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Physicochemical properties, microbial indicators, and heavy metal risk profiling of groundwater quality near a dumpsite in Warri, Delta State, Nigeria

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Abstract

Groundwater is essential for drinking and domestic use. However, its proximity to improperly managed dumpsites make it highly vulnerable to contamination from leachate. This study evaluates the quality of groundwater from wells and boreholes near a dumpsite in Warri, Delta State, Nigeria, where groundwater is heavily relied upon. pH and electrical conductivity, microbial contamination, and selected heavy metal concentrations were analyzed. All samples were acidic (pH <6), with well samples exhibiting consistently higher electrical conductivity and microbial contamination exceeding WHO safety thresholds. Lead concentrations in well water sample B (0.028 mg/L) and cadmium in sample C (0.007 mg/L) exceeded WHO permissible limits. The single factor pollution index (Pi), degree of contamination (Cd), heavy metal evaluation index (HEI), and heavy metal toxicity load (HMTL) highlighted the severity of contamination in the well water samples and the hidden toxicity risk in boreholes. These findings reveal that proximity to dumpsite activities adversely affects groundwater sources. This calls for the urgent need for improved waste management practices and regular monitoring to mitigate groundwater pollution and protect public health.

Keywords: Dumpsites; Groundwater Quality; Heavy Metals; Electrical Conductivity

Introduction

Groundwater sources located near dumpsites face possible contamination, especially in areas characterized by poor solid waste management strategies (Uchacha *et al.* 2024). Dumpsites tend to produce leachate, which is a complex mixture of organic and inorganic pollutants that permeate the soil and are translocated into groundwater systems (Anand *et al.* 2021). Contaminants like heavy metals and pathogenic microorganisms are introduced into groundwater by leachate infiltration, resulting in diminished water quality, increasing exposure of the consuming populace to heavy metal poisoning, waterborne disease, and several other long-term consequences (Igwegbe *et al.* 2024).

Groundwater quality is usually evaluated using physicochemical parameters, microbial presence and heavy metal concentration, which are indicators of water suitability for use (Alao *et al.* 2024; Edet and Offiong, 2002). pH and electrical conductivity influence the mobility and solubility of heavy metals and other contaminants. Low pH, for instance, facilitates the leaching of cadmium and other heavy metals, increasing toxicity risks (Goli and Singh, 2025). Microbial contamination is indicated by the presence of faecal coliforms. Their presence indicates the enteric pathogens such as *Salmonella, Shigella* and *E.coli* in the groundwater via surface runoff or infiltration from sewage or septic tanks (Gomaa *et al.* 2022; WHO, 2017). The WHO recommends zero faecal coliform per 100 milliliters of water, emphasizing the health risks associated with microbial pathogens.

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Heavy metals in groundwater are typically caused by geological or anthropogenic activities (Sanad *et al.* 2024). High levels of toxic heavy metals may cause a variety of health problems, including carcinogenic, neurological, and developmental issues, particularly in pregnant women and children (Lawal *et al.* 2021; Jomova *et al.* 2025). Concentrations of toxic heavy metals such as lead, chromium, and cadmium have been found to exceed permissible levels in some parts of Nigeria (Kana *et al.* 2022; Izah *et al.* 2016). Heavy metals are bioaccumulative and toxic; hence, it is critical to quantify them to ensure that water is safe to use.

The risk profiling of heavy metals in environmental matrices such as water allows for the identification of pollution hot spots. It serves as a framework for interpreting the quantity and potential health effects of heavy metals in groundwater. Several indices are used, including the degree of contamination (Cd), Heavy Metal Evaluation Index (HEI), Heavy Metal Toxic Load (HMTL), and others (ATSDR, 2022).

Recent research across different regions in Nigeria have shown that dumpsites adversely affect groundwater quality to a large extent. For instance, high levels of some heavy metals and microbial pollution in groundwater near dumpsites in cities such as Lagos, Ibadan, and Port Harcourt, exceeding the World Health Organization maximum permissible limits, have been reported (Ferreira *et al.* 2023; Yahaya *et al.* 2022; Benjamin *et al.* 2019). These contaminants most often pose a serious environmental and public health risk. The continuous monitoring of groundwater located near dumpsites has been advocated by several researchers and environmentalists (Igwegbe *et al.* 2024) and Egbueri *et al.* (2023) to protect public health and ensure environmental sustainability.

