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ORIGINAL ARTICLE

Heavy metal content and health risk assessment at Akri waste dumpsite, Niger Delta Region of Nigeria

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Abstract

In most parts of the world, solid waste management is a serious worry and unsolved problem, particularly in poor countries, where solid waste is dumped in unregulated dumpsites in public spaces. This research aims to provide a comprehensive understanding of the contamination levels, sources, and associated health risks in the groundwater around the Akri solid waste dumpsite. The methodology involves a combination of field sampling, laboratory analysis, and statistical techniques to draw conclusions about the current state of groundwater quality and propose recommendations for future actions. This method has the potential to contaminate environmental compartments, such as soil, surface water, and groundwater, putting human health at risk. Groundwater samples were taken from 18 locations in and near the Akri solid waste dumpsite in Warri, Nigeria, for physicochemical analysis following the American Public Health Association (APHA) set standard. Principal component analysis (PCA) results revealed that that the loadings in components were essentially from enduring or potentially filtering of loess. The correlation index witnessed poor correlation within elements. Contamination factor values of less than 1 were observed in the entire study area except for Fe which had values ranging from moderate contamination to extremely high contamination. Pollution load index (PLI) values had values of less than one, implying low pollution. Metal Pollution Index (MPI) values in the entire samples had their concentration levels less than 0.3. The values of Pollution Index of Groundwater (PIG) showed that the entire samples within the study area were below 0.1. Contamination Index values showed that the entire water samples ranged between clean water to heavy polluted water, especially boron (Br) and Iron (Fe). Furthermore, the hazard quotients (HQ) reported that the non-carcinogenic risk posed by drinking water containing trace metals for both children and adults in the research area is in the trend of As > Fe > Ni > Cu > Cr > Pb > Br > Hg. It was observed that anthropogenic activities are the major cause of heavy metals in groundwater within the study. Regular appraisal of groundwater sources is highly recommended.

Keywords Pollution indices · Index · Heavy metals · Human health risk · Nigeria

Introduction

Water covers nearly three-quarters of the earth's surface (roughly 71%), with only a small percentage designated as "freshwater" and a larger percentage as "saline water." Approximately 68% of freshwater is trapped in ice caps and glaciers (Li and Qian 2018). The only ones that can be accessed are the underground and surface waters (lakes, streams, and springs). However, several factors have harmed the quality of these available freshwaters on a seasonal basis. Because the quality of available water is deteriorating from day to day, the increased rate of urbanization and industrialization has remained a present-day challenge in demand and the search for a quality water supply (Li et al. 2017). Solid waste disposal and management is a major problem

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for the majority of large agglomerations in many countries especially as regards groundwater contamination. Many densely populated developing countries are facing this practical problem (Ulakpa and Eyankware 2021; Marshall and Farahbakhsh 2013; Akakuru et al. 2017) of which the study area is not left out. Environmental health problems have arisen as a result of Nigeria's rapid population growth and development (Adefemi and Awokunmi 2009). Delta state is twelfth most populous in Nigeria with an estimated population of over 5.6 million as of 2016 (Population 2006–2016". National Bureau of Statistics. Retrieved 14 December 2021). In most Nigerian cities, waste is generated as a result of human activities and is frequently mismanaged (Eyankware and Ephraim 2021; Adefemi and Awokunmi 2009; Aurangabadkar et al. 2001; Akakuru, et al. 2022). This results in poor environmental quality, which is responsible for 25% of all preventable disease worldwide (Turekian and Wedepohl 1961). Waste is collected and disposed of in most cases near residential buildings in uncontrolled or unengineered dumpsite sites. These wastes are piled up and/or burned, causing pollution in the environment (Akpan 2004; Eyankware et al. 2022; Akinseye et al. 2023). Dumpsite leachates pollute both the soil and the aquatic environment with heavy metals (Harichandan et al. 2005; Igwe, et al. 2022). Biological and chemical contaminants make up the majority of water contaminants (Akinseye et al. 2023). The indiscriminate dumping of rubbish in the environment, as well as leachate contamination, has harmed the quality of subsurface water (David and Oluyege, 2014). Similarly, leachate, a waste product that forms as landfills decompose (Africa et al. 2020; Akakuru et al. 2023a, b), is one of the waste products that jeopardizes the quality of water resources. Ngah and Abah (2016) also stated that leachate, which occurs at the end of the degradation of solid waste and is mixed with surface water precipitates, can harm the ecosystem. As a result, leachate has contaminated these water-bearing units, which has led to the occurrence of heavy metals in groundwater across most urban areas. Furthermore, leachate is a major threat in areas near landfills (open dumpsites), as it is derived from nearby dumpsites. The impact of heavy metals and landfill leachate on groundwater has recently drawn attention from academics worldwide (Eyankware 2019). Similar to this, growing urbanization has led to an increase in trash production, which is usually disposed of carelessly in open spaces close to populated areas, with little thought given to how it may affect the environment, public health, or water sources. Several experts have described unclean landfilling, or open dumpsites, as one of the most common waste disposal strategies because of its advantageous economics (Africa et al. 2020; Eyankware and Ephraim 2021). Freshwater bodies in the research area have been impacted by this waste disposal technique. The chemical composition of freshwater bodies is exclusively dependent on multiple sources of influx, according to Ojiambo et al. (2001), Alexakis et al. (2011), and Kazi et al. (2009). Many factors impact the chemistry and quality of groundwater. Omo-Irabor et al. (2018) proposed and used it to investigate an integrated source-risk method for source apportionment and risk assessment. The PMF model, the geodetector model, and the health risk assessment model (HRA) were used to develop the method. The average concentrations of eight heavy metals were reported to be 1.87–5.86 times higher than the corresponding background values. Cd and As levels were relatively high, exceeding the soil risk screening values. Heavy metal high-value areas are mostly concentrated in the study area's center. According to research, these heavy metals are not only limited to soil and water in an area, but have also been found in animals such as cows, possibly due to food consumption during breeding. Boudebbouz et al. (2023) investigated heavy metal levels in raw milk collected from autochthonous bovine breeds in Algeria’s eastern region. The results revealed that the amounts of Pb (0.94 0.49 mg/kg), Cd (0.03 0.01 mg/kg), and Cu (0.14 0.08 mg/kg) in all of the samples tested exceeded their maximum residue levels (MRLs). This meant that babies could be exposed to heavy metals, particularly lead, by drinking raw cow milk.

