorunda Local Government is located within the Osogbo metropolitan area. Osogbo shares its boundaries with several neighboring local government areas, including Ede North, Ifelodun, Atakumosa West, Egbedore, Ibokun, and Boripe. Geographically, Osogbo is situated between latitudes 7°42′ and 7°49′ North and longitudes 4°30′ and 4°38′ East, in the southern part of Nigeria. As of 2017, the estimated population of Osogbo was 527,953. This study was conducted at the abandoned landfill located in Ido-Osun, within Egbedore Local Government Area, which is integral part of the Osun Capital Territory Development Area. The dumpsite has historically been one of the biggest waste disposal sites serving the Osogbo metropolis and nearby local government areas. Figure 1 presents the map of the study area (Ido-Osun dumpsite), while Figure 2 shows the Ido-Osun Dumpsite in Osogbo, Osun State.

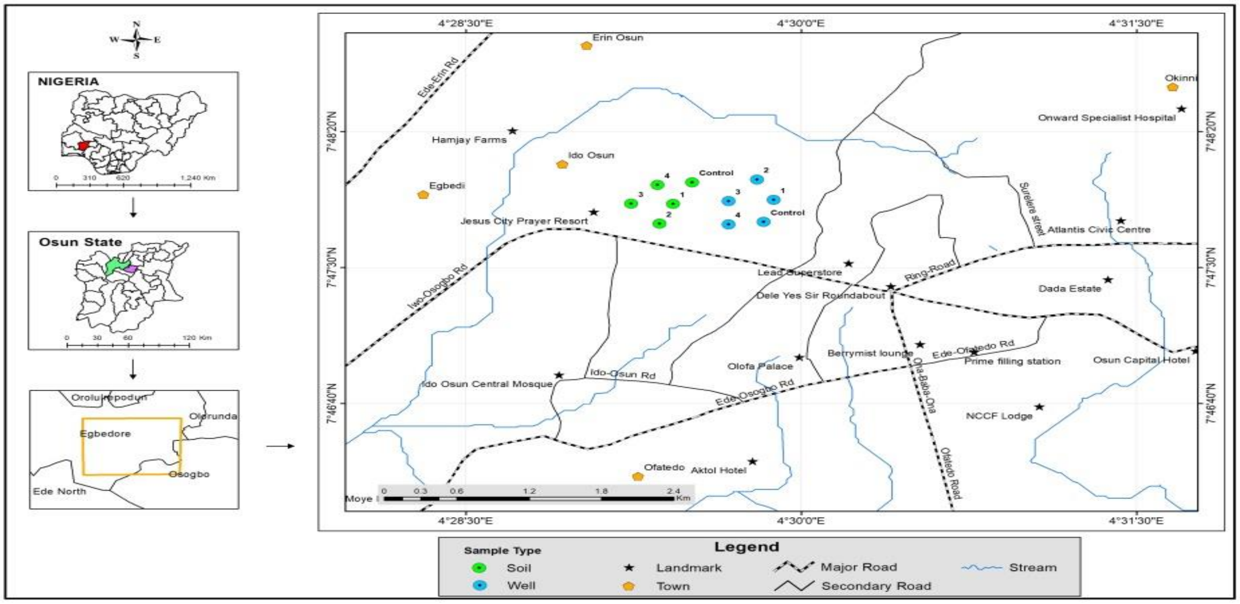

Figure 1: The Map of Osogbo Township Showing the Investigated dumpsite (Ido-Osun)

