Groundwater Quality Assessment in Akoko District, Southwestern Nigeria: A GIS-Based Hydrogeochemical and Statistical Analysis

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Abstract

The practice of exclusive rain-fed agriculture may not guarantee food security in today's rapidly growing and urbanizing Nigerian society due to seasonality of rainfall regimes. This study employed index-based analytical and statistical techniques in GIS environment to evaluate the hydrogeochemical processes influencing groundwater quality in the Akoko area of Nigeria with a view to determining the suitability of the groundwater for drinking and irrigation purposes. On-site pH, TDS, and EC were measured in situ using Hanna meter. While SO_4^{2+} was determined using a colorimeter, Ca^{2+}, Na^+, and K^+ were measured using a flame photometer. Titrimetric approach was adopted for estimating HCO_3^-, Cl-, and TH. The predominance of the cations and anions followed $Ca^{2+}>Mg^{2+}>Na^+>K^+$ and $HCO_3^->Cl^->SO_4^{2-}>NO_3^-$ order respectively. Alkali earth metals ($Ca^{2+} + Mg^{2+}$) dominated over alkali metals ($Na^+ + K^+$), and ($CO_3^- + HCO_3^-$) exceeded ($SO_4^{2-} + Cl^-$), suggesting continental environment. Negative chloro-alkaline indices suggested exchange of ($Ca^{2+} + Mg^{2+}$) in groundwater for ($Na^+ + K^+$) in the aquifer. Ionic ratios exhibited depletion of Na^+ against Cl^-, and prevalence of weathering processes. The pH values ranged from 6.4 to 7.8 (slightly acidic to alkaline). The groundwater was moderately hard to hard, signifying a strong influence of bicarbonate ions. The most prevalent water type was $Ca-HCO_3$, indicating silicate minerals dissolution consistent with Gibbs plot. From PCA results, strong correlations existed between DWQI and EC, TDS, Cl^-, SO_4^{2-}, Na^+, and K^+. Generally, the groundwater is drinkable and largely suitable for irrigation following WHO standards and FAO benchmarks with possible salinity management.
Keywords Water quality index, Irrigation, GIS, Hydrogeochemical facies, Food security, SAR

Introduction

Water is essential for human existence and a crucial component of any country's socioeconomic progress. Given the various daily requirements for essential residential, agricultural, industrial, and recreational activities, its importance cannot be overstated. Within the hydrological cycle, there are spatiotemporal fluctuations in the quantity and quality of water in various forms at various storage points with varying resident times. The variations are influenced by both manmade and natural factors. As a result of climate change-related global warming, water resources are currently being depleted in many places of the world. Water's acceptance and use depend on its physical, chemical, biological, and radioactive qualities (surface and subterranean). Groundwater is a valuable supply of freshwater because it is less susceptible to environmental pollution than surface water (EPA, 2003). However, whenever there is any appreciable change in quality, groundwater is frequently refused. Such degradation could result from anthropogenic or natural activities. For example, improper waste management may cause groundwater quality to degrade, impacting people's willingness to accept and use it.

In Akoko senatorial district, Nigeria, groundwater is found in fractured crystalline rocks and shallow weathered zones (aquifers). For a variety of domestic, agricultural, municipal, and industrial uses in the area, the locals rely largely on this source. Due to economic conditions, the majority of households in the area extract groundwater by hand-dug wells, however some who can afford it have motorized boreholes. In Akoko, farming is the primary economic activity. Inhabitants grow both food crops such rice, yam, cassava, and maize as well as cash crops like cocoa, palm trees, and kola nuts. The economics of the people in the area is also influenced by trade and pottery. Most areas in the study area have a long history of exclusive rain-fed agriculture, which is only possible during the wet season (March/April to September/October). At the beginning of the dry season in September or October, farmers frequently take a holiday to resume farming work when the rains arrive around March of the following year. As a result, there are just a few months per year when farming is productive and there is sufficient rainfall. As expected, this method cannot ensure food security since seasonal rainfall patterns prevent year-round farming. It's important to halt this distasteful trend of crop production and farming decline. For better water security, which would enhance food security with high crop yields and sustained food production (both subsistence and commercial), dry season farming must be incorporated and made possible through irrigation. Some farmers may not have easy access to the amount and quality of surface water supplies needed for irrigation and consumption. This is in part because surface water is difficult to reach everywhere, especially in areas without rivers.

Other elements include the negative consequences of climate change on the hydrological cycle, population growth (or density), and increasingly prevalent anthropogenic activities worldwide. In areas without rivers, wells and/or boreholes can be drilled or sunk to extract groundwater for irrigation purposes. According to Aribisala et al. (2015), the impact of climate change on groundwater resources in southwest Nigeria was minimal because borehole yields in the Akoko district varied only little over a 30-year period between 0.85 and 1.20 l/s. However, Falowo et al. (2020) reported relatively high yielding aquifer units with hydraulic conductivities of 0.14 - 48.12 m/d, transmissivities of 2.47 - 221.36 m^2/d, storage coefficients of 0.000069 - 0.0075, and yield capacities of 17.28 - 110.59 m^3/d. Therefore, groundwater resources could help the local food security by supplying irrigation and drinking water needs. In Akoko North-west Local Government Area, Oyedotun and Obatoyinbo (2012) identified probable anthropogenic contamination but still acknowledged overall good groundwater quality. Despite the fact that groundwater is less prone to environmental deterioration, it is nevertheless required to evaluate its quality and suitability for irrigation. The suitability of Akoko North's groundwater for irrigation and drinking was evaluated by Falowo et al. (2017), but they neglected to take into account the hydrogeochemical processes that cause regional variations in groundwater quality. Therefore, a thorough assessment of the hydrogeochemical mechanisms responsible for the geographical variations in groundwater quality was conducted for the current study. This is done with a view to assessing the hydrochemical quality of the groundwater and its appropriateness for drinking and irrigation.

Materials and Methods

The study area

In Ondo State, southwest Nigeria, Akoko is situated in the northern senatorial district. It is between the longitudes of 5°41′55″ and 6°02′15″E and the latitudes of 7°29′25″ and 7°46′40″N. Ikare-Akoko, Oke-Agbe Akoko, Arigidi Akoko, Ajowa Akoko, Ikaram Akoko, and Akunu Akoko are some of the neighbouring towns or communities in the region (Figure 1).

Both highways and walkways lead to the location. The topography is characterized by gradually sloping terrain with a few isolated hills and nearby valleys. The tropical climate characterized by varied wet and dry seasons enhance chemical weathering and the production of residual lateritic soils. An average of 1318 millimeters of rain falls each year. In August and March, respectively, average minimum and maximum temperatures were recorded as being around 22.6°C and 26.9°C.
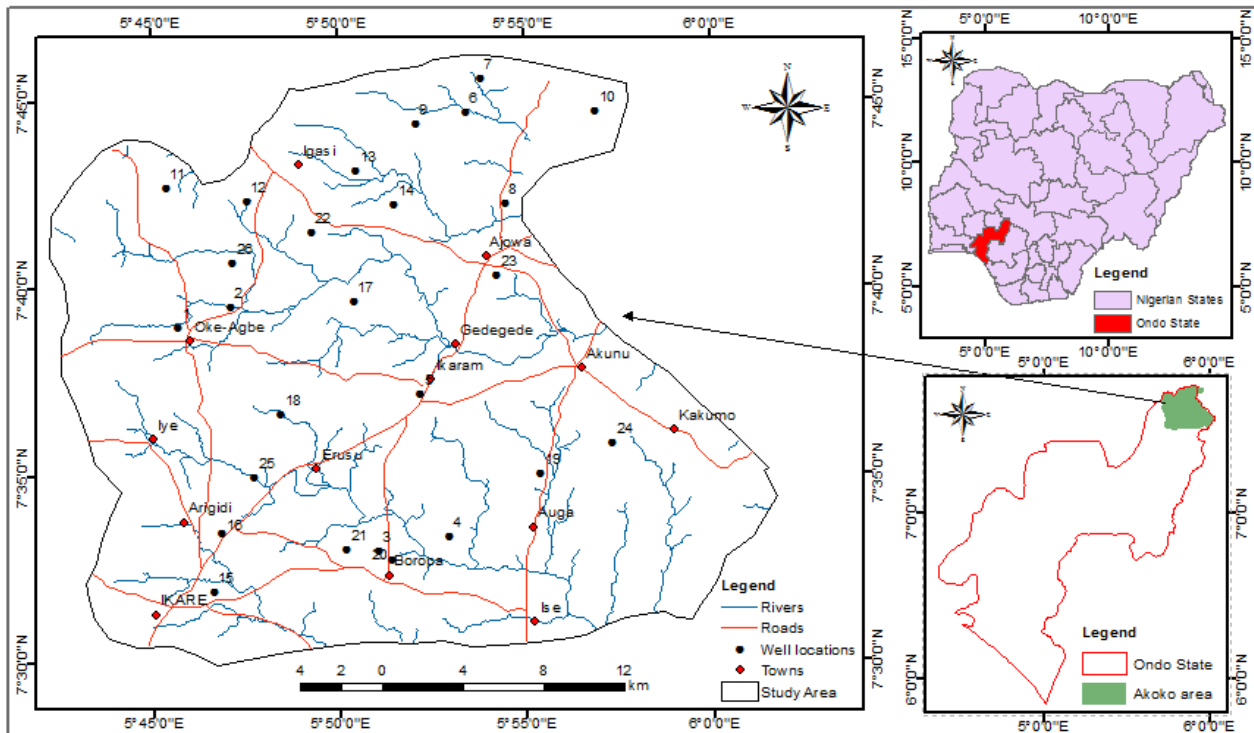