The residents of Warri rely extensively on groundwater for their daily domestic chores, farming, and industrial activities. This makes it more vulnerable to contamination from waste disposal spots or dumpsites within its vicinity. Despite being a significant resource, there is limited research data on the impact of these dumpsites on groundwater in the area, particularly on wells. Borehole water has been the primary focus of several researchers (Rawlings and Seghosime, 2022; Agori *et al.* 2021; Izeze and Kobonye, 2018), leaving out wells, which are more within reach of the low-income population and also more prone to contamination from surface pollutants.

This study is aimed at bridging this research gap by evaluating selected physicochemical and microbial properties and determining the concentrations of heavy metals in groundwater from wells and boreholes near a major dumpsite. The novelty of this study lies in integrating a toxicity-weighted index (Heavy Metal Toxicity Load, HMTL) with conventional contamination indices such as Single Factor Pollution Index (Pi), degree of contamination (Cd), Heavy Metal Evaluation Index (HEI), and Heavy Metal Toxicity Load (HMTL) to provide a more robust risk interpretation for groundwater affected by dumpsite activities. Unlike conventional indices that emphasize cumulative concentration relative to guideline values, HMTL incorporates toxicity weighting and can reveal "hidden" health burdens even when cumulative concentration indices appear low. This combined index-based approach improves the interpretive power of routine groundwater monitoring and strengthens evidence for risk-informed management in Warri, Delta State. This research will provide critical baseline data that could inform waste management policies and contribute to mitigating public health issues that may stem from improper waste disposal strategies.

Materials and methods

Study area

The study was undertaken in March 2023 in Warri, Delta State, where groundwater is mostly relied upon due to limited pipe-borne water. The study area is situated in the southern region of Delta State, Nigeria, and is bordered to the south by the Atlantic Ocean. Geographically, it lies approximately between latitudes 5°00' and 6°30' North and longitudes 5°00' and 6°45' East. This region hosts various industrial activities, including oil exploration, servicing operations, and port activities.

Sample collection and analysis

Groundwater samples were collected from six different locations at varying distances around the dumpsite, including both boreholes and hand-dug wells. Additionally, control samples were taken from a borehole situated several kilometers away from the dumpsite to provide a baseline for comparison (Table I). Each water sample was collected in a 1.5-liter plastic bottle, thoroughly cleaned and sterilized to prevent contamination, sealed, and labeled accordingly for onward transmission to the laboratory for analysis. The samples were analyzed for pH, electrical conductivity, and concentrations of heavy metals, including copper, zinc, lead, chromium, cadmium, iron, and nickel.

Table I. Sample codes and location for groundwater

S/N	Sample code	Sample type	Latitude (°N)	Longitude (°E)
1.	A	Well Water	5.5543	5.7860
2.	TA	Borehole Water	5.5540	5.7871
3.	B	Well Water	5.5526	5.7860
4.	TB	Borehole Water	5.5530	5.7849
5.	C	Well Water	5.5565	5.7835
6.	TC	Borehole Water	5.5511	5.7888
7.	Control	Borehole Water	5.5743	5.8064

Analytical methods

Analytical procedures followed the standard methods outlined in the Nigerian Standard for Drinking Water Quality (NSDWQ) (SON, 2007) and the relevant APHA Standard Methods (APHA, 2017). pH was measured with a Hanna HI 9813 pH meter, and electrical conductivity was measured with a Labman LMCM-19 conductivity meter. Heavy metal concentrations were determined using atomic absorption spectroscopy (AAS) with a Perkin-Elmer AAnalyst 800 spectrophotometer. Each sample was analyzed in triplicate to ensure the accuracy and reliability of the results. Faecal coliforms were enumerated using the serial dilution–pour plate technique, rather than the Most probable number (MPN) or membrane filtration methods to enumerate coliform bacteria (APHA, 2017). Serial dilutions (10^{-1}–10^{-5}) were plated (1 mL) on MacConkey and Violet Red Bile agar, incubated at 37 °C for 48 h, and colonies counted on plates containing 30–300 colonies. Results were expressed as CFU/mL. Quality control included sterility checks, duplicate plating, and reagent blanks.

