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ORIGINAL ARTICLE

Hydrogeochemical evolution, water quality indices, irrigation suitability and pollution index of groundwater (PIG) around eastern Niger Delta, Nigeria

O. C. Akakuru[1] · C. U. Eze[1] · O. C. Okeke[1] · A. I. Opara[1] · A. O. Usman[2] · O. Iheme[3] · S. I. Ibeneme[1] · P. O. Iwuoha[1]

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Abstract
The study was done to assess groundwater for different uses. Groundwater samples were collected from 17 locations and analyzed for physicochemical attributes. Hydrogeochemical data identified three significant Principal Components; PC1, 53.8% loadings, PC2, 46.2% loadings, PC3, 30.8% positive loadings. Correlation matrix analysis observed strong correlations in the majority of the parameters. Contamination Factor results reveal that HCO_3, NO_3, Na, Ca, and Mg had relatively low concentration < 1; Fe had a mean concentration of 1.18 (moderate contamination), while SO_4, and Cl, had mean concentrations of 6.43 and 9.41, respectively. PLI result reveals that the samples had values less than 1. WQI result revealed that 11.7% of the samples are excellent, 82.4% of the water is of good quality, 5.9% are of poor quality. PIG result shows insignificant pollution of groundwater. The hydrogeochemical evolution shows Ca + Mg and Cl are the dominant ionic species in the cation and anion areas, respectively; and they are within the geochemical zone of 6 (calcium chloride water type) with a trend of $Cl > SO_4 > Ca > Mg > HCO_3 > Na + K$. From the Gibbs plot, rock-dominance zone is dominant in the groundwater samples. The suitability for irrigation analysis reveals that SAR, %NA, KR, and SSP in the entire study area are 100% suitable and fit for irrigation purposes, while MH had 88.2% of the sample as good and 11.8% as unsafe. The Wilcox plot shows that 70.6% of the entire sample belong to the excellent category whereas, 29.4% are of good to permissible category. Normal observing of groundwater in the review region is of major significance.

Keywords Hydrogeochemical evolution · Pollution index of groundwater (PIG) · Water quality assessment · Irrigation · Groundwater · Suitability

Introduction

Groundwater remains the predominant source of freshwater, which gives water to billions of people throughout the world (Akakuru et al., 2021a; Umar & Igwe, 2019). This has increased the demand for this freshwater resource for domestic, industrial, and agricultural purposes; thus, increasingly made safe and clean water has become of fundamental importance to the development of social and human activities (Eyankware et al., 2020; Urom et al., 2021). Records show that 80% of water supplies for domestic, agriculture and industrial activities come from groundwater resources. This could be as a result it is readily available and its proximity, especially to the final consumers. (Ibe et al., 2020; Obiora et al., 2015).

Due to the increasing demand and overstretching of groundwater, resulting from urbanization, accelerated industrialization and pollution explosion, increased waste generation and discharge, the quality status of groundwater has become of questionable standard; this has indeed made degradation of groundwater quality a global discussion since it has the potential consequences on human existence and wellbeing (Akakuru et al., 2013; Liu et al., 2003; Mosuro et al., 2017).

✉ O. C. Akakuru
obinna.akakuru@futo.edu.ng

[1] Department of Geology, Federal University of Technology, Owerri, Imo State, Nigeria

[2] Department of Physics, Geology and Geophysics, Alex Ekwueme Federal University, Ndufu-Alike, Ikwo, Ebonyi State, Nigeria

[3] Department of Geology, University of Ilorin, Ilorin, Nigeria

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It is worthy to note that groundwater susceptibility to contamination from other sources greatly depends on the porosity, permeability, and overburden thickness of geologic formation (Ibe et al., 2020; Obiora et al., 2015; Opara et al., 2020). The constant overstretching of the aquifer comes in different forms through: leachates movement, saltwater intrusion, dumpsites close to aquifer systems, underground and surface leakages, oil spills, milling of water, leaky petroleum, and septic tanks (Umar & Igwe, 2019; Yahaya et al., 2021). Saltwater intrusion in coastal aquifers is linked to several factors including: hydraulic gradient, groundwater recharge, and discharge rate, and nature of geological formations (Mosuro et al., 2017; Yetiş et al., 2019).

It is imperative to constantly monitor the available groundwater quality around the coastal aquifer since the groundwater is exposed to saline water intrusion. Increased saline water harms animals and plants. Plants cannot survive optimally in a saline environment as they distort the rate at which plants grow (Egbueri, 2019; Eyankware et al., 2020). A plant's ability to absorb nutrients will be drastically affected in any saline water environment; this could be attributed to dissolved solutes and density that are high. The elevated density is usually from the groundwater acidity increase (Akakuru et al., 2017; Eyankware et al., 2021; Yetiş et al., 2019). Assessing, verifying, and certifying water fit for irrigation is of great importance before it could be used for irrigation purposes.

In Nigeria, and indeed most developing countries in the world, irrigation seems to be a modern method adopted in agriculture. It is heartwarming to note that agriculture has become vital in boosting the economy and reducing the over-dependence on petroleum products. Constant monitoring of the available groundwater for irrigation will greatly be appreciated by the farmers in the Niger Delta Region, as availability of groundwater is not the problem, rather its quality. It is also very important to check the groundwater chemistry to ascertain the ionic composition and makeup, thus known the suitability of groundwater recourse for various purposes. So, many hydrogeochemical processes are noticed beneath the surface. They can be rock–water interaction, hydrology, mineral dissolution, and evaporation, which are man-made; and mining, agriculture, industry, and urbanization which are anthropogenic. These hydrogeochemical processes vary temporally and spatially (Das et al., 2018; Paul et al., 2019).

Several authors have assessed groundwater quality by integrating geostatistical and hydrogeochemical approaches; in Palestine, Abu-alnaeem et al. (2018) assessed groundwater salinity and quality in Gaza coastal aquifer, by integrating statistical, geostatistical, and hydrogeochemical approaches; Ben Moussa et al. (2020) evaluated groundwater resources in Tunisia for irrigation suitability purposes in the Mornag region, Tunisia. In the same vein, Ahmad et al. (2020) characterized groundwater and also evaluated the quality status of groundwater for agricultural and domestic usage in Qatar; Mthembu et al., (2020) studied the human health impact of hydrogeochemical and the concentration of trace metals in groundwater around coastal aquifers of South Africa.

Ben Moussa et al. (2020) assessed the hydrogeochemistry of groundwater for water system ease of use in Tunisia; Barzegar et al. (2017) read the confirmations for the event of hydrogeochemical measures in groundwater in Iran; Esimaeli et al. (2018) coordinated multivariate insights and hydrogeochemical demonstrating for the recognizable proof of significant component source in substantial metals in Iran; Papazotos et al. (2019) evaluated the reasonableness of groundwater in Greece by examining the hydrogeochemical viewpoints in seaside springs; Kanagaraj et al. (2018) considered the hydrogeochemical cycles and impact of seawater interruption in waterfront springs in India; Paul et al. (2019) distinguished some hydrogeochemical measures controlling groundwater quality in India utilizing multivariate factual and GIS techniques; Seddique et al. (2019) contemplated the hydrogeochemical and isotopic marks for the ID of seawater interruption in the paleo sea shore spring in Bangladesh; Umarani et al. (2019) surveyed the hydrogeochemical and factual parts of groundwater quality in beach front springs in India.

Locally, some works have been carried out on the coastal aquifers and also on the hydrogeochemical evaluation of groundwater. Nwankwoala and Udom (2011) assessed the hydrogeochemical facies and ionic ratios of groundwater in Port Harcourt; Eyankware et al. (2020) studied the hydrogeochemistry and water quality suitability for irrigation in groundwater within Warri; other studies undertaken within the area show that there exist groundwater pollution (Akakuru et al., 2021a, 2021b; Egbueri, 2019; Ibe et al., 2020; Urom et al., 2021).

Despite these works done within this area, little or no work has been undertaken by integrating geostatistical and hydrogeochemical signatures in assessing the hydrogeochemical evolution, water quality indices and irrigation suitability and Pollution Index of Groundwater (PIG) around Port Harcourt and environs, eastern Niger Delta, as it affects its suitability for irrigation and domestic purposes. This study is of fundamental importance and very useful for managers of groundwater resources as it will serve as a groundwater guide for managers and planners within the area. The end-product of this review will shape the reason for resulting works to investigate the different appropriateness records of groundwater.

Description of the study area

The study area is a blend of the hinterland and coastal towns of Port Harcourt and its environs. Communities of interest for this study include Rumuodara, Rumuokoro, Abuloma, Elelenwo, Rumuokurushi, Mgbuogba, Naval Base Area, etc. (Fig. 1). These are the functional base for a large number of the oil-creating and adjusting organizations in Nigeria. Its populace is assessed to be more than 5,000,000 individuals (NBS, 2017). The consumable water supply in the city is from both the public authority organizations (state public water use board) and people. As urbanization and industrialization keep on expanding, there is a going with expansion in homegrown and modern squanders, expanded development of individual homegrown septic tanks, unpredictable boring of boreholes with its orderly over-deliberation and conceivable saline water, interruption into the groundwater assets (Nwankwoala & Udom, 2011).

Geological setting

The region is essential for the Niger Delta Basin which has an elevated of 75,000 km^2. It has a generally speaking backward exemplary arrangement and is partitioned into three going from Eocene to ongoing age (Short & Stauble, 1967). They incorporate the accompanying: Benin Formation, Agbada Formation, and Akata Formation. The Akata Formation is made fundamentally out of shale kept as turbidity and mainland slant channel fills (Nwankwoala & Udom, 2011). The Agbada development comprises predominantly of sandstone and shale caught by a few development deficiencies and a quickly vertical and horizontal facies change. The Benin Formation of which the review is found is made of permeable sand and rock with restricted shale/earth between beds happening as point bars or channel fills (Akakuru et al., 2021b; Reyment, 1965). They are deposited in continental fluviatile conditions.

The Benin Formation is the most youthful lithostratigraphic unit of the three-sided region of the Niger Delta. The Niger Delta is basically a Paleocene-Recent bowl then, at that point, started progradation during the late Eocene times (Essien & Okon, 2016). The clastic fills of the Niger Delta and other waterfront sedimentary bowls in Nigeria created because of variations among intrusive and backward stages (Essien & Okon, 2016; Ibe et al., 2020).