Fig. 1 Location map of the study area

Geology and hydrogeology

South-western Nigeria's Precambrian Basement Complex rocks form the foundation of the Akoko senatorial district. The regional assemblages, according to Adekoya et al. (2003), include migmatite-gneiss-quartzite complex, schist belts, older granites, and minor intrusive rocks. The regional lithologies are composed of migmatite-gneiss-quartzite complex rocks with foliations, microfolds, veinlets, and quartzo-feldspar veins as structural components (Figure 2). Unconsolidated residual soil that varies in thickness spatially makes up the majority of the area's aquifer system. Additionally, there are instances of shallow metamorphic crystalline rock aquifers that are partially weathered and fractured. Direct precipitation and flows from rivers and their tributaries recharge the groundwater in the area primarily. However, seepages, evapotranspiration, springs, and flow into streams and rivers all resulted in groundwater discharges.

Groundwater discharge in the area also took the form of well water abstraction. The spatiotemporal distribution of groundwater in the research area was controlled by the thickness of the overburden soil material as well as the frequency and length of fractures in the underlying crystalline rocks (Owoseni et al., 2013). The Ose River and its tributaries served as the region's primary source of surface water.

Sample collection and geochemical analysis

Based on APHA (2005) recommendations, 26 groundwater samples were systematically taken from dug wells in September 2018. Prior to water sampling, the surface elevation and geographic coordinates of each well were recorded. On the field, water samples were tested for electrical conductivity (EC), total dissolved solids (TDS), and pH using a hand-held HANNA COMBO meter (HI98129 model). Groundwater from wells was sampled using plastic rubber containers, with the utmost caution to prevent metallic contamination. Prior to sampling, samples were placed in polythene containers that had been cleaned with the appropriate tested water. Before being subjected to chemical examination, the samples were stored at a temperature of 4°C in the Geochemistry lab of the Department of Applied Geology at the Federal University of Technology, Akure, Nigeria. Calcium (Ca^{2+}), sodium (Na^+), and potassium (K^+) were analyzed using the JENWAY Flame photometer (PFP 7 model). For the measurements of bicarbonate (HCO3-), chloride (Cl-), and total hardness (TH), the EDTA Titrimetric technique was used. Sulfate concentration (SO42-) was determined using a JENWAY Colorimeter (model 6015). By applying equation (1) to calculate percent charge errors (% CBE), the measurements' accuracy was checked.

$$\% \, CBE = \frac{\sum cations - \sum anions}{\sum ctions + \sum anions} \, X \, 100\% \qquad (1)$$

The current study's CBE was below the accepted level of 5%, validating the measures for use in further data analysis.
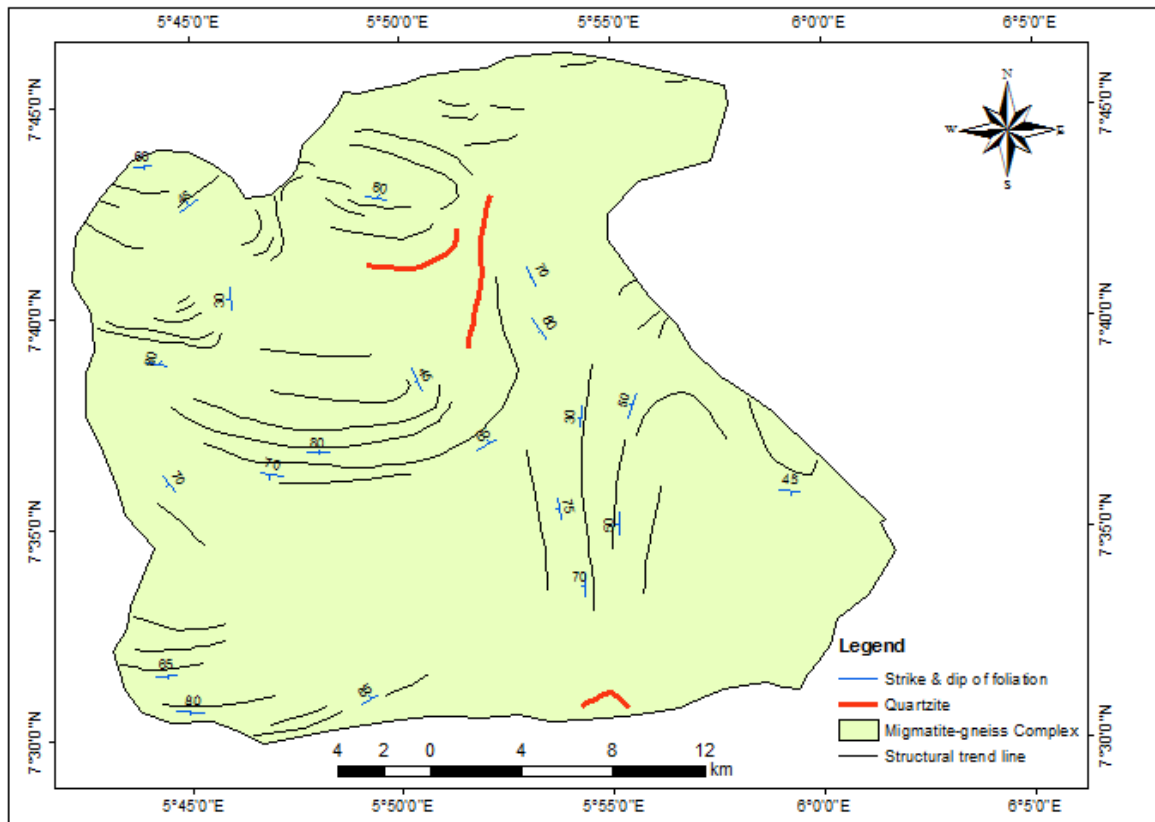

Fig. 2 Geological map of the study area

Geospatial data Analysis

In creating spatial distribution maps for point data in the ArcGIS environment, the inverse distance weighted (IDW) statistical technique was used. It is a geostatistical model that uses readily available adjacent sites to estimate unknown values. The practice of mapping the spatial variation of physico-chemical variables frequently employed as indicators of the quality of drinking water has gained widespread support among researchers. Total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), hydrogen ion activity (pH), major cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+), and major anions (HCO_3^-, Cl^-, SO_4^{2-}, and NO_3^-) were all the focus of spatial variation maps. The Drinking Water Quality Index (DWQI) and Irrigation Water Quality Index (IWQI) final spatial variation maps for the research area were also produced using the IDW approach.