Data analysis

Results were compared against the WHO standards for drinking water quality to evaluate compliance and identify potential health risks. All physicochemical, microbial, and heavy metal measurements were performed in triplicate, and results are presented as mean values.

Water quality indices

Four water quality indices were used to evaluate contamination severity

Single factor pollution index (Pi)

The single-factor index (Pi) measures water quality by comparing the measured concentration of a single heavy metal with the relevant standard limit. It is mostly useful for identifying the most problematic pollutants in a given water body. It is given by the equation

$$P_i = \frac{C_i}{S_i} \quad (1)$$

Where *Pi* represents the pollution index of a single factor or metal, *Ci* is the measured concentration of the pollutant or heavy metal (mg/L); *Si* is the standard value(mg/L). *Pi* values < 1, indicate no pollution, values between 1 and 2 indicate slight pollution, values between 2–3 indicate light pollution, 3–5 indicate moderate pollution, and *Pi* values >5 reflect severe pollution (Preonty *et al.* 2025; Su *et al.* 2022).

Degree of contamination (Cd)

This is an aggregate of each metal's contamination factor. It is the sum of the deviation ratios for multiple metals computed through Eqs. (2) and (3).

$$C_d = \sum_{i=1}^{n} Cf_i \quad (2)$$

$$Cf_i = \frac{M_I}{S_I} - 1 \quad (3)$$

where, *Cfi* is the contamination factor for the ith HMs, *Mi* is the analyzed value of the ith HMs, and Si is the standard value of the ith HMs. Based on computed Cd, water with Cd greater than 1 is considered highly contaminated. It can be classified into three categories such as low (Cd > 1); moderate (1 < Cd < 3), and high (Cd > 3) (Preonty *et al.* 2025; Edet and Offiong, 2002).

Heavy metal evaluation index (HEI)

HEI is a measure of the overall pressure exerted by all the metals by adding the ratios of the observed concentrations of heavy metals in a water sample to their maximum permissible limits (Prasanna *et al.* 2012). It helps to determine the cumulative stress of the metal on the environment. HEI values can be interpreted as low when the value is less than 10, medium when the value is between 10 and 20, and high when greater than 20 (Preonty *et al.* 2025).

HEI can be calculated using equation 4:

$$HEI = \sum_{i=1}^{n} \frac{C_i}{MAC_i} \tag{4}$$

where *Ci* is the measured concentration of the heavy metal and *MACi* is the maximum allowable concentration of metal i. . A HEI less than 10 is indicative of low pollution risk, between 10 and 20 is medium risk, while HEI values above 20 indicate a high pollution risk (Prasanna *et al.* 2012; Kwaya *et al.* 2019).

Heavy Metal Toxicity Load (HMTL)

HMTL, a valuable index score for risk assessment, is defined by the Agency for Toxic Substances and Disease Registry (ATSDR) as an integration of both metal concentration and toxicity, obtained by multiplying the concentration of each metal by its hazard index score (HIS). (ATSDR, 2022). It estimates the cumulative impact of all metals using the formula in eqn 5:

$$\text{HMTL} = \sum_{i=1}^{n} C \times \text{HIS} \tag{5}$$

where *C* is the metal concentration, *HIS* represents the hazard intensity score, and n, the number of metals. Higher values indicate greater toxicity burden. The hazard index scores for the investigated metals are Pb (1531), Cd (1320), Cr (807), Ni(73), Fe(10), Cu(9) and Zn(8). (ATSDR, 2017; Preonty *et al.* 2025).