Surface and groundwater are undeniably important sources of water for drinking, domestic, agricultural, and industrial reasons in many parts of the world. However, because to contamination from both natural and anthropogenic processes, their purity and suitability for specific uses has recently been questioned (Almahbashi et al. 2023a; Igwe et al. 2022; Onwe et al. 2022; Gorgij et al. 2017). In many parts of the world, the demand for freshwater has increased as a result of significant population growth, increased socioeconomic activity, and unplanned development. However, many parts of the world are today experiencing a severe scarcity of fresh water. According to the World Health Organization’s most recent report, half of the world's population would live in water-stressed areas by the year 2025 (Singh et al. 2019). Onwe et al. (2022) reported that the climate and vegetation influences groundwater chemistry. Hence, a brief description of climate and vegetation of the study area is described. The research area is in the tropical zone and has two seasons: the rainy season and the dry season. The research area has 1000–2000 mm of rainfall on average each year, according to Nwankwor et al. (2016) and Eyankware et al. (2021a, b). They also noted that the rainy season lasts from mid-April to early November and that the months of July and October have the heaviest rainfall. The research area's temperature ranges from 26 to 28 °C, and the vegetation is normally mangrove swamp forest; however, it has been significantly changed by human activities including farming, lumbering, and exploratory activities, and in many cases, grassland has taken its place. The Tropical Continental Air Mass or the North-East Trade Winds, which originate in Arabia-Eurasia and have a high pressure belt, are other characteristics. They are foggy, dry, and dusty (Nwankwor et al. 2016; Obasi et al. 2022). Eyankware and Akakuru (2022) and Akakuru et al. (2022) were of the view that groundwater within the tropical region of Nigeria is highly altered by human and geogenic activities. Similarly, many water quality specialists around the world are concerned about nitrates and heavy metals, which are typical water contaminants (Igwe et al. 2021; Adimalla and Li 2019; Eyankware and Akakuru 2022). Although some natural processes might cause them to accumulate in the water environment, anthropogenic activities such as agriculture, industry, improper waste disposal/management, and urbanization have had a significant impact on their accumulation in recent years (Igwe et al. 2021; Barzegar et al. 2019; Ezugwu et al. 2019; Eyankware and Ephraim 2021; Eyankware et al 2021a; Agidi et al. 2022). Hye-Sook et al. (2008) stated that the potentiality of harmful element in any contaminant is dependent on the component element. Extrinsic quantity or intake of the toxic substance is one of the major indices in risk assessment. Some heavy metals are required for growth and development in the human body in modest amounts (Chowdhury and Chandra 1987). Pollution of water systems, on the other hand, has created a serious threat to both human and environmental health. Drinking water is rendered unfit for human consumption in such a scenario. Some heavy metals are carcinogenic (cancer-causing); nevertheless, others have a tendency to induce other serious, long-term disorders (Eyankware et al. 2021a; Eyankware and Akakuru 2022). Furthermore, knowing the chemistry of groundwater will help in figuring out how beneficial it is for certain tasks. Groundwater potability for residential use has been addressed in a number of ways. For instance, some writers have employed techniques like artificial neural networks (ANN), multiple linear regressions (MLR), and hierarchical cluster analyses (HCA). Water quality Index (WQI), and Heavy Metal Index such as PLI, CF, and many others to identify the chemistry of groundwater (Egbueri and Unigwe 2019). (Akakuru et al. 2022; Egbueri 2019; Egbueri and Unigwe 2020). When compared to its disadvantage, the aforementioned strategy has a greater advantage (Obasi et al. 2022; Onwe et al. 2022).To the authors' knowledge, the disadvantage of this strategy may result from the steps we skipped during the research to avoid the computation of the examined data obtained from the laboratory. On the other side, the heavy metal index has also been used to evaluate the appropriateness of water supplies for drinking (Eyankware and Akakuru 2022; Egbueri and Unigwe 2019; Egbueri et al. 2020). It is critical to encourage and implement continual monitoring and assessment of water quality for drinking purposes in any attempt to maintain and sustain human health and the environment. Monitoring and analyzing water quality allow us to better understand how geogenic and anthropogenic activities may negatively impact water systems, as well as how to minimize or mitigate the effects. A thorough study on the assessment of the impact of waste around the study area to the best of our knowledge has not been done, despite the fact that similar studies have been carried out in other parts of the world (Rockhold et al. 2020; Jagloo 2002; Saadi et al. 2014). As a result, this research is urgently needed. This study is aimed at assessment the effect of heavy metal on groundwater around Akri dumpsite, using the following;

i. Statistical analysis such as Principal Component Analysis (PCA) and Pearson's correlation matrix
ii. Heavy metal index such as Metal Pollution Index, Contamination Factor, Pollution Index of Groundwater, and contamination index
iii. Health risk assessment.

The study area's background information

The research area is located in Delta State, southern Nigeria, between 5° 05′ N and 5° 09′ N, and 6° 39′ E and 6° 41′ E (Fig. 1). The study area is located close to two oil pipe line and the vegetation in the study area varies from saline water wetlands along the coast to rain forests in the state's far north (Eyankware and Ephraim 2021; Olobaniyi et al. 2007). The vegetation is typically mangrove swamp forest, though it has been considerably influenced by human activities such as farming, lumbering, and exploration, and grassland has taken its place in many cases (Eyankware et al. 2020).

Geology of the study area

The Niger Delta is a 75,000-square-kilometer coastal arcuate delta on the Niger River (Fig. 1). For most of the coastline, the subaerial Niger Delta includes a wide saline/brackish mangrove swamp belt separated from the sea by sand beach ridges (Oteri and Atolagbe 2003). Salinity-related water supply issues are limited to the saline mangrove swamp and its accompanying sandy islands and barrier ridges along the coast. The Niger Delta Formation was classified into three formations by Short and Stauble (1967), namely the Akata, Agbada, and Benin Formations. In the delta, the Benin Formation, which is mostly large extremely porous sands and gravels with thin shale/clay interbeds, forms a multi-aquifer system. Several boreholes have been dug into the Benin Formation aquifers, delivering high-quality water, but many have been abandoned due to high salinity (Oteri and Atolagbe 2003). The Benin Formation has a sediment thickness of roughly 2100 m and was deposited during the Niger Delta's continental period (Weber and Daukoru 1976). The Benin Formation, according to Onyeagocha (1980), is mostly composed of sandstone, sands, and gravel with clays appearing in lenses. The sands and sandstones are

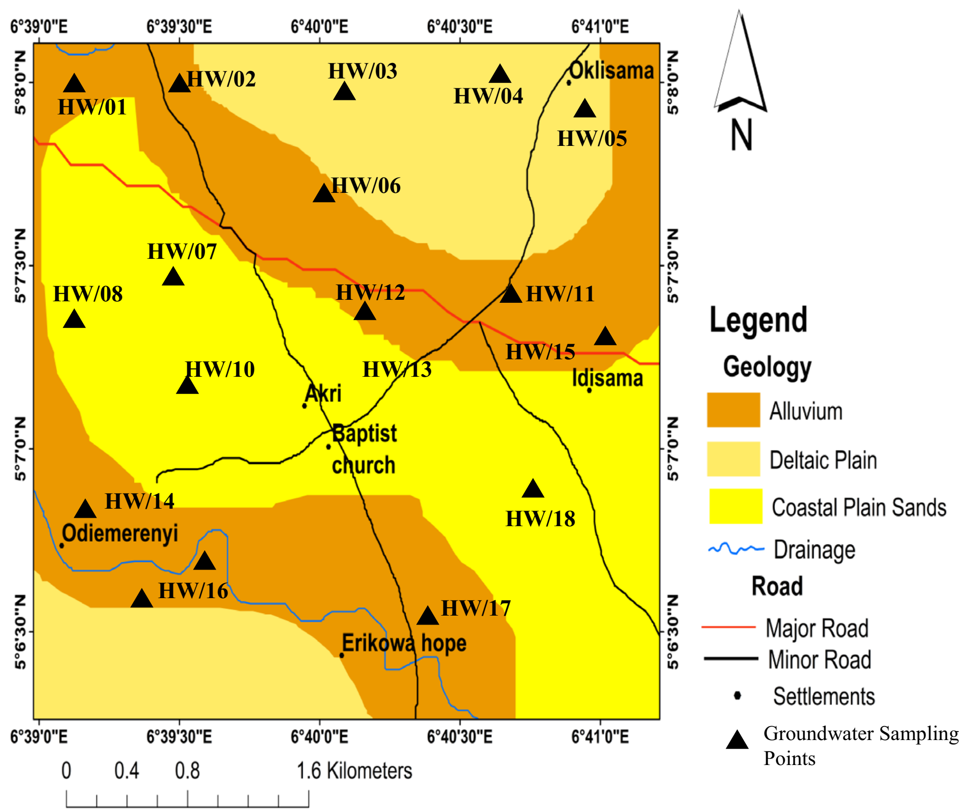

Fig. 1 Geology map of the study area showing groundwater sampling points.

fine-to-coarse grained and partly unconsolidated with varied thicknesses. The Benin Formation is primarily composed of freshwater-resistant continental sand and gravel with clay and shale intercalations (Oteri 1990).