Evaluation of water quality indices

Drinking water quality index (DWQI)

Using a 4-step evaluation process, the Drinking Water Quality Index (DWQI) was computed to determine the potability of groundwater in the Akoko area. First, weights (Wi) ranging from 1 to 5 to were assigned to each chemical variable based on their unique proportional impact on human health. Secondly, equation (2) was used to determine the corresponding relative weights (Ri) for the provided weights. Utilizing equation (3), the third step is the calculation of the quality rating scale (Qi) from the measured concentration of the groundwater parameters (Pi) and the corresponding drinking water standard specification for each groundwater parameter (Si). Four, using equation (4) to calculate the DWQI from Qi and Ri.

$$R_i = \frac{W_i}{\Sigma_{i=1}^n W_i} \tag{2}$$

$$Q_i = \frac{P_i}{S_i}(100) \tag{3}$$

$$DWQI = \Sigma_{i=1}^n (Q_i)(R_i) \tag{4}$$

where P_i is the measured concentration of groundwater parameter and S_i is the drinking water standard specification used for each groundwater parameter (WHO, 2011).

Irrigation water quality index (IWQI)

By calculating IWQI for the groundwater samples in the Akoko area in accordance with equations 5 to 12, the suitability of the groundwater for irrigation purposes was determined. The Sodium Adsorption Ratio (SAR) proposed by the United States Salinity Laboratory (USSL) was calculated using Equation (5) (Richards, 1954). For determining sodium risks in the form of Soluble Sodium Percent (SSP), Wilcox's (1955) equation (6) was computed as the ratio of sodium to the total cations in the groundwater. Using Schoeller's (1965) formula (Equations 7 and 8), the ion exchange processes between groundwater and its surroundings were calculated as chloro-alkaline indices (CAI-1 and CAI-2). Equation (9) (Kelly, 1963) was used to calculate the Kelley ratio, while equation (10) (Doneen, 1964) was used to estimate the Permeability Index (PI). Using equation (11) in accordance with Eaton (1950) and Ragunath (1987), the relative amount of surplus sodium carbonate contained

in the groundwater samples was calculated as Residual Sodium Carbonate (RSC). Equation (12) was used to calculate the magnesium hazards expressed as the magnesium adsorption ratio (MAR).

$$SAR = \frac{Na^+}{\sqrt{[(Ca^{2+} + Mg^{2+})/2]}} \tag{5}$$

$$\% \, Na = \frac{(Na^+ + K^+) \times 100}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \tag{6}$$

$$CAI - 2 = \frac{[Cl^- - (Na^+ + K^+)]}{Cl^-} \tag{7}$$

$$CAI - 2 = \frac{[Cl^- - (Na^+ + K^+)]}{SO_4^{2-} + HCO_3^- + CO_3^- + NO_3^-} \tag{8}$$

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})} \tag{9}$$

$$PI = \frac{Na^+ + \sqrt{[HCO_3^- \times 100]}}{Ca^{2+} + Mg^{2+} + Na^+} \tag{10}$$

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \tag{11}$$

$$MAR = \frac{(Mg^{2+}) \times 100}{(Ca^{2+} + Mg^{2+})} \tag{12}$$

Where all ionic constituents are in milliequivalents per litre (meq/l).

Statistical analysis

The degree of relationship between two pairs of quantitative variables is frequently determined using bivariate correlation (Mertler and Reinhart, 2017). To assess the strength of the linear relationship between pairs of hydrogeochemical variables, the Pearson correlation coefficient (r), which has been successfully implemented by water researchers including Owoseni et al. (2012), Wu et al. (2014), and Kawo and Karuppannan (2018), was adopted. Applying uncorrelated linear combinations of the original variables that accounted for as much of their total variance as possible, the study's bulk hydrogeochemical datasets were reduced. The data reduction was accomplished using the varimax rotation technique and principal component analysis (PCA). The final outcome gave insights on the underlying hydrogeochemical mechanisms thought to be responsible for local differences in groundwater quality. Principal components (PCs) were extracted sequentially from the total variance, each PC being independent of the preceding one (Owoseni et al., 2013; Mertler and Reinhart, 2017). Every PC was determined using equation (13). First, the initial linear combination that explained the most variance was extracted. The next amount of variance is taken from the second linear combination, which is not correlated with the first. The three factors that determine how many PCs are retained, analyzed, and regarded statistically significant are as follows: The first requirement is cumulative loading that accounts for at least 70% of total variability. Second, the eigenvalue higher than one criteria proposed by Kaiser in 1958. Lastly, the scree plot test.

$$PC_{ab} = M_{a1}N_{1b} + M_{a2}N_{2b} + \cdots + M_{an}N_{nb} \tag{13}$$

where PC is score for each principal component, M is component loading, N is measured value of the original variable, a is component number, b is sample number, n is total number of original variables.

Results and discussion

Table 1 presents the descriptive statistics for ionic concentrations and associated drinking water standards.

Hydrogeochemical processes

Ion-exchange reactions

According to Singh et al. (2012) and Sethy et al. (2016), ion-exchange reactions frequently provide information on the hydrogeochemical processes that contribute to groundwater chemistry. Chloro-alkaline indices (CAI-1 and CAI-2) readings frequently show the cation exchange reactions responsible for the variation in groundwater chemical quality. Groundwater samples in the research area had CAI-1 and CAI-2 values that ranged from -7.447 to 0.606 and -2.437 to 0.714, respectively, with average values of -1.246 and -0.357 (Table 2). Four samples reported positive values for CAI-1 and CAI-2, whereas 22 samples had negative values for both. About 84.62% were negative, suggesting that $Na^+ + K^+$ and $Ca^{2+} + Mg^{2+}$ exchanged more frequently in aquifer materials than in groundwater. Also, the majority of the samples recorded Chloro-Alkaline Index values that were less than zero, indicating a direct ion exchange reaction (Asiwaju-Bello et al., 2021).

The plot of Na^+ versus Cl^- ions (Figure 3a) revealed that a substantial proportion (77%) of the samples plot above the 1:1 line. This suggests that Na^+ is depleted against Cl^- in ion-exchange processes (Sethy et al., 2016). Additionally, the percentage of groundwater samples (approximately 58%) below the 1:1 line on the plot of $(Ca^{2+} + Mg^{2+})$ versus $(HCO_3^- + SO_4^{2-})$ (Figure 3b) (Singh et al., 2012) confirmed ion-exchange mechanisms and a high level of weathering.

Correlation analysis

The matrix of Pearson correlation coefficients for various pairs of hydrochemical variables in the research area was displayed in Table 3.

Table 1. Descriptive statistics of parameters and drinking water standards

Parameters	Groundwater (n = 26)				WHO (2011) Standards Max. desirable	SON (2007) Standards Max. desirable
	Min.	Max.	Mean	SD		
pH	6.41	7.83	7.19	0.35	6.5 – 8.5	6.5 – 8.5
EC (µS/cm)	26.20	1180.00	482.63	371.43	500	-
TDS (mg/l)	96.00	590.00	281.81	153.72	500	500
TH (mg/l)	32.35	291.01	158.50	58.35	100	150
Cl^- (mg/l)	3.64	98.40	46.82	28.32	250	250
HCO_3^- (mg/l)	24.00	280.00	154.15	62.69	500	-
SO_4^{2-} (mg/l)	3.43	15.24	8.00	3.06	250	100
NO_3^- (mg/l)	0.05	0.16	0.09	0.03	45	50
Ca^{2+} (mg/l)	9.79	60.38	34.12	11.46	75	-
Mg^{2+} (mg/l)	1.92	34.08	17.82	7.95	50	-
Na^+ (mg/l)	12.30	90.00	39.20	23.96	200	200
K^+ (mg/l)	4.40	56.00	18.30	12.64	12	-

Table 2 Chloro-alkali indices

Sample code	CAI-1	CAI-2
S1	0.606	0.714
S2	-1.090	-0.477
S3	-0.911	-0.441
S4	-0.728	-0.314
S5	-0.849	-0.762
S6	-0.991	-2.437
S7	0.570	0.325
S8	-0.433	-0.090
S9	-7.447	-0.242
S10	-3.803	-0.216
S11	-2.793	-0.210
S12	-0.042	-0.023
S13	-0.387	-0.276
S14	-1.073	-0.543
S15	-2.746	-0.178
S16	0.146	0.202
S17	0.319	0.188
S18	-0.673	-0.627
S19	-1.315	-0.262
S20	-1.784	-1.713
S21	-0.339	-0.206
S22	-1.107	-0.178
S23	-1.969	-0.631
S24	-0.285	-0.215
S25	-1.110	-0.111
S26	-2.166	-0.566
Average	-1.246	-0.357

Drinking Water Quality Index (DWQI) and EC (0.826), TDS (0.887), Cl^- (0.686), SO_4^{2-} (0.598), Na^+ (0.794), and K^+ (0.703) all showed significant and high correlations. These significant positive correlations suggested that EC, TDS, Cl^-, SO_4^{2-}, Na^+, and K^+ had significant effects on DWQI and were related to mineral dissolution via water-rock interaction. Other significant positive associations were those between K^+ and Cl^- (0.674), Na^+ and K^+ (0.802), Mg^{2+} and Ca^{2+} (0.810), TDS and EC (0.842), Cl^- and EC (0.692), Cl^- and TDS (0.803), SO_4^{2-} and TDS (0.668), Ca^{2+} and TH (0.944), and Mg^{2+} and TH (0.958).