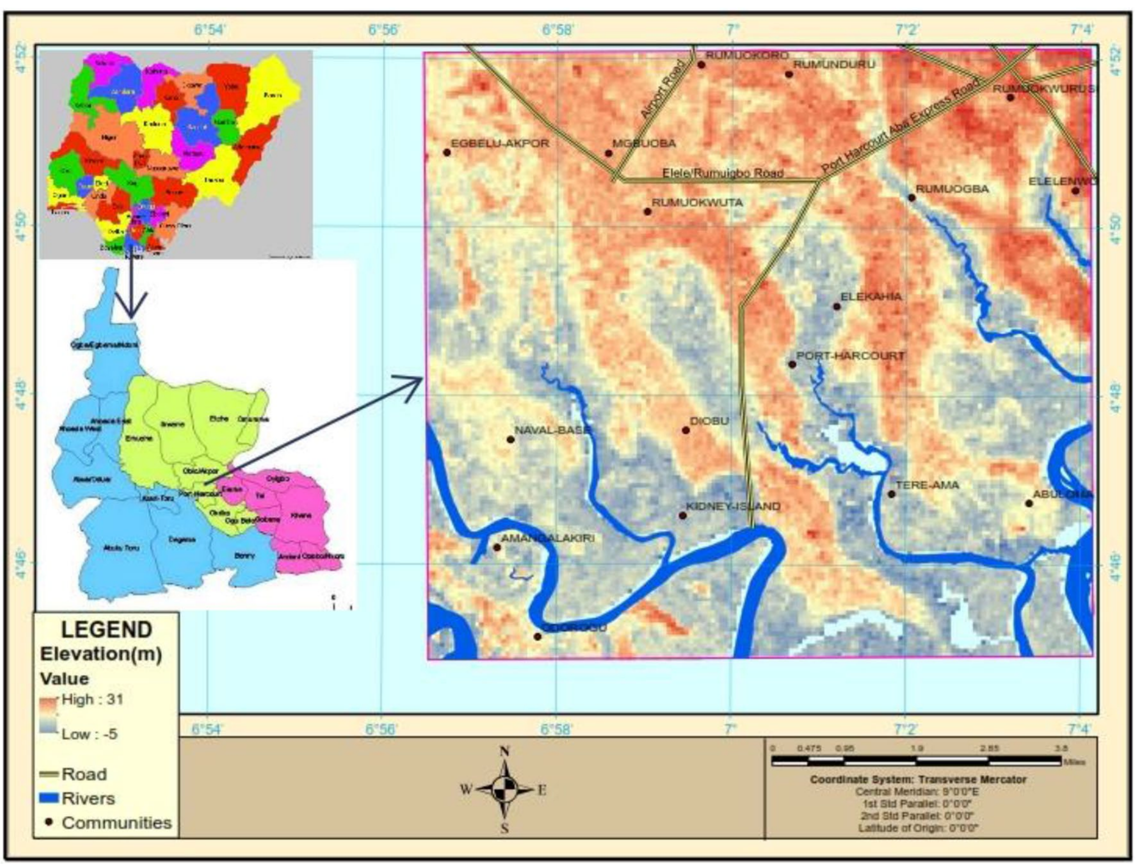


Fig. 1 Location map of the study area

Rivers State is dominated by the Alluvium deposits at the South East, Benin Formation to the North East, Meandering belt along the coastal part at Ogba/ Egbema/Ndoni, and Abua-Odual Local Government. Deltaic Plain falls within the region of Ahoada East and West and parts of Emuohua. However, my research is confined to Alluvium, Benin Formation, and Mangrove Swamps (Fig. 2).

Materials and methods

Water sampling and analysis

Tests from groundwater sources were gathered from boreholes inside the review region between April 2020 and July 2020, covering wet seasons. The wet seasons happen during the long rains of April–May and the short rains of October–December. A total of seventeen (17) boreholes samples at seventeen locations were collected. Sample locations include: Rumuokoro, Rumunduru, Egbelu-Akpor, Mgbuoba, Rumuokuta, Rumuogba, Elelenwo, Elekahia, Port Harcourt, Naval Base, Diobu, Amagalakiri, Kidney Island, Tere-Ama, Abuluoma, Odorogu. Sample were gathered following five minutes the borehole was siphoned to eliminate stale water. Water from the examining borehole was utilized to flush the container multiple times, before the water test assortment. Aligned Aqua Probe A-700 m was utilized to quantify the Electrical Conductivity and pH.The samples collected were acidified using 0.5 mL concentrated nitric acid; this was done to prevent the precipitation of trace elements and cations. All collected samples were transported within the same day for testing. This avoided a change in the quality of collected samples. HCO_3 and CO_3 were analyzed immediately using a standard method of titration. Determination of Sulphate: 100 mL of the example was placed into a 500 mL volumetric flagon and 2 M HCI of 5 mL was added to it. The arrangement bubbled until it got to 50 mL on a hot plate; BaCl2 was added until the accelerates evaporated.

The Nitrate degree not set in stone the utilization of PD303 UV Spectrophotometer, even as the Luton chloride meter changed into used to quantify the Chloride. For deciding Bicarbonate; 100 mL of the water test transformed into filled an Erlenmeyer carafe of 250 mL, then, at that point, it was titrated to an unpracticed bromcresol ($pH = 4.5$) stop-factor in accordance with the technique referenced with the guide of APHA (1998). Table 1 presents the geo-referred to test locale.

Irrigation water quality indicators

Different equations were used in assessing the water quality indices for irrigation purposes as shown in Table 2.

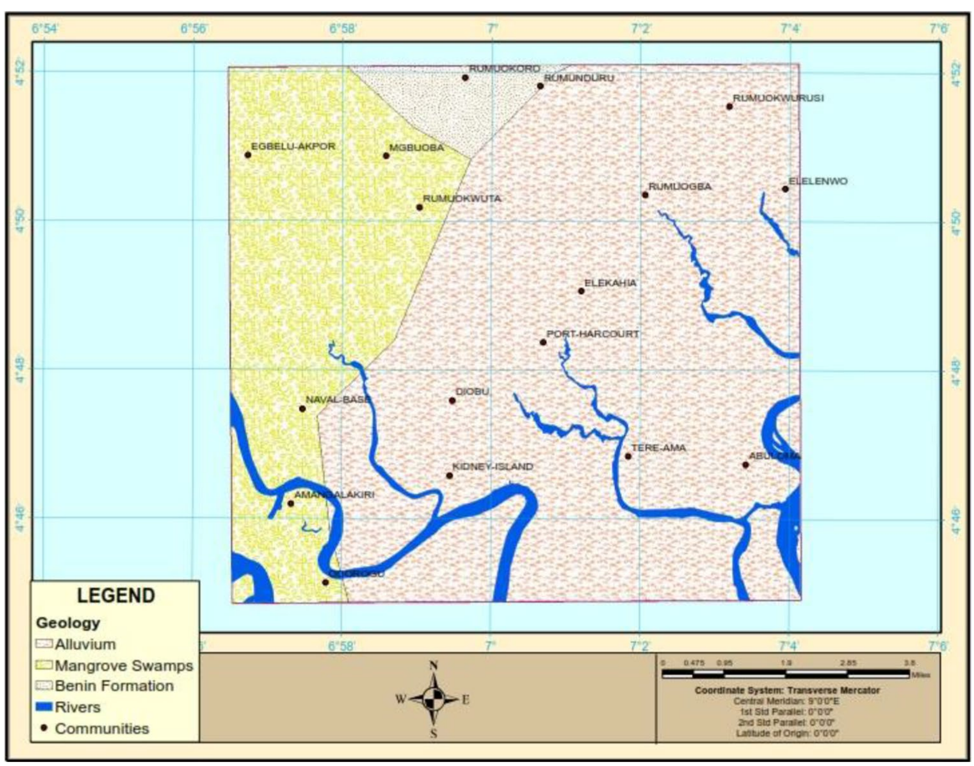


Fig. 2 Geologic map of Port Harcourt and environs (After NGSA, 2006)

Table 1 Sample collection location

S/N	Location	Longitude (East)	Latitude (North)	Elevation (m)
P1	Odorogwu	6.5753	4.4631	31
P2	Amangala Kiri	7.70395	4.5727	29
P3	Kidney Island	7.0052	4.7761	26
P4	Abuloma	7.0329	4.7941	37
P5	Tere-Ama	7.0355	4.783	20
P6	Naval Base	4.8168	6.9821	16.3
P7	Diobu	6.998	4.7863	35
P8	Port Harcourt	7.0201	4.758	30
P9	Elekahia Estate	7.0267	4.8230	42
P10	Rumuokuta	6.9921	4.8406	18.3
P11	Rumuogba	7.0474	4.837	38
P12	Elelewon	7.412	4.8013	41.5
P13	Rumuokwurishi	7.0556	4.8514	40
P14	Egbelu-Akpor	7.2167	5.0167	19
P15	Mgbuoba	6.9692	4.8421	19.4
P16	Rumunduru	7.148	4.5216	22
P17	Rumuokoro	6.9880	4.8651	18.0

Pollution and water quality indices

Contamination factor (CF)

The CF was calculated using the Hakanson (1980) formula

$$CF = \frac{C_n}{B_n}, \tag{8}$$

where C n is the metal concentration, B n is the background/target value (Akakuru et al., 2021b; DPR, 2002; Yahaya et al., 2021).

Pollution load index

The PLI was calculated using the Hakanson (1980) formula

$$PLI = \sqrt[n]{CF1 \times CF2 \times CF3 \times \cdots \times CFn}, \tag{9}$$

where CF = contamination factor; n = element number.

Water quality index (WQI)

The weighted arithmetic index equation changed into used to decide WQI every parameter's satisfactory score scale (q_i) become computed by manner of dividing the pattern attention (C_i) in every groundwater pattern by its respective fashionable (S_i). The end result is then elevated through one hundred (Akakuru & Akudinobi, 2018; Gopinath et al., 2019).

$$q_i = \frac{C_i}{S_i} \times \frac{100}{1}. \tag{10}$$

Relative weight (W_i) was acquired from the contrarily corresponding of the worth to the WHO standard (S_i) of the comparing boundary:

$$W_i = \frac{1}{S_i}, \tag{11}$$

$$WQI = \sum q_i W_i, \tag{12}$$

where q i : ith parameter quality, w i : weight of the unit ith parameter.

Pollution index of groundwater (PIG)

The PIG has been a tool used in the assessment of groundwater quality status for drinking (Subba Rao et al., 2018).

