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ORIGINAL ARTICLE

Assessment of heavy metal pollution on groundwater quality in the Niger Delta Region of Nigeria

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Abstract
Heavy metal (HM) pollution in groundwater poses a significant environmental threat to the Niger Delta region of Nigeria, principally because of the activities of oil companies within the locality. The current study considered it necessary to measure the HM level in the groundwater of this location. 18 groundwater samples were collected and tested for physical parameters (pH, EC, TDS), as well as heavy metals (Cr, Cu, Zn, Co, Fe, Mn, B, Ni, and Cd). Results from the principal component analysis (PCA) analysis reveal the influence of heavy metals on groundwater chemistry. The correlation matrix results showed that there exists a weak and positive correlation among elements, revealing that heavy metals in water with a low pH tend to be more toxic, as they become more soluble and bioavailable. HM pollution assessment results revealed that the values were considered low, with values ranging from 0 to 0.33 with an average value of 0.07. Metal pollution index (MPI) results showed that the groundwater sample was very pure. Nemerow Pollution Index (PNI) results revealed that the groundwater samples were heavily polluted. Results from the modified degree of contamination (MCd), showed that the majority of the samples had a very low degree of contamination. The pollution load index (PLI) results indicated that the entire samples were polluted. Quantification of contamination (QoC) results showed a geogenic impact on the samples. Based on the findings, monitoring groundwater quality and using appropriate treatment technologies to purify the water before consumption are recommended.

Keywords Heavy metals · Contamination · Groundwater · Pollution · And index

Abbreviations

MPI	Metal pollution index
PN	Nemerow pollution
mCd	Modified degree of contamination
Ti	Toxic response coefficient of HM
P.I	Single pollution index
HM	Heavy metal

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Introduction

Though water is necessary for human survival, demand for it grows in perfect agreement with population expansion. Cities and towns, like Port Harcourt, have been seriously undergoing urbanization in recent years. The majority of solid waste disposal sites in Port Harcourt are still open dumpsites (Fig. 1a, b). The quality of water resources is jeopardized by solid waste disposal. Leachate is a waste product that forms as landfills decompose (Africa et al. 2020; Akakuru et al. 2023a, b). 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, and this has led to the occurrence of heavy metals in groundwater across most urban areas. Therefore

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Fig. 1 **a** Solid waste dumpsite within the study area. **b** Solid waste site close to a pond within the study area

there is an urgent need to evaluate the presence of heavy metals in groundwater within the area of the study. More so, leachate originates from local dumpsites and this major threat occurs in areas close to landfills (open dumpsites). The influence of landfill leachate/heavy metals on groundwater has recently become a topic of concern for scholars all over the world (Eyankware 2019). Similarly, rapid urbanization has resulted in garbage generation, which is typically dumped in open areas near human settlements, with little regard for the impact on the environment, health, or water supplies. Due to its favorable economics, unclean landfilling (open dumpsite) has been described by several experts as one of the most popular waste disposal strategies (Africa et al. 2020; Eyankware and Ephraim 2021).

This method of waste disposal has had an impact on the research area's freshwater bodies. According to Ojiambo et al. (2001), Alexakis et al. (2011), and Kazi et al. (2009), the chemical composition of freshwater bodies is solely dependent on numerous sources of influx (2009). Groundwater quality and chemistry are affected by several things. According to several authors, heavy metals are capable of entering natural streams as a result of mineral deposit–water interactions, metal waste dumping, mining, sewage sludge, and the overuse of chemical fertilizers and pesticides (Minhaz et al. 2018). These sources include precipitations and discharges derived from areas dominated by anthropogenic activities, rivers, surface runoff, and groundwater discharges. All types of pollutants are transported through water bodies, thereby contaminating water resources. Contamination of water, particularly heavy metal (HM) contamination, has been shown to shorten human life expectancy (Eyankware and Obasi 2021). According to Oves et al. (2012), HMs are defined as any metallic element with a relatively high density, which includes metals and metalloids with atomic densities larger than 5gcm-3. According to multiple studies completed over the last 8 years by various scholars, heavy metals from geogenic and human sources were ubiquitous and persistent in the study area (Eyankware et al. 2020a; Igwe et al. 2021; Eyankware and Akakuru 2022).

Liu et al. (2016) and Yang et al. (2019) were of the view that HM buildup in water and soil over time has resulted in severe global pollution due to its toxicity, biological enrichment by the food chain in aquatic settings, and non-biodegradable nature. Most HMs discharged into water bodies could precipitate and accumulate in sediment over time. When water fluctuation occurs, these sediments may become a source of pollution by releasing heavy metals into the overlying water, according to Fang et al. (2019), Hwang et al. (2019), Zhao et al. (2018), and Deng et al. (2020). Several factors influence the chemistry and quality of groundwater. According to several authors, heavy metals are likely to enter natural streams as a result of mineral deposit–water interactions, metal waste dumping, mining activities, sewage sludge, and misuse of chemical fertilizers and pesticides (Igwe et al. 2022; Minhaz, et al. 2018). According to Eyankware and Obasi (2021), heavy metals occur naturally in water; however, the majority of HM occurrences are caused by human activity. The amounts of heavy metals in water can be measured to determine contamination (Senarathne and Pathiratne 2007). Namaghi et al. (2011) acknowledge that HM poisoning of water has recently become one of humanity's key worries, especially within areas close to the coastline of Nigeria (Akakuru et al. 2021a, b; Eyankware et al. 2022a, b; Agidi et al. 2022). The amounts of heavy metals in water can be examined (Senarathne and Pathiratne 2007). Namaghi et al. (2011) state that HM poisoning of water has recently become one of humanity's major worries. When consumed in large quantities, these necessary elements can be harmful (Ellias 2009). They are, nevertheless, considered to have a high level of biological toxicity and are hazardous to human health. According to Elliot et al. (2001) and Flieder and Poon (2000), HM exposure to neighboring residents can result in stillbirths, low birth weight, congenital malformations, cancer, and other public health issues. From the aforementioned literature, it was observed that anthropogenic activities have seriously altered groundwater quality via the infiltration process. Hence, according to Nwankwoala et al. (2016), constant assessment of groundwater quality is necessary because most people rely on it. Continuous groundwater monitoring is essential in Port Harcourt City due to the presence of industry and urbanization. Because of the foregoing, it is critical to assess the impact of heavy metals in groundwater to determine their toxicity level. It is important to note that several authors have worked on the assessment of heavy metals in groundwater within the locality, but none has integrated GIS in the assessment of pollution indices. The study aims at applying the spatial distribution model and heavy metal indices in the assessment of groundwater resources in the coastal aquifer of the Niger Delta Region of Nigeria. Specifically, the study assessed heavy metal distribution, evaluated pollution levels using pollution indices, calculated the relationship existing between the heavy metals, and finally quantified the contamination within the study area. This study is of fundamental importance, as water management still relies heavily on groundwater quality assessment, since anthropogenic activities like industrial and agricultural processes can have a negative effect on groundwater quality.

Study area

The study area is in Port Harcourt, River State, Nigeria, and is situated between latitudes 4°47/N–5°04/N and longitude 6°41/N–6°59/E, as shown in Fig. 2. As illustrated in Fig. 2, the research area comprises a network of major and small roads.