The relationship between these factors suggested that evaporation and seasonal variations may have had an impact on the groundwater chemistry in the region (Abbasnia et al., 2018). On the other hand, some weak negative correlations between Ca^{2+} and NO_3^- (-0.060), Mg^{2+} and NO_3^- (-0.184), Na^+ and NO_3^- (-0.176), and K^+ and NO_3^- (-0.110) were observed, indicating that the groundwater acquired NO_3^- from a variety of sources (Kawo and Karuppannan, 2018).
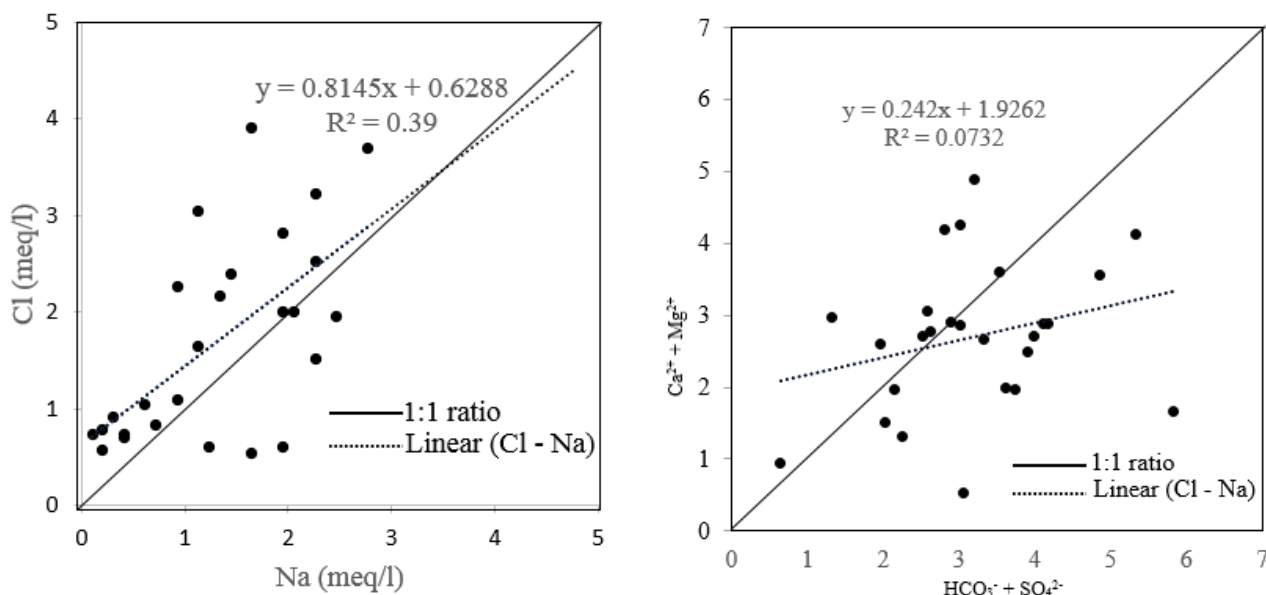
Fig. 3 Scatter plots of (a) Na^+ versus Cl^- (b) $(Ca^{2+} + Mg^{2+})$ versus $(HCO_3^- + SO_4^{2-})$ with 1:1 lines

Gibbs plot

According to Gibbs (1970), the main factors affecting a region's groundwater chemistry are evaporation, precipitation, and rock weathering. Additionally, anthropogenic activities can change the chemical composition of groundwater. Almost all of the 26 groundwater samples from the research area were plotted in the Gibbs diagrams' rock weathering dominance field (Figure 4). This implied that rock-water interaction was the primary factor influencing the chemical composition of the groundwater in the region.

Principal component analysis (PCA)

A well-known statistical method for finding patterns that represent the chemical facies of groundwater is the principal component analysis (PCA). It assists in explaining the hydrogeochemical processes that are thought to be the basis of water quality variations (Vasanthavigar et al., 2012; Owoseni et al., 2013; Sethy et al., 2016; Selvakumar et al., 2017; Kawo and Karuppannan, 2018; Asiwaju-Bello et al., 2021). Based on eigenvalues greater than one and the scree plot, three principal components (PC-1, PC-2, and PC-3) were selected and retained (Figure 5 and Table 4). Together, they jointly account for 72.41% of the total variance in the dataset. TDS (0.911), Cl^- (0.857), SO_4^{2-} (0.721), Na^+ (0.765), and K^+ (0.844) were all highly loaded in PC-1, explaining 36.63% of the overall variation was accounted for. The high concentrations of Na^+ and K^+ indicated weathering of silicate minerals including ion exchange and dissolution processes (Drever, 1997; Asiwaju-Bello et al., 2021).

Table 3 Pearson's Correlation matrix of groundwater quality parameters

	DWQI	pH	EC	TDS	TH	Cl⁻	HCO₃⁻	SO₄²⁻	NO₃⁻	Ca²⁺	Mg²⁺	Na⁺	K⁺
DWQI	1												
pH	-0.283	1											
EC	**0.826**	-0.115	1										
TDS	**0.887**	-0.384	**0.842**	1									
TH	_0.408_	-0.162	-0.088	0.076	1								
Cl⁻	**0.686**	-0.352	**0.692**	**0.803**	-0.098	1							
HCO₃⁻	0.356	0.239	0.098	0.275	0.274	0.109	1						
SO₄²⁻	**0.598**	-0.195	**0.590**	**0.668**	0.011	_0.486_	0.228	1					
NO₃⁻	-0.113	0.280	0.005	-0.138	-0.133	-0.063	-0.066	-0.238	1				
Ca²⁺	_0.392_	-0.240	-0.045	0.062	**0.944**	-0.116	0.197	0.018	-0.060	1			
Mg²⁺	0.385	-0.079	-0.118	0.081	**0.958**	-0.073	0.317	0.003	-0.184	**0.810**	1		
Na⁺	**0.794**	**-0.513**	**0.520**	**0.690**	0.363	**0.624**	0.255	0.363	-0.176	0.337	0.352	1	
K⁺	**0.703**	-0.386	**0.552**	**0.653**	0.044	**0.674**	0.235	_0.476_	-0.110	0.022	0.058	**0.802**	1