Table 2 Equations used for water quality indices calculation

Water quality indices	Equations	Units	Equation number	References
Sodium absorption ratio (SAR)	$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$	meq/L	1	Sherrard et al. (1987)
Percentage sodium (%Na)	$\%Na^+ = \left[\frac{(Na^+ + K^+)}{Ca^{2+}+Mg^{2+}+Na^+ +K^+}\right] \times 100$	%	2	Kacmaz and Nakoman (2010)
Magnesium hazard	$MH = \left[\frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}}\right] \times 100$	%	3	Szabolcs and Darab (1964)
Kelly's ratio	$KR = \frac{Na^+}{Ca^{2+}+Mg^{2+}}$	meq/L	4	Kelly (1963)
Gibbs Plots	For Cation : $\frac{Na^+ +K}{Na^+ +K +Ca^{2+}}$	meq/L	5	Gibbs (1970)
	For Anion: $\frac{CL^-}{Cl^- +HCO_3^-}$	meq/L	6	
Soluble sodium percentage	$SSP = \frac{(Na^+ +K^+)\times 100}{Ca^{2+}+Mg^{2+}+Na^+ +K^+}$	%	7	Richards (1969)

Five steps must be considered in making use of the PIG. Step I: is the Relative weight (R_w) estimation (on a scale of 1–5), this scale is given based on each element's significance in the assessment of water quality as it relates to human health (Table 8). Step II: is the weight parameter (W_p) determination for each of the groundwater quality variables, this is aimed at ascertaining its relative contribution to the entire groundwater quality status (Eq. 13). Step III: involves the estimation of the status of concentration (S_c) which was derived by dividing each of the water variable content (C) in each of the samples by its respective quality standard limit (Ds) (Eq. 14). This work used WHO (2017) standard in the assessment of the PIG. Step IV: involves the computation of the overall quality of groundwater (Ow) by multiplying the weight parameter (Wp) with the status of concentration (Sc) (Eq. 15). Step V: involves the summation of the entire Ow values per sample (Eq. 16).

$$\mathrm{Wp} = \frac{R_w}{\sum R_w}, \tag{13}$$

$$\mathrm{Sc} = \frac{C}{D_c}, \tag{14}$$

$$\mathrm{Ow} = \mathrm{Wp} * \mathrm{Si}, \tag{15}$$

$$\mathrm{PIG} = \sum O_w. \tag{16}$$

Statistical and hydrogeochemical analyses

The scatter diagrams were plotted with Microsoft Excel software program. The statistical package deal for the social sciences (SPSS) version 17.0 was used to calculate the Pearson's correlation coefficients. Hydrogeochemical evolution plots were done using RockWare Aq.QA model 1.1.1[1.1.5.1], SURFER 15 software was used to draw the Variogram, while ArcGIS 10.8 was used for the Kriging (Geostatistical distribution of the parameters in the study area).

Results and discussion

Groundwater quality assessment

The results of the physicochemical analyses of samples of groundwater are presented in Table 3.

From Table 3, the pH values from Points 1 to 17 were within the range of 5.3–6.4, with an average of 5.8, while 0.3 is the standard deviation. The result indicated that the entire sample in the study area is below the World Health Organization (WHO) Standard for drinking water. This implies that the solutions have a high concentration of hydrogen ions which resulted in the low concentration of pH (Adimalla & Venkatayogi, 2018). The low concentration of bicarbonate ions is also attributed to the low pH of groundwater (Olofinlade et al., 2018). It further depicts the water as slightly acidic (Fig. 3a, b). Groundwater pH measurement contains essential information about the geochemical equilibrium (Ahmad et al., 2020; Mallick et al., 2018).

EC fixation (µS/cm) in the review is between 197.1 and 679.4, with a mean of 382.5 and a standard deviation of 136.6 (Table 3). The qualities fell beneath the adequate furthest reaches of the WHO Standard for drinking water, aside from tests P2 and P6, which had a higher fixation over the suggested standard. This suggests that the groundwater in the review region is marginally saline. EC is an extremely valuable device for arranging groundwater for water system and different purposes. It additionally exhibits the accessibility of anion and cation in groundwater (Akakuru et al., 2021a; Eyankware et al, 2021; Vincy et al., 2015). This finding is reliable with the discoveries of Olofinlade et al. (2018) in southwestern Nigeria. TDS (mg/L) goes from 70 to 1107.2, a mean of 376.3 and standard deviation of 260.6. (Table 3). P4 and P5 are over the WHO guideline and standard, though the rest are inside the suggested range. The TDS in groundwater gives an understanding into the quantity of measure of broke up inorganic salts in a given water (Adimalla & Venkatayogi, 2018; Urom et al., 2021). Geochemical measures and other anthropogenic exercises are significant records that influence the TDS in groundwater (Akakuru et al., 2021a, 2021b; Raju et al., 2011; Yetis et al. 2019). Centralizations of broke down salt in a given volume of water are saltiness.

The qualities for saltiness (mg/L) at Points 1–17 were inside the scope of 112.2–250.4 with a normal of 166.8 and a standard deviation of 39.8 (Table 3). Saltiness is either communicated in grams of salt per kilogram of water, or parts per thousand (ppt, or ‰). Groundwater can likewise become saltier as it goes through salt-bearing beds or layers and gets salts from broke down minerals (Ibe et al., 2020; Olofinlade et al., 2018). Salts in groundwater start either from minute amounts broke down in water, from the substance breakdown of rocks, or direct association with seawater (Eyankware et al., 2020; Vincy et al., 2015).

Inland pungency is similarly caused in light of preparing of surface water framework without considered groundwater status. In the occasion that water has an impactful postponed flavor impression, it is conceivable achieved by a high gathering of chloride particles just as sulfates in the water supply. This is a result of present day squander, water framework drainage, or seawater entering area supplies in the sea shore front swamp spring (Olofinlade et al., 2018).The concentration of HCO_3 (mg/L) at Points 1–17 ranges between 6 and

Table 3 Physicochemical result of groundwater samples in the study area

Sampling community	pH	EC (uS/cm)	TDS (mg/L)	Salinity (mg/L)	HCO_3 (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)
WHO (2017)	6.5–8.5	500	500	600	200	50	250	250	200	200	7.5	50	0.3
P1	5.8	485	477.8	194.3	14.6	0.000649	54	155.5	1.9	0.46	7.4	6.3	0.059
P2	5.5	577.4	251.3	222.9	16.4	0.000456	64.6	154.7	1.8	0.37	6.7	7.2	0.039
P3	5.7	426.9	373.8	179.5	11.1	0.000327	61.3	206.9	1.4	0.47	8.5	5.8	0.042
P4	6.4	305.6	1107.2	146.8	14.9	0.001004	21.8	116.8	2.3	0.6	7.2	3	0.088
P5	6.2	303.9	932.7	138.1	9.3	0.00049	41.7	201.7	1.5	0.56	9.4	3.4	0.057
P6	5.3	679.4	70.6	250.4	19.9	0.000093	73.6	145.5	2.1	0.27	6.1	8.5	0.022
P7	5.5	458.9	195	192.5	10.6	0.000214	68.6	218.9	1.2	0.46	8.4	6.4	0.036
P8	5.9	197.1	207.5	112.2	6.0	0.000281	62.3	287.8	0.8	0.53	11.1	4.4	0.026
P9	5.9	242.6	269	124.2	12.4	0.00067	42.1	179	1.4	0.49	9	3.4	0.034
P10	5.5	487.6	244.7	201	13.5	0.000802	59.5	166.7	1.4	0.45	7.2	6.2	0.048
P11	5.9	238.4	284.3	123	16.1	0.000994	29	118.7	1.7	0.47	7.9	2.6	0.039
P12	6	220.2	359.3	121.1	17.1	0.001144	23.5	103.9	2	0.5	7.5	2.5	0.053
P13	5.6	460.4	275.3	191.8	13.8	0.001274	55.4	157.8	1.5	0.46	7.2	5.8	0.052
P14	5.7	454.7	263.8	187.4	14.2	0.002587	52.8	143	1.6	0.46	7.1	5.9	0.061
P15	6	253.7	385.1	131	16	0.001234	29	118.5	1.9	0.5	7.6	3.1	0.056
P16	5.8	335.9	358.5	154.3	14.3	0.001351	41.6	145.1	1.7	0.49	7.7	4.3	0.055
P17	5.8	375.26	341.5	165.8	14	0.001571	46	149	1.7	0.48	7.5	4.8	0.034
Min	5.3	197.1	70.6	112.2	6.0	0.000093	21.8	103.9	0.8	0.2	6.1	2.5	0.022
Max	6.4	679.4	1107.2	250.4	19.9	0.001571	73.6	287.8	2.3	0.56	11.1	8.5	0.088
Mean	5.8	382.5	376.3	166.8	13.8	0.000891	48.6	162.9	1.6	0.5	7.9	4.9	0.04
Standard dev	0.3	136.6	260.6	39.8	3.2	0.00062	16	45.6	0.4	0.1	1.2	1.8	0.01

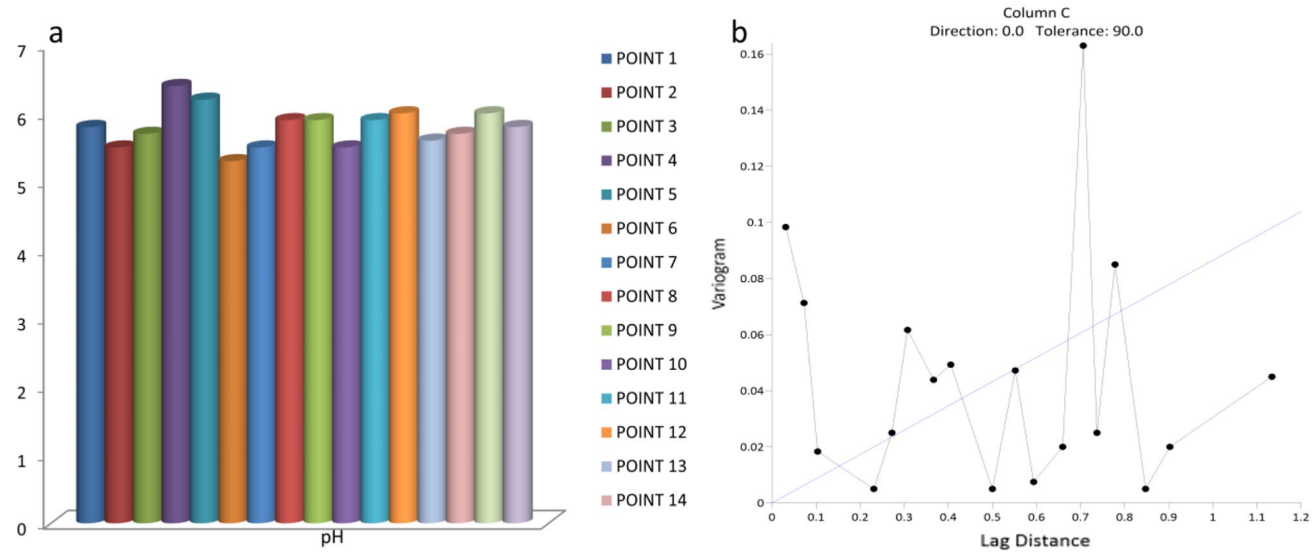


Fig. 3 **a** pH values for borehole water samples from points 1 to 17; **b** variogram of pH in the study area

19.9, with a mean of 13.8, and 3.2 is the standard deviation. The finding reveals that the groundwater samples are within the acceptable limits of the WHO standard (Table 3).

HCO_3 concentration in groundwater is usually linked to carbonate weathering (silicate weathering). If feldspar minerals and carbonic acids react with water, carbonic acid dissolution is formed. Dissolution of minerals results in increased HCO_3 levels in groundwater (Akakuru et al., 2021a, 2021b; Ghalib et al., 2017; Kumar et al., 2012). Figure 4a, b presents the spatial distribution and variogram of EC, TDS, salinity, and HCO_3 in the study area.

The concentration of NO_3 (mg/L) at Points 1–17 ranges between 0.000093 and 0.001274, with an average of 0.000891 and a standard deviation of 0.00062 (Table 3). The values were within acceptable limits. Under natural conditions, the concentration of NO_3 does not go above 10 mg/L (Adimalla & Venkatayogi, 2018). Nitrate high concentration in any groundwater is attributed to leaching from agricultural fertilizers, organic matter effluent, and leaky septic tanks (Kihumba et al., 2016). Nitrate has the most noteworthy entrance profundity into soil skylines and groundwater assets (Adimalla & Venkatayogi, 2018; Subba Rao, 2018).