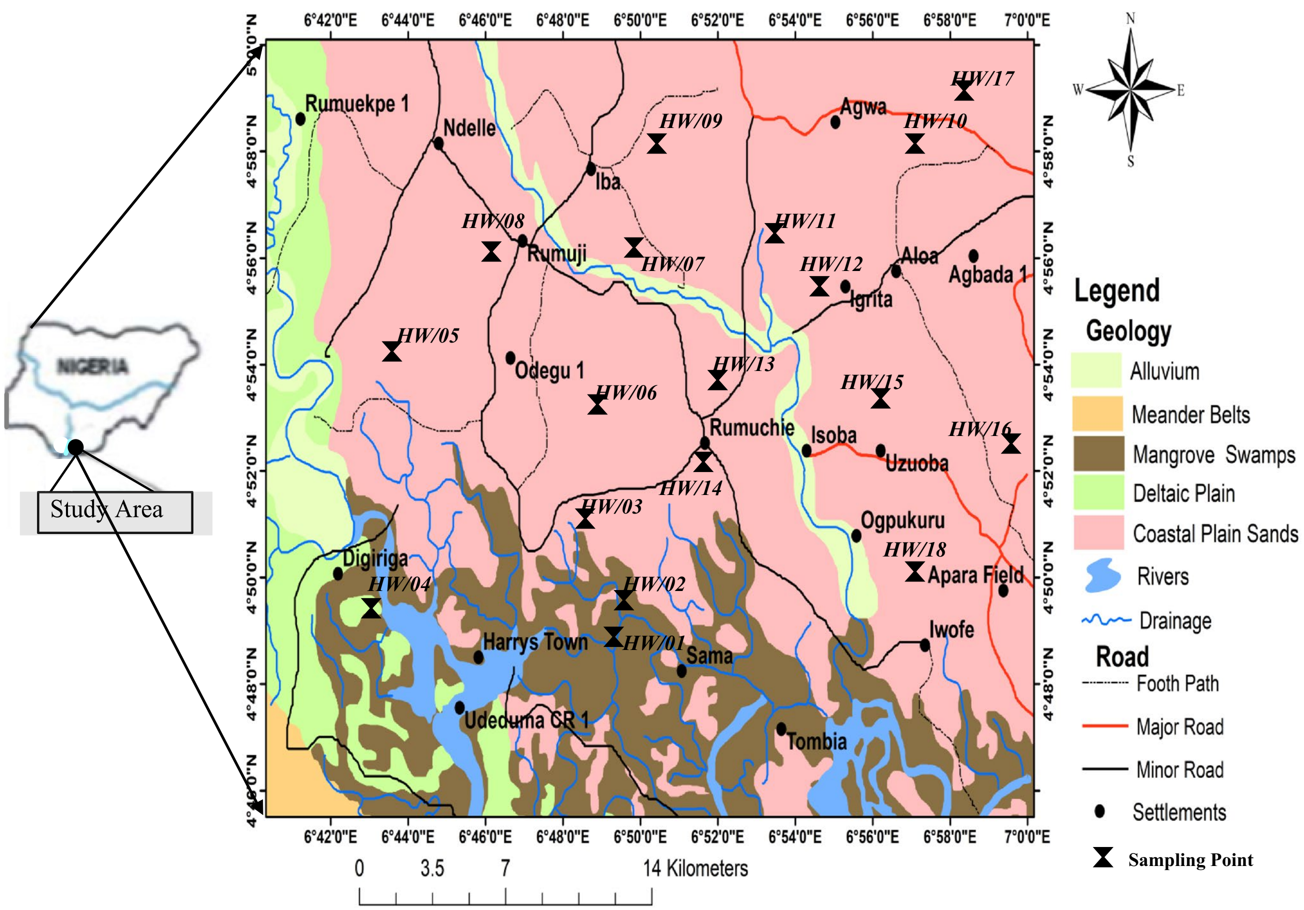

Fig. 2 The study area's geology and sampling points are depicted on a map

Geology/hydrogeology

A large saline/brackish mangrove swamp belt separates the study region from the sea, particularly along the coast (Oteri and Atolagbe 2003). The saline mangrove swamp and its associated sandy islands and barrier ridges along the coast are the only places with salinity-related water supply difficulties. Short and Stauble (1967) divided the Niger Delta Formation into three groups: Akata, Agbada, and Benin (Fig. 1). In the delta, the Benin Formation is a system of several aquifers made up primarily of huge, extremely porous sands and gravels with thin shale/clay interbeds. Although numerous boreholes into the Benin Formation aquifers have been drilled with encouraging results, many of them have been abandoned because of excessive salinity (Oteri and Atolagbe 2003). According to Weber and Daukoru (1976), the Benin Formation, which was created during the Niger Delta's continental period, has a sediment thickness of roughly 2100 m. According to Onyeagocha (1980), the Benin Formation is largely made up of sandstone, sands, and gravel, with clays appearing in lenses. Sands and sandstones are fine to coarse grained, partially unconsolidated, and of varying thickness. The Benin Formation is mostly made up of high-resilience fresh water-bearing continental sand and gravel with intercalations of clay and shale (Oteri 1990). In the Niger Delta Basin, which is made up of large, porous sands and gravels, there is a multi-aquifer system. In the unconfined aquifer of the coastal beach ridges, a freshwater lens overlays seawater. In most confined aquifers within the study region, fresh water is underlain by salt water. With salt water-bearing sands overlying fresh water-bearing sands in specific zones of the Niger Delta, saltwater intrusion into limited aquifers has occurred. Salt water-bearing sands are then laid on top of these Oteri and Atolagbe (2003). The Niger Delta also experiences saltwater intrusion into both unconfined and confined aquifers. Freshwater lens float above the salt water-bearing sands that are present in the unconfined aquifers of coastal beach ridges or sandy islands within the saline mangrove belt (Oteri 1990). Based on the depth of occurrence of saline water sands, the Benin Formation's confined aquifers were further divided into two major areas: areas where freshwater sands are encountered at shallow depths underlain by saline water sands, and areas where saline water sands are encountered at shallow depths underlain successively by freshwater sands and saline water sands (Oteri and Atolagbe 2003).

Methods and materials

Laboratory analysis

After collection, the samples were housed in polypropylene beakers for examination. The sample beakers/containers to be utilized were well cleansed and immersed in distilled water acidified with 1.0 ml of HNO3 for three (3) days before the field sampling exercise. A total of 18 water samples were gathered systematically from various water sources across the country. To obtain a representative sample that genuinely represents the water resources, borehole samples were collected after 5–10 min of pumping. After rinsing the bottle with the aliquot, each sample was filtered into a sample bottle using disposable filters with a diameter of 0.45 m to ensure that all suspended pollutants were removed completely. To minimize HM precipitation, the samples were acidified in the field with 1.0 ml of conc. HNO3; to avoid sorption, new syringes were used to add the three drops of HNO3. At a temperature of 4 °C, the obtained samples were appropriately stored in ice-packed beakers that were tightly sealed. While in transit to the analytical laboratory, the temperature was kept constant to prevent evaporation (Singh et al. 2005; Sehgal et al. 2012). The samples were chemically analyzed using a fast sequential (FS) (Varian 240 AA) atomic absorption spectrophotometer for heavy metals Fe, Cu, Co, Br, Mn, Zn, Cr, Ni, and Pb (AAS). Even though the temperature of each sample was taken with a potable thermometer, the pH values were obtained using a portable pH meter (WGS 84) with temperature electrode accessories. All data collection and analysis were done following APHA guidelines (1995, 2012).

Metal pollution index (MPI)

The combined effect of individual heavy metals on water quality was calculated using MPI equation (Horton 1965; Eyankware and Akakuru 2022a) and evaluated using Caeiro et al. (2005) as shown in Eq. 1:

$$MPI = \sqrt[n]{M_1 \times M_2 \times M_3} \ldots \mathrm{Mn} \tag{1}$$

where Mn = concentration of the metal.

Nemerow pollution index (NPI)

NPI $\left(PI_{Nemerow}\right)$ assesses the total degree of soil pollution and takes into account the contents of all heavy metals tested (Gong et al. 2008; Cheng, et al. 2007). It is calculated with the following formula:

$$PI_{nemerow} = \sqrt{\frac{\left(\frac{1}{n}\sum_{i=1}^{n} PI\right)^2 PI_{\max}^2}{n}}, \tag{2}$$

where PI represents the calculated single pollution index values, PI max represents the highest value for the single pollution index of all heavy metals, and n represents the number of heavy metals.

Modified degree of contamination (mC_d)

According to Abrahim and Parker (2008), the Hakanson (1980) equation for determining the overall degree of contamination for a given sample or coring site is as follows: (i) the degree of contamination is defined as the sum of all contamination factors for a given set of estuarine pollutants divided by the number of analyzed pollutants; (ii) the mean concentration of a pollutant element is determined from at least three samples; and (iii) the baseline concentrations are calculated using the modified formula for standard earth materials. Equation 3 is a modified equation for estimating the degree of contamination using an extended process.

$$mC_d = \frac{\sum_{i=1}^{i=n} C_f^i}{n}, \tag{3}$$

where n is the number of elements examined and C_f^i denotes the contamination factor. The use of this broad and vague formula to determine the mC_d allows the study to include as many metals as it wants with no upper restriction.

Pollution load index (PLI)

Hakanson's (1980) and Eyankware and Akakuru (2022) formula was used to calculate the PLI.

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

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

Quantification of contamination (QoC)

QoC is a pollution assessment technique used to determine the source of a pollutant (geogenic or anthropogenic).

It was determined by using Eq. 5:

$$\frac{C_n - B_n}{C_n} \times \frac{100}{1}, \tag{5}$$

where QoC denotes the contamination index, Cn denotes the metal concentration in the sample, and Bn denotes the background metal concentration.

Contamination factor (CF)

The CF was calculated using the Hakanson (1980) formula

$$\text{CF} = \frac{C_n}{B_n}, \tag{6}$$

where Cn represents the metal concentration and Bn represents the background/target value (Eyankware and Akakuru 2022).

The concentration configuration and dispersion trend in the area were modeled using Microsoft Excel and Surfer 12 software. The Statistical Package for Social Science (SPSS) version 23 was used to calculate Pearson's correlation coefficient.

Potential ecological risk index (ERI)

ERI was first proposed by Hakanson (1980).

$$E_r^i = C_f^i * T_r^i = T_r^i * {C_i}/{C_b}, \tag{7}$$

where E_r^i represents the ERI of themetal; T_r^i is the ith metal response factor to toxicity. The C_f^i is the contamination factor.Ci represents the metal concentration and Cb represents the background/target value.

$$RI = \sum_i^n E_r^i. \tag{8}$$

Result and discussion

Tables 1, 2, 3, 4, 5, 6, 7 show the results of HMs concentrations in groundwater samples.