Results and discussion

Physicochemical parameters

pH, electrical conductivity, and faecal coliform count of the six groundwater samples and the control sample are presented in Table II. All the samples analyzed were acidic with pH levels ranging from 5.06 (borehole TA) to 5.97 (well water C) which were below the WHO's prescribed limit of 6.5-8.5 for potable water. (WHO, 2017). Acid conditions in water are a result of leachate infiltration, organic matter decomposing, and the intrinsic geogenic nature of the soil (Lawal *et al.* 2025; Bewaji *et al.* 2025). Acidic groundwater samples are unfit for domestic use as they could lead to skin irritation upon dermal contact and even corrode plumbing infrastructure.

Table II. Comparison of physicochemical parameters and microbial load of sampled groundwater around the dumpsite against WHO standards

Parameters	Sample							
	A	TA	B	TB	C	TC	CONTROL	WHO standard
pH	5.16	5.06	5.46	5.63	5.97	5.53	5.40	6.5–8.5
Electrical Conductivity (µS/cm)	92.40	76.31	165.90	60.10	134.40	109.20	52.30	1000
Faecal Coliform (cfu/100mL)	23	0	11	0	11	7	0	0

Electrical conductivity was notably lower than the WHO's permissible limit of 1000µS/cm, indicating relatively low levels of dissolved ions (WHO, 2017). EC was consistently higher in well water than in borehole samples from the same sites, with the control sample having the lowest EC (52.30 µS/cm). Well water B displayed the highest EC (165.9 µS/cm), nearly thrice that of the control borehole, suggesting higher ionic content probably resulting from leachate intrusion. Elevated levels of EC in wells suggest more exposure to surface contaminants. Similar studies have reported higher EC levels in well water located near dumpsites (Useh *et al.* 2022; Bewaji *et al.* 2025), also supports the fact that EC can be an indication of surface contamination.

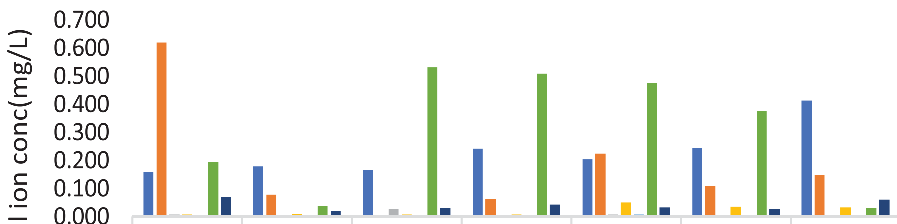
All the well water samples had varying amounts of faecal coliform exceeding the WHO limit of 0 CFU in potable water. The borehole samples (TA, TB, TC, and control) showed no contamination, indicating that deep aquifers have some natural filtration mechanism and are more protected. The contamination in all well samples indicate contamination pathways such as poorly sealed wells or proximity to the dumpsite. These findings are in tandem with research by Dey *et al.* (2022), who reported that shallow groundwater sources close to dumpsites were more vulnerable to microbial contamination.

The results of this study show consistency with previous research on groundwater contamination near dumpsites in other regions. Low pH values (5.4-6.23) were reported by Arimieari and Olayinka (2020) in groundwater near a dumpsite in Rivers State, Nigeria, and they attributed the acidity to leachate infiltration. Elevated faecal coliform levels were reported in groundwater around uncontrolled dumpsites in parts of Abuja and Nasarawa States, highlighting microbial contamination's health risks (Okeh *et al.* 2024). The EC values in this study were lower than those reported by Ibrahim *et al.* (2023), who documented values greater than 400 µS/cm in a dumpsite study in Kano, Nigeria, indicating that the dumpsite in Warri has comparatively lower ionic contributions. These findings highlight the widespread occurrence of groundwater contamination near poorly managed waste disposal sites and show that there is a critical need for improved waste management strategies to protect public health and environmental quality.

Heavy metal concentrations

Heavy metal concentration in the groundwater samples are presented in Figure 1.