Bold indicates correlation is significant at the 0.01 level (2-tailed).
Underline and italics indicate correlation is significant at the 0.05 level (2-tailed)
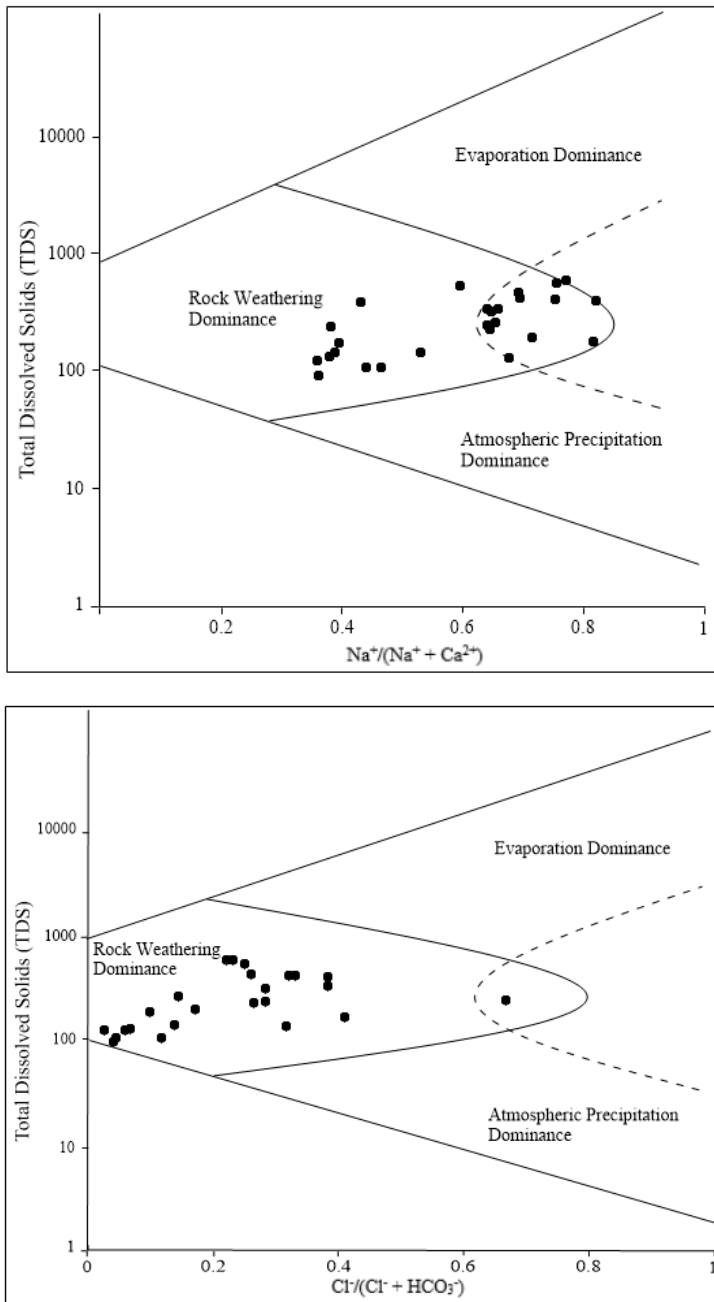
Fig. 4 Gibbs plots depicting dominant mechanism controlling groundwater chemistry

The elevated Cl^- and SO_4^{2-} loadings, however, may indicate the impacts of domestic and atmospheric processes (Sethy et al., 2016). Additionally, PC-2, which accounted for 21.39% of the overall variation, had significant Ca^{2+} (0.911) and Mg^{2+} (0.941) loadings. This demonstrated ionic exchange related to the weathering of silicate. High pH (0.832) and HCO_3^- (0.671) loadings in PC-3 explained 14.38% of the overall variance. The groundwater samples' pH values (6.41–78.3) revealed that bicarbonate ions had a significant impact (Singh et al., 2012). High pH loadings indicated both biological and atmospheric controls as well as speciation reactions that resulted in inorganic carbon ions in solution.
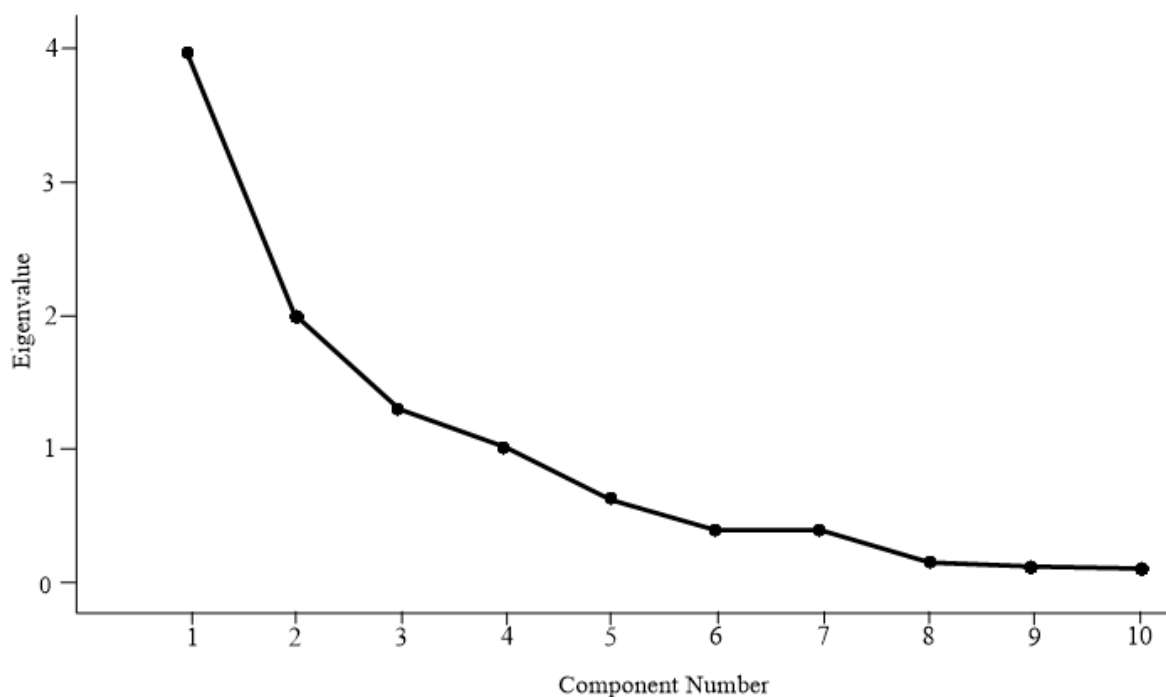
Fig. 5 Scree plot showing Eigenvalues of the principal components

Table 4 Varimax orthogonal rotated loadings from Principal component analysis (PCA) of standardized water quality parameters

Parameters	Rotated Components		
	PC-1	PC-2	PC-3
pH	-0.336	-0.133	**0.832**
TDS	**0.911**	0.057	-0.086
Cl	**0.857**	-0.152	-0.153
HCO3	0.383	0.430	**0.671**
SO4	**0.721**	-0.007	0.044
NO3	-0.143	-0.212	0.367
Ca2+	-0.039	**0.911**	-0.157
Mg	0.010	**0.941**	-0.009
Na	**0.765**	0.384	-0.284
K	**0.844**	0.060	-0.151
Eigen value	3.663	2.139	1.438
% variance	36.631	21.392	14.382
Cumulative % variance	36.631	58.023	72.405

Groundwater drinking quality

The spatial distribution maps for physic-chemical properties, major cations and anions are presented in Figure 6. TDS levels were low, with a mean value of 282 mg/l and a range of 96 mg/l to 590 mg/l. The groundwater's low salt concentration made it safe to drink without worrying about purgative effects or digestive discomfort (WHO, 2011; Prasanth et al., 2012; Selvakumar et al., 2014; Sethy et

al., 2016; Sharma et al., 2017). According to Davis & Dewiest's (1966) classification system, about 88.5% of the groundwater samples could be desirable, while the remaining 11.5% might be permissible for drinking (Table 5).

The average total hardness (TH) of the groundwater samples was 158.5 mg/l, ranging from 32.35 mg/l to 291 mg/l. These are moderate to high values, which show that in the groundwater of the study area, divalent alkali earth metals prevailed over monovalent alkali metals. The groundwater samples were soft (7.7%), moderately hard (34.6%), and hard (57.7%), according to Sawyer and McCarthy (1967). With an average of 483 µS/cm, the electrical conductivity (EC) values ranged from 26 µS/cm to 1180 µS/cm. Mineral dissolution and ion-exchange influence EC variation (Singh et al., 2012; Asiwaju-Bello et al., 2021).