Figure 2: Ido-Osun Dumpsite, Osogbo

Sample Collection and Preservation

Sampling Plan

Water sampling for this study was conducted between November 2023 and August 2024 in the Ido-Osun area of Onibueje, Osogbo, Nigeria. The purpose of the sampling was to assess the extent of groundwater contamination potentially resulting from leachate migration and other waste-related pollutants originating from the Ido-Osun dumpsite. A total of five (5) groundwater samples were collected from five hand-dug wells located at varying distances and elevations in relation to the dumpsite. The selection of these sampling points was based on key environmental and human factors, including: Proximity to the dumpsite**,** elevation **g**radient (to determine the direction of potential contaminant flow) and oral interviews with local residents**,** which provided anecdotal evidence on changes in water quality and frequency of use. Each sampling point was georeferenced using a Global Positioning System (GPS) device to document the precise longitude and latitude of the well locations. This ensured accuracy in spatial mapping and subsequent correlation of pollution levels with site characteristics. Water samples were collected in pre-cleaned, sterilized plastic containers, labeled appropriately, and transported in an icebox to the laboratory for physico-chemical and heavy metal analysis. Standard procedures for sample preservation and quality control, including on-site measurement of temperature and pH, were followed as outlined by the APHA (2017) guidelines for water and wastewater examination. While the sampling strategy aimed to capture diverse environmental conditions near the Ido-Osun dumpsite, some limitations exist. The small number of samples (five hand-dug wells) may not reflect the broader groundwater condition. Sampling sites selected through oral interviews could introduce subjective bias. Additionally, differences in well structure and uncontrolled pollution sources may affect the consistency and accuracy of results.

Sample Treatment

The water samples for physico-chemical analysis were collected using 1 L plastic containers while those of soil samples were collected in polythene bags and transported to the laboratory. Water samples for physicochemical analysis were collected using one litre (1 L) plastic containers while those for heavy metals analysis were rinsed with (1: 1) HNO_3 acid. The water samples were then acidified with HNO_3 to a pH of 2. The HNO_3 acid prevents the growth of moulds and release all metals present in the water for analysis. The temperature and pH of water samples were also measured at the time of collection on the field.

Quality Control Protocol

Quality assurance and quality control were ensured by meticulously following the written procedures for sample handling both on the field and in the laboratory. Instruments and equipment used were calibrated. Quality control techniques were performed such as cleaning of apparatus, glassware and method blank determination. The apparatus used for the analyses were soaked overnight in detergent solution, rinsed many times with tap water and then soaked overnight in dilute HNO_3. The apparatus were rinsed many times with tap water until they were acid free and then finally rinsed with deionized water. This step was repeated in between analyses to avoid cross contamination. Standards were used to verify calibration accuracy. Analytical procedures were validated by carrying out duplicate analysis.

Laboratory Analysis and Procedures

All the samples were analysed for physico-chemical parameters namely pH, colour and turbidity, conductivity, alkalinity, acidity, dissolved oxygen (DO), Total Dissolved Solids (TSS). Major anions such as Chloride, Sulphate, Carbonate, and nutrients (Nitrate and Phosphate). Main group metals such as Aluminium, Potassium, and Magnesium, and some selected heavy metals such as Cadmium, Chromium, Copper, Iron, Manganese, Lead, Arsenic and Zinc were determined using Atomic Absorption Spectrophotometer (AAS). Samples were analysed within the holding time of the respective parameters using standard methods with adequate quality control measures.

Digestion of Groundwater Samples

Digestion of the samples was done using standard methods by APHA, *et. al.* 1998 to bring metals into solution and to ensure metals present are atomised in AAS machine. Exactly 2.5 mL of concentrated HNO_3 was added to 25 mL each of the samples in clean Teflon beakers. This was heated on a water bath to concentrate the sample to about 10 mL. Heating continued with periodic addition of 1mL concentrated HNO_3 until a clear solution was obtained. This was allowed to cool and then transfer into clean 25 mL flask, filled up to mark with distilled water and used for analyses of metals with AAS.

Analysis of Heavy Metals in Water

The digested samples were used for the determination of metals with the Atomic Absorption Spectrophotometer (AAS). Part of the digested samples was used directly for metals and cations (K, Mg, Cr, Cd, Fe, Mn, Cu, Pb, As and Zn) determination using the Perkin Elmer 400 Atomic Absorption Spectrophotometer.

Ecological and Health Risk Assessment

Pollution Index (PI)

The Pollution Index (PI) in other to assess the extent of heavy metal contamination in water samples, PI was calculated. It is expressed as how many times the concentration of an individual metal in the water sample is higher than the maximum tolerable value set by the World Health Organization (WHO) (Arisi *et al*., 2019).

The formula for PI is:

$$PI = \frac{C}{WHO}$$

Where:

PI = Pollution Index

c = concentration of the metal in the water sample, WHO = maximum tolerable value for the metal (WHO standard). **Note**: a PI value below 100 indicates non-contaminated water, while a PI value above 100 signifies contamination by heavy metals.