Assessment of heavy metals in the groundwater used for drinking purpose

pH

As indicated in Fig. 2a, the pH of the analyzed groundwater samples ranged from 4.5 to 7.4, with an average value of 6.0. From Fig. 2a, it was noticed that the pH values were slightly acidic (above 7) around Agwa, Rumuchie, Aloa community, Iba, Agbada, Igrita, and some selected parts of Apara Field, Iwofe, and Digiriga, representing sites HW/01, 02, 03, 04, 05, 06, 07, 08, 10, 11, 12, 14, 15, and 16, while basic groundwater was found at sample locations HW/09, 13, and 17. According to the World Health Organization (WHO), the acceptable pH range for residential use water is 6.5–8.5. The research area's groundwater was found to be acidic to basic, as shown in Table 1. According to Eyankware et al. (2018, 2022a), biogeochemical reactions are prone to pH fluctuations, even though pH has no direct impact on human health.

Electrical conductivity (EC)

As indicated in Table 1, the EC value for this study ranges from 109 to 723 µS/cm, see Fig. 3b. From Fig. 2b, it was noticed that a high EC value was observed around Rumuji

Table 1 The result of the study area's groundwater

Sample code	Co-ordinate		Name of sampling points	pH	TDS (mg/L)	Ec (µS/cm)	Pb (mg/L)	Cr (mg/L)	Cu (mg/L)	Zn (mg/L)	Co (mg/L)	Fe (mg/L)	Mn (mg/L)	Br (mg/L)	Ni (mg/L)	Cd (mg/L)
	Latitude	Longitude														
HW/01	4°48′12″N	6°51′09″E	Sama	5.75	17.4	184.3	BDL	0.04	0.65	0.06	0.02	1.72	0.01	1.65	0.04	0.35
HW/02	4°48′48″N	6°50′03″E	Around Harry's town	4.90	173.3	355.2	BDL	0.01	0.43	1.73	0.01	0.05	0.05	2.05	0.16	0.59
HW/03	4°50′33″N	6°47′11″E	Close to Rumuchie	6.35	203.4	163.2	BDL	0.03	1.01	0.94	0.04	1.65	0.38	1.08	1.03	0.64
HW/04	4°51′02″N	6°47′51″E	Digiriga	6.44	132.8	193.8	BDL	0.11	0.83	0.27	0.01	0.08	0.53	4.74	0.93	0.37
HW /05	4°45′22″N	6°44′21″E	Close to Odegu	4.71	152.3	273.1	BDL	0.10	0.27	1.13	0.20	0.32	BDL	0.78	1.35	1.04
HW /06	4°53′50″N	6°48′12″E	Close to Odegu	5.28	98.2	109.0	BDL	0.03	0.35	0.28	0.13	1.39	1.28	2.54	1.07	0.57
HW/07	4°45′22″N	6°47′13″E	Close to Rumuji	6.36	104.2	487.9	BDL	0.02	0.46	0.74	0.28	0.21	0.35	0.75	0.53	0.91
HW/08	4°56′02″N	6°46′20″E	Rumuji	5.85	292.4	723.0	BDL	0.01	0.27	2.55	0.13	0.37	0.23	3.53	0.85	0.48
HW/09	4°48′12″N	6°50′17″E	Close to Iba	7.39	53.7	361.6	BDL	0.03	0.19	0.04	0.02	0.44	1.38	4.11	1.36	0.52
HW/10	4°58′02″N	6°55′48″E	Close to Agwa	6.89	62.9	285.2	BDL	0.02	0.12	1.01	0.02	1.49	1.93	2.43	1.42	1.34
HW/11	4°56′11″N	6°53′19″E	Iboa	5.25	107.4	482.7	BDL	0.30	0.18	1.49	0.18	0.38	BDL	3.64	0.91	0.91
HW /12	4°56′24″N	6°55′17″E	Igrita	6.31	301.3	691.3	BDL	0.13	0.28	0.11	0.12	0.89	0.26	4.32	0.84	1.02
HW/13	4°53′33″N	6°53′20″E	Close to Rumuchie	7.4°	176.7	543.1	BDL	0.39	0.39	1.44	0.21	1.42	0.34	6.59	1.35	0.57
HW/14	4°52′02″N	6°53′01″E	Rumuchie	6.42	281.2	602.3	BDL	0.53	0.71	0.31	0.24	0.92	0.17	2.44	0.96	0.86
HW/15	4°50′49″N	6°55′48″E	Isoba	5.38	66.7	519.8	BDL	0.22	0.32	1.44	0.10	1.38	0.23	1.59	1.84	1.95
HW/16	4°52′12″N	6°57′05″E	Close to Uzuoba	4.58	92.9	429.3	BDL	0.03	0.14	1.21	0.17	0.69	BDL	1.96	0.47	0.84
HW/17	4°48′23″N	6°58′03″E	Close to Agwa	7.39	183.2	397.2	BDL	0.23	0.22	0.93	0.37	2.01	1.62	2.28	1.32	0.46
HW/18	4°49′47″N	6°57′01″E	Close to Ogpukuru	6.45	109.5	184.8	BDL	0.40	0.16	0.45	0.28	1.95	0.18	4.01	1.26	1.38
Min				**4.58**	**17.4**	**109**		**0.01**	**0.12**	**0.04**	**0.01**	**0.05**	**0.01**	**0.75**	**0.04**	**0.35**
Max				**7.4**	**301.3**	**723**		**0.53**	**1.01**	**2.55**	**0.37**	**2.01**	**1.93**	**6.59**	**1.84**	**1.95**
Ave				**6.05**	**146.41**	**390.94**		**0.15**	**0.40**	**0.93**	**0.14**	**0.97**	**0.59**	**2.89**	**0.97**	**0.85**
Std. dev.				**0.90**	**83.43**	**185.78**		**0.16**	**0.25**	**0.68**	**0.11**	**0.67**	**0.62**	**1.55**	**0.46**	**0.42**

Bold indicates Minimum, Maximum, Average, and Standard deviation

BDL below detection limit

Table 2 The statistical results of HMs in analyzed groundwater compared to drinking water standards are summarized (WHO 2011; NSDWQ 2007)

Parameters	Range of analyzed parameters	Min	Max	Average	NSDWQ, 2007	WHO, 2011
pH	4.58–7.4	4.58	7.4	6.05	6.5–8.5	6.5–8.5
TDS	17.4–301.3	17.4	301.3	146.41	500	500
Ec	109–723	109	723	390.94	1000	1000
Pb	BDL	BDL	BDL	BDL		0.01
Cr^{3+}	0.01–0.53	0.01	0.53	0.15	0.05	0.05
Cu	0.12–1.01	0.12	1.01	0.40	1	1
Zn	0.04–2.55	0.04	2.55	0.93	3	3
Co	0.01–0.37	0.01	0.37	0.14	–	–
Fe^{2+}	0.05–2.01	0.05	2.01	0.97	0.3	0.3
Mn	0.01–1.93	0.01	1.93	0.59	–	0.1
Br	0.75–6.59	0.75	6.59	2.89	–	NFL
Ni	0.04–1.85	0.04	1.85	0.97	–	–
Cd^{2+}	0.35–1.95	0.35	1.95	0.85	0.003	0.003

NFL no fixed limit

Table 3 Principal component values of analyzed heavy metals in sampled groundwater

Parameters		Component			
	Communalities	1	2	3	4
pH	0.805	**0.657**	− 0.14	**0.549**	− 0.23
TDS	0.723	0.107	**0.826**	0.172	− 0.02
Ec	0.829	0.3	**0.802**	− 0.19	− 0.244
Cr	0.868	**0.66**	0.326	0.194	**0.537**
Cu	0.709	**− 0.559**	0.114	0.4	**0.473**
Zn	0.601	− 0.006	**0.486**	**− 0.509**	− 0.325
Co	0.585	**0.634**	0.268	0.061	0.327
Fe	0.673	**0.491**	**− 0.43**	− 0.046	0.495
Mn	0.8	0.373	**− 0.64**	0.066	**− 0.496**
Br	0.604	**0.427**	0.249	**0.485**	− 0.353
Ni	0.729	**0.787**	− 0.226	− 0.215	− 0.113
Cd	0.797	**0.415**	− 0.083	**− 0.742**	0.26
	Eigenvalues	**4.286**	**1.552**	**0.225**	**0.311**
	Variance (%)	**13.69534**	**20.78284**	**15.10718**	**13.8677**
	Cumulative var. (%)	**13.695**	**34.478**	**49.585**	**63.453**

Bold indicates loading

and Igrita areas with values of 292.4 and 619.3 µS/cm, respectively. Nwamkwoala et al. (2014) and Eyankware et al. (2022b), who worked in the Port Harcourt coastal aquifer, reported that the EC value was below the WHO (2011) permissible limit. Groundwater is deemed appropriate for home and industrial use based on the results of EC values. The interaction of groundwater with dissolved inorganic elements can be attributed to high EC concentrations within the aforementioned sites, according to Eyankware et al. (2016).