Using Todd's classification (Todd, 1980), Table 5 shows that 26.9%, 42.3%, and 30.8% of the groundwater samples were permissible, good and excellent for drinking respectively. The groundwater samples' hydrogen-ion activity (pH), which ranged from 6.4 to 7.8, had a mean value of 7.2. As a result, 20% of samples were mildly acidic, and 80% of samples were alkaline. However, all of the pH levels were within the range (6.5 - 8.5) recommended for drinking by the Standard Organization of Nigeria (SON, 2007) and the World Health Organization (WHO, 2011). As may be expected naturally in such a continental region, the groundwater in the research location was predominately composed of calcium carbonate (Ca^{2+} and HCO_3^- ions). The order of the major anions in terms of relative abundance was $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$, whereas $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ was the order of the major cations. The most likely source of the calcium ions (Ca^{2+}) whose values ranged between 9.79mg/l and 60.38 mg/l was calcite/dolomite or silicate. The concentrations of magnesium ions (Mg^{2+}) varied from 1.92 mg/l to 34.08 mg/l. Instead of magnesite and dolomite, detrital minerals were the most likely sources of magnesium in the groundwater samples.

Table 5 Classification of groundwater of the study area for drinking and irrigation purposes based on Total dissolved solids, TDS, total hardness and electrical conductivity

Parameter	Range	Classification	No. of samples	% of samples
TDS (mg/l) (Davis and Dewiest, 1966)	< 500	Desirable for drinking	23	88.5
	500 – 1000	Permissible for drinking	3	11.5
	1000 – 3000	Useful for irrigation	-	-
	> 3000	Unfit for drinking and irrigation	-	-
TH as $CaCO_3$ (mg/l) (Sawyer and McCarthy, 1967)	< 75	Soft	2	7.7
	75 – 150	Moderately hard	9	34.6
	150 – 300	Hard	15	57.7
	> 300	Very hard	-	-
EC (µS/cm) (Todd, 1980)	< 250	Excellent	8	30.8
	250 – 750	Good	11	42.3
	750 – 2000	Permissible	7	26.9
	2000 – 3000	Doubtful	-	-
	> 3000	Unsuitable	-	-

The interpolated spatial distribution for the major cations and anions are presented in Figure 6b and 6c. The level of dissolved sodium (Na^+), which ranged from 12.30 to 90.0 mg/l, may have been caused by anthropogenic activities or by the weathering of sodic silicates. K^+ levels ranged from 4.40 to 56.00 mg/l in the groundwater samples. The acceptable limits for Ca^{2+}, Mg^{2+}, and Na^+ concentrations in drinking water were 75 mg/l, 50 mg/l, and 200 mg/l, respectively (SON, 2007; WHO, 2011). However, only 11 samples (42.3%) out of 26 samples reached the permissible drinking water level of 12 mg/l based on K^+ concentration values. Chloride (Cl^-) concentration ranged from 3.64 to 98.40 mg/l whereas bicarbonate ion (HCO_3^-) concentration varied from 24.00 to 280.00 mg/l. The fact that bicarbonate and chloride have such a large concentration difference (HCO_3^- >>> Cl^-) implies a continental environment and points to the breakdown of carbonate minerals. The ranges for SO_4^{2-} and NO_3^- concentrations were respectively 3.43 to 15.24 mg/l and 0.05 to 0.16 mg/l.
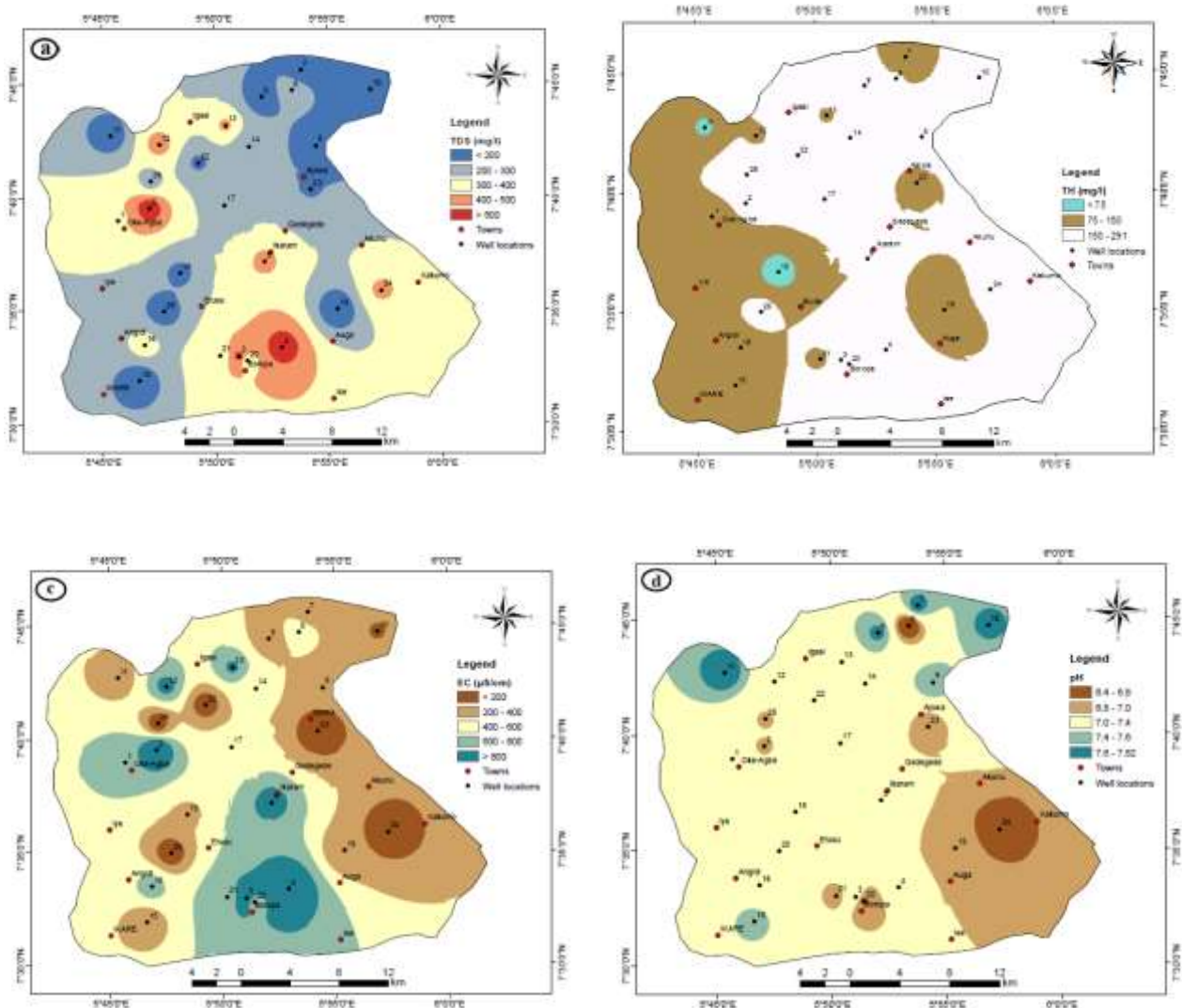

Fig. 6a. Spatial distribution of (a) TDS (b) Total hardness (TH) (c) Electrical conductivity (EC) (d) Hydrogen ion concentration (pH)