Water Quality Index

In order to evaluate the water quality of the study areas, the Water Quality Index model was used. The Water Quality Index (WQI) was calculated typically, using the weighted arithmetic index for several water quality parameters.

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}$$

$$W_i = \frac{W_i}{\sum_{i=1}^{n} W_i}$$

$$Q_i = \left(\frac{C_n - C_i}{C_i - C_i}\right) \times 100$$

Where W_i is the assigned weight ($W_{i=}$) W_I is the relative weight, Q_i is the quality rating for the i^{th} water quality parameter, C_n is the concentration of i^{th} water quality parameter,, C_i is the ideal value of the i^{th} water quality parameter (C_i for pH=7 for other parameters, C_i $_{=}$0) (Alobaidy *et al.,* 2010, Otene & Nnadi 2019)

Non-carcinogenic Risk

Non-carcinogenic risk was evaluated using a concept known as the Hazard Quotients (HQ). HQ is the ratio of the estimated exposure to a substance and its reference dose (RfD) (Zakir *et al.,* 2020; Yahaya *et al*., 2021).

$$\mathrm{CDI} = \frac{C_w \times IR \times EF \times ED}{BW \times AT} \tag{4}$$

$$HQ = \frac{CDI}{RfD} \tag{5}$$

$$HI = \sum_{k=1}^{n} HQ_{-} \tag{6}$$

where CDI = Chronic daily intake (mg/kg per day), HQ = is the health risk index, Cw is the pollutant concentration (mg/L), IR is the drinking water consumption (L/day); EF is the exposure frequency (days/year), ED is the exposure duration (year), BW is the body weight (kg/person) and AT (days) is the average time.; CSF = Cancer slope factor.

Carcinogenic Risk

Carcinogenic risk was assessed to estimate the Lifetime Cancer Risk (LCR). This approach calculates the additional risk of cancer over a lifetime of exposure to carcinogenic substances, and it is calculated using LCR = CDI x CSF.

Statistical Analysis of Data

The data obtained were analyzed using descriptive statistics, using SPSS v23.0

Results and Discussion

The Table 1 reveals noticeable seasonal differences in groundwater quality between the dry and rainy seasons in Osogbo, Osun State. These variations align with prior research on the seasonal influence on water chemistry in tropical regions (Olalekan et al., 2020; Afolabi et al., 2019). Temperature was higher during the dry season (30.45°C) than the rainy season (28.74°C), which is expected due to the warmer ambient conditions. As noted by Edet et al. (2021), increased temperature may promote microbial activity and chemical reactions. The pH remained consistent at 8.23, reflecting a slightly alkaline condition attributed to carbonate-rich geology, similar to Adekunle et al. (2017)'s findings.

A significant difference was seen in Total Dissolved Solids (TDS), with much higher levels in the dry season (1268.57 mg/L) compared to the rainy season (625.24 mg/L), likely due to dilution effects from increased rainfall. High TDS levels may suggest leachate contamination, particularly in urban areas (WHO, 2017). Sulphate levels remained constant (21.40 mg/L), suggesting minimal seasonal impact and a possible geogenic source. Total hardness dropped significantly from 1268.57 mg/L in the dry season to 115.43 mg/L in the rainy season, likely due to the dilution of calcium and magnesium ions. Omole & Longe (2018) observed a similar trend in Nigerian aquifers. Aluminium was far higher in the dry season (0.44 mg/L) than in the rainy season (0.02 mg/L), exceeding WHO's safe limit and possibly indicating industrial contamination. Dissolved Oxygen (DO) dropped drastically from 6.18 mg/L in the dry season to 0.21 mg/L in the rainy season, possibly due to microbial consumption and oxygen depletion caused by organic runoff (Oketola et al., 2022). Similarly, ammonium and nitrate were both higher in the dry season (0.44 mg/L and 51.54 mg/L, respectively), reflecting reduced dilution and potentially unsafe pollution levels from waste or agricultural runoff (UNEP, 2020; Ezeh et al., 2021).