Total dissolved solids (TDS)

TDS concentrations varied from 17.4 to 301.3 mg/L in this study. TDS concentrations were found to be below the WHO (2011) and NSDWQ (2007) acceptable limits as shown in Table 2. The variance in TDS geology and human activities within the research area was reported by Eyankware et al. (2022a). TDS concentrations were found to be particularly high around Rumuji, Ndelle, and Igrita, as seen in the spatial distribution map in Fig. 3c. The elevated concentration is likely due to wastewater

Table 4 shows the Pearson's correlation coefficients (*r*) for several HMs in groundwater samples evaluated in the research area

	pH	TDS	Ec	Cr	Cu	Zn	Co	Fe	Mn	Br	Ni	Cd
pH	1											
TDS	.110	1										
Ec	.084	.591*	1									
Cr	.280	.264	.271	1								
Cu	.084	.205	− .265	− .004	1							
Zn	− .317	.248	.418*	− .086	− .254	1						
Co	.153	.249	.285	.561*	− .307	.072	1					
Fe	.371	− .151	− .298	.301	− .004	− .239	.235	1				
Mn	.476*	− .312	− .276	− .243	− .439*	− .165	.017	.231	1			
B	.485*	.207	.250	.398	− .155	− .045	− .023	− .008	.000	1		
Ni	.377	− .032	.033	.355	− .279	.042	.203	.327	.471*	.213	1	
Cd	− .185	− .178	.150	.262	− .373	.107	.136	.191	− .044	− .215	.518*	1

*Weak correlation

**Strong correlation

Table 5 CF, PLI, PNI, and mCd of analyzed HMs in groundwater

Name of locations	Contamination factor									PLI	PNI	mCd
	Cr	Cu	Zn	Co	Fe	Mn	Br	Ni	Cd			
Sama	0.0004	0.018056	0.000429	0.000588	43	0.000118	0.0165	0.000286	0.4375	1.38E−10	30.78	2.17
Around Harry's town	0.0001	0.011944	0.012357	0.000294	1.25	0.000588	0.0205	0.001143	0.7375	2.35E−10	0.91	0.10
Close to Rumuchie	0.0003	0.028056	0.006714	0.001176	41.25	0.004471	0.0108	0.007357	0.8	2.79E−08	29.54	2.10
Digiriga	0.0011	0.023056	0.001929	0.000294	2	0.006235	0.0474	0.006643	0.4625	5.11E−09	1.44	0.12
Close to Odegu	0.001	0.0075	0.008071	0.005882	8	–	0.0078	0.009643	1.3	0	5.77	0.46
Close to Odegu	0.0003	0.009722	0.002	0.003824	34.75	0.015059	0.0254	0.007643	0.7125	4.02E−08	24.88	1.77
Close to Rumuji	0.0002	0.012778	0.005286	0.008235	5.25	0.004118	0.0075	0.003786	1.1375	8.81E−09	3.78	0.32
Rumuji	0.0001	0.0075	0.018214	0.003824	9.25	0.002706	0.0353	0.006071	0.6	1.30E−08	6.63	0.49
Close to Iba	0.0003	0.005278	0.000286	0.000588	11	0.016235	0.0411	0.009714	0.65	3.51E−09	7.88	0.58
Close to Agwa	0.0002	0.003333	0.007214	0.000588	37.25	0.022706	0.0243	0.010143	1.675	3.14E−08	26.69	1.94
Iboa	0.003	0.005	0.010643	0.005294	9.5	–	0.0364	0.0065	1.1375	0	6.84	0.53
Igrita	0.0013	0.007778	0.000786	0.003529	22.25	0.003059	0.0432	0.006	1.275	2.51E−08	15.94	1.17
Close to Rumuchie	0.0039	0.010833	0.010286	0.006176	35.5	0.004	0.0659	0.009643	0.7125	4.15E−07	25.42	1.81
Rumuchie	0.0053	0.019722	0.002214	0.007059	23	0.002	0.0244	0.006857	1.075	1.16E−07	16.48	1.20
Isoba	0.0022	0.008889	0.010286	0.002941	34.5	0.002706	0.0159	0.013143	2.4375	1.68E−07	24.73	1.84
Close to Uzuoba	0.0003	0.003889	0.008643	0.005	17.25	0	0.0196	0.003357	1.05	0	12.36	0.91
Close to Agwa	0.0023	0.006111	0.006643	0.010882	50.25	0.019059	0.0228	0.009429	0.575	3.47E−07	35.97	2.54
Close to Ogpukuru	0.004	0.004444	0.003214	0.008235	48.75	0.002118	0.0401	0.009	1.725	1.74E−07	34.92	2.52

Table 6 Nemerow Pollution Index classification

Pollution rank	Pollution index	Pollution level
I	$P \leq 0.7$	Clean
II	$0.7 < P \leq 1.0$	Slightly clean
III	$1.0 < P \leq 2.0$	Slightly polluted
IV	$2.0 < P \leq 3.0$	Moderately polluted
V	$P > 3.0$	Heavy pollution

discharge near the aforementioned locations (Eyankware et al. 2021b; Eyankware et al. 2020b).

Iron (Fe^{2+})

Fe concentrations range between 0.05 and 2.01 mg/L. From Fig. 3d, it was observed that a high concentration of Fe was observed around Apara Field, Agwa, Iwofe, Agbada,

Table 7 Status of modified degree of contamination mC_d in water (Hakanson 1980)

S/No	mC_d class	Modified degree of contamination	Percentage sample
1	mC_d<1.5	Nil to very low degree of contamination	
2	1.5 ≤ mC_d<2	Low degree of contamination	
3	2 ≤ mC_d<4	Moderate degree of contamination	
4	4 ≤ mC_d<8	High degree of contamination	
5	8 ≤ mC_d<16	Very high degree of contamination	
6	16 ≤ mC_d<32	Extremely high degree of contamination	
7	mC_d≥32	Ultrahigh degree of contamination	

Rumuchie, Ogpukuru, Sama, and Tombia. Results obtained from Table 2 suggest that the concentration of Fe was above that recommended by WHO (2011) and NSDWQ (2007) except for sample locations HW/02 and 07. Natural deposits, industrial wastes, iron ore refining, and corrosion of iron-containing metals all have the potential to release Fe into the water, resulting in a high concentration of Fe in the water. A mixture of naturally occurring organic material and iron is found in shallow wells and surface water (Eyankware et al. 2022a).

Chromium (Cr^{3+})

Cr values in groundwater in the study area range between 0.01 and 0.52 mg/L, as shown in Table 2. Groundwater at sampling locations HW/02, 07, 08, 10, and 16 were found to be safe to drink, according to Table 2, because they were under the WHO and NSDWQ's set limits. While groundwater at sample locations HW/01, 03, 04, 05, 06, 09, 11, 12, 13, 14, 15, 17, and 18. Similarly, it was that high concentrations of Cr were observed around Rumuchie, AparaField, Isoba, Igrita, and Iwola. Although industrial effluent, agricultural runoff, and sewage discharge are the principal sources of chromium in groundwater, small levels of Cr can be found in ultramafic and basic rocks and soils (Dixit and Tiwari 2008). The high Cr concentration, according to Mahapatra et al. (2020), indicates a hexavalent form of Cr, which has a variety of health implications in humans, including mutagenic and carcinogenic risks.

Copper (Cu)

Table 2 reveals that the Cu concentration in groundwater was within WHO's (2011) and NSDWQ's (2007) acceptable limits. Cu concentrations were found in high concentrations at Digiriga, Harry's Town, Udeduma, and Sama, as shown in Fig. 3f. Cu levels in the research region are likely to be high due to wastewater discharge and other anthropogenic activities very close to Rumuchiearea (majorly manufacturing). In the same vein, Cu pollution in water may be caused by a surge in industrial and residential trash (Zahir and Mohamed 2013; Kannan and Mani 2015). Mining, farming, manufacturing, and municipal or industrial wastewater discharges into rivers and lakes can all cause Cu contamination (Eyankware and Akakuru 2022). Cu can infiltrate the drinking water by direct pollution of well water or corrosion of copper pipes if the water is acidic. Pipe corrosion is by far the most important threat. Cu values ranged from 0.12 to1.01 mg/L in this investigation, with an average of 0.40 mg/L.

Boron (B)

B concentrations ranged from 0.75 to 6.59 mg/L with an average value of 2.89 mg/L as shown in Table 1. A high concentration of B was observed around Rumuchie, Igrita, Apara Field, Iwofe, and Rumuji as shown in Fig. 3g, although B finds its way into the groundwater via geogenic and anthropogenic sources. Further findings from Table 2 reveal that there is no fixed limit for the excess concentration of B in groundwater. More so, chemical weathering of rocks, soil erosion, and air depositions are only a few examples of natural processes that can deposit heavy metals into water resources.

Cadmium (Cd^{2+})

Cd concentrations range from 0.35 to 1.95 mg/L in this study, with an average of 0.85 mg/L. In the locations near Apara Field, Iwofe, Ogpukuru, Uzuoba, and Isoba, there was a high concentration of Cd, as shown in Fig. 3h. The high levels of Cd can be directly traced to both geological (rock weathering) and anthropogenic (solid waste, fertilizer application, and sewage sludge) sources. Tables 1 and 2 reveal that Cd concentrations were above the WHO (2011) and NSDWQ (2007) limits from sample locations HW/01 to HW/18. In humans, persistent Cd exposure causes a wide range of acute and chronic effects. Cadmium builds up in the human body, particularly in the kidneys.