The Niger Delta Basin is a multi-aquifer system made up of huge, very permeable sands and gravels. In the unconfined aquifers, fresh water lenses floating atop salt water-bearing sands have been discovered (Oteri 1990). The delta can be divided into two major areas based on the depth at which the first saline water sands were encountered in the confined aquifers of the Benin Formation: areas where fresh water sands are encountered at shallow depths underlain by saline water sands, and places where saline water sands are encountered at shallow depths underlain successively by fresh water sands and saline water sands (Oteri and Atolagbe 2003).

Materials and methods

Sampling and analysis

Boreholes and hand-dug wells were used to collect water samples around the Akri waste dumpsite from the January (Fig. 2), 2022 to April, 2022 during the dry season. Before any water samples could be taken, the owners of the boreholes had to grant permission. In some cases, the community chiefs had to convince borehole owners to consent to the taking of samples. The bottles were meticulously cleaned with distilled water and then rinsed with clean water and cleaning agents prior to gathering a water sample from the site. Groundwater was collected and stored in plastic beakers for analysis once it was collected. Before the field sampling activity, the sample beakers/containers were meticulously cleaned and soaked in distilled water acidified with 1.0 ml HNO_3 for three (3) days. To gather samples that accurately reflect the water resource, eighteen (18) groundwater samples were collected in a methodically manner from various water sources (Fig. 2). Potential surface films in open hand-dug wells and surface water sources were removed before sampling, and samples from boreholes were acquired after 5–10 min of pumping. Each sample was filtered into a sample bottle using disposable filters with a diameter of 0.45 m after washing the bottle with the aliquot to ensure full removal of suspended particles (Fig. 3). The samples were acidified in the field with 1.0 ml of conc. HNO_3 to prevent heavy metal precipitation, and three drops of HNO3 were added with new syringes to prevent sorption. The samples were stored in hermetically sealed ice-packed beakers at 4 °C. To avoid evaporation, the temperature was maintained during the journey to the analytical laboratory (Singh et al. 2019; Sehgal et al. 2012). Heavy metals like Pb, Cr, Cu, Ni, PO3, Fe, As, Hg, and Br were measured with

Fig. 2 Photography of sample collections and water quality experimental setup

Fig. 3 Photograph showing full water quality experimental setup

a fast sequential (FS) (Varian 240 AA) atomic absorption spectrophotometer (AAS) (Table 1), and all data collection and analysis followed the APHA guidelines (1995, 2012). All samples were sampled and delivered to the lab in ice-packed beakers for analysis within 24 h (Fig. 3). In villages with poor roads that caused delays in sample transportation, groundwater samples were first kept in a station nearer to accessible roads for laboratory analyses. A generator was used to power a refrigerator at this location. All laboratory analyses were finished 48 h after sampling. According to Omaka et al. (2015), these actions are required to prevent rainwater infiltration of chemical precipitations from changing the sample quality.

Principal component analysis (PCA)

In the PCA, component loading entailed reducing a large dataset of many variables into a smaller number of linear combinations in the component that accounted for an appropriate fraction of the total data variance and easily associated the variables to the sources or processes via Eq. (1)

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(X_{N\_}N)^2. \tag{1}$$

When Xi represents the statistical mean, *I* represents the intervals between variables, and *N* represents the number of outcomes.

The Metal Pollution Index (MPI), (see Table 2) which estimated the aggregate impact of individual heavy metals on water quality (Horton 1965; Mohan et al. 1996), was evaluated using Caeiro et al. (2005) (Eq. 2)

$$MPI = \sqrt[n]{M_1 \times M_2 \times M_{3\_\_\_\_\_\_\_\_}Mn}, \tag{2}$$

where Mn = concentration of the metal.

Statistical analysis

The findings were matched to WHO guidelines. Pearson's correlation coefficient was calculated using the Statistical Package for Social Science (SPSS) version 23.

Contamination factor (CF)

The CF was calculated using the Hakanson (1980) formula

Table 1 Result of heavy metals across the study area

Sample code	pH	Ec (µS/cm)	Pb (mg/L)	Cr (mg/L)	Cu (mg/L)	Ni (mg/L)	PO3 (mg/L)	Fe (mg/L)	As (mg/L)	Hg (mg/L)	Br (mg/L)
RWR/01	6.7	589.7	0.0001	N/A	0.014	0.02	0.004	2.50	0.001	0.001	9.37
RWR /02	7.0	704.8	0.0010	N/A	0.010	0.008	0.016	0.018	0.006	0.005	6.48
RWR /03	6.6	403.7	0.0011	N/A	0.005	0.0017	0.002	0.024	0.003	0.001	2.41
RWR /04	7.4	382.3	0.0010	0.0010	0.015	0.001	0.004	0.162	0.0054	0.0001	10.39
RWR /05	6.9	608.5	N/A	N/A	0.002	0.001	0.001	0.022	0.013	0.005	16.31
RWR /06	7.1	499.3	0.0001	0.0001	0.0014	0.0001	0.017	0.031	0.0016	0.0074	9.31
RWR /07	6.8	508.6	0.010	N/A	0.014	0.001	0.033	1.060	0.0012	0.006	9.28
RWR /08	7.5	704.3	0.0001	0.0001	0.02	0.001	0.025	0.065	0.013	N/A	6.07
RWR /09	7.0	449.8	0.0001	0.0001	0.16	0.001	0.007	1.071	0.015	N/A	11.07
HW/10	7.1	716.0	0.0001	N/A	0.05	0.001	0.102	1.063	0.001	0.0001	15.66
HW/11	7.4	1103.7	N/A	N/A	0.059	0.001	0.006	0.007	0.0012	0.001	20.41
HW /12	6.3	290.3	N/A	N/A	0.065	N/A	0.052	1.03	N/A	0.001	5.27
HW/13	6.9	486.5	0.0010	0.0010	0.207	0.001	0.017	2.055	N/A	0.001	8.01
HW/14	7.0	469.3	0.0001	0.0001	0.05	N/A	0.009	0.064	N/A	0.0001	12.21
HW/15	7.2	460.6	0.0001	0.0001	0.015	0.0017	0.024	0.017	0.0014	0.001	6.35
HW/16	6.5	704.3	0.0001	0.0001	0.02	0.0001	0.015	0.062	0.0012	0.0001	9.66
HW/17	7.3	369.9	N/A	N/A	0.12	0.002	0.024	0.053	N/A	0.001	12.00
HW/18	7.0	759.7	N/A	N/A	0.01	0.0001	0.018	0.015	0.0051	0.001	4.57

Table 2 MPI classification in the study area

Range	Zone	Sample no	Sample %	Groundwater pollution degree
< 1	S1	All samples	100	Pollution is insignificant
1–1.5	S2			Low levels of pollution
1.5–2.0	S3			Pollution levels are moderate
2.0–2.5	S4			Pollution levels are high
> 2.5	S5			Pollution levels are extremely high

$$\mathrm{CF} = \frac{C_n}{B_n}, \tag{3}$$

where C_n is the metal concentration and B_n is the background/target value (Akakuru et al. 2021b; Yahaya et al. 2021).