Phosphate levels also declined during the rainy season, while alkalinity increased, suggesting enhanced carbonate leaching during rainfall (Faleye & Adekoya, 2022). Lastly, turbidity rose sharply from 8.99 FTU in the dry season to 35.80 FTU in the rainy season, indicating increased suspended particles from runoff and erosion, which may hinder disinfection (WHO, 2022).

Table 2 shows that several studies have documented how seasonal changes significantly influence groundwater quality in tropical regions. In Osogbo, Osun State, variations between the dry and rainy seasons reveal important patterns in physico-chemical parameters. Temperature levels were higher in the dry season (30.00–31.20°C) than in the rainy season (28.70–28.80°C), aligning with tropical climatic norms (Olalekan et al., 2020). Higher temperatures can speed up chemical reactions and microbial processes in groundwater (Edet et al., 2021). The physico-chemical parameters of hand-dug well water in Osogbo exhibit clear seasonal variations, consistent with patterns reported in similar tropical urban settings.

Table 1: Physico-chemical characteristics of hand-dug wells in Osogbo

Parameters	Osogbo (Dry)	Osogbo (Rainy)
Temperature (^{0}C)	30.45± 0.54	28.74±0.05
pH	8.23 ±0.82	8.23±0.83
Total Dissolved Solid (mg/L)	1268.57±88.63	625.24±300.56

Sulphate (mg/L)	21.40±2.20	21.40±2.20
Total Hardness (mg/L)	1268.57±88.63	115.43± 65.54
Aluminiun (mg/L)	0.44±0.88	0.02±0.02
Dissolved Oxygen (mg/L)	6.18±3.07	0.21±0.02
Ammonium (mg/L)	0.44±0.44	0.04±0.03
Nitrate (mg/L)	51.54±6.79	40.80±4.68
Phosphate (mg/L)	0.64±0.81	0.33±0.13
Alkalinity (mg/L)	110.40±30.85	168.97±95.54
Turbidity (FTU)	8.99±14.51	35.80±25.27

The pH values ranged from 7.33 to 9.33 during the dry season and from 6.25 to 7.08 in the rainy season. While most values were within the WHO and FMoH recommended range of 6.5–8.5, the upper limit was exceeded in the dry season, possibly due to alkaline leachates or the dissolution of carbonate rocks, as similarly observed by Adekunle et al. (2017). Total Dissolved Solids (TDS) were significantly elevated in the dry season (1114.67–1339.60 mg/L), surpassing the WHO threshold of 500 mg/L. This trend supports Omole and Longe's (2018) findings, which linked high TDS during dry periods to reduced dilution and increased urban runoff and leachate infiltration. Despite this, chloride concentrations remained well within the WHO guideline of 500 mg/L, indicating low salinity risk and aligning with the results of Ezeh et al. (2021). Dissolved oxygen levels were sufficient in both seasons, promoting aerobic conditions and reflecting the findings of Oketola et al. (2022). However, phosphate levels surged during the rainy season, peaking at 205.00 mg/L—a sign of eutrophication likely caused by nutrient-laden runoff, similar to trends identified by UNEP (2020).

In terms of heavy metals (Table 3), mean iron and manganese concentrations (0.05 ± 0.07 mg/L and 0.003 ± 0.002 mg/L, respectively) were well below national and WHO limits. This agrees with Akinbile and Yusuff (2018), who reported naturally low iron levels in groundwater, and Olanrewaju et al. (2019), who noted minimal manganese contamination in non-industrial zones. Copper levels (0.16 ± 0.25 mg/L) were also within safe limits, consistent with Oyedele et al. (2020), affirming the trace presence of essential metals without toxic implications. In contrast, lead concentrations (3.75 ± 6.84 mg/L) were alarmingly high, far above the permissible 0.01 mg/L. This poses serious health risks, particularly for children, and reflects the concerns raised by Nwachukwu et al. (2018) regarding contamination from battery waste, lead-based pipes, and indiscriminate dumping. The non-detection of arsenic is a positive indicator, considering its carcinogenicity. Chromium and zinc were also within acceptable limits, suggesting limited industrial influence.