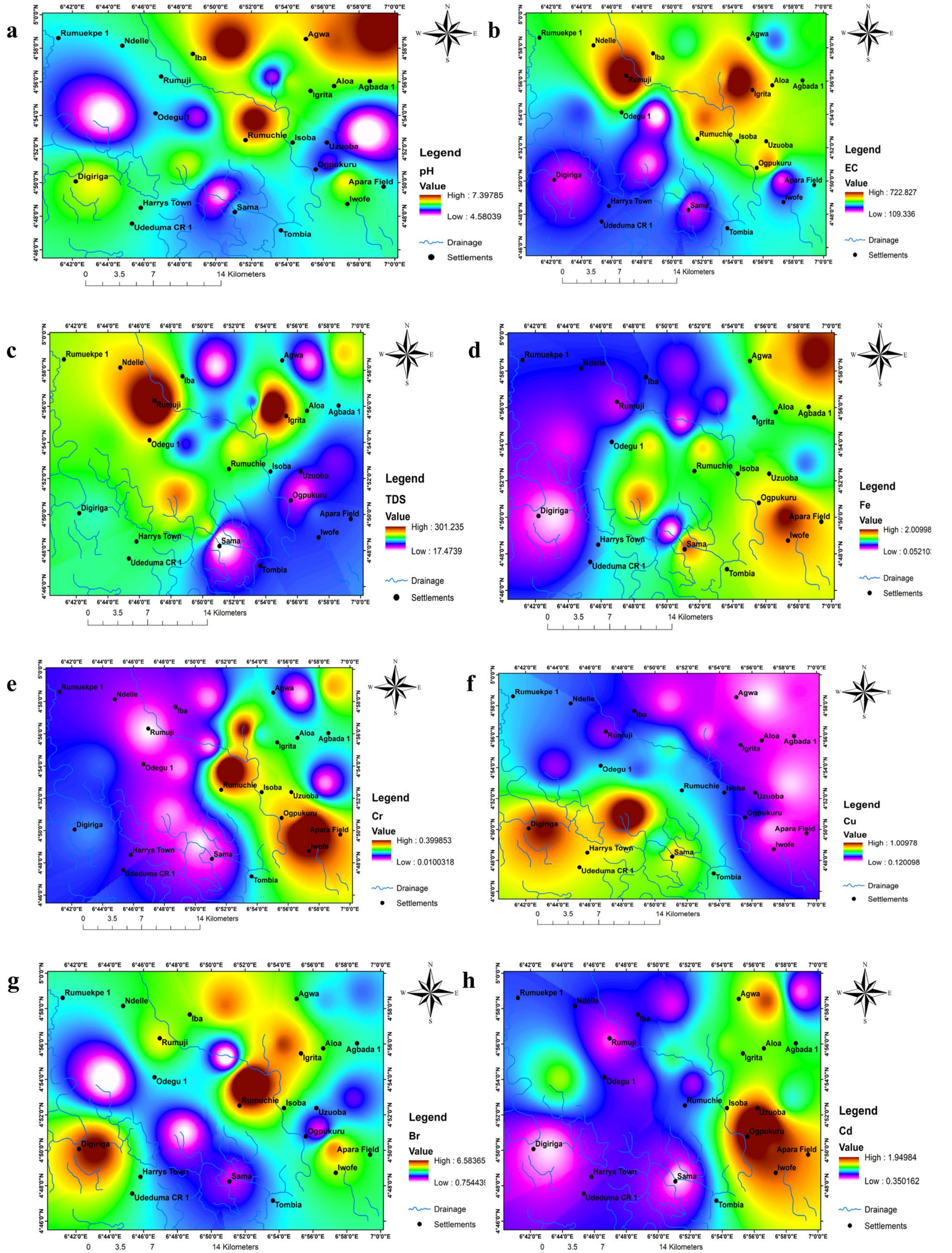

Fig. 3 **a**–**j** Spatial distribution map of pH, EC, TDS, Fe, Cr, Cu, Br, Cd, Mn, and Ni, respectively

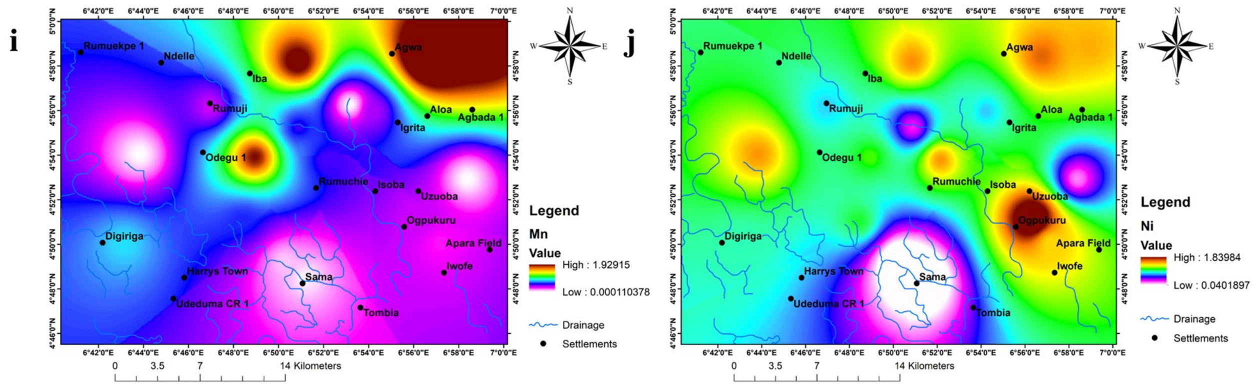

Fig. 3 (continued)

Manganese (Mn)

The concentrations of Mn range from 0.01 to 1.93 mg/L, with an average value of 0.59 mg/L, as shown in Table 1. Although there is no set limit for Mn in groundwater by WHO, the set limit for Mn in groundwater according to NSDWQ (2007) is 0.1 mg/L. Further findings from Table 2 suggest that the concentration of Mn at sample locations HW/03, 04, 06, 07, 08, 09, 10, 12, 13, 14, 15, and 17 was above the set limit by NSDWQ (2007). This implies groundwater at the aforementioned sampling points is to be considered unsafe for drinking. Infants and toddlers who drink manganese-rich water for an extended period may experience memory, attention, and motor ability impairments. If babies under the age of 1 year drink manganese-rich water, they may develop learning and behavior problems (Eyankware et al. 2022a).

Nickel (Ni)

The concentration of Ni in this study ranged from 0.04 to 1.84 mg/L, with an average value of 0.97 mg/L, as shown in Tables 1 and 2. There is likely no set limit for Ni in groundwater. WHO (2019) states that the toxicity information for water-soluble Ni salts is the most useful for determining the health concerns of Ni exposure in drinking water. After acute Ni exposure, humans have gastrointestinal and neurological symptoms, and Ni sensitization can occur through skin or inhalation. A high concentration of Ni was observed around Ogpukuru, Apara Field, Iwofe, and Uzuoba as shown in Fig. 3j.

Multivariate statistical analysis for identification of pollution source

Principal component analysis (PCA)

PCA has been an important statistical approach for determining the relationship between many processes that impact water quality (Subba Rao et al. 2007). PCA is a technique for lowering the dimensionality of such datasets while minimizing information loss and boosting interpretability (Akakuru et al 2023a). It explains the link between the factors to identify the most likely sources of groundwater contamination. There were four significant principal components discovered. In the analysis interpretation, all loadings greater than 0.4 (+ or −) are considered significant contributors. From the result, as presented in Table 8, in principal component 1(PC1), 66.7% had loadings (pH, Cr, Cu, Co, Fe, Br, Ni, Cd), representing the influence of heavy metals on groundwater chemistry and geochemical interactions. For PC 2, 41.7% of the variables had loading (TDS, Ec, Zn, Fe, Mn), signifying the influence of physical and heavy metal pollutants on groundwater geochemistry. Also due to dissolved ions in the groundwater, PC3 had 47.7% of the variables with loadings (pH, Cu, Zn, Br, Cd). This further shows the influence of heavy metals on groundwater chemistry and the interaction that exist between pH and other heavy metals. PC 4 had 33.3% loadings (Cr, Cu, Fe, Mn). This component significantly shows the interactions of heavy metals in groundwater. It