SO_4 values (mg/L) ranged from 21.8 to 73.6 with a mean of 48.6 and a standard deviation of 16 (Table 3). The whole samples in the review region are within the WHO Standard for drinking water. Akakuru et al. (2017) underlined that high SO4 focus represents a unique issue in the molding of water; it connotes outrageous hardness, high sodium salt fixation, and high sharpness. SO_4 is delivered in groundwater by the sulfide mineral collaboration with water through the oxidation measures (Akakuru et al., 2021a).The values for chloride (mg/L) range between 103.9 and 287.8, with a mean value of 162.9, and 45.6 as its standard deviation (Table 3). P8 value was greater than the permissible limit of the WHO standard for drinking water. The chloride particle is broadly appropriated in nature as sodium (NaCl), potassium (KCl), and calcium salts ($CaCl_2$). Regular and anthropogenic wellsprings of chloride in surface and groundwater incorporate run-off containing street de-icing salts, the utilization of inorganic manures, landfill leachates, septic tank effluents, creature takes care of, water system waste, and seawater interruption in beach front regions (Ahmad et al., 2020; Srinivasa-moorthy et al., 2014).

In the entire locality, Na values (mg/L) ranged between 0.8 tand 1.9, with a mean of 1.6 and a standard deviation of 0.4. (Table 3). These qualities were inside the OK furthest reaches of the WHO Standard. The spatial appropriation of NO_3, SO_4, Cl, and Na are shown in Fig. 5a, while the variogram is shown in Fig. 5b.

Mg and Ca values (mg/L) range from 3 to 8.5 at Points 1–17, while 4.9 is the mean and 1.8 is the standard deviation (Table 3). The results were within acceptable bounds. Magnesium is the fourth most bountiful cation in the body and the second most plentiful cation in intracellular liquid (Olofinlade et al., 2018).

Ca values (mg/L) range from 6.1 to 11.1, 7.9 is the mean, while 1.2 is the standard deviation (Table 3). In the review region, the potassium concentration (mg/L) goes from 0.2 to 0.56, with a mean of 0.5, while 0.1 is the standard deviation. The K qualities are within the WHO regulatory limit. K is a fundamental supplement in people and is seldom, if at any point, found in drinking water at levels that could be hurtful to sound individuals. The day-by-day necessity is

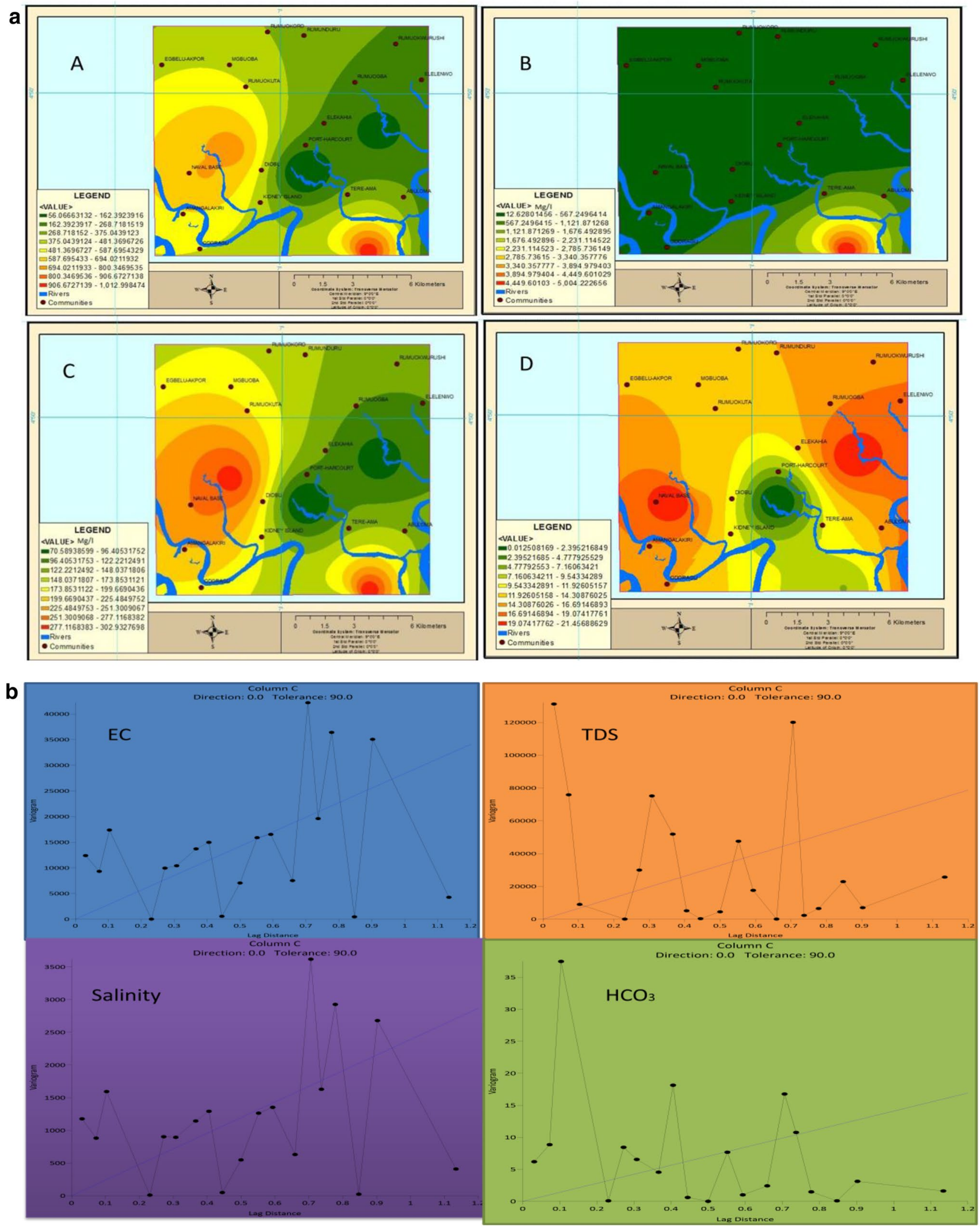
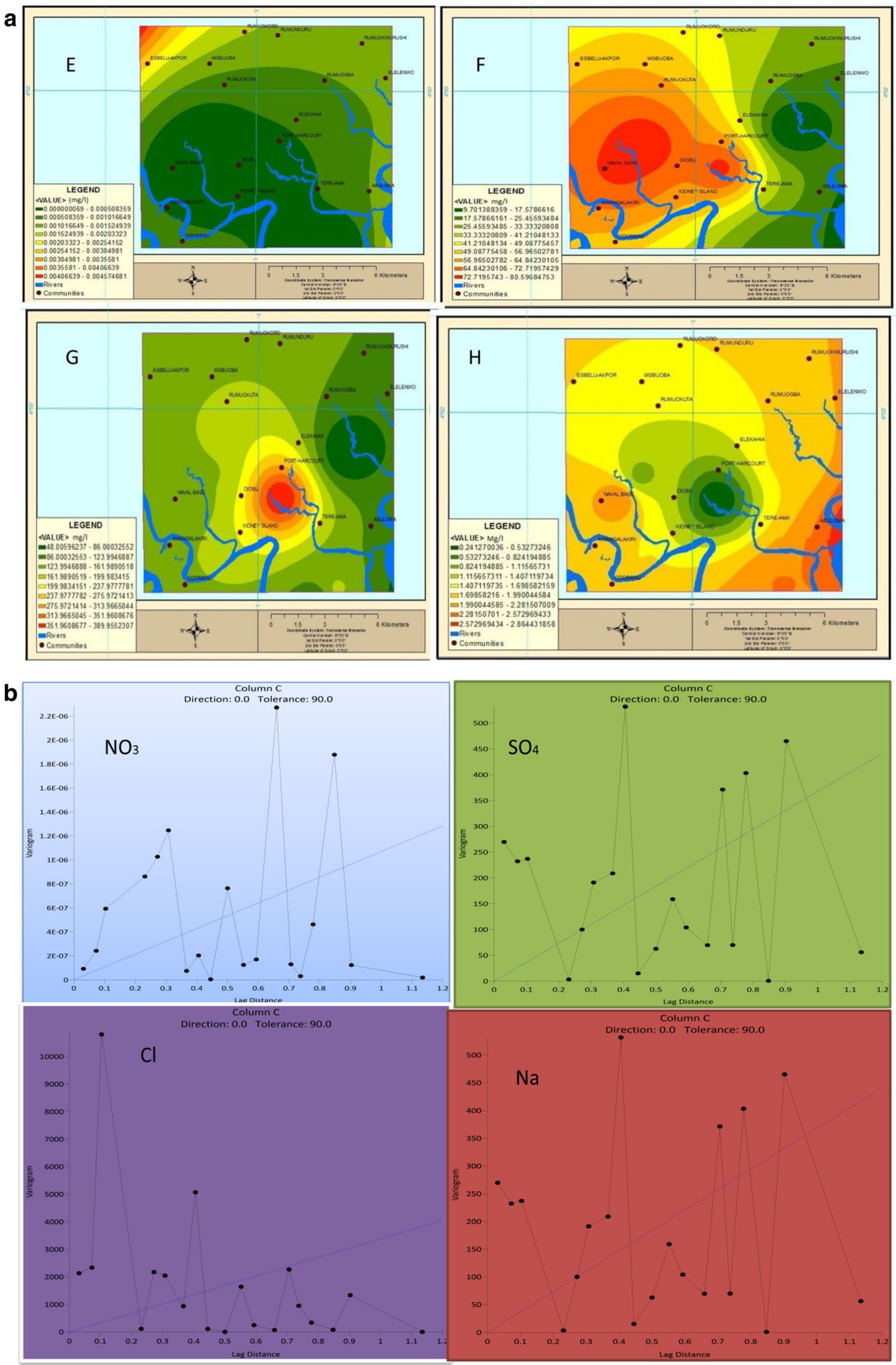


Fig. 4 **a** Spatial distribution of EC (A), TDS (B), Salinity (C), and HCO_3 (D) within the study area. **b** Variogram of EC, TDS, Salinity, and HCO_3 showing the variation between the data values at increasing distances from each other within the study area


a
E
F
G
H
LEGEND
Rivers
Communities
6 Kilometers
b
Column C
Direction: 0.0 Tolerance: 90.0
NO3
SO4
Cl
Na
Variogram
Lag Distance

◂**Fig. 5** **a** Spatial distribution of NO_3 (E), SO_4 (F), Cl (G), and Na (H) within the study area. **b** Variogram of NO_3, SO_4, Cl, and Na showing the variation between the data values at increasing distances from each other within the study area

more noteworthy than 3000 mg/L (Akakuru et al., 2021a; Tiwari et al., 2017).