Mineral dissolution, anthropogenic effects, and atmospheric deposition are common sources of sulfates (WHO, 2011). Anthropogenic activities associated with the emission of inorganic nitrogenous fertilizers and manures, industrial wastes, and home activities are potential sources of nitrate concentrations in groundwater. The source was most likely natural and not human, though, because the groundwater samples' nitrate concentration was low (10 mg/l) (Selvakumar et al., 2017). The interpolated spatial fluctuations of HCO_3^-, Cl^-, SO_4^{2-}, and NO_3^- for the study region were displayed in Figures 6c. All the anionic concentrations were well below drinking water permissible limits (SON, 2007; WHO, 2011).
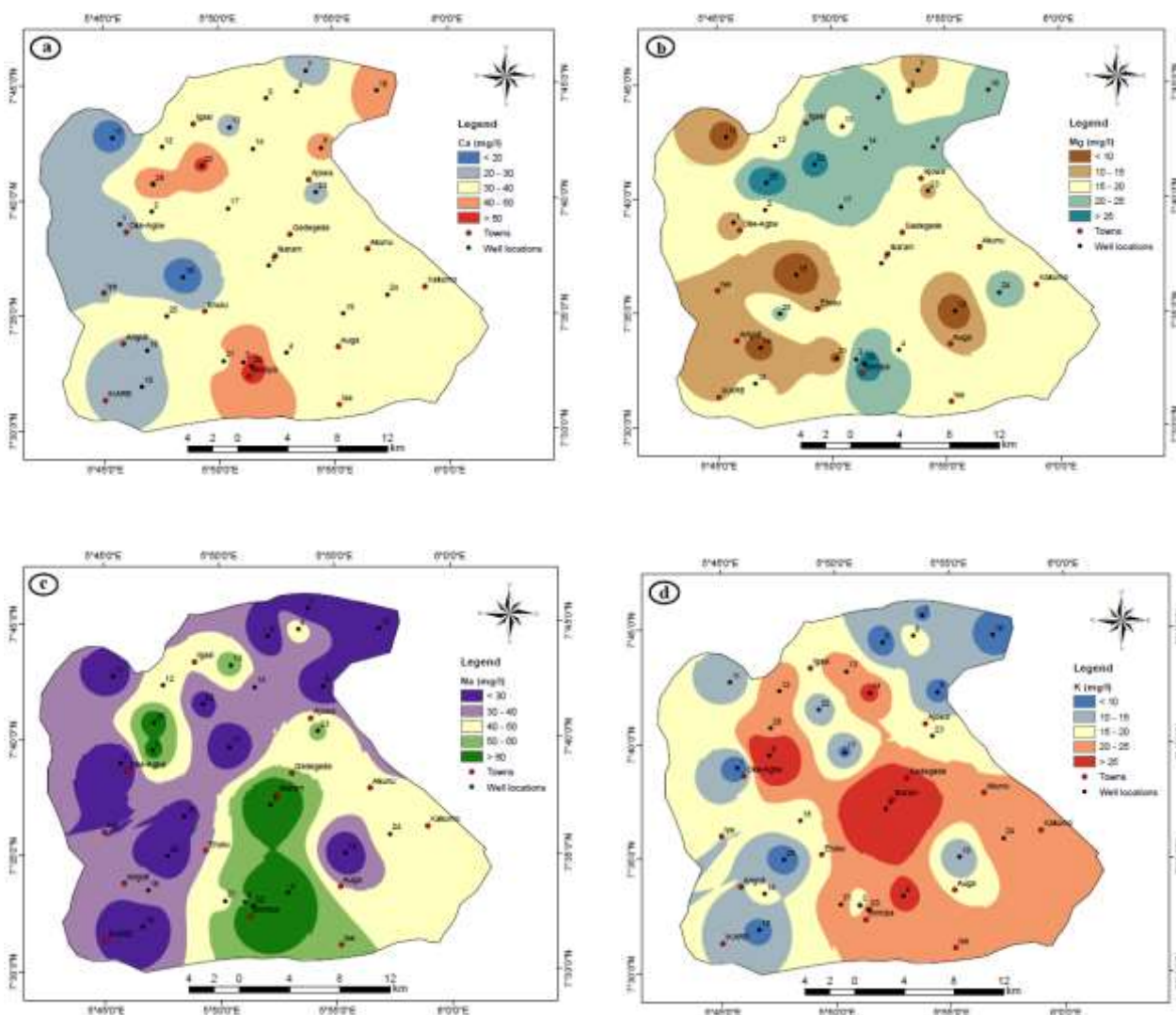

Fig. 6b. Spatial distribution of major cations (a) Ca^{2+} (b) Mg^{2+} (c) Na^+ (d) K^+

Hydrogeochemical facies

The Piper (1944) diagram is a tool for identifying different types of water in a region, which provides information about how groundwater's hydrogeochemical components have changed over time and helps to understand the region's hydrogeological regime (Sethy et al., 2016). The Piper plot showed that there were four different water types in the study area, with Ca-HCO3, mixed Ca-Na-HCO3,

mixed Ca-Mg-Cl, and Na-Cl hydrochemical facies dominating the others (Figure 7). Twenty-six groundwater samples totaled, with sixteen (or about 62%) plotted in the Ca-HCO₃ field, four (or roughly 15%) in the Mixed CaNaHCO₃ field, four more (or roughly 15%) in the CaMgCl field, and the final two samples (or roughly 8%) in the NaCl field. Twenty of the samples (about 77%) were plotted on the left side of the diamond field, according to the Piper diagram. This supports the earlier inference made by moderate to high values of total hardness that alkaline earth metals ($Ca^{2+} + Mg^{2+}$) predominated over alkali metals ($Na^+ + K^+$).
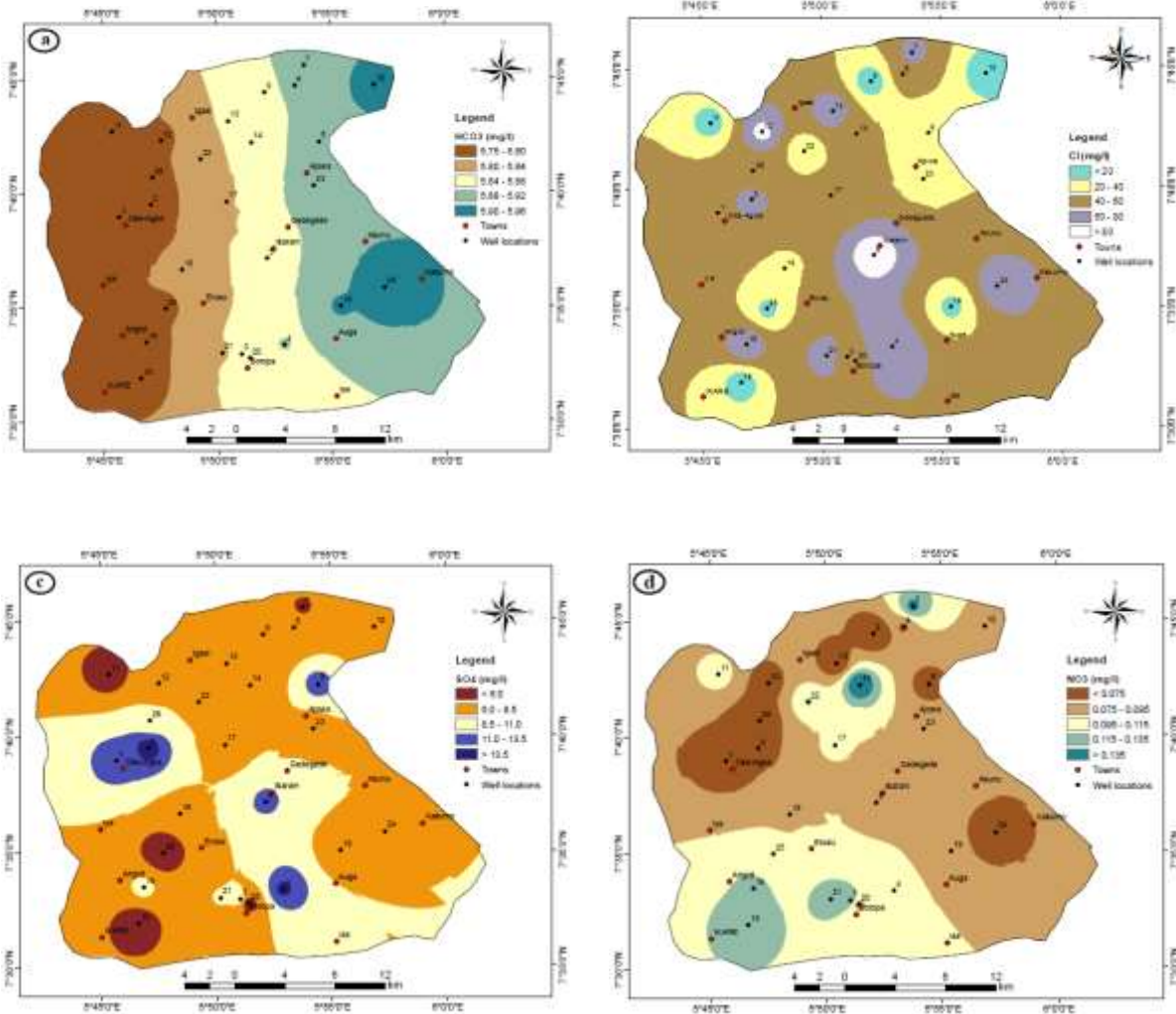

Fig. 6c. Spatial distribution of anions (a) HCO_3^- (b) Cl^- (c) SO_4^{2-} (d) NO_3^-

Additionally, $CO_3^- + HCO_3^-$ (about 75%) outperformed $SO_4^{2-} + Cl^-$ (about 25%) in the diamond field. Ca^{2+} and HCO_3^- predominance indicated a continental environment as would be expected inland. According to data from different sections of the region (Owoseni et al., 2013; Asiwaju-Bello et al., 2021) on basement complex terrain, the hydrochemical facies (Ca-HCO₃) that was most common showed silicate minerals were dissolving as a result of water-rock interactions (Mondal *et al.,* 2012). Two of the samples have NaCl facies that may be a result of anthropogenic activity.