Table 2: Comparison of physicochemical parameters results of hand-dug wells

	Osogbo (Dry)	**Osogbo (Rainy)**

Parameters	Min	Max	Min	Max	Max	FmoH (2023)	WHO limit (2023)
Temperature (°C)	30.00	31.20	28.70	28.80	29.45		
pH	7.33	9.33	6.25	7.08	9.15	6.5-8.5	6.5-8.5
Total Dissolved Solids (TDS) (mg/L)	1114.67	1339.60	458.40	1153.60	1467.40	500	500
Chloride (Cl^-)	23.00	152.00	NS	145.33	66.00	500	NS
Total Hardness (as $CaCO_3$) (mg/L	0.15	2.03	0.005	0.03	0.02	0.2	0.2
Dissolved Oxygen (DO) (mg/L	1000.47	1866.00	825.80	1310.80	1042.70		
Conductivity	47.00	63.40	32.67	43.67	37.50	50	50
Nitrate (NO_3^-) (mg/L	0.21	1.54	NS	2.35	0.36	NS	NS
Phosphate (PO_4^{3-}) (mg/L	78.67	144.67	9.67	205.00	326.00		500
Alkalinity	78.67	144.67	2.10	34.95	49.00	500	NS

Table 3: Comparison of mean values for heavy metal concentration of hand-dug wells

Heavy Metals	Osogbo	NSDWQ (2015)	WHO Standard (2008)
Iron (mg/L)	0.05±0.07	0.3	0.3
Manganese(mg/L)	0.003±0.002	0.2	0.05
Copper (mg/L)	0.16±0.25	1.0	2.0
Lead (mg/L)	3.75±6.84	0.01	0.01
Arsenic (mg/L)	ND	0.001	0.001
Chromium(mg/L)	0.03±0.04	0.05	0.05
Zinc (mg/L)	0.24±0.27	3	5

ND = Not Detected; WHO = World Health Organization; NSDWQ = Nigerian Standards for Drinking Water Quality

From Table 4a, the pollution index revealed that most hand-dug wells were contaminated with lead, while other metals remained within safe limits. Lead pollution likely stems from improper disposal of batteries, paints, industrial waste, and runoff from dumpsites (Dooyema *et al*., 2012; Flora *et al.,* 2012). Such contamination poses serious health risks, including cognitive impairment, kidney damage, and developmental delays in children (Bellinger, 2013; Flora *et al.,* 2012). Chronic exposure in adults is linked to hypertension and reproductive issues. These findings highlight the need for regular monitoring and effective remediation efforts to safeguard public health (Prasad *et al.,* 2020; Mondal *et al.,* 2019). The Water Quality Index (WQI) values of Osogbo (358.84) and Ikire (167.55) indicate extremely poor water quality, unfit for human consumption (Afolabi *et al.,* 2022. These high values point to pollution from heavy metals, waste dumps, and poor sanitation. The situation poses significant public health risks, including waterborne diseases. Urgent interventions are needed, such as better waste management and alternative water sources. Regular monitoring is crucial to protect affected communities (Adeoye *et al*., 2019).

Table 4b shows that HQ values for Pb in Osogbo (29.25) indicate high health risks, mainly due to improper waste disposal and leaching from dumpsites. Cu showed low or no risk, while Cr, Fe, and Zn posed no immediate threat. The carcinogenic risk values for lead and chromium exceeded acceptable USEPA limits, highlighting a lifetime risk of cancer from exposure. Study by Olatunji *et al*. (2020) confirmed similar findings in Nigeria. Limited data on cancer slope factors for some metals restricted full risk evaluation; the results underscore the urgent need for groundwater protection and landfill.

Table 4a: Pollution indices of the heavy metals in groundwater in study site

Heavy Metal	Osogbo	Remark
Iron	0.33	non-contamination
Manganese	0.4	non-contamination
Copper	0.07	non-contamination
Lead	5718	Contamination
Arsenic	ND	non-contamination
Chromium	1.60	non-contamination

Sites	WQI	Water Quality Status
Osogbo	358.84	Extremely poor (Unwholesome for human consumption)

WQI	Water Quality
<25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
>100	Extremely poor

Table 4b: Non Carcinogenic Value

Heavy metals	Osogbo	HQ Status	
Pb	29.25	HQ>10	(High risk)
Cu	0.125	HQ <1	No risk
Cr	0.313	HQ <1	No risk
Fe	0.0022	HQ <1	No risk
Zn	0.188	HQ <1	No risk