Table 8 MPI of analyzed HMs in groundwater

Sample locations	Cr	Cu	Zn	Co	Fe	Mn	Br	Ni	Cd	MPI
Sama	0.04	0.65	0.06	0.02	1.72	0.01	1.65	0.04	0.35	0.000111
Around Harry's town	0.01	0.43	1.73	0.01	0.05	0.05	2.05	0.16	0.59	0.00019
Close to Rumuchie	0.03	1.01	0.94	0.04	1.65	0.38	1.08	1.03	0.64	0.022551
Digiriga	0.11	0.83	0.27	0.01	0.08	0.53	4.74	0.93	0.37	0.004129
Close to Odegu	0.1	0.27	1.13	0.2	0.32	–	0.78	1.35	1.04	0
Close to Odegu	0.03	0.35	0.28	0.13	1.39	1.28	2.54	1.07	0.57	0.032457
Close to Rumuji	0.02	0.46	0.74	0.28	0.21	0.35	0.75	0.53	0.91	0.007119
Rumuji	0.01	0.27	2.55	0.13	0.37	0.23	3.53	0.85	0.48	0.010474
Close to Iba	0.03	0.19	0.04	0.02	0.44	1.38	4.11	1.36	0.52	0.002837
Close to Agwa	0.02	0.12	1.01	0.02	1.49	1.93	2.43	1.42	1.34	0.025389
Iboa	0.3	0.18	1.49	0.18	0.38	–	3.64	0.91	0.91	0
Igrita	0.13	0.28	0.11	0.12	0.89	0.26	4.32	0.84	1.02	0.020286
Close to Rumuchie	0.39	0.39	1.44	0.21	1.42	0.34	6.59	1.35	0.57	0.335572
Rumuchie	0.53	0.71	0.31	0.24	0.92	0.17	2.44	0.96	0.86	0.093919
Isoba	0.22	0.32	1.44	0.1	1.38	0.23	1.59	1.84	1.95	0.135486
Close to Uzuoba	0.03	0.14	1.21	0.17	0.69	–	1.96	0.47	0.84	0
Close to Agwa	0.23	0.22	0.93	0.37	2.01	1.62	2.28	1.32	0.46	0.28016
Close to Ogpukuru	0.4	0.16	0.45	0.28	1.95	0.18	4.01	1.26	1.38	0.140484
Min.	**0.01**	**0.12**	**0.04**	**0.01**	**0.05**	**0.01**	**0.75**	**0.04**	**0.35**	**0**
Max.	**0.53**	**1.01**	**2.55**	**0.37**	**2.01**	**1.93**	**6.59**	**1.84**	**1.95**	**0.335572**
Average	**0.13**	**0.20**	**0.55**	**0.09**	**0.59**	**0.51**	**1.26**	**0.35**	**0.32**	**0.140484**

Bold indicates Minimum, Maximum, and Average

is important to note that a positive coefficient indicates that the variable is positively correlated with the new variable, while a negative coefficient indicates a negative correlation. According to Kaiser's model, also known as the eigenvalue-one measure, which is one of the most widely used guidelines for dealing with the quantity of parts issue in PCA (Akakuru et al. 2021a; Agidi et al. 2022), any part with an eigenvalue greater than 1.00 should be held and deciphered. It is important to note that from the result, the component loadings tell us how much of the variation in a variable is explained by the component. The loading that each variable in the original data contributes to the principal components enables the grouping of data with similar behaviors. Values below the detection limit were replaced by half of the method detection limits for the statistical analysis (Akakuru et al 2023b). This is because each of the elements they discovered adds one unit of variation to the overall diversity in the data collection. Anthropogenic sources could be said to be the principal cause of these loadings. Furthermore, pH and concentration parameters in the formation of complex compounds affect the mobility of heavy metals in the groundwater. At low pH, heavy metals will be released and thus the mobility will increase in the area.

As a result, every portion with an eigenvalue greater than 1.00 is assumed to be responsible for a greater measure of variety than one variable. A trademark with an eigenvalue under 1.00, on the other hand, is liable for a lot of variation and should be held, whereas a part with an eigenvalue under 1.00 is liable for less variation than is supplied by one variable. Nonetheless, the fundamental point of PCA is to reduce the number of noticed factors to a generally smaller number of parts without jeopardizing the true translation of the information being referred to; thus, holding parts that record less fluctuation than individual factors contributes defeats the purpose of PCA. As a result, components with eigenvalues less than 1.00 are regarded as insignificant and are not retained (Subba Rao et al. 2007). The results of this study can be attributed to geogenic processes such as weathering and redox reactions (Akakuru et al. 2021b; Yahaya et al. 2021; Agidi et al. 2022).

Correlation matrix

In statistics, we are often interested in understanding the relationship between two variables. For example, we might want to understand the relationship between the number of hours a student studies and the examination score received.

One way to quantify this relationship is to use the Pearson correlation coefficient, which is a measure of the linear association between two variables. It has a value between -1 and 1, where -1 indicates a perfect negative linear correlation between two variables, 0 indicates no linear correlation between two variables, and 1 indicates a perfectly positive linear correlation between two variables. The correlation matrix examination is a reliable tool for determining the relationship and origin of hydrogeochemical boundaries in groundwater quality assessment (Akakuru et al. 2021a; Agidi et al 2022; Eyankware et al. 2022a, b, c; Akakuru et al 2023a, b). The further away the correlation coefficient from zero, the stronger is the relationship between the two variables. The points are considered to be uncorrelated if the value is zero. The correlation matrix (Table 4) showed that there was a positive correlation between pH and Mn (0.475) and B (0.485) at low pH, the solubility of metals tends to be high, and chemicals such as cyanide and sulfide become more toxic. Acidic waters also corrode metal pipes. As a result, heavy metals in low-pH water, such as TDS and Ec (0.591), become more toxic as they become more soluble and bioavailable. Because TDS measurement is time-consuming, it is often estimated from electrical conductivity (EC) assuming dissolved solids are predominantly ionic species of low enough concentration to yield a linear TDS–EC relationship: Ec and Zn (0.418). Chemical analysis of precipitation water and groundwater of shallow circulation zone indicated precipitation as the main contemporary source of copper and zinc in the investigated environment. Cr and Co (0.561); Cu and Mn (− 0.439); the negative value implies that copper and Mn are related in a negative sense; Mn and Ni (0.471); Ni and Cd (0.518). A closer observation in Table 4 shows that the majority of the values are negatively correlated. A negative correlation is a relationship between two variables such that as the value of one variable increases, the other decreases. Correlation is expressed in a range from + 1 to − 1, known as the correlation coefficient. It is important to note that the percolating water picks up a large number of heavy metals and reaches the aquifer system and contaminates the groundwater. The usage of contaminated bore water causes diseases. From Table 8, there exists a weak and positive correlation among elements. Toxic metals in groundwater affect water quality and its potability, and their presence in aquatic systems also facilitates the production of reactive oxygen species that can damage physiological processes in fishes and other aquatic organisms. This also suggests that salt water was not a substantial source of groundwater recharge in the study area (Eyankware et al. 2021a, b; Agidi et al. 2022; Akakuru et al. 2023a, b).

Heavy metal pollution assessment

HM pollution has become a significant environmental issue. This is because drinking water that has been contaminated with heavy metals has an adverse impact. The HM evaluation index is used for a straightforward understanding of the pollution index and the amount of pollution (Edet and Ofong 2002; Prasanna et al. 2012).

Nemerow pollution index (PNI)

PNI (Nemerow 1974) is another numerical index that incorporates multiple factors into a single factor. The NPI value, on the other hand, represents the combined water quality level of various pollution parameters. In terms of empirical validity, using an integrated water quality index to evaluate an intrinsic groundwater risk assessment is preferable to merely examining the concentrations of one or two specific contaminants (Kowalska et al. 2018; Kong et al. 2019). The PNI calculates the relative pollution contribution of each parameter in a water sample. The parameter(s) responsible for the quality status will be identified in this manner.

PNI value of ≤ 0.7 indicates that the water is clean, PNI value of $0.7 < PNI \leq 1.0$ implies slightly clean, PNI value of $1.0 < PNI \leq 2.0$ implies slightly polluted, and PNI value of $2.0 < PNI \leq 3.0$ implies moderately polluted, while PNI value of > 3.0 implies heavy pollution (Table 6). The results in Table 5 show that 5.6% of the entire sample had a value < 1, indicating that the sample is slightly clean, 5.6% of the entire sample had a value < 2, indicating that the sample is slightly polluted, 88.8% of the entire samples had values > 3, implying that the samples are heavily polluted. A close look at Fig. 4 a shows that PNI in the study area flows from the north towards the south with varying flows within the area. Anthropogenic factors could be responsible for the high levels of pollution seen in this study. This finding contradicts a study conducted in Nigeria by Egbueri and Mgbenu (2020).

Modified degree of contamination (mCd)

As a result, the computed Cd is equal to the sum of the Cf of five pollutant samples Hakanson (1980). Cd is used to determine the overall level of contamination in surface layers at a given sampling location. The Hakanson classification terminologies and calculation formulas, on the other hand, are based on and limited to the seven metals plus PCB listed in Hakanson's study. In addition, to calculate the correct Cd for the range of classes defined, all five species must be analyzed, making this index more difficult to use.