Potassium is bountiful in the climate, including normal waters. It can likewise be found in drinking water because of utilizing potassium permanganate as an oxidant in water treatment. The concentrations of Fe (mg/L) at Points 1–17 range between 0.022 and 0.088, 0.04 is the mean wand 0.01 is the standard deviation. These values were within the WHO drinking water standard's acceptable range. Sharma (2006) discovered that groundwater with pH ranges of 5–8 can carry up to 50 mg/L of ferrous ions are at harmony if bicarbonate action doesn't surpass 60 mg/L (Table 3). It ought to be noticed that under lessening conditions (pH under 7). Iron exists in the solvent ferrous state. On openness to air (i.e., expansion of oxygen), ferrous iron is oxidized to the insoluble ferric state and may hydrolyze to shape insoluble hydrated ferric oxide (Akakuru et al., 2015; Urom et al., 2021). Figure 6a presents the spatial distribution of Mg, Ca, K and Fe while Fig. 6b is the variogram of the parameters presented in Fig. 6a

Multivariate statistical analyses of hydrogeochemical data

Principal component analysis (PCA)

PCA is a major tool in identifying designs and investigate the fluctuation of sets of between connected factors and furthermore separating the Eigenvalues and Eigenvectors (loadings) for head parts from their related change (Ahmad et al., 2020; Yahaya et al., 2021). It explains the relationship that exists between the parameters to identify the likely wellsprings of contamination of groundwater in the review region.

Three significant Principal Components were identified. All loadings that are greater than 0.4 (+ or −) are considered in the analysis interpretation as a significant contributor. From the result as presented in Table 4, in PC1, 53.8% had loadings, 30.8% are positive (EC, Salinity, Mg, and SO4), while 23% are negative (pH, K and Ca); this is attributive of the factors that are contributing to the expanded saltiness of the groundwater in the review region, this could be due to saltwater intrusion and the subsequent mineralization of soils and rock. Also, it could be attributed to being of geogenic processes like weathering and redox reactions (Egbueri, 2019; Yahaya et al., 2021).

For PC2, 46.2% of the variables had loadings; HCO_3, Na and NO_3 are positive (15.4%), while SO_4, Cl, and Ca had negative loading (30.8%). This implies that they are of geogenic origin (rock–water–environment interactions). PC3, 30.8% of the variables had positive loadings for pH, K, TDS, and Fe had negative loading. This also indicates that the groundwater is predominantly of geogenic origin (Ahmad et al., 2020; Egbueri, 2019; Yahaya et al., 2021). Figure 7 presents a component plot in rotated space.

Correlation matrix analysis

Correlation matrix analysis is a reliable tool to ascertain the association and origin of hydrogeochemical parameters in groundwater quality evaluation (Akakuru et al., 2021a, 2021b; Egbueri, 2019). Correlation coefficients more prominent than 0.7 demonstrate a solid relationship between's two boundaries; correlation coefficients somewhere in the range of 0.5 and 0.7 show a frail connection infers a moderate correlation (Akakuru et al., 2021b; Shyu et al. 2011; Qian et al., 2016). From Table 5, there is a correlation between pH and EC, TDS, Salinity, SO_4, K, Mg, Fe; EC and Salinity, SO_4, K, Ca, Mg; TDS and SO_4, K, Mg, Fe; Salinity and SO_4, K, Ca, Mg; HCO_3 and Cl, Na, K, Ca; NO_3 and SO_4, Cl, Fe; SO_4 and Cl, Na, K, Mg Fe; Cl and Na, Ca, Fe; Na and Ca, Fe; K and Ca, Mg, Fe; Ca and Mg. Strong correlations observed in the majority of the parameters imply that the groundwater mixed with saline water could be a result of saltwater intrusion. This further means that saltwater was the major recharge source for the groundwater in the review region (Egbueri et al., 2019; Yahaya et al., 2021) (Fig. 8).

Pollution indices determination

Contamination factor (CF)

The CF has been utilized in groundwater studies to obtain the concentration ratio of heavy metals to the background values. The following criteria are used to describe the values of the contamination factor: CF < 1, low contamination; 1 ≤ CF ≥ 3, moderate contamination; 3 ≤ CF ≥ 6, considerable contamination; and CF C > 6, very high contamination. (Akakuru et al., 2021a, 2021b; Bhutian et al., 2017). The CF of this study, as presented in Table 6, reveals that HCO_3, NO_3, Na, Ca, Mg had relatively low concentrations < 1 in the entire study area; Fe has a mean concentration of 1.18 (moderate contamination), while SO_4, Cl, had mean concentrations of 6.43 and 9.41, respectively, implying high concentration value (> 6). This result reveals that the major contamination source is principally from geogenic processes. This finding is similar to that of Bhutian et al. (2017) in India and Nigeria (Yahaya et al., 2021).

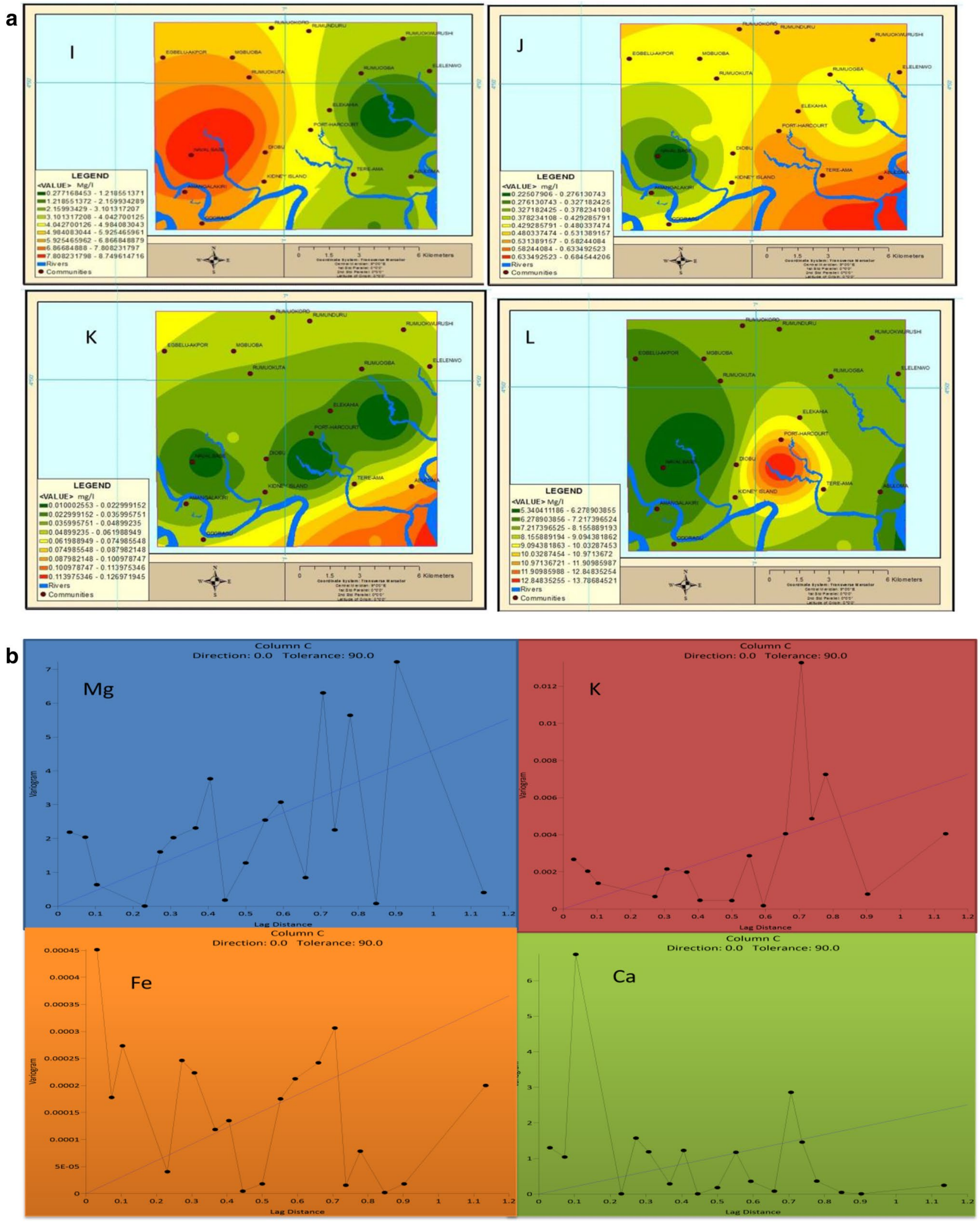


Fig. 6 **a** Spatial distribution of Mg (I), K (J), Fe (K) and Ca (L) within the study area. **b** Variogram of Mg, Fe, and Ca showing the variation between the data values at increasing distances from each other within the study area

Table 4 Factor loadings of various parameters derived from the principal component extraction method

Parameters	Communalities	Component		
		1	2	3
EC	0.993	**0.976**	0.15	− 0.091
Salinity	0.992	**0.973**	0.161	− 0.093
Mg	0.975	**0.95**	− 0.098	− 0.243
SO_4	0.982	**0.795**	**− 0.458**	− 0.369
pH	0.959	**− 0.733**	0.008	**0.648**
K	0.951	**− 0.716**	− 0.234	**0.602**
Cl	0.987	0.104	**− 0.952**	− 0.124
HCO_3	0.941	0.238	**0.883**	− 0.145
Ca	0.985	**− 0.513**	**− 0.817**	− 0.024
Na	0.878	0.107	**0.789**	0.367
NO_3	0.4	− 0.319	**0.538**	0.066
TDS	0.962	− 0.249	0.015	**0.948**
Fe	0.888	− 0.214	0.386	**0.827**
	Eigenvalues	1.399	0.371	2.369
	Variance (%)	40.70	31.05	19.34
	Cumulative var. (%)	40.70	71.76	91.1

Bold values indicate significant contributor (loadings greater than 0.4 (+ or −))

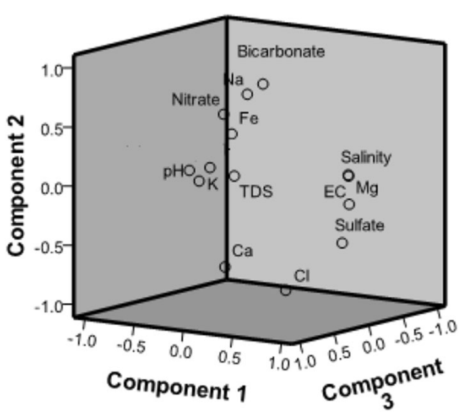


Fig. 7 Principal component plot in rotated space

Pollution load index

PLI is a valuable tool for determining toxicity level of heavy metals in representative samples (Akakuru, et al., 2021a, 2021b; Yang et al. 2011). PLI is typically classified as having no pollution (PLI1), moderate pollution (PLI > 2), heavy pollution (2PLI > 3), or extremely heavy pollution (3 > PLI). The study area's groundwater had a concentration value of less than one, according to the results (Table 6). This implies that no pollution exists. This work contradicts the study undertaken in India (Bhutian et al., 2017; Gopinath et al., 2019), but it is consistent with the work done in Nigeria by Yahaya et al. (2021).