Pollution Load Index (PLI)

Hakanson's (1980) formula was used to calculate the PLI

$$\mathrm{PLI} = \sqrt[n]{CF1 \times CF2 \times CF3 \times \cdots \times CFn}, \tag{4}$$

where CF stands for contamination factor and n stands for element number.

Pollution Index of groundwater (PIG)

The PIG is a tool for evaluating the quality of groundwater for drinking purposes (Subba et al. 2018). When using the PIG, there are five steps to consider. Step I: Determine the relative weight (Rw) of each factor in the assessment of water quality as it relates to human health (on a scale of 1–5) (Table 3). Step II is the determination of the weight parameter (Wp) for each of the groundwater quality factors, intending to determine the relative contribution of each to the overall groundwater quality status (Eq. 5). Step III entails calculating the concentration status (Sc), which was calculated by dividing each sample's water variable content (C) by its associated quality standard limit (Ds) (Eq. 6). In this study, the PIG was assessed using the WHO (2017) criteria. Step IV entails calculating the overall quality of groundwater (Ow) by multiplying the weight parameter (Wp) by the concentration status (Sc) (Eq. 7).

Table 3 Results of pollution (PIG)

	Ow = Wp*Sc											PIG
	pH	Ec	Pb	Cr	Cu	Ni	PO3	Fe	As	Hg	Br	
RWR/01	0.073626	0.090723	0.00102	0.002041	0.001143	0.291546	0.002449	0.8547	0.010204	0.017007	1.092716	**2.437175**
RWR/02	0.076923	0.108431	0.010204	0.002041	0.000816	0.116618	0.009796	0.006154	0.061225	0.085034	0.755688	**1.23293**
RWR/03	0.072527	0.062108	0.011225	0.002041	0.000408	0.024781	0.001224	0.008205	0.030612	0.017007	0.281051	**0.511189**
RWR/04	0.081319	0.058815	0.010204	0.002041	0.001224	0.014577	0.002449	0.055385	0.055102	0.001701	1.211667	**1.494484**
RWR/05	0.075824	0.093615	0.102041	0.002041	0.000163	0.014577	0.000612	0.007521	0.132653	0.085034	1.902049	**2.416132**
RWR/06	0.078022	0.076815	0.00102	0.002041	0.000114	0.001458	0.010408	0.010598	0.016327	0.125851	1.085719	**1.408373**
RWR/07	0.074725	0.078246	0.102041	0.002041	0.001143	0.014577	0.020204	0.362393	0.012245	0.102041	1.08222	**1.851876**
RWR/08	0.082418	0.108354	0.00102	0.002041	0.001633	0.014577	0.015306	0.022222	0.132653	0.102041	0.707875	**1.19014**
RWR/09	0.076923	0.0692	0.00102	0.002041	0.013061	0.014577	0.004286	0.366153	0.153062	0.102041	1.290968	**2.093332**
HW/10	0.078022	0.110154	0.00102	0.002041	0.004082	0.014577	0.062448	0.363418	0.010204	0.001701	1.826247	**2.473914**
HW/11	0.081319	0.1698	0.102041	0.002041	0.004816	0.014577	0.003673	0.002393	0.102041	0.017007	2.380185	**2.879893**
HW/12	0.069231	0.044661	0.102041	0.002041	0.005306	0.087464	0.031836	0.352136	0.061225	0.017007	0.61458	**1.387528**
HW/13	0.075824	0.074846	0.010204	0.002041	0.016898	0.087464	0.010408	0.702563	0.061225	0.017007	0.934115	**1.992595**
HW/14	0.076923	0.0722	0.00102	0.002041	0.004082	0.087464	0.00551	0.02188	0.061225	0.001701	1.423913	**1.757958**
HW/15	0.079121	0.070861	0.00102	0.002041	0.001224	0.024781	0.014694	0.005812	0.014286	0.017007	0.740528	**0.971376**
HW/16	0.071429	0.108354	0.00102	0.002041	0.001633	0.001458	0.009184	0.021197	0.012245	0.001701	1.126535	**1.356795**
HW/17	0.08022	0.056908	0.102041	0.002041	0.009796	0.029155	0.014694	0.01812	0.102041	0.017007	1.399423	**1.831444**
HW/18	0.076923	0.116877	0.102041	0.002041	0.000816	0.001458	0.01102	0.005128	0.052041	0.017007	0.532947	**0.918299**

Bold indicates for <1, pollution is insignificant, 1 to 1.5, low level of pollution, 1.5 to 2.0, pollution level are moderate. 2.0 to 2.5, pollution levels are high. For values >2.5, pollution levels are extremely high

Step V entails adding up all of the Ow values per sample (Eq. 8)

$$\mathrm{Wp} = \frac{R_w}{\sum R_w} \tag{5}$$

$$\mathrm{Sc} = \frac{C}{D_c} \tag{6}$$

$$\mathrm{Ow} = \mathrm{Wp} * \mathrm{Si} \tag{7}$$

$$\mathrm{PIG} = \sum O_w. \tag{8}$$

Contamination index (Pi)

The contamination index (Pi) for groundwater in the area of the described parameters was calculated based on the following formula (Table 4):

$$\mathrm{Pi} = \frac{\mathrm{C_n}}{\mathrm{S_i}}, \tag{9}$$

where C_n is concentration and S_i is WHO standard

Results and discussion

Statistical approach

Multivariate statistical approaches have been widely applied to help solve environmental problems and provide evidence for understanding some natural and anthropogenic processes. The statistical analysis in this research work plays a crucial role in providing a quantitative understanding of the heavy metal contamination in the groundwater through data interpretation [principal component analysis (PCA)], correlation analysis, contamination assessment of all the adopted indexes, health risk assessment, data validation, comparative analysis, and relevant recommendations based on the quantitative findings derived from statistical methods. Hence, it serves as a tool for extracting meaningful insights from complex datasets, enabling a more rigorous assessment of heavy metal contamination in groundwater and providing a basis for informed decision-making and environmental management.

Principal component analysis (PCA)

PCA is a powerful technique for pattern recognition that attempts to explain the variance of a large set of inter-correlated variables. It indicates association between variables, thus, reducing the dimensionality of the dataset. Similarly,

Table 4 Result of contamination Index (PI)

	pH	Ec	Pb	Cr	Cu	Ni	Fe	As	Hg	Br
RWR/01	0.957143	1.1794	0.01	0.02	0.014	2.857143	8.333333	0.1	0.166667	13.38571
RWR /02	1	1.4096	0.1	0.02	0.01	1.142857	0.06	0.6	0.833333	9.257143
RWR /03	0.942857	0.8074	0.11	0.02	0.005	0.242857	0.08	0.3	0.166667	3.442857
RWR /04	1.057143	0.7646	0.1	0.02	0.015	0.142857	0.54	0.54	0.016667	14.84286
RWR /05	0.985714	1.217	1	0.02	0.002	0.142857	0.073333	1.3	0.833333	23.3
RWR /06	1.014286	0.9986	0.01	0.02	0.0014	0.014286	0.103333	0.16	1.233333	13.3
RWR /07	0.971429	1.0172	1	0.02	0.014	0.142857	3.533333	0.12	1	13.25714
RWR /08	1.071429	1.4086	0.01	0.02	0.02	0.142857	0.216667	1.3	1	8.671429
RWR /09	1	0.8996	0.01	0.02	0.16	0.142857	3.57	1.5	1	15.81429
HW/10	1.014286	1.432	0.01	0.02	0.05	0.142857	3.543333	0.1	0.016667	22.37143
HW/11	1.057143	2.2074	1	0.02	0.059	0.142857	0.023333	1	0.166667	29.15714
HW /12	0.9	0.5806	1	0.02	0.065	0.857143	3.433333	0.6	0.166667	7.528571
HW/13	0.985714	0.973	0.1	0.02	0.207	0.857143	6.85	0.6	0.166667	11.44286
HW/14	1	0.9386	0.01	0.02	0.05	0.857143	0.213333	0.6	0.016667	17.44286
HW/15	1.028571	0.9212	0.01	0.02	0.015	0.242857	0.056667	0.14	0.166667	9.071429
HW/16	0.928571	1.4086	0.01	0.02	0.02	0.014286	0.206667	0.12	0.016667	13.8
HW/17	1.042857	0.7398	1	0.02	0.12	0.285714	0.176667	1	0.166667	17.14286
HW/18	1	1.5194	1	0.02	0.01	0.014286	0.05	0.51	0.166667	6.528571