Heavy Metals	Osogbo	Status	USEPA Value
Pb	0.00057	cancer risk	1.0×10^{-6} to 1.0×10^{-4}
Cr	0.00027	cancer risk	

Conclusion and Recommendations

The physicochemical characteristics and heavy metal concentrations in groundwater and soil samples from the Ido-Osun dumpsite area in Osogbo have been critically evaluated. Results revealed that while most parameters in the groundwater met the permissible limits of WHO and the Nigerian Standard for Drinking Water Quality, the concentration of lead (Pb) significantly exceeded these standards in both groundwater and soil samples. This suggests a strong likelihood of lead leaching from the dumpsite into surrounding groundwater sources, rendering them unsafe for direct consumption without appropriate treatment.

In light of these findings, it is crucial for stakeholders such as local government authorities, environmental health professionals, and waste management agencies to take proactive measures. Strengthening waste management practices through controlled landfilling, proper waste segregation, and recycling is essential to reduce contamination risks. Additionally, public awareness programs should be implemented to educate residents on the dangers of consuming untreated groundwater and the importance of safe waste disposal. The provision of community-level water treatment facilities should also be prioritized to ensure safe drinking water access. Furthermore, policies enforcing environmental protection and routine monitoring of soil and water quality around dumpsites must be enacted and strictly followed.

To deepen understanding and inform future interventions, further research is recommended. This could include seasonal monitoring of contaminant levels, studies on the bioaccumulation of heavy metals in crops grown nearby, and assessments of long-term health impacts on the affected population.

Environmental Health Implications of the Study

Contamination of Drinking Water: The elevated levels of heavy metals such as lead and chromium in groundwater pose a significant risk to public health, making the water unsafe for consumption without extensive treatment.

Non-Carcinogenic Health Risks: The high non-carcinogenic hazard index indicates an immediate health threat, particularly from lead exposure, which can affect various bodily systems and lead to serious health conditions.

Potential Cancer Risk: The carcinogenic risk values for lead and chromium exceeding safe thresholds suggest a long-term risk of cancer for individuals consuming contaminated groundwater, especially over extended periods.

Impact on Vulnerable Populations: Children, pregnant women, and the elderly are particularly susceptible to heavy metal exposure, potentially leading to developmental issues, reproductive problems, and other health complications.

Ecosystem Disruption: Groundwater contamination can adversely affect local ecosystems, as pollutants can leach into surrounding soils and affect flora and fauna, disrupting ecological balances.

Economic Consequences: The contamination may impact agricultural activities, particularly if groundwater is used for irrigation, leading to potential crop failures and economic losses for local farmers.

Need for Remediation and Management: The findings underscore the urgent need for effective waste management practices and groundwater remediation strategies to protect public health and restore water quality, which requires significant resources and community engagement.

Limitations of the Study

This study was limited by financial constraints, which restricted the number of water samples and parameters analyzed. Seasonal variations were not fully captured, as data collection occurred within a specific period. Some hand-dug wells were inaccessible due to refusal of access or physical barriers. Limited laboratory equipment affected the range of toxicological tests conducted. Advanced analysis such as microbial and organic pollutant testing was not performed. Health outcome data from residents was not collected, limiting direct health risk linkage. The study area was localized, which may affect the generalization of findings. Data on long-term groundwater changes was unavailable for comparison. Human errors in sample handling or testing may have slightly influenced results. Despite these challenges, the findings still offer useful insight into groundwater safety.

Acknowledgements

I give thanks to Almighty God for His guidance throughout this research. My sincere appreciation goes to Prof. Adewoye S.O. for his mentorship and invaluable support. Special thanks to Dr. Opasola A.O. and Dr. Adiamo Y. for their expert guidance and encouragement. I am grateful to all lecturers and staff of the Department of Environmental Health Science, Fountain University, Osogbo. Your contributions greatly enhanced the quality of this work.
I sincerely appreciate Adeyeye Oluwaseun for his assistance in data collection and analysis. To my colleagues and friends, thank you for your support and cooperation. I also appreciate everyone who contributed in one way or another. Your support made this project a success. May God bless you all abundantly.

Conflict of interest

The authors declare no conflict of interest.