Table 5 Correlation matrix of the various parameters in studied groundwater

	pH	EC	TDS	Salinity	HCO_3	NO_3	SO_4	Cl	Na	K	Ca	Mg	Fe
pH	1.000												
EC	**− 0.784**[a]	1.000											
TDS	**0.819**[a]	− 0.327	1.000										
Salinity	**− 0.792**[a]	**0.998**[a]	− 0.337	1.000									
HCO_3	− 0.230	0.391	− 0.149	0.395	1.000								
NO_3	0.198	− 0.180	0.060	− 0.166	0.234	1.000							
SO_4	**− 0.833**[a]	**0.740**[a]	**− 0.573**[b]	**0.735**[a]	− 0.207	**− 0.430**[b]	1.000						
Cl	− 0.156	− 0.052	− 0.171	− 0.061	**− 0.875**[a]	**− 0.513**[b]	**0.593**[b]	1.000					
Na	0.218	0.201	0.373	0.199	**0.845**[a]	0.217	**− 0.463**[b]	**− 0.869**[a]	1.000				
K	**0.877**[a]	**− 0.798**[a]	**0.709**[a]	**− 0.789**[a]	**− 0.549**[b]	0.233	**− 0.659**[b]	0.112	− 0.150	1.000			
Ca	0.381	**− 0.645**[b]	0.100	**− 0.659**[b]	**− 0.895**[a]	− 0.303	− 0.008	**0.785**[a]	**− 0.761**[a]	**0.558**[b]	1.000		
Mg	**− 0.865**[a]	**0.944**[a]	**− 0.493**[b]	**0.943**[a]	0.165	− 0.269	**0.906**[a]	0.225	− 0.073	**− 0.794**[a]	**− 0.412**[b]	1.000	
Fe	**0.640**[a]	− 0.204	**0.787**[a]	− 0.189	0.123	**0.549**[b]	**− 0.624**[b]	**− 0.499**[b]	**0.517**[b]	**0.615**[b]	− 0.267	− 0.397	1.000

Bold values indicate moderate and strong correlations (values greater than 0.4 (+ or −))

[a]Strong correlation

[b]Moderate correlation

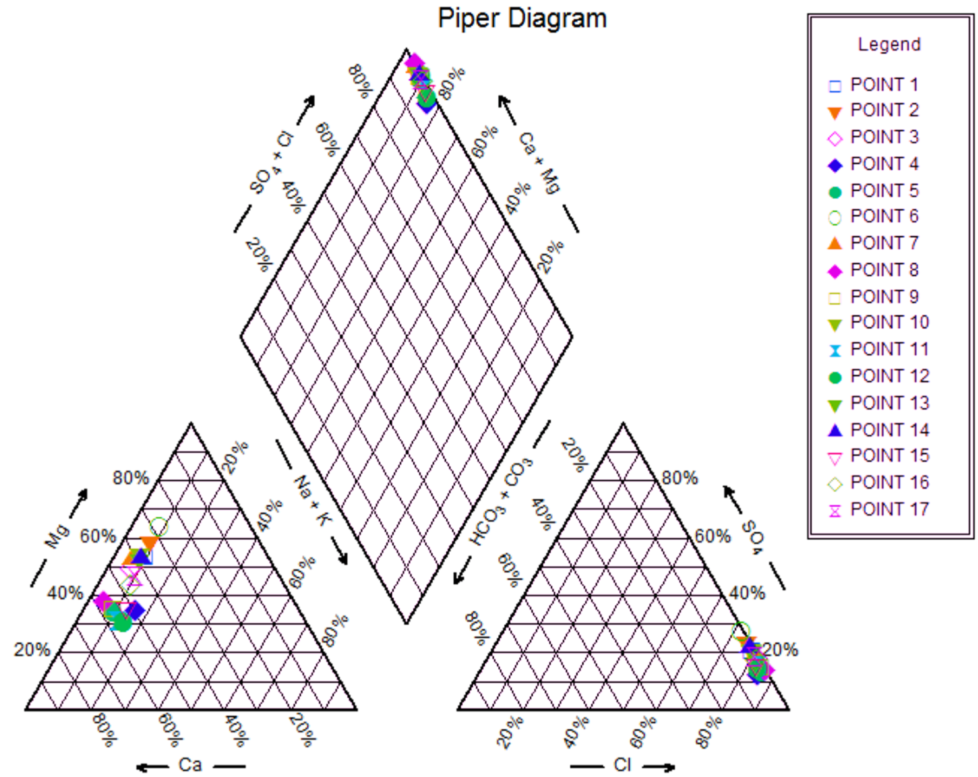


Fig. 8 Piper diagram showing dominant ionic species

Table 6 Summary of CF, PLI and WQI

	Contamination factor								PLI	WQI
	HCO_3	NO_3	SO_4	CL	Na	Ca	Mg	Fe		
P1	0.25	0.000049	7.142857	8.97806	0.425926	0.206704	0.286364	1.475	0.00547	79.14
P2	0.29	0.000035	8.544974	8.931871	0.342593	0.187151	0.327273	0.975	0.00394	55.69
P3	0.19	0.000025	8.108466	11.94573	0.435185	0.23743	0.263636	1.05	0.00365	62.20
P4	0.26	0.000076	2.883598	6.743649	0.555556	0.201117	0.136364	2.2	0.00360	110.99
P5	0.16	0.000037	5.515873	11.6455	0.518519	0.26257	0.154545	1.425	0.00341	80.49
P6	0.35	0.000007	9.73545	8.400693	0.25	0.170391	0.386364	0.55	0.00135	35.77
P7	0.18	0.000016	9.074074	12.63857	0.425926	0.234637	0.290909	0.9	0.00300	55.34
P8	0.10	0.000021	8.240741	16.61663	0.490741	0.310056	0.2	0.65	0.00246	48.94
P9	0.22	0.000051	5.568783	10.33487	0.453704	0.251397	0.154545	0.85	0.00308	53.97
P10	0.24	0.000061	7.87037	9.624711	0.416667	0.201117	0.281818	1.2	0.00555	66.51
P11	0.28	0.000076	3.835979	6.853349	0.435185	0.22067	0.118182	0.975	0.00248	57.48
P12	0.30	0.000087	3.108466	5.998845	0.462963	0.209497	0.113636	1.325	0.00266	72.33
P13	0.24	0.000097	7.328042	9.110855	0.425926	0.201117	0.263636	1.3	0.00676	70.92
P14	0.25	0.000197	6.984127	8.256351	0.425926	0.198324	0.268182	1.525	0.00985	80.71
P15	0.28	0.000094	3.835979	6.841801	0.462963	0.212291	0.140909	1.4	0.00365	75.89
P16	0.25	0.000103	5.502646	8.377598	0.453704	0.215084	0.195455	1.375	0.00557	75.05
P17	0.24	0.000119	6.084656	8.602771	0.444444	0.209497	0.218182	0.85	0.00513	51.42
MIN	0.24	0.00	6.43	9.41	0.44	0.22	0.22	1.18		

Water quality index

WQI is a ranking tool that allows for the easy and better water classification into various categories. Groundwater quality is critical in determining the suitability of water for drinking, irrigation, and industrial purposes (Gopinath et al., 2019; Subba Rao et al., 2012). The WQI of the entire samples revealed that 11.7% of the samples are excellent for industrial use, irrigation and for drinking purposes, 82.4% of the samples are of acceptable water quality and can be utilized for drinking, water system, and modern purposes, and 5.9% of the groundwater tests have worrisome water quality status henceforth, it must be valuable for irrigation proposes (Table 7). This outcome is comparable to the work carried out in North and South India (Brindha et al., 2020, Gopinath et al., 2019).

Pollution index of groundwater (PIG) The PIG of the entire samples was calculated. According to Subba Rao 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 a distinct information on the influence of the parameter contaminating the groundwater body. From the PIG result, it shows that Ec (P6), TDS (P4 and P5), and Cl (P8) had Ow values greater than 0.1 indicating that they were the major contributors to groundwater contamination, whereas the rest of the samples were below 0.1 (Table 8).

The values of PIG in the study area ranged between 0.301 and 0.472 (Table 10). Pollution degree of drinking water is classified into five categories: less than 1(< 1) implies insignificant pollution, 1–1.5 indicates low pollution, 1.5–2.0 implies moderate pollution, 2.0–2.5 indicates high pollution, while > 2.5 indicates very high pollution (Table 9). The result of this study shows that the entire samples are < 1, indicating that the area has insignificant pollution. This result is contrary to the independent works done by Egbueri, (2019) in Nigeria and Subba Rao et al., (2018) in India (Table 10).

Hydrogeochemical evolution

Piper diagram

The Piper Trilinear plot (Piper, 1944) is one of the most useful graphical representations in groundwater quality studies; which helps in understanding the geochemistry of shallow groundwater, in bringing out chemical relationships in more definite terms, than with the other possible plotting methods (Eyankware et al., 2020; Sakram et al., 2013). Piper trilinear diagram for the study area shows that the Ca + Mg are the dominant ionic species in the cation area, while Cl is the dominant ionic species in the anion area.

The diagram further reveals that the groundwater resources in the study area are within the geochemical zone of 6, this implies that it is of calcium chloride water type. Limestone and carbonate rocks are the major sources of Ca in groundwater; they are dissolved by carbonic acid in groundwater. Also, the calcic-plagioclase feldspars and pyroxenes chemical breakdown can be attributed to the presence of Ca. In the same vein, the presence of chlorides could be from rocks, evaporates, seawater intrusion, connate and juvenile water, or contamination by industrial waste or domestic sewage (Egbueri, 2019; Saha et al., 2019). This finding is contrary to the findings from the work undertaken in Bangladesh (Saha et al., 2019); Qatar (Ahmad et al., 2020); and Nigeria (Akakuru et al., 2021a, 2021b; Egbueri, 2019; Olofinlade et al., 2018).