Table 5 Principal component analysis (PCA)

	Communalities	PC1	PC2	PC3
pH	0.778505	**0.599133**	−0.10919	−0.26192
Ec	0.7718	**0.675471**	−0.18736	0.288644
Pb	0.912287	0.392384	−0.00484	−0.0173
Cu	0.880567	0.179733	**0.844684**	−0.21239
Ni	0.874564	−0.39097	**0.482341**	0.256735
PO	0.777437	0.183278	0.012054	**0.610585**
Fe	0.853176	−0.24651	**0.775618**	0.299148
As	0.854626	**0.45676**	0.341526	**−0.7127**
Hg	0.415465	−0.04831	−0.10534	**−0.62594**
Br	0.766535	**0.845724**	0.231248	0.195654
	Eigenvalues	2.646696	2.280744	−0.17949
	Variance (%)	16.38241	13.95507	18.44835
	Cumulative var. (%)	16.38241	30.337	48.785

Bold indicates loading

PCA is frequently used to reduce the dimensionality of independent variables and data sets by explaining the variance of a large dataset of correlated variables (Eyankware and Akakuru 2022). PCA extracts the eigenvalues and eigenvectors from the covariance matrix of original variables (Eyankware and Akakuru 2022. The principal components (PCs) are the uncorrelated (orthogonal) variables, obtained by multiplying the original correlated variables with the eigenvector (loadings). According to Table 5's PCA results and Fig. 4's expression, there is a PCI loading of 40% in pH, Ec, As, and Br. Cu, Ni, and Fe loadings in PC2 are 30%, while loadings of 30% in PC3 were found in PO, As, and Hg. The results clearly demonstrate that the loadings in components were primarily caused by the loess's enduring or possibly filtering properties, and that the sorption and desorption behavior of these components may be comparable. Certain characteristics of the loess, such as its fine grain size and hydrous oxide particles, can accelerate the sorption of these components in the surface water of a waterway (Ulakpa and Eyankware 2021).

Pearson's correlation matrix

Pearson's correlation matrix is used to signify the association among the pairs of variables, to assess and determine the strength of a linear relationship between two variables, Information about the origins and pathways of the heavy metals is provided by inter-element interaction (Henry et al. 2021). Pearson correlation analysis is frequently utilized. Table 6 provides the values of the correlation coefficients, which were determined between various water quality metrics (Akakurur et al. 2022; Eyankware and Akakuru 2022). The correlation coefficient matrix measures how well the variance of each constituent can be explained by relationship with each other (Eyankware et al. 2020). The Pearson correlation matrix of heavy metals are shown in Table 3. The table shows a weak correlation between Ec and Br (0.47), which suggests that groundwater and seawater may combine in the coastal region, a poor correlation between Cu and Fe (0.45), and a reasonably significant association between Ni and Fe (0.666). Poor correlation observed in Table 6 could be attributed to differences in mixed sources of origin and behavior of those heavy metals,

Fig. 4 Component loading of elements

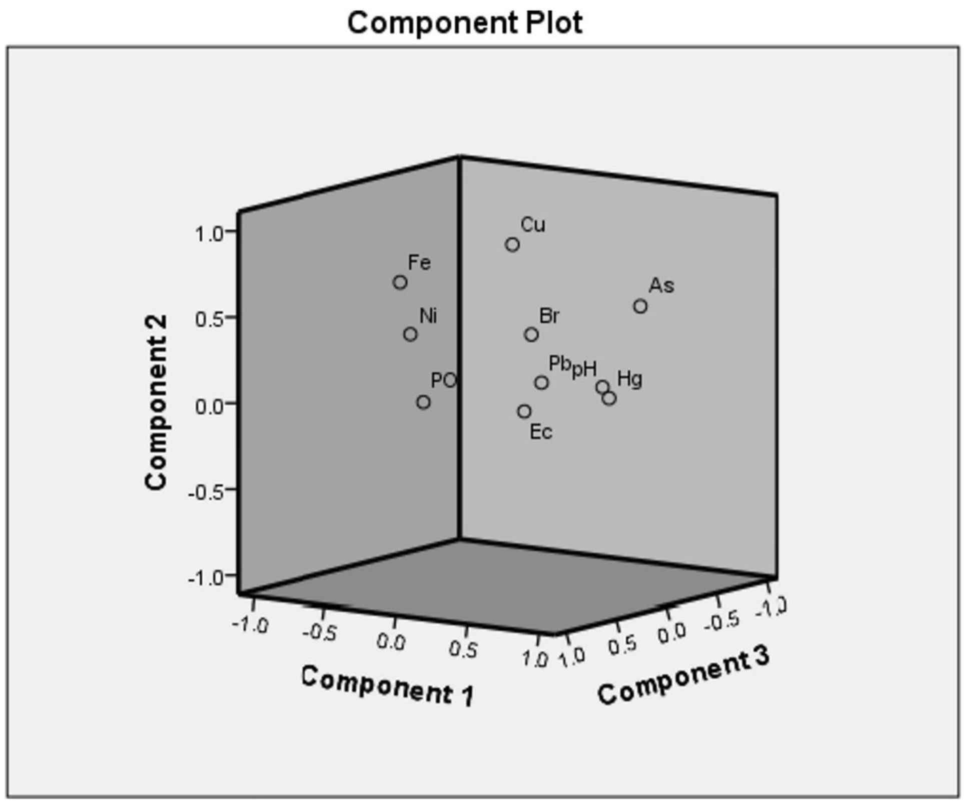

Table 6 Pearson correlation of analyzed parameters

	pH	Ec	Pb	Cu	Ni	PO	Fe	As	Hg	Br
pH	1									
Ec	0.318607	1								
Pb	−0.08012	0.135136	1							
Cu	0.038278	−0.20798	−0.01048	1						
Ni	−0.32102	−0.09548	−0.21034	0.032837	1					
PO	−0.05832	0.00921	0.02311	0.059795	−0.14002	1				
Fe	−0.36547	−0.17866	−0.14647	**0.452782**	**0.666****	0.195554	1			
As	0.379175	0.102032	0.263546	0.397261	−0.21883	−0.30134	−0.19954	1		
Hg	0.152833	0.009574	0.007034	−0.11408	−0.18675	−0.14639	−0.09498	0.337539	1	
Br	0.366899	**0.470***	0.233732	0.149404	−0.12835	0.08363	−0.02746	0.291887	−0.05478	1

Bold values indicate significant values

* implies moderate correlation

** implies strong correlation

as well as an anthropogenic influence (Akakuru et al. 2022; Agidi et al. 2022).