Copper and zinc in all the samples analyzed ranged from 0.159-0.414 mg/L, and below the detection limit < 0.001mg/L - 0.620 mg/L, respectively. These values were within the permissible limits established by the WHO of 1.0 mg/L for Cu and 5.0 mg/L for Zn (WHO, 2017). The high concentration of copper in the control sample may have resulted from natural geochemical sources or corrosion rather than direct dumpsite influence (Chávez, 2021). A marked difference in the zinc concentrations between well water A (0.6198 mg/L) and borehole water TA (0.07



	Sample A	Sample TA	Sample B	Sample TB	Sample C	Sample TC	Control
Cu	0.159	0.179	0.165	0.242	0.203	0.244	0.414
Zn	0.620	0.079	0.000	0.062	0.223	0.108	0.148
Pb	0.007	0.003	0.028	0.001	0.006	0.002	0.003
Cr	0.006	0.008	0.008	0.006	0.050	0.035	0.031
Cd	0.005	0.002	0.004	0.001	0.007	0.003	0.000
Fe	0.194	0.036	0.532	0.509	0.476	0.376	0.030
Ni	0.070	0.020	0.030	0.043	0.033	0.027	0.060

Fig. 1. Concentrations of heavy metals (mg/L) in groundwater samples

mg/L) was observed. This disparity may stem from the fact that there is a higher chance of zinc-containing waste materials, paint residues, abandoned electrical equipment, and scraps of metal leaching into the wells near the dumpsite (Igboama *et al.* 2022). The well water samples had higher Zn concentrations than the borehole samples, except for B, which had almost no zinc (<0.0001 mg/L), suggesting localized contamination and a probable potential dilution at depth to account for the differences between boreholes and wells. Some have suggested that this variation in concentrations is most likely caused by the different rates at which materials containing these metals, for instance, batteries or galvanized metals, leach into the groundwater, highlighting the influence of surrounding waste characteristics on groundwater contamination (Adeyi and Majolagbe, 2014; Okoro *et al.* 2012).

Lead and cadmium concentrations were, however, observed to follow a contrasting trend. Lead concentrations in sample B were particularly higher in well water B (0.028 mg/L) compared to borehole water TB (0.008 mg/L), above the WHO maximum permissible limits of 0.01 mg/L. Lead is a known carcinogen and neurotoxicant, which has been reported to lead to cognitive developmental delays, among other related health diseases. Similar results were reported by Ibrahim *et al.* (2023), who reported high levels of lead in groundwater near dumpsites in northern Nigeria. Lead contamination near dumpsites is well documented, owing primarily to leachate infiltration from discarded batteries, paints, and electronic waste, which are common components of municipal solid waste (Ferreira *et al.* 2023; Adeyi and Majolagbe, 2014). Cadmium (Cd) was found in low concentrations in several samples, with well water Sample C having the highest value of 0.007 mg/L, which exceeded the WHO permissible limit of 0.003 mg/L (WHO, 2017). Batteries and industrial waste are the usual sources of cadmium, a hazardous

Table III. Single pollution indices for metals in groundwater samples

Metal	Si (mg/L)	A	TA	B	TB	C	TC	Control
Cu	2.000	0.08	0.09	0.08	0.12	0.10	0.12	0.21
Zn	3.000	0.21	0.03	0.00	0.02	0.07	0.04	0.05
Pb	0.010	0.72	0.28	2.84	0.08	0.64	0.16	0.32
Cr	0.050	0.12	0.17	0.15	0.12	1.01	0.70	0.62
Cd	0.003	1.73	0.50	1.27	0.23	2.43	1.03	0.03
Fe	0.300	0.65	0.12	1.77	1.70	1.59	1.25	0.10
Ni	0.070	1.00	0.29	0.43	0.62	0.47	0.38	0.86

Table IV. Cd, HEI, and HMTL with threshold levels and classifications for groundwater samples

Index	A	TA	B	TB	C	TC	Control	Threshold Levels / Classification
Cd	0.73	0.00	2.88	0.70	2.03	0.28	0.00	<1: Low; 1–3: Moderate; >3: High (Backman *et al.* 1997)
HEI	4.51	1.48	6.54	2.89	6.31	3.68	2.19	<10: Low; 10–20: Medium; >20: High (Edet and Offiong, 2002)
HMTL	36.16	63.62	70.88	17.11	17.91	43.49	39.80	<15: Low; 15–30: Moderate; >30: High (Edet and Offiong, 2002)

metal. Cadmium is known to be carcinogenic, causes bone disorders, and kidney damage (Ibrahim *et al.* 2023). These results are in line with those of Adeyi and Mojolagbe (2014), who posited that industrial and municipal waste in Lagos, Nigeria, was responsible for cadmium contamination in groundwater.