Table 8 PIG assessment components

	Rw	Wp	WHO (2017)
pH	3	0.076923	7
EC (µS/cm)	3	0.076923	500
TDS (mg/L)	3	0.076923	500
Salinity (mg/L)	3	0.076923	600
HCO_3 (mg/L)	3	0.076923	200
NO_3 (mg/L)	5	0.128205	50
SO_4 (mg/L)	5	0.128205	250
Cl (mg/L)	4	0.102564	250
Na (mg/L)	4	0.102564	200
K (mg/L)	1	0.025641	200
Ca (mg/L)	2	0.051282	7.5
Mg (mg/L)	2	0.051282	50
Fe (mg/L)	4	0.102564	0.3
Summation	39	1	

Table 7 Groundwater water quality index classification

WQI values	Water quality status	Sample no.	Percentage (%)	No. of samples	Possible usage
< 50	Excellent	P6, P8	11.7	2	Dinking, Irrigation, and Industrial
50–100	Good	P1, P2, P3, P5, P7, P9, P10, P11, P12, P13, P14, P15, P16, P17	82.4	14	Dinking, Irrigation, and Industrial
100–200	Poor	P4	5.9	1	Irrigation and Industrial
200–300	Very poor	–	–	–	Irrigation
> 300	Unsuitable for drinking	–	–	–	Proper treatment required before use
Total			100	17	

Table 9 PIG classification

Range	Zone	Sample no.	Sample %	Groundwater pollution degree
<1	S1	P1–P17	100	Insignificant pollution
1–1.5	S2	–	–	Low pollution
1.5–2.0	S3	–	–	Moderate pollution
2.0–2.5	S4	–	–	High pollution
>2.5	S5	–	–	Very high pollution

Schoeller semi-logarithm diagram

Schoeller semi-logarithm chart is one more technique for relationship that uses direct diagrams. The most popular charts utilizing math or logarithmic scales to communicate water quality (Sakram et al., 2013). The chart proposed by (Schoeller, 1977) portrays a gathering of investigations on equidistant verticals, the quantity of which relies upon the quantity of constituents being communicated. This diagram is particularly valuable for looking at waters of low focus and waters which don't vary incredibly in fixation (Saha et al., 2019; Sakram et al., 2013; Olofinlade et al., 2018). The Schoeller graph of the review region (Fig. 9) uncovers a hydrogeochemical pattern of $Cl^{+} > SO_4 > Ca^{+} > Mg^{+} > HCO_3^{-} > Na^{+} + K^{+}$, in the request for the most noteworthy to the least constituent. The Schoeller semi-logarithmic plots of the information further affirmed this water type from the past plot. The pinnacles demonstrate the prevailing particles in the water tests while the box shows the less predominant particles.

Mechanisms of groundwater chemistry formation

Several factors influence the groundwater formation chemistry, including; crystallization, precipitation, rock weathering, and evaporation. For a better understanding of the dominant factor controlling the chemistry mechanism, the Gibbs is used (Amiri et al., 2015; Eyankware et al., 2020; Salem et al., 2016). In this study, the entire samples are in the rock-dominance zone (Fig. 10), suggesting that enduring from the stone framing mineral affected the significant particle science of Cretaceous and Quaternary groundwater (Murkute, 2014). This study is similar to concentrates on directed in China (Qian et al., 2016), Italy (Tiwari et al., 2017), and Nigeria (Egbueri, 2019; Eyankware et al., 2020), yet it does not compare to the review led in Tunisia by Ben Moussa et al. (2020).

Quality assessment for irrigation

The results of the calculated quality assessment for irrigation are presented in Table 11.

SAR

The sodium composition in water is considered important in irrigation as it affects plants growth. When sodium combines with carbonate, alkaline soils will be formed. The combination of sodium and chloride gives rise to saline soil (Amiri et al., 2015; Eyankware et al., 2020). Similarly, the sodium absorption on clay surfaces produces alkaline earth minerals; this is achieved by destroying the soil structure, thus rendering the soil compact and impervious, and this drastically reduces plants growth (Ahmad et al., 2020; Eyankware et al., 2020; Yetis et al., 2019).

It is important that SAR clarifies the different cycles including ionic trade responses in soil. SAR esteems (meq/L) from groundwater in the review region went from 0.07 to 0.14, with a mean of 0.09 and a standard deviation of 0.02. (Table 11). In Table 12, SAR arrangement shows that the groundwater in the whole region is in the amazing classification (S1) (Egbueri et al., 2019; Ben Moussa et al., 2020; Subba Rao et al., 2012). This implies that the groundwater in the whole region is great for water system. This outcome is tantamount to the discoveries of Mokoena et al. (2020), Eyankware et al. (2020), and Ben Moussa et al. (2020) in their autonomous groundwater contemplates in South Africa, Nigeria, and Tunisia, separately.

Percentage sodium (%Na^{+})

The increment in %Na^{+} is thought unqualified for water system yet shows a trade of cations with magnesium and calcium in the dirt (Richards, 1954). This trade decreases the dirt's porousness and waste. Dampness on the dirt decreases air and water dissemination, and the dirt is somewhat extreme in dry conditions (Akakuru & Akudinobi, 2018; Li et al., 2016).When sodium chloride is present in the presence of inorganic carbon, alkaline soils are formed, which eventually lead to saline soils. These soil types are unsuitable for plant growth (Keesari et al., 2016). The percentage of sodium in agricultural products is thus critical for determining the suitability of groundwater for irrigation. The percent Na^{+} values (percent) in Table 11 range from 7.9 to 20.0, with a mean of 14.46 and a standard deviation of 3.5. The criteria for groundwater quality (Table 13) show that the total sample is less than 20, indicating that the groundwater in the study area is suitable for irrigation. This result authenticates the SAR result, which showed that the entire sampled groundwater are excellently suitable for irrigation The result is in agreement and similar to the work of Li et al. (2016), Tiwari et al. (2017), Talib et al. (2019) and Sakram and Adimalla (2018) done in China, Italy, Pakistan, and India, respectively.

Table 10 Values of Ow and PIG of groundwater in the study area

	Ow													PIG
	pH	EC (uS/cm)	TDS (mg/L)	Salinity (mg/L)	HCO_3 (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	
P1	0.063736	0.074615	0.073508	0.02491	0.005615	1.66E−06	0.027692	0.063795	0.000974	5.90E−05	0.050598	0.006462	0.020171	0.412137
P2	0.06044	0.088831	0.038662	0.028577	0.006308	1.17E−06	0.033128	0.063467	0.000923	4.74E−05	0.045812	0.007385	0.013333	0.386915
P3	0.062637	0.065677	0.057508	0.023013	0.004269	8.38E−07	0.031436	0.084882	0.000718	6.03E−05	0.05812	0.005949	0.014359	0.408629
P4	0.07033	0.047015	**0.170338**	0.018821	0.005731	2.57E−06	0.011179	0.047918	0.001179	7.69E−05	0.049231	0.003077	0.030085	0.454983
P5	0.068132	0.046754	**0.143492**	0.017705	0.003577	1.26E−06	0.021385	0.082749	0.000769	7.18E−05	0.064274	0.003487	0.019487	0.471884
P6	0.058242	**0.104523**	0.010862	0.032103	0.007654	2.38E−07	0.037744	0.059692	0.001077	3.46E−05	0.041709	0.008718	0.007521	0.36988
P7	0.06044	0.0706	0.03	0.024679	0.004077	5.49E−07	0.035179	0.089805	0.000615	5.90E−05	0.057436	0.006564	0.012308	0.391763
P8	0.064835	0.030323	0.031923	0.014385	0.002308	7.21E−07	0.031949	**0.118072**	0.00041	6.79E−05	0.075897	0.004513	0.008889	0.383573
P9	0.064835	0.037323	0.041385	0.015923	0.004769	1.72E−06	0.02159	0.073436	0.000718	6.28E−05	0.061538	0.003487	0.011624	0.336693
P10	0.06044	0.075015	0.037646	0.025769	0.005192	2.06E−06	0.030513	0.06839	0.000718	5.77E−05	0.049231	0.006359	0.01641	0.375743
P11	0.064835	0.036677	0.043738	0.015769	0.006192	2.55E−06	0.014872	0.048697	0.000872	6.03E−05	0.054017	0.002667	0.013333	0.301732
P12	0.065934	0.033877	0.055277	0.015526	0.006577	2.93E−06	0.012051	0.042626	0.001026	6.41E−05	0.051282	0.002564	0.01812	0.304927
P 13	0.061538	0.070831	0.042354	0.02459	0.005308	3.27E−06	0.02841	0.064738	0.000769	5.90E−05	0.049231	0.005949	0.017778	0.371558
P14	0.062637	0.069954	0.040585	0.024026	0.005462	6.63E−06	0.027077	0.058667	0.000821	5.90E−05	0.048547	0.006051	0.020855	0.364748
P15	0.065934	0.039031	0.059246	0.016795	0.006154	3.16E−06	0.014872	0.048615	0.000974	6.41E−05	0.051966	0.003179	0.019145	0.325978
P 16	0.063736	0.051677	0.055154	0.019782	0.0055	3.46E−06	0.021333	0.059528	0.000872	6.28E−05	0.05265	0.00441	0.018803	0.353511
P17	0.063736	0.057732	0.052538	0.021256	0.005385	4.03E−06	0.02359	0.061128	0.000872	6.15E−05	0.051282	0.004923	0.011624	0.354132

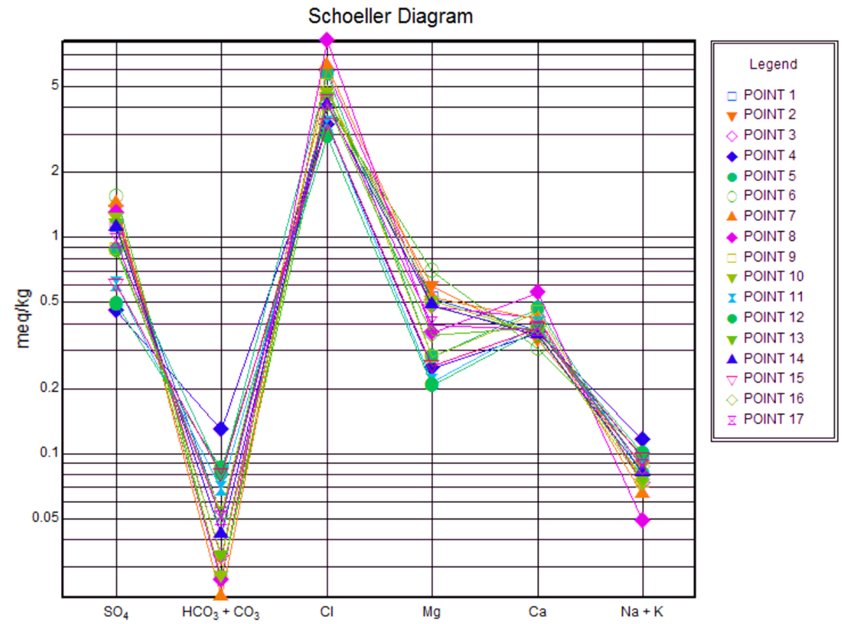


Fig. 9 Schoeller semi-logarithm diagram showing hydrogeochemical trend

Magnesium hazard Magnesium hazard is a crucial device in deciding the water reasonableness limit with regards to water system purposes. Magnesium values in water that are too high reason pungency, which eases back plant development and yield (Mokoena et al., 2020; Qian et al., 2016; Talib et al., 2019). A MH proportion of more than 50 is unsatisfactory and considered unsafe/unsuitable for water system purposes. A MH convergence of 50, then again, is considered appropriate for water system (Akakuru et al., 2021a; Eyankware et al., 2020). Table 11 shows that the MH esteems in the review region went from 24 to 58, with a mean of 37.7 and a standard deviation of 10.32.

Besides, the outcomes show that 88.2% of the complete examples are 50, suggesting that they are fit and truly appropriate for water system purposes, while 11.8% of the groundwater tests are > 50, inferring that they are horribly ill suited/hazardous for irrigation purposes (Table 14). This outcome is steady with the discoveries of Talib et al. (2019) in Pakistan, Qian et al. (2016) in China, yet it is not predictable with the discoveries of work done in South Africa (Mokoena et al. 2020).