Heavy metal indices

Pollution indices

This study used pollution indices grouped into four types (Eyankware and Akakuru 2022) to analyze heavy metal contamination: Metal Pollution Index (MPI), Contamination Factor (CF), Pollution Index of Groundwater (PIG), and Health Risk Assessment (HRA).

Contamination factor (CF)

The concentration ratio of heavy metals to background values has been calculated using the CF in groundwater study. The following criteria are used to describe the contamination factor's values: low contamination (CF < 1), moderate contamination (CF < 3), significant contamination (CF < 6), and extremely high contamination (CF > 6) (Akakuru et al. 2017a, b; Bhutian et al. 2017; Eyankware and Akakuru 2022). From the results in Table 7, it clearly shows that the entire elements had CF values of less than 1 in the entire study area except Fe which had values ranging from moderate contamination to extremely high contamination. High concentrations of iron (Fe) in groundwater are a very common occurrence, particularly in hot, humid climates. Fe often occurs in groundwater in the reduced dissolvable divalent ferrous iron (Fe^{2+}) oxidation state. When groundwater interacts with oxygen of the environment, the Fe is oxidized to the ferric state and is accelerated as Fe mineral. Groundwater's high Fe content is significantly impacted by subsurface decreasing conditions (Eyankware and Akakuru 2022; Agidi et al. 2022). Fe can be released into the water by a variety of processes, including natural deposits, industrial wastes, iron ore refining, and corrosion of metals containing iron. This can lead to an excessive concentration of Fe in the water. Shallow wells and surface water contain a naturally occurring organic material and iron mixture (Eyankware et al. 2023).

Pollution load index (PLI)

PLI is a valuable tool for determining toxicity level of heavy metals in representative samples (Akakuru, et al., 2021). PLI is typically classified as having no pollution (PLI < 1), moderate pollution (PLI < 2), heavy pollution (2 < PLI < 3), or extremely heavy pollution (PLI > 3). The study area's groundwater had a concentration value of less than one, according to the results (Table 7). This implies that no pollution exists. This is in consonance with the CF result in this present study that had CF values less than 1, except for the Fe values. The research conducted in India (Gopinath et al. 2019; Bhutian et al. 2017) is in conflict with the findings of this study; however, the research was conducted in Nigeria (Yahaya et al. 2021; Akakuru et al. 2021) is in agreement with them (2022).

Metal pollution index (MPI)

The metal pollution index (MPI) model is a useful instrument for determining the overall level of metal pollution in groundwater. In the classification of groundwater, MPI has proven to be a beneficial tool. Very pure water has an MPI of 0.3 or less, while pure water has an MPI of 0.3–1.0. Class III is for those with an MPI of 1.0–2.0, whereas Class IV is for those who are seriously impaired. Moderately impacted with an MPI of 2.0–4.0. Water samples with an MPI of 4.0 to 6.0 are classed as significantly affected in Class V, while those with an MPI of > 6.0 are classified as severely affected in Class VI. It was observed that from the results as presented in Tables 2 and 3 that the entire samples had their concentration levels less than 0.3, this goes to say that the water are very pure, and the result is in line with study conducted elsewhere in southern Benue Trough, Nigeria by Eyankware

Table 7 Results of Contamination factor (CF), Pollution Load Index (PLI), and Metal Pollution Index (MPI)

	Contamination factor									PLI
	Pb	Cr	Cu	Ni	Fe	As	Hg	Br	MPI	
RWR/01	0.000001	0.00001	0.000389	0.000143	62.5	0.0002	0.005	0.0937	1.62E-09	1.90E-14
RWR/02	0.00001	0.00001	0.000278	5.71E-05	0.45	0.0012	0.025	0.0648	2.12E-09	2.48E-14
RWR/03	0.000011	0.00001	0.000139	1.21E-05	0.6	0.0006	0.005	0.0241	5.70E-11	6.69E-16
RWR/04	0.00001	0.00001	0.000417	7.14E-06	4.05	0.00108	0.0005	0.1039	2.34E-10	2.74E-15
RWR/05	0.0001	0.00001	5.56E-05	7.14E-06	0.55	0.0026	0.025	0.1631	6.83E-10	8.02E-15
RWR/06	0.000001	0.00001	3.89E-05	7.14E-07	0.775	0.00032	0.037	0.0931	2.85E-11	3.35E-16
RWR/07	0.0001	0.00001	0.000389	7.14E-06	26.5	0.00024	0.03	0.0928	1.81E-08	2.12E-13
RWR/08	0.000001	0.00001	0.000556	7.14E-06	1.625	0.0026	0.03	0.0607	1.24E-09	1.46E-14
RWR/09	0.000001	0.00001	0.004444	7.14E-06	26.775	0.003	0.03	0.1107	1.09E-08	1.28E-13
HW/10	0.000001	0.00001	0.001389	7.14E-06	26.575	0.0002	0.0005	0.1566	9.21E-10	1.08E-14
HW/11	0.0001	0.00001	0.001639	7.14E-06	0.175	0.002	0.005	0.2041	2.25E-09	2.64E-14
HW/12	0.0001	0.00001	0.001806	4.29E-05	25.75	0.0012	0.005	0.0527	8.13E-08	9.54E-13
HW/13	0.00001	0.00001	0.00575	4.29E-05	51.375	0.0012	0.005	0.0801	4.57E-08	5.36E-13
HW/14	0.000001	0.00001	0.001389	4.29E-05	1.6	0.0012	0.0005	0.1221	3.56E-10	4.18E-15
HW/15	0.000001	0.00001	0.000417	1.21E-05	0.425	0.00028	0.005	0.0635	9.62E-11	1.13E-15
HW/16	0.000001	0.00001	0.000556	7.14E-07	1.55	0.00024	0.0005	0.0966	1.47E-11	1.72E-16
HW/17	0.0001	0.00001	0.003333	1.43E-05	1.325	0.002	0.005	0.12	1.91E-08	2.25E-13
HW/18	0.0001	0.00001	0.000278	7.14E-07	0.375	0.00102	0.005	0.0457	2.51E-10	2.94E-15

and Akakuru (2022). Similarly, this finding is in line with the studies of Akakuru et al. (2021, 2022) in Nigeria, which found out that there were less MPI values in the samples studies. This result of the MPI authenticates the results of the CF and PLI in this present study which found out that there was no pollution in the studied samples.

Pollution index of groundwater (PIG)

Many studies have applied PIG to measure the quality of water (both surface and groundwater) (Subba 2012; SubbaRao and Chaudhary 2019). The PIG of the entire samples was calculated. According to Subba et al. (2018), an Ow that is greater than 0.1 implies that the sample contributes 10% value of 1.0 of the PIG. This provides distinct information on the influence of the parameter contaminating the groundwater body. Pollution degree of drinking water is classified into five; less than 1 (< 1) implies insignificant pollution, 1–1.5 indicates low pollution, 1.5–2.0 implies moderate pollution, and 2.0–2.5 indicates high pollution, while > 2.5 indicates very high pollution. From the PIG result as presented in Table 8, it shows that the entire samples within the study area were below 0.1. However, the Br values in majority of the samples had Ow values greater than 0.1, implying that Br were the major contributor to groundwater contamination. The values of PIG in the study area are shown in Tables 7 and 8; it shows that 16.7% of the samples were less than 1, 33.3% of the samples were between 1 and 1.5 (low pollution), and 22.2% of the samples were between 1.5 and 2.0 (high pollution), while 5.6% of the samples were above 2.5 (very high pollution). The PIG values represent the contributions of each groundwater sample's examined chemical factors. Areas with high PIG values could be attributed to areas with high anthropogenic activities or area where waste was able to percolate into groundwater. This outcome is consistent with independent research by Subba et al. (2018) and Egbueri (2019) in India and Nigeria, respectively.