Chromium levels in all samples ranged from 0.006 to 0.050 mg/L and were within the WHO guideline limit of 0.05 mg/L (WHO, 2017). However, the proximity of the concentration in well water sample C (0.0504 mg/L) to this threshold suggests that such values may still pose potential health risks. Chromium, particularly hexavalent chromium [Cr(VI)], is a known carcinogen, and chronic exposure has been linked to cancer and other serious health effects (Ibrahim *et al.* 2023). Chromium was quantified as total chromium using AAS; therefore, speciation into Cr(VI) and Cr(III) was not performed.

High concentrations of Fe were also detected in well water sample B and borehole water sample TB, exceeding the WHO aesthetic threshold of 3.0 mg/L. Although elevated Fe concentrations can adversely affect water aesthetics, they are not generally associated with direct health risks (WHO, 2017; Xia *et al.* 2022).

All samples had nickel concentrations within permissible limits. However, long-term exposure to elevated nickel levels can still impact the environment. Chronic nickel exposure for a long term can cause respiratory issues, skin dermatitis, and possibly kidney damage (ATSDR, 2005). It is also classified as a human carcinogen by the IARC (1990), though the risk from drinking water is generally lower unless exposure is significant. The elevated levels of lead and cadmium indicate the urgent need for public health interventions in communities relying on contaminated groundwater for drinking and domestic use.

Water Quality Indices

Single Pollution Index (Pi)

Groundwater quality around the dumpsite, upon evaluation using these water quality indices, reveals different patterns of toxicological burden. According to Table III, the single pollutant index results indicate metal contamination exceeding threshold levels of 1 in some well samples. Cadmium levels in samples A, B, and C were above permissible limits with Pi values of 1.73, 1.27, and 2.43, respectively, with sample C having severe cadmium contamination.

Pb surpassed the threshold limit to a greater extent with a Pi value of 2.84 in sample B, suggesting acute lead contamination, while Cr slightly exceeded the threshold in sample C (1.01). Fe exceeded the threshold limits in well water samples B (1.77) and C (1.59). These excesses reflect the vulnerability of shallow groundwater sources such as wells to heavy metal contamination when located in a dumpsite vicinity. The borehole samples had lower Pi values for most metals; however, some exceeded the safe threshold levels. TC had Pi values in excess of for Cd (1.03) and Fe (1.25). These results suggest a relatively safer quality of borehole water. It was noted that in the control sample, the Pi values for Ni and Cr even though below the threshold, were a little high, which suggests the need for continuous monitoring even in groundwater distally located from dumpsites

Table IV depicts the degree of contamination, heavy metal evaluation index, and heavy metal toxicity load results. The use of these indices offers a multidimensional overview of the pollution severity by integrating both the concentration and the toxicity profiles of the heavy metals.

The degree of contamination (Cd), which is derived as a sum of all the Pi values exceeding unity minus one, was highest for Sample B (2.880), closely followed by Sample C (2.03), classifying both well water samples as moderately contaminated. These results suggest that sample B poses a notable health risk from the cumulative pollution from Pb, Cd, and Fe (See Table 3). All the borehole samples and the control had Cd values below the lower threshold value of 1, implying low contamination. The results reveal that less contamination pressure was experienced in the boreholes than in the well water samples. The control sample, which was obtained from the farthest distance from the dumpsite, had a Cd value of 0.00, indicative of its relatively clean status and supporting the fact that distance from the dumpsite is a factor influencing contamination. These observations are in line with findings by Ibrahim *et al.* (2023), where higher Cd levels were reported for well water near dumpsites in Kano, Nigeria. Similarly, Sanad *et al.* (2024) in Morocco reported Cd values between 2.90 and 11.73 in agricultural zones impacted by landfill leachate.