Because of the constraints of estimating Cd, the following modified and generalized equation was developed for computing the overall degree of contamination at a specific sample or coring site: (1) the modified formula is generalized by defining the degree of contamination (mCd) as the total of all contamination factors (Cf) for a particular set of pollutants divided by the number of analyzing pollutants; (2) a pollutant element's mean concentration is calculated using at least three samples of impacted soils or water (taken from

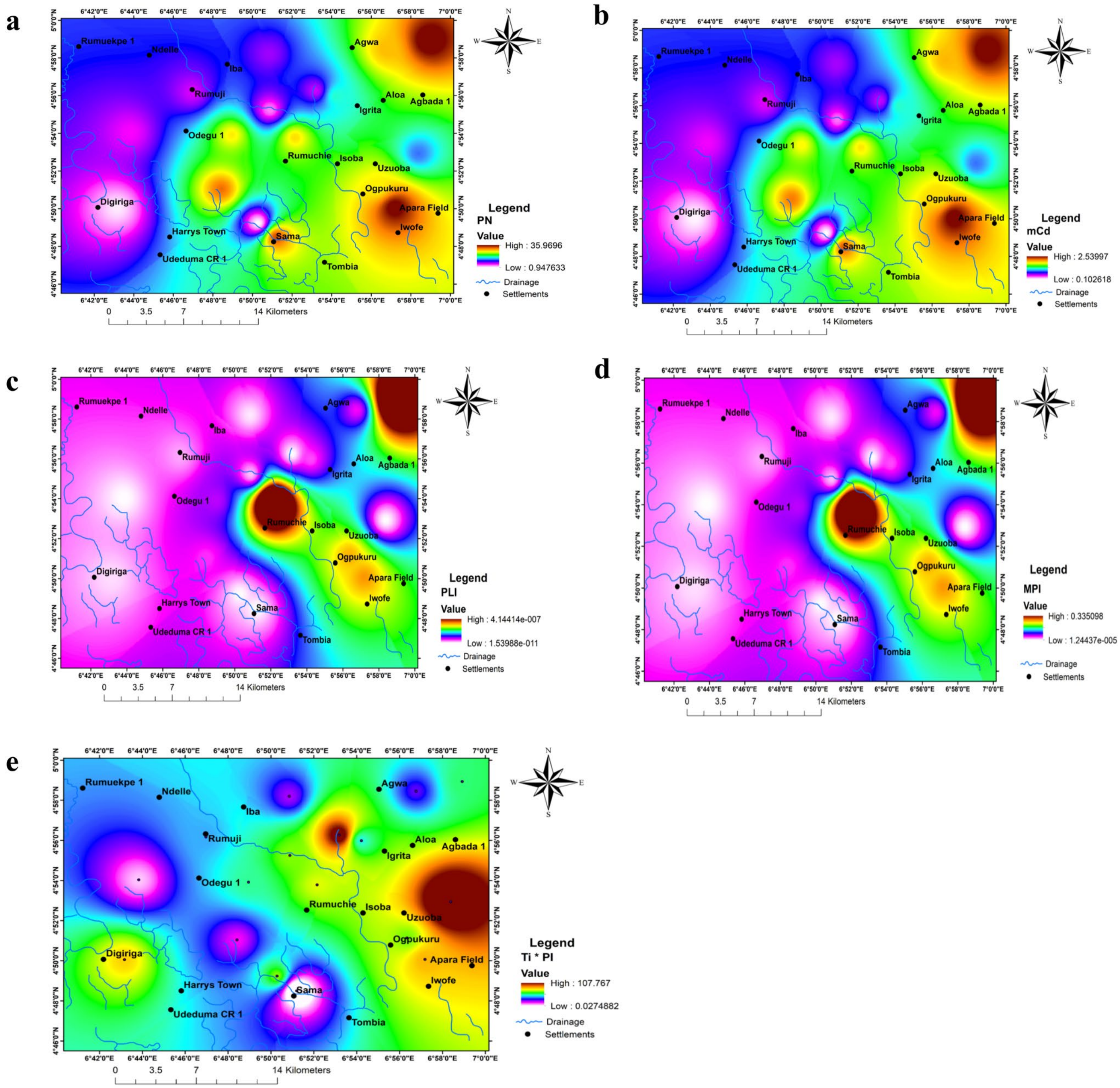

Fig. 4 **a**–**d** Spatial distribution of map of MPI, PN, MCd, and PLI. **e** Spatial distribution of map of ERI

the associated surficial soils); (3) lower core concentrations or similar surrounding uncontaminated soils and water are used to establish the baseline concentrations.

Classification and description of the modified degree of contamination (mCd): $mCd < 1.5$ is a very low degree of contamination, $1.5 \leq mCd < 2$ a low degree of contamination, $2 \leq mCd < 4$ a moderate degree of contamination, $4 \leq mCd < 8$ high degree of contamination, $8 \leq mCd < 16$ a very high degree of contamination, $16 \leq mCd < 32$ an extremely high degree of contamination, and $mCd > 32$ an ultrahigh degree of contamination (Table 7). According to the mCd results in Table. 5, 44.5% of samples have a very low degree of contamination, 33.3% have a low degree of contamination, and 22.2% have a moderate degree of contamination. It is important to note that Fig. 4 b, shows the spatial distribution of mCd in the area and that the Cd values flow from the north toward the south.

Pollution load index (PLI)

PLI has proven to be a useful method for evaluating the amount of toxicity in groundwater samples that have been contaminated (Akakuru et al. 2021b; Agidi et al. 2022; Eyankware and Akakuru 2022). PLI is typically classified as having no pollution (PLI < 1), moderate pollution (1 < PLI < 2), heavy pollution (2 < PLI < 3), or extremely heavy pollution (3 > PLI). According to the results in Tables 2 and 5, 100% of the groundwater has a concentration value of less than one, indicating that there is no contamination. Anthropogenic activities are a primary contributor to a high PLI in a given area. Figure 4 c shows the spatial distribution of PLI in the study area. It shows that the flow of PLI is from the north toward the center of the area. The PLI's findings imply that anthropogenic activities in the area have no direct connection to the available groundwater. This work is comparable to the findings of a separate study in Nigeria (Akakuru et al. 2021a; Agidi et al. 2022), but it is not similar to the research conducted by Yahaya et al. (2021) in Nigeria.

Metal pollution index (MPI)

In the classification of groundwater, MPI has proven to be a useful technique. Very pure water has an MPI of 0.3 or less, while pure water has an MPI of 0.3–1.0. Those with an MPI of 1.0–2.0 are classed as seriously affected in Class III, whereas those with an MPI of 1.0–2.0 are classified as slightly afflicted in Class IV and moderately affected with an MPI of 2.0–4.0. According to Ogunkunle et al. (2015) and Singovszka et al. (2017), water samples with MPI between 4.0 and 6.0 are classed as considerably affected in Class V, while those with MPI > 6.0 are classified as badly affected in Class VI (2017). The MPI results in Table 8 show that the groundwater sample in the study area has a value of less than 0.3, implying that it is in Class I and hence very clean (Akakuru and Akudinobi 2018; Eyankware et al. 2016, 2017). Figure 4d shows the special distribution of MPI, in which it moves from the northern part of the study area toward the epicenter. This could be attributed to the anthropogenic activities t are done in the area. These activities have ways of affecting the water resources in the area (Akakuru et al 2023a, b).

Quantification of contamination (QoC)

Because heavy metals were identified as substantial pollutants in the study area, it was necessary to utilize the QoC model to investigate HM sources. As a result, in this review, the QoC model was introduced, and the source division completed the PLI model. Table 6 displays the obtained QoC values for each dissected heavy metal. Positive QoC values often indicate manmade influence, whereas negative QoC values indicate geogenic influence. Cr, Cu, Zn, Co, Fe, Mn, B, Ni, and Cd in the study region are all 100% negative, according to the results shown in Table 9. This means that the region's groundwater was contaminated as a result of geogenic activity. However, little is known about the potential geogenic processes that may influence the

Table 9 Quantification of contamination (QoC) of analyzed HMs in groundwater

Name of locations	Cr	Cu	Zn	Co	Fe	Mn	B	Ni	Cd
Sama	− 364.96	− 56.27	− 1483.27	− 699.98	− 54.09	− 4999.99	− 168.05	− 2449.96	− 233.94
Around Harry's town	− 1459.99	− 85.62	− 49.72	− 1399.99	− 1919.95	− 999.95	− 134.54	− 612.34	− 138.39
Close to Rumuchie	− 486.64	− 35.62	− 93.74	− 349.96	− 56.53	− 131.20	− 258.18	− 94.12	− 127.49
Digiriga	− 132.62	− 43.75	− 329.36	− 1399.99	− 1199.92	− 93.81	− 54.33	− 104.45	− 221.25
Close to Odegu	− 145.90	− 136.77	− 77.63	− 69.80	− 299.68	–	− 358.19	− 71.24	− 77.81
Close to Odegu	− 486.64	− 105.36	− 317.58	− 107.56	− 67.67	− 37.78	− 107.70	− 90.52	− 143.29
Close to Rumuji	− 729.98	− 79.97	− 119.53	− 49.72	− 456.93	− 142.51	− 372.58	− 184.38	− 89.20
Rumuji	− 1459.99	− 136.77	− 32.35	− 107.56	− 259.09	− 217.16	− 75.79	− 114.44	− 170.35
Close to Iba	− 486.64	− 194.55	− 2224.96	− 699.98	− 217.74	− 34.85	− 64.02	− 70.70	− 157.17
Close to Agwa	− 729.98	− 308.21	− 87.11	− 699.98	− 62.94	− 23.98	− 112.80	− 67.59	− 59.85
Iboa	− 48.37	− 205.38	− 58.24	− 77.60	− 252.25	–	− 73.28	− 106.78	− 89.20
Igrita	− 112.18	− 131.86	− 808.98	− 116.55	− 106.98	− 192.05	− 60.49	− 115.83	− 79.37
Close to Rumuchie	− 37.05	− 94.48	− 60.37	− 66.46	− 66.19	− 146.72	− 35.90	− 71.24	− 143.29
Rumuchie	− 27.02	− 51.40	− 286.79	− 58.09	− 103.43	− 293.95	− 112.31	− 101.12	− 94.49
Isoba	− 66.14	− 115.31	− 60.37	− 139.90	− 68.19	− 217.16	− 174.51	− 51.42	− 40.10
Close to Uzuoba	− 486.64	− 264.15	− 72.34	− 82.18	− 138.44	–	− 140.90	− 208.04	− 96.78
Close to Agwa	− 63.25	− 167.96	− 94.77	− 37.47	− 45.75	− 29.24	− 120.53	− 72.92	− 177.80
Close to Ogpukuru	− 36.10	− 231.09	− 197.33	− 49.72	− 47.28	− 277.60	− 65.82	− 76.52	− 58.04

progression of these metals in water assets. HM toxicity has been a long-standing and growing environmental problem. Several heavy metals have burdened the soil by geogenic sources such as the leaching and weathering of rocks, as well as anthropogenic activities such as intense metal mining, smelting, burning of fossil fuels, pesticide use, and sewage sludge (Egbueri and Mgbenu 2020; Agidi et al. 2022). When these metals enter the food chain, they not only have a detrimentalal impact on plant development physiology, but also poses a chronic and epidemic health risk to humans. The findings of this study contradict the findings of Egbueri and Mgbenu (2020) in Ojoto, Nigeria.