References

Adebayo, O., & Olayemi, M. (2021). Assessment of groundwater contamination around waste dumpsites in Nigeria. *Environmental Monitoring and Assessment, 193*(3), 1–12.

Adekunle, I. M., Adetunji, M. T., Gbadebo, A. M., & Banjoko, O. B. (2017). Assessment of groundwater quality in a typical rural settlement in southwest Nigeria. *International Journal of Environmental Research and Public Health, 4*(4), 307–318.

Adeoye, G. O., Adeyemi, A. M., & Adeleke, B. O. (2019). Groundwater quality deterioration due to leachate migration in urban areas of Nigeria. *Journal of Water and Health, 17*(3), 439–449.

Adeoye, T. O., Aladejana, J. A., & Olayiwola, M. A. (2021). Hydrochemical and multivariate statistical techniques for groundwater quality evaluation in a developing urban area, Southwestern Nigeria. *Journal of African Earth Sciences, 174*, 104019.

Adesakin, T. A., Akinbile, C. O., & Bello, S. A. (2022). Groundwater contamination risk assessment near waste dumpsites in Southwestern Nigeria. *Environmental Monitoring and Assessment, 194*(1), 29. https://doi.org/10.1007/s10661-021-09667-0

Afolabi, A. A., Fadare, O. A., & Akinbile, C. O. (2021). Impact of solid waste dumpsite on nearby groundwater quality in Osogbo, Nigeria. *Environmental Challenges, 5*, 100263.

Afolabi, O. T., Adegbite, A. A., & Salawu, M. A. (2019). Seasonal variation in groundwater quality and health implications in Ibadan, Nigeria. *Nigerian Journal of Environmental Sciences and Technology, 3*(2), 175–184.

Afolabi, T. S., Ogunlade, T. O., & Ajiboye, T. K. (2022). Water quality index and health risk assessment of hand-dug wells in southwest Nigeria. *Environmental Research and Public Health, 19*(1), 215–230.

Akinbile, C. O., & Yusuff, A. A. (2018). Metal analysis of groundwater in selected locations in Ibadan metropolis, Nigeria. *Water Science and Technology: Water Supply, 18*(2), 456–466.

Akinlolu, T. A., Osinowo, O. O., & Oyedele, K. F. (2023). Evaluating groundwater vulnerability and contamination risk in parts of Osun State, Nigeria. *Journal of Hydrology: Regional Studies, 49*, 101392.

Bellinger, D. C. (2013). Prenatal exposures to environmental chemicals and children's neurodevelopment: An update. *Safety and Health at Work, 4*(1), 1–11.

Dooyema, C. A., Neri, A., Lo, Y. C., Durant, J., Dargan, P. I., Swarthout, T., ... & Rubin, C. H. (2012). Outbreak of fatal childhood lead poisoning related to artisanal gold mining in Northwestern Nigeria, 2010. *Environmental Health Perspectives, 120*(4), 601–607.

Edet, A., Okereke, C., & Ukpong, A. (2021). Seasonal variation in physicochemical properties of groundwater in the Niger Delta region. *Nigerian Journal of Hydrology, 31*(2), 78–90.

Ezeh, H. N., Anike, O. L., & Emenike, C. P. (2021). Assessment of groundwater vulnerability to pollution in urban settings of southeastern Nigeria. *Groundwater for Sustainable Development, 12*, 100545.

Faleye, O. A., & Adekoya, J. A. (2022). Carbonate weathering and groundwater alkalinity in southern Nigeria: A seasonal approach. *Environmental Earth Sciences, 81*(12), 307.

Federal Ministry of Health (FMoH). (2023). *Nigerian standard for drinking water quality*. Abuja: FMoH.

Flora, G., Gupta, D., & Tiwari, A. (2012). Toxicity of lead: A review with recent updates. *Interdisciplinary Toxicology, 5*(2), 47–58.

Ganiyu, S. A., Adesakin, T. A., & Akinbile, C. O. (2017). Effect of landfill leachate on groundwater quality in urban settlements: A case study from Nigeria. *Environmental Science and Pollution Research, 24*(25), 20460–20470.