The HEI values, which are the sum of all the Pi, provide a cumulative pollution index for the studied groundwater samples and are also reported in Table 4. The highest HEI values were exhibited by the well water samples B (6.54), C (6.31), and A (4.51), exhibiting a higher cumulative stress when compared to the borehole samples, whose HEI fell within 1.48 to 3.68, being consistent with their Pi and Cd values. Edet and Offiong (2002) earlier reported similar trends in groundwater impacted by industrial waste in southeastern Nigeria, reinforcing their vulnerability to contamination. Rao *et al.* (2022) reported similar HEI values in their study, where HEI was used to measure groundwater quality in an industrial zone in India. Badamasi *et al.* (2021) found that groundwater in a mining area had higher HEI values than the threshold of 20. The values reported herein, while lower than the threshold, are still indicative of cumulative stress.

The HMTL values, which combine concentration and toxicity using hazard index scores, provide a useful toxicity-weighted assessment of groundwater samples (ATSDR, 2022). Well sample B had the highest toxicity load with HMTL of 70.88, depicting high heavy metal toxicity, while C and A fell within moderate levels. These, when compared with their low HEI values, are indicative of the fact that low levels of trace heavy metals can substantially affect the overall health burden. The borehole samples also exhibited high HMTL Scores, TA (63.62), TC (43.49) despite their low HEI values. This discrepancy buttresses the need for the complementary use of multiple indices in evaluating groundwater quality, as even low concentrations of toxic metals such as cadmium and lead can unduly increase health risks. Similar findings have been reported in recent studies where toxicity-weighted and holistic risk indices revealed priority metal risks not fully captured by conventional pollution indices in contaminated aquatic and groundwater environments (Khatoon *et al.* 2025; Karmaker *et al.* 2024; Shorna *et al.* 2021). The discrepancy observed between the HEI and the HMTL of the borehole samples TA, TC, and the control sample shows that it is important to take note of toxicity considerations in risk assessment. Also, deep aquifers like boreholes are not immune to contamination, especially when toxic heavy metals are involved. An important observation is the elevated HMTL recorded in the control borehole despite a comparatively low HEI. This apparent discrepancy is expected because HEI is concentration-ratio-based and reflects cumulative metal loading relative to guideline limits, whereas HMTL is toxicity-weighted; thus, even low concentrations of highly hazardous metals can yield a relatively high toxicity burden (Ghosh *et al.* 2025). In addition to dumpsite influence, elevated toxicity-weighted indices in control or distal sites may reflect regional background (geogenic) contributions, hydrogeologic connectivity, or longer-range contaminant transport pathways that are not captured by proximity alone (Egbueri *et al.* 2023). Similar studies have shown that toxicity-weighted indices can unmask risk patterns and source contributions that differ from concentration-only indices, emphasizing the need to interpret multiple indices jointly (Khatoon *et al.* 2024; Chaturvedi, 2019).

Conclusion

Heavy metal and faecal coliform concentrations in groundwater sources near a dumpsite in Warri, Delta State, Nigeria, were determined and presented in this study. The findings revealed that wells are more vulnerable to leachate contamination than boreholes. Well water Sample B was the most contaminated, while all well samples showed the presence of coliform. The extent of contamination in the well samples was determined by advanced water quality indices, which were used to evaluate the risk profile. The heavy metal toxicity load (HMTL) index revealed hidden toxicity risks in boreholes, which did not reflect in HEI scores, which were quite low, emphasizing the need to use multiple indices for accurate risk profiling. This study demonstrates that having improperly managed dumpsites close to shallow groundwater sources seriously compromises groundwater quality and endangers public health. Therefore, it is recommended that prompt interventions such as proper solid waste management and regular groundwater monitoring be implemented in such areas to preserve this important resource and protect public health.

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