Potential ecological risk index (ERI)

Swedish scientist Hakanson (1980) created a potential ecological risk index. It reflects the toxicity and ecological susceptibility of pollutant concentrations and has been used to assess the harmful effects of pollutants on the environment and humans (Hakanson 1980; Weihua et al. 2010; Suresh et. al. 2012). Initially, it served as a tool for assessing sediment load in aquatic environments. Soil, dust, and air risk assessments were successfully performed (Riyad et al. 2015; Osipova et al. 2016). ERI values are classified as follows: ERI < 150, low potential ecological risk for the water system; 150 ≤ ERI < 300, moderate potential ecological risk for the water system; 300 ≤ ERI < 600, considerable potential ecological risk for the water system, ERI ≥ 600, very high ecological risk for the water system (Eyankware et al. 2021a, b). From Table 10, the entire groundwater sample is within the low potential risk (ERI < 150). Figure 4e shows the spatial distribution of ERI in the study area. The flow of ERI is from the east toward the west. The implication of this ERI results indicates that the anthropogenic activities within the locality had not much effect on the groundwater resources. Figure 4 shows the spatial distribution of ERI in the study area.

According to Rao and Rao (1991), pH is a critical factor in HM breakdown in groundwater. The processes of ion and HM concentration in groundwater, according to Harichandan et al. (2021) and (Eyankware and Aleke, (2021), include rock alteration, dissolution, mineralization, leaching from rocks, percolation, or seepage from active mines quarry/mine pits via rocks and human activities. The link between groundwater pH and the metal load was estimated to identify the water samples (Ficklin et al. 1992; Caboi et al. 1999; Eyankware et al. 2022a). Figure 5 shows that acid extreme metal and near-neutral high metal are found in 3.66% and 96.34% of the samples, respectively.

Conclusion

Using the HM index and statistical analysis has helped to develop factors influencing the effect of heavy metals on groundwater. The study revealed HM pollution in analyzed water samples. PCA results further showed the influence of heavy metals on groundwater chemistry and

Table 10 Potential ecological risk index of analyzed HMs in groundwater

Ti * PI										$ERI = \sum Ti * PI$
Name of the locations	Cr	Cu	Zn	Co	Fe	Mn	Br	Ni	Cd	
Sama	0.0004	0.09028	0.000429	0.00294	43	0.000118	0.0165	0.00143	13.125	56.23
Around Harry's town	0.0001	0.05972	0.012357	0.00147	1.25	0.000588	0.0205	0.005715	22.125	23.47
Close to Rumuchie	0.0003	0.14028	0.006714	0.00588	41.25	0.004471	0.0108	0.036785	24	65.45
Digiriga	0.0011	0.11528	0.001929	0.00147	2	0.006235	0.0474	0.033215	13.875	16.08
Close to Odegu	0.001	0.0375	0.008071	0.02941	8	–	0.0078	0.048215	39	47.13
Close to Odegu	0.0003	0.04861	0.002	0.01912	34.75	0.015059	0.0254	0.038215	21.375	56.27
Close to Rumuji	0.0002	0.06389	0.005286	0.041175	5.25	0.004118	0.0075	0.01893	34.125	39.51
Rumuji	0.0001	0.0375	0.018214	0.01912	9.25	0.002706	0.0353	0.030355	18	27.39
Close to Iba	0.0003	0.02639	0.000286	0.00294	11	0.016235	0.0411	0.04857	19.5	30.63
Close to Agwa	0.0002	0.016665	0.007214	0.00294	37.25	0.022706	0.0243	0.050715	50.25	87.62
Iboa	0.003	0.025	0.010643	0.02647	9.5	–	0.0364	0.0325	34.125	43.75
Igrita	0.0013	0.03889	0.000786	0.017645	22.25	0.003059	0.0432	0.03	38.25	60.63
Close to Rumuchie	0.0039	0.054165	0.010286	0.03088	35.5	0.004	0.0659	0.048215	21.375	57.09
Rumuchie	0.0053	0.09861	0.002214	0.035295	23	0.002	0.0244	0.034285	32.25	55.45
Isoba	0.0022	0.044445	0.010286	0.014705	34.5	0.002706	0.0159	0.065715	73.125	107.78
Close to Uzuoba	0.0003	0.019445	0.008643	0.025	17.25	0	0.0196	0.016785	31.5	48.83
Close to Agwa	0.0023	0.030555	0.006643	0.05441	50.25	0.019059	0.0228	0.047145	17.25	67.68
Close to Ogpukuru	0.004	0.02222	0.003214	0.041175	48.75	0.002118	0.0401	0.045	51.75	100.65

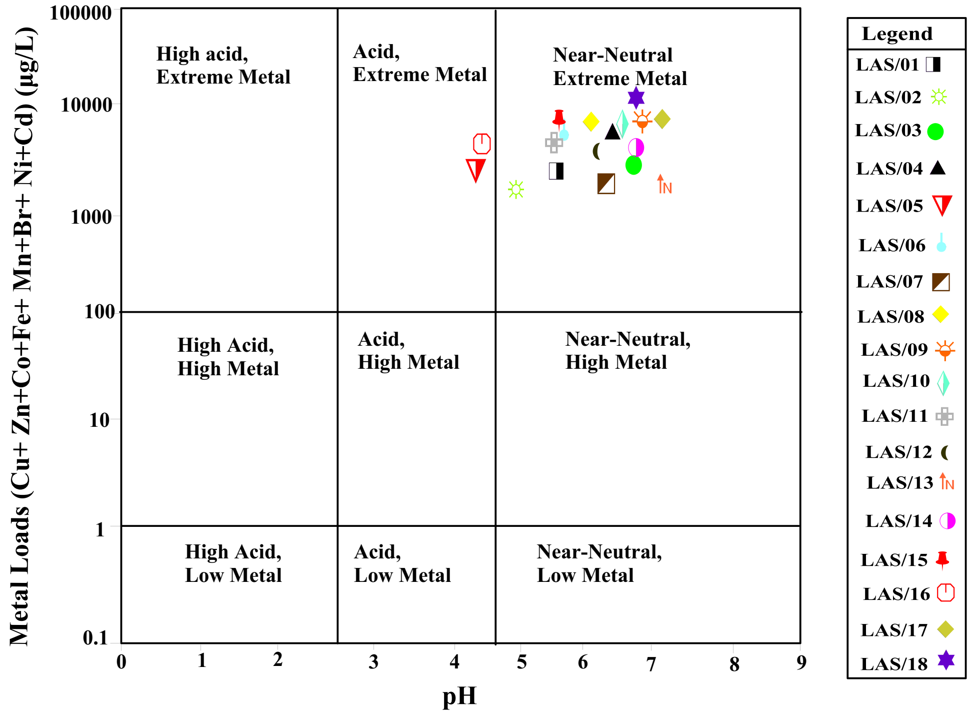

Fig. 5 Classification of groundwater samples (pH versus metal load)

the interaction that exists between pH and other heavy metals. The correlation matrix showed that there were weak relationships between the parameters. The MPI and PLI values showed low pollution and the PNI within the study area showed heavy pollution, while the mCd concentrations showed a moderate degree of pollution. The ERI showed low potential risk and QoC revealed that the geogenic activities contributed to most of the pollution. The findings from this study showed that both geogenic processes and anthropogenic activities were shown to be contributing causes to HM concentrations in groundwater, according to the findings. Furthermore, high concentrations of heavy metals were observed around Rumuche, Rumuji, Apara Field, Igirita, and Ogpukuru, which is highly polluted and can attract anthropogenic activities that may introduce heavy metals into groundwater. Due to the adverse impact on public health, continued exposure to heavy metals will result in serious issues in the future. In the study region, adequate measures for preventing HM toxicity will be developed by monitoring groundwater quality and applying appropriate treatment technologies to treat the water before consumption.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author declares that there is no conflict of interest. Potential conflicts do not exist regarding the work.

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