Ige, O. O., Akinpelu, A. A., & Ajayi, T. I. (2020). Analysis of potable water accessibility in peri-urban areas of Osun State, Nigeria. *International Journal of Water Resources and Environmental Engineering, 12*(3), 45–53.

Mishra, S. (2023). Groundwater: A critical resource for sustainable development. *Hydrogeology Journal, 31*(2), 451–469.

Mondal, D., Banerjee, M., & Das, S. (2019). Lead-induced oxidative stress and its impact on brain function: A review. *Environmental Science and Pollution Research, 26*(3), 1781–1792.

Nigerian Standard for Drinking Water Quality (NSDWQ). (2015). *National guidelines and standards for water quality in Nigeria*. Abuja: Federal Ministry of Water Resources.

Nwachukwu, M. A., Akpan, U. G., & Olayiwola, O. (2018). Lead contamination from indiscriminate waste disposal in urban Nigeria. *International Journal of*

Environmental Science and Technology, 15(1), 225–234.

Oketola, A. A., Osibanjo, O., & Oludare, O. A. (2022). Dissolved oxygen dynamics and organic matter decomposition in tropical groundwater. *Journal of Environmental Science and Water Resources, 37*(2), 103–112.

Olanrewaju, O. E., Oyinloye, A. O., & Adediran, J. A. (2019). Groundwater contamination in agricultural areas of southwestern Nigeria. *Journal of Water and Land Development, 41*(IV–VI), 113–120.

Oladeji, F. O., Ajayi, A. O., & Adebayo, K. J. (2024). Assessment of groundwater contamination around a municipal dumpsite in Osun State, Nigeria. *Nigerian Journal of Environmental Health, 21*(1), 33–41.

Olalekan, R. M., Yusuf, R. O., & Adedayo, O. K. (2020). Comparative study of seasonal variation in groundwater quality in parts of Osun State, Nigeria. *International Journal of Environmental Research, 14*(1), 1–12.

Omole, D. O., & Longe, E. O. (2018). Leachate characterization and groundwater pollution in urban Nigeria. *International Journal of Environmental Research and Public Health, 15*(6), 1123–1134.

Olatunji, A. S., Ayeni, A. O., & Aladejana, J. A. (2020). Carcinogenic risk assessment of heavy metals in water sources in southwest Nigeria. *Ecotoxicology and Environmental Safety, 189*, 109992.

Oyedele, A. J., Oyeleke, O. E., & Adebayo, M. A. (2020). Trace metal assessment in groundwater sources of peri-urban Nigeria. *Environmental Monitoring and Assessment, 192*(9), 1–10.

Prasad, M. N. V., Vithanage, M., & Kapley, A. (2020). Groundwater pollution and remediation. In *Groundwater: Resource characterization and management* (pp. 345–375). Springer.

RamyaPriya, K., & Elango, L. (2022). Hydrogeochemical evaluation of groundwater quality for drinking and irrigation: A case study from South India. *Groundwater for Sustainable Development, 18*, 100743.

United Nations Environment Programme (UNEP). (2020). *Groundwater and climate change: Mitigating the global crisis*. Nairobi: UNEP.

United States Environmental Protection Agency (USEPA). (2023). *Integrated Risk Information System (IRIS): Human health risk assessment*. https://www.epa.gov/iris

World Bank. (2022). *The hidden wealth of nations: The economics of groundwater in times of climate change*. World Bank Group.
World Health Organization (WHO). (2008). *Guidelines for drinking-water quality* (3rd ed.). Geneva: WHO.

World Health Organization (WHO). (2017). *Total dissolved solids in drinking water: Background document for development of WHO guidelines for drinking-water quality*. Geneva: WHO.

World Health Organization (WHO). (2022). *Water sanitation hygiene: Water quality and health*. Geneva: WHO.

World Health Organization (WHO). (2023). *Guidelines for drinking-water quality* (4th ed.). Geneva: WHO.

Citation:
Oladeji, F.O., Adewoye, S.O., Opasola A.O., & Yusuf B.A. (2025). Evaluation of Ecological and Health Risks of Heavy Metals in Selected Hand-Dug Wells around Ido-Osun Landfill Site in Osogbo, Osun State, Nigeria. *Fountain Journal of Basic Medical and Health Sciences (FUJBMHES), 1(2),* 77-89.