Table 8 PIG assessment components

	Rw	Wp	WHO (2017)
pH	3	0.076923	7
EC (uS/cm)	3	0.076923	500
Fe (mg/L)	4	0.102564	0.3
Pb	5	0.102041	0.01
Cr	5	0.102041	0.05
Cu	4	0.081633	1
Ni	5	0.102041	0.007
PO3	3	0.061224	0.1
As	5	0.102041	0.01
Hg	5	0.102041	0.006
Br	4	0.081633	0.7
Summation	46	0.991104	

Contamination index (Pi)

The first index was first introduced by Backman et al. (1998). The index is a measure of the pollution reflecting the level of pollutants in groundwater in relation to the natural hydrochemical background. Contamination index of Pi < 1 indicates clean water, Pi values of less than or equal to 1 and less than 2 ($1 \leq Pi < 2$) indicate potential pollution, and Pi values of less than or equal to 2 and less than 3 ($2 \leq Pi < 3$) indicate slight pollution, whereas Pi values of more than 3 (Pi > 3) indicates heavy pollution. From the results as presented in Table 3 shows that the entire water samples ranged between clean water and heavy polluted water, especially the Br and Fe. This result could be attributed to the anthropogenic activities within the study area that greatly influence the quality of groundwater. Eyankware et al. (2023) were of the view that in most of the Niger Delta region of Nigeria, excessive fertilizer use, poor landfill and waste disposal practices, intense urbanization and industrialization, and unhygienic conditions have contaminated groundwater.

Health risk assessment

To evaluate the possible non-carcinogenic health risk of the aforementioned heavy metals in groundwater through oral consumption and dermal pathways, the current study performed health risk assessments (HRA) of adults and children (Table 9). Drinking water contaminated with heavy metals poses a variety of health risks. Residents are more sensitive to health risks from metal eating, because most metals have a high contamination factor. In addition to causing an unpleasant taste in beverages, heavy metals in water can cause stains on items and laundry, sticky coatings, and depositions in water distribution pipes (WHO 2017; Mgbenu and Egbueri 2019). Despite the lack of a health-based temperature guideline, it has been discovered that high water temperatures encourage the growth of bacteria that may be harmful to human systems, as well as taste, odor, color, and corrosion issues (WHO 2017; Mgbenu and Egbueri 2019). In a attempt to reduce the effect of heavy metals on health risk, Almahbashi et al. (2023b) looked into how activated carbon made from sewage sludge could be used to get rid of copper (Cu) and cadmium (Cd) ions from water-based solutions. The activated carbon capacity for removing copper and cadmium was reported to be 16 mg/g and 17.6 mg/g, respectively. The sulfurization process increased copper and cadmium ion removal percentages by 14.5 and 18.7%, respectively. Furthermore, Table 10 shows the hazard quotients (HQ) (for heavy metals). Furthermore, the hazard quotients (HQ) (for heavy metals) reported in Table were used

Table 9 CDI

	Pb (A)	Pb (C)	Cr (A)	Cr (C)	Cu(A)	Cu(C)	Ni (A)	Ni (C)	Fe (A)	Fe(C)	As (A)	As (C)	Hg (A)	Hg (C)	Br (A)	Br (C)
RWR/01	1865.15	31.974	18,651.5	319.74	261,121	4476.36	373,030	6394.8	46,628,750	799,350	18,651.5	319.74	18,651.5	319.74	1.75E+08	2,995,964
RWR /02	18,651.5	319.74	18,651.5	319.74	186,515	3197.4	149,212	2557.92	335,727	5755.32	111,909	1918.44	93,257.5	1598.7	1.21E+08	2,071,915
RWR /03	20,516.65	351.714	18,651.5	319.74	93,257.5	1598.7	31,707.55	543.558	447,636	7673.76	55,954.5	959.22	18,651.5	319.74	44,950,115	770,573.4
RWR /04	18,651.5	319.74	18,651.5	319.74	279,772.5	4796.1	18,651.5	319.74	3,021,543	51,797.88	100,718.1	1726.596	1865.15	31.974	1.94E+08	3,322,099
RWR /05	186,515	3197.4	18,651.5	319.74	37,303	639.48	18,651.5	319.74	410,333	7034.28	242,469.5	4156.62	93,257.5	1598.7	3.04E+08	5,214,959
RWR /06	1865.15	31.974	18,651.5	319.74	26,112.1	447.636	1865.15	31.974	578,196.5	9911.94	29,842.4	511.584	138,021.1	2366.076	1.74E+08	2,976,779
RWR /07	186,515	3197.4	18,651.5	319.74	261,121	4476.36	18,651.5	319.74	19,770,590	338,924.4	22,381.8	383.688	111,909	1918.44	1.73E+08	2,967,187
RWR /08	1865.15	31.974	18,651.5	319.74	373,030	6394.8	18,651.5	319.74	1,212,348	20,783.1	242,469.5	4156.62	111,909	1918.44	1.13E+08	1,940,822
RWR /09	1865.15	31.974	18,651.5	319.74	2,984,240	51,158.4	18,651.5	319.74	19,975,757	342,441.5	279,772.5	4796.1	111,909	1918.44	2.06E+08	3,539,522
HW/10	1865.15	31.974	18,651.5	319.74	932,575	15,987	18,651.5	319.74	19,826,545	339,883.6	18,651.5	319.74	1865.15	31.974	2.92E+08	5,007,128
HW/11	186,515	3197.4	18,651.5	319.74	1,100,439	18,864.66	18,651.5	319.74	130,560.5	2238.18	186,515	3197.4	18,651.5	319.74	3.81E+08	6,525,893
HW /12	186,515	3197.4	18,651.5	319.74	1,212,348	20,783.1	111,909	1918.44	19,211,045	329,332.2	111,909	1918.44	18,651.5	319.74	98,293,405	1,685,030
HW/13	18,651.5	319.74	18,651.5	319.74	3,860,861	66,186.18	111,909	1918.44	38,328,833	657,065.7	111,909	1918.44	18,651.5	319.74	1.49E+08	2,561,117
HW/14	1865.15	31.974	18,651.5	319.74	932,575	15,987	111,909	1918.44	1,193,696	20,463.36	111,909	1918.44	1865.15	31.974	2.28E+08	3,904,025
HW/15	1865.15	31.974	18,651.5	319.74	279,772.5	4796.1	31,707.55	543.558	317,075.5	5435.58	26,112.1	447.636	18,651.5	319.74	1.18E+08	2,030,349
HW/16	1865.15	31.974	18,651.5	319.74	373,030	6394.8	1865.15	31.974	1,156,393	19,823.88	22,381.8	383.688	1865.15	31.974	1.8E+08	3,088,688
HW/17	186,515	3197.4	18,651.5	319.74	2,238,180	38,368.8	37,303	639.48	988,529.5	16,946.22	186,515	3197.4	18,651.5	319.74	2.24E+08	3,836,880
HW/18	186,515	3197.4	18,651.5	319.74	186,515	3197.4	1865.15	31.974	279,772.5	4796.1	95,122.65	1630.674	18,651.5	319.74	85,237,355	1,461,212