Kelly's ratio

KR has been a veritable tool based on its efficacy in assessing the irrigation suitability of groundwater (Eyankware et al., 2020; Mokoena et al., 2020). A KR value greater than one indicates that Na in groundwater is high, whereas any value less than one is suitable for irrigation. Table 11 shows that KR values range from 0.03 to 0.14, with a mean of 0.09 and a standard deviation of 0.03. This result also shows that 100% of the groundwater sample is suitable for irrigation (Table 15). The result confirms the findings of other irrigation assessment tools, which all agree that the

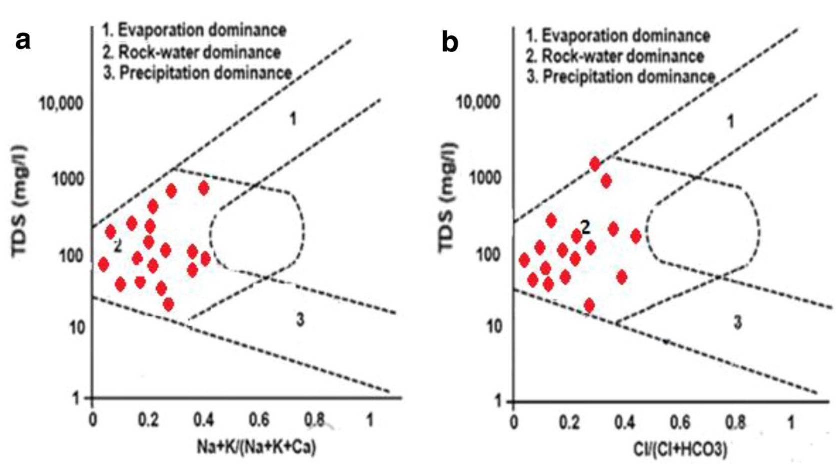


Fig. 10 Gibbs diagram of groundwater samples in the study area

Table 11 Values of SAR, %Na, MH, KR and SSP in the study area

	SAR (meq/L)	%Na (%)	MH (%)	KR (meq/L)	SSP (%)
P1	0.10	14.69	45.99	0.09	2.98
P2	0.10	13.5	51.8	0.09	2.41
P3	0.07	11.56	40.56	0.07	2.99
P4	0.14	22.14	29.41	0.16	4.76
P5	0.09	13.86	26.56	0.09	3.87
P6	0.11	13.97	58.22	0.09	1.71
P7	0.06	10.09	43.24	0.05	2.87
P8	0.03	7.9	28.39	0.03	3.2
P 9	0.08	13.23	27.42	0.08	3.53
P10	0.08	12.13	46.27	0.07	3.04
P11	0.10	17.13	24.76	0.12	3.84
P12	0.12	20	25	0.14	4.16
P13	0.09	13.1	44.62	0.08	3.18
P14	0.09	13.68	45.38	0.08	3.16
P15	0.11	18.32	28.97	0.13	3.96
P16	0.09	15.43	35.83	0.09	3.57
P17	0.09	15.06	39.02	0.09	3.43
Mean	0.09	14.46	37.73	0.09	3.33
Standard deviation	0.02	3.5	10.32	0.03	0.70

water is suitable for irrigation. This finding is consistent with the findings of Olofinlade et al. (2018) in Nigeria and Sakram and Adimalla (2018) in India. This result, however, contradicts the findings of Mokoena et al. (2020) in South Africa.

Table 12 SAR-based irrigation suitability classification criteria

Sodium hazard	Zone	Sample no.	Sample %	Class of water
< 10	S1	P1–P17	100	Excellent
10–18	S2	–	–	Good
18–26	S3	–	–	Permissible
> 26	S4	–	–	Unsuitable

Table 13 $\%Na^{+}$ Groundwater quality criteria for irrigation

Class	Sample no.	No of samples	Sample %	Class of water
< 20	P1–P17	17	100	Excellent
20–40	–	–	–	Good
40–60	–	–	–	Permissible
60–80	–	–	–	Doubtful
> 80	–	–	–	Unsuitable

Soluble sodium percentage

SSP has been utilized by scholars in the assessment of the suitability of groundwater for irrigation purposes. It assesses the percentage of soluble sodium in groundwater. SSP less than 50 is suitable for irrigation, while above 50 is considered unsuitable. The result from Table 11 shows that SSP values range between 1.71 and 4.76 with a mean of 3.33 and a standard deviation of 0.7. Table 16 shows that the entire samples are safe and suitable for irrigation. SSP aligns with other irrigation assessment tools. This result is in agreement with the work of Eyankware (2020) done in the Niger Delta Nigeria.

Wilcox diagram

Wilcox's (1955) plot was also utilized in this study, to relate EC to %Na. According to the diagram, 70.6% of the entire sample in the study area fall into the excellent category and are very good to be used for irrigation purposes, while 29.4% fall into the good to permissible category (Fig. 11). This result implies that the groundwater in the entire study area is suitable and hazard-free for irrigation. It further validates other irrigation assessment tools employed in this present study, as all are in agreement that the water is suitable for irrigation. This result is in agreement with the results obtained from studies in Italy,

Table 14 MH classification of groundwater for irrigation

MH range	Sample no.	% Sample	Class of water
< 50	P1, P3, P4, P5, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17	88.2	Safe
> 50	P2, P6	11.8	Unsafe

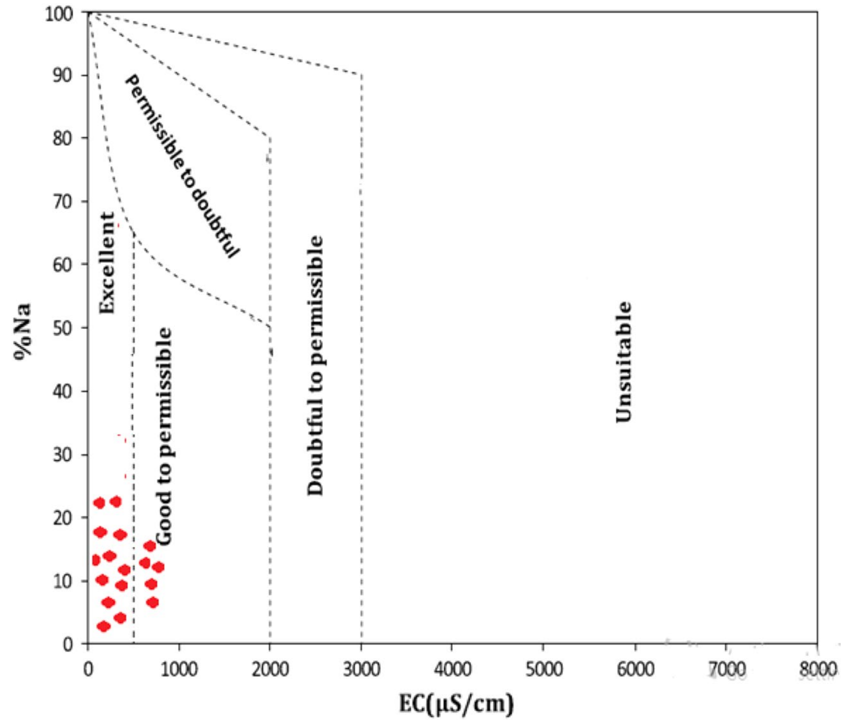
Table 15 Groundwater KR classification for irrigation

KR range	Sample no.	% Sample	Class of water
< 1	P1–P17	100	Suitable
> 1	–	–	Unsuitable

Table 16 Groundwater SSP classification for irrigation

SSP range	Sample no.	% Sample	Class of water
< 50	P1–P17	100	Safe
> 50	–	–	Unsafe

Fig. 11 Wilcox diagram in the study area



Mozambique, and Nigeria by Tiwari et al. (2017), Barbieri et al. (2018), Eyankware et al. (2020), respectively.

Conclusion

The hydrogeochemical evolution, water quality indices and irrigation suitability of groundwater around eastern Niger Delta, Nigeria have been copiously done, the following was observed:

1. The entire values of elements were within the WHO standard for drinking water except for pH which was low (slightly acidic), TDS (P4 and P5), high salinity values, and Cl (P8) that was above recommended standard. There is a need for peruse treatment.
2. The multivariate statistical analysis for hydrogeochemical data identified three significant Principal Components; PC1, 53.8% loadings (30.8% positive, 23% negative), PC2, 46.2% loadings (15.4% positive, 30.8% negative), PC3, 30.8% positive loadings. These results indicate that the groundwater is predominantly of geogenic origin.
3. Correlation matrix analysis observed strong correlations in the majority of the parameters; implying that the groundwater mixed with saline water, probably from saltwater intrusion.
4. The Contamination Factor results reveal that HCO_3, NO_3, Na, Ca, Mg had relatively low concentration < 1; Fe has a mean concentration of 1.18 (moderate contamination), while SO_4, Cl, had mean concentrations of 6.43 and 9.41, respectively; implying high concentration value (> 6). This result implies that the major contamination source is principally from geogenic processes. Similarly, the results from the PLI reveals that the total concentration of groundwater in the area was less than one, indicating no pollution.
5. WQI of groundwater tests uncovered that 11.7% of the examples are amazing for drinking, irrigation, and industrial purposes, 82.4% of the examples are of acceptable water quality and can be utilized for drinking, irrigation, and industrial purposes, and 5.9% of the groundwater tests are of worrisome water quality and must be utilized for irrigation and in the industries.
6. The PIG assessment shows that the entire groundwater sample values are < 1, indicating that there is an insignificant pollution.
7. The hydrogeochemical signatures shows Ca + Mg are the dominant ionic species in the cation area, while Cl is the dominant ionic species in the anion; groundwater in the study area are within the geochemical zone of 6, which implies that it is of calcium chloride water type, with a trend of $Cl^+ > SO_4 > Ca^+ > Mg^+ > HCO_3^- > Na^+ + K^+$.
8. The Gibbs plot shows that the entire sample is in the rock-dominance zone, implying that the major ion chemistry of the Cretaceous and Quaternary groundwater was heavily influenced by weathering from the rock-forming mineral.

9. The suitability for irrigation analysis reveals that SAR, %NA, KR, and SSP in the entire study area were 100% suitable and fit for irrigation purposes, while MH had 88.2% of the sample as good and 11.8% as unsafe. The Wilcox plot shows that 70.6% of the entire sample in the study area belong to the excellent category and are very good to be used for irrigation purposes, whereas 29.4% are of good to permissible category.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Compliance with ethical standards This research work is carried out in compliance with transparency, moral values, honesty, and hard work. No human participation or animals are involved in this research work.

Conflict of interest The authors declare that they have no competing interests.

Ethical approval As per the literature review, this is neither a repetition of any work nor copied key data from other's work. The methodology, findings, and conclusions made here belong to original research work as per our knowledge and belief.

Informed consent Every step of processing for publication informed to all co-authors of this paper at the earliest, and everything is carried out with collective decision and consent.

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