Table 10 Result of Health Risk Assessment HQ and HI

	Pb (A)	Pb (C)	Cr (A)	Cr (C)	Cu(A)	Cu(C)	Ni (A)	Ni (C)	Fe (A)	Fe(C)	As (A)	As (C)	Hg (A)	Hg (C)	Br (A)	Br (C)
RWR/01	0.011429	0.000196	7.777778	0.133333	350	6	58,333.33	1000	3571.429	61.22449	194,444.4	3333.333	0.035575	0.00061	24,305.56	416.6667
RWR /02	15.87302	0.272109	1080.247	18.51852	41.66667	0.714286	3888.889	66.66667	5.142857	0.088163	233,333.3	4000	0.257202	0.004409	24,305.56	416.6667
RWR /03	13.09524	0.22449	810.1852	13.88889	41.66667	0.714286	1652.778	28.33333	34.28571	0.587755	583,333.3	10,000	0.138313	0.002371	24,305.56	416.6667
RWR /04	1.763668	0.030234	120.0274	2.057613	69.44444	1.190476	540.1235	9.259259	2314.286	39.67347	10,500,000	180,000	0.003208	5.5E-05	24,305.56	416.6667
RWR /05	129.8701	2.226345	883.8384	15.15152	3.846154	0.065934	224.359	3.846154	6.285714	0.107755	505,555.6	8666.667	0.102187	0.001752	24,305.56	416.6667
RWR /06	0.921659	0.0158	627.2401	10.75269	21.875	0.375	182.2917	3.125	5.984556	0.102592	42,042.04	720.7207	0.264948	0.004542	24,305.56	416.6667
RWR /07	2.695418	0.046207	18.34382	0.314465	291.6667	5	2430.556	41.66667	252.381	4.326531	38,888.89	666.6667	0.215517	0.003695	24,305.56	416.6667
RWR /08	0.43956	0.007535	299.1453	5.128205	38.46154	0.659341	224.359	3.846154	15.47619	0.265306	421,296.3	7222.222	0.329489	0.005648	24,305.56	416.6667
RWR /09	0.026677	0.000457	18.15541	0.311236	266.6667	4.571429	194.4444	3.333333	255	4.371429	486,111.1	8333.333	0.180668	0.003097	24,305.56	416.6667
HW/10	0.026878	0.000461	18.29205	0.313578	1250	21.42857	2916.667	50	15,185.71	260.3265	1,944,444	33,333.33	0.002129	3.65E-05	24,305.56	416.6667
HW/11	408.1633	6.997085	2777.778	47.61905	147.5	2.528571	291.6667	5	10	0.171429	1,944,444	33,333.33	0.016332	0.00028	24,305.56	416.6667
HW /12	2.773925	0.047553	18.8781	0.323625	270.8333	4.642857	2916.667	50	1471.429	25.22449	1,166,667	20,000	0.063251	0.001084	24,305.56	416.6667
HW/13	0.139034	0.002383	9.462017	0.162206	862.5	14.78571	2916.667	50	2935.714	50.32653	1,166,667	20,000	0.041615	0.000713	24,305.56	416.6667
HW/14	0.446429	0.007653	303.8194	5.208333	208.3333	3.571429	2916.667	50	914.2857	15.67347	11,666,667	200,000	0.00273	4.68E-05	24,305.56	416.6667
HW/15	1.680672	0.028812	1143.791	19.60784	267.8571	4.591837	3541.667	60.71429	24.28571	0.416327	272,222.2	4666.667	0.052493	0.0009	24,305.56	416.6667
HW/16	0.460829	0.0079	313.6201	5.376344	416.6667	7.142857	243.0556	4.166667	885.7143	15.18367	2,333,333	40,000	0.003451	5.92E-05	24,305.56	416.6667
HW/17	53.90836	0.924143	366.8763	6.289308	300	5.142857	583.3333	10	75.71429	1.297959	1,944,444	33,333.33	0.027778	0.000476	24,305.56	416.6667
HW/18	190.4762	3.265306	1296.296	22.22222	49.01961	0.840336	57.18954	0.980392	21.42857	0.367347	991,666.7	17,000	0.072939	0.00125	24,305.56	416.6667
HI	**822.7724**	**14.10467**	**10,113.77**	**173.379**	**4898.004**	**83.96578**	**84,054.71**	**1440.938**	**27,984.56**	**479.7352**	**36,435,561**	**624,609.6**	**1.809824**	**0.031026**	**437,500**	**7500**

Bold values indicate moderate and strong correllation to determine the non-carcinogenic risk posed by drinking water containing trace metals for both children and adults in the research area. As > Fe > Ni > Cu > Cr > Pb > Br > Hg is the HQ order for both children and adults, indicating that As and Fe are the most polluting elements in water supplies. The findings suggest that injecting heavy metal poses a substantial health risk to both adults and children. Mgbenu and Egbueri (2019) found similar results somewhere in Nigeria. In a similar line, a research by Egbueri and Mgbenu (2020) in southeast Nigeria claimed that the high Pb HQ values of the samples were the cause of their elevated HI. This metal can be absorbed by people when it is taken in by food, drink, or air. It is vital to note that one of the components necessary for human metabolism is iron. Due to the accumulation of heavy metals above the advised limits, prolonged exposure could have biotoxic effects (Ibironke et al. 2018). In addition, Shi et al. (2023) published the results of a review of studies conducted between 1977 and 2020 to assess the spatiotemporal distribution of soil heavy metal concentrations and estimate ecological and human health risks on a national scale. Pollution was reported to be worse in southeast China than in the northwest, with children and adult females identified as the priority groups for protection. The statistical findings emphasize the need for ongoing monitoring and intervention to safeguard water quality and public health.

Contamination Index

See Tables 6, 7, 8, 9, and 10.

Conclusion

In conclusion, this research has shed light on the critical issue of solid waste management, particularly in impoverished regions where unregulated dumpsites pose a significant threat to public health. The comprehensive study conducted around the Akri solid waste dumpsite in Warri, Nigeria, employed a rigorous methodology involving field sampling, laboratory analysis, and statistical techniques. The findings reveal a potential risk to environmental compartments, such as soil, surface water, and groundwater due to contamination. Groundwater samples from various locations near the dumpsite underwent thorough physicochemical analysis, with notable observations including the prevalence of heavy metals. Principal Component Analysis (PCA) indicated that enduring or potentially filtering loess contributed significantly to the components, while poor correlation within elements suggested mixed sources of origin and anthropogenic influences. Contamination assessments, including Contamination Factor (CF), Pollution Load Index (PLI), Metal Pollution Index (MPI), Pollution Index of Groundwater (PIG), and Hazard Quotients (HQ), collectively portrayed the current state of groundwater quality. Despite contamination factors of less than 1 in most cases, certain elements, particularly Iron (Fe) and Boron (Br), exhibited concerning levels ranging from moderate-to-extremely high contamination. Furthermore, the hazard quotients (HQ) (for heavy metals) reported that the non-carcinogenic risk posed by drinking water containing trace metals for both children and adults in the research area are in the trend of As > Fe > Ni > Cu > Cr > Pb > Br > Hg, is the HQ order for both children and adults, indicating that As and Fe are the most polluting elements in water supplies. The Health Risk Assessment based on daily intake and exposure for both adults and children identified Arsenic (As) and Iron (Fe) as the most alarming elements, emphasizing the importance of addressing anthropogenic activities as a primary cause of heavy metal infiltration into groundwater. In light of these findings, regular and vigilant appraisal of groundwater sources, coupled with strategic interventions for sustainable waste management practices is strongly recommended. The data presented in this study can serve as a foundation for informed decision-making, guiding policies and actions to mitigate the potential risks posed by contaminated water sources and safeguard the well-being of the communities in the study area.

Data availability My manuscript has associated data in a data repository.

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