Groundwater irrigation quality

To assess the quality and suitability of groundwater in the study area, comparative ratios of Na^+ (sodium adsorption ratio, residual sodium carbonate, and soluble sodium percent), total salt concentration (electrical conductivity, EC), water hardness (as total hardness), soil permeability (permeability index), relative proportions of Mg^{2+} (magnesium adsorption ratio), and Kelly ratio were used.
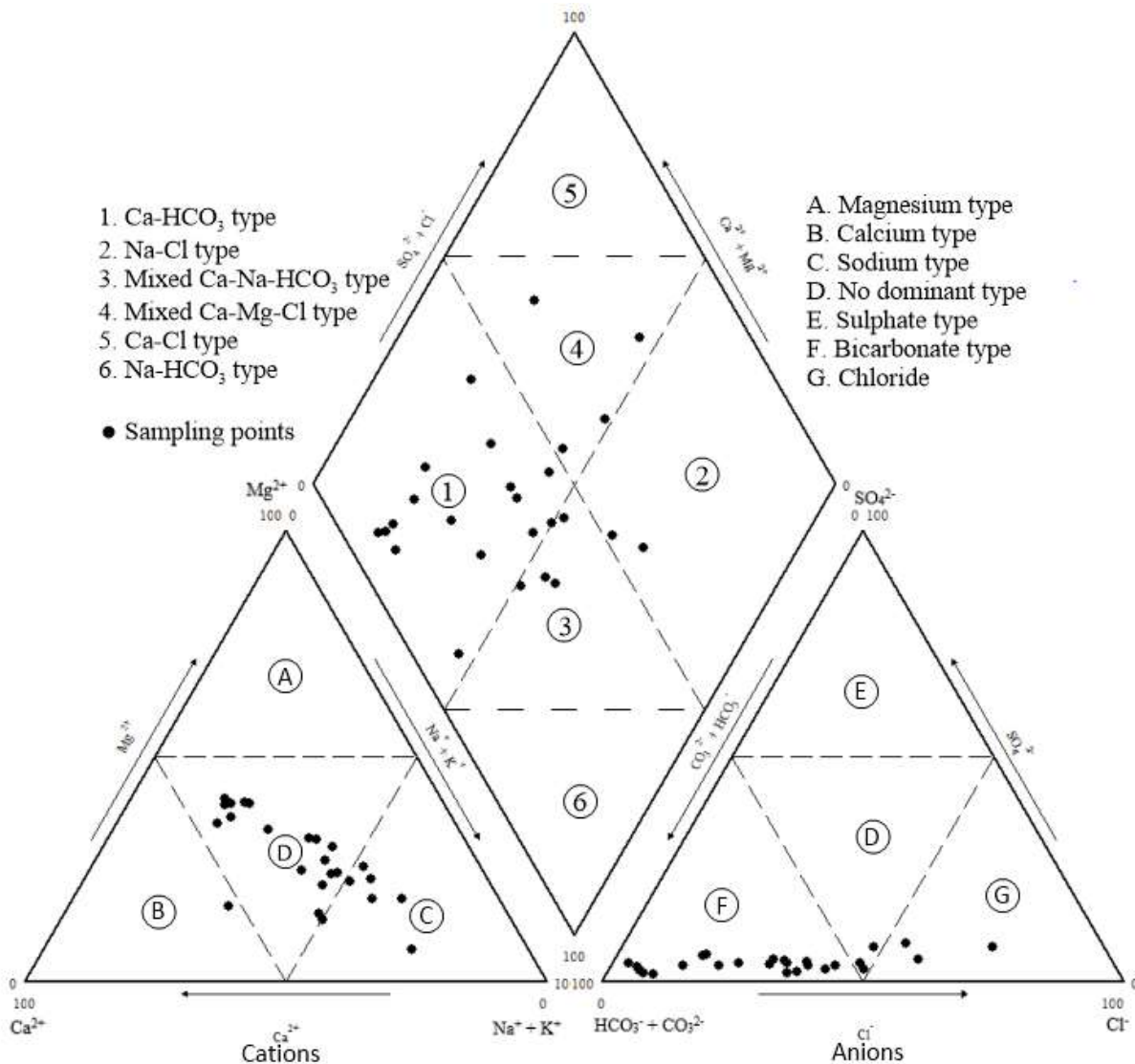

Fig. 7 Piper trilinear diagram showing groundwater hydrochemical facies

The groundwater samples collected from the research region for irrigation are shown in Table 6 with their descriptive statistics and classification. According to Hanson et al. (2006), Singh et al. (2008), Li et al. (2011), and others, the impacts of excess salts in groundwater modify osmotic pressure and metabolic processes, limit water intake, and slow plant development and yield. SAR values ranged from 0.45 to 3.012 (Figure 8a). All of the groundwater samples met Richards' (1954) classification criteria and were suitable for irrigation. The percentage of soluble sodium (SSP or %Na) has an

impact on soil permeability. It was therefore considered when analyzing the groundwater. With a mean value of 39.262, the values of %Na ranged from 18.215 to 70.514 (Figure 8b). According to Wilcox (1955; Todd 1980), of the 26 samples, 5 (19.2%), 6 (23.1%), 13 (50%) and 2 (7.7%) were excellent, good, permissible, and doubtful respectively (Figure 9). No sample was inappropriate. The average value of the electrical conductivity (EC), which ranged from 26.22 to 1180, was 482.63. According to the findings, 8 (30.8%), 11 (42.3%), and 7 (26.9%) samples, respectively, belonged to excellent, good, and allowable for irrigation (Todd, 1980). Out of the 26 groundwater samples, around 31% fell into the low salinity with low sodium risk group (C1S1), making them the most suitable for irrigational use, according to the plot of SAR vs EC on the US salinity map (Figure 10).

Table 6 Descriptive statistics and classification of groundwater samples of the study area for irrigation purposes

| Parameters	Groundwater (n = 26)				Range	Class	No. of samples	% of samples
	Min.	Max.	Mean	SD				
SAR (Richards, 1954)	0.453	3.012	1.380	0.745	<10	Excellent	26	100
					10 - 18	Good	-	-
					18 - 26	Doubtful	-	-
					> 26	Unsuitable	-	-
% Na (Wilcox, 1955; Todd, 1980)	18.215	70.514	39.262	15.087	<20	Excellent	5	19.2
					20 – 40	Good	6	23.1
					40 – 60	Permissible	13	50.0
					60 – 80	Doubtful	2	7.7
					> 80	Unsuitable	-	-
EC (Todd, 1980)	26.200	1180.0	482.63	364.221	< 250	Excellent	8	30.8
					250 – 750	Good	11	42.3
					750 – 2000	Permissible	7	26.9
					2000 – 3000	Doubtful	-	-
					> 3000	Unsuitable	-	-
RSC (Raghunath, 1987)	-4.201	2.690	-0.327	1.429	< 1.25	Good	22	84.6
					1.25 – 2.50	Doubtful	3	11.5
					> 2.50	Unsuitable	1	3.8
MAR (Paliwal, 1972)	23.937	53.414	44.716	8.614	< 50	Suitable	19	73.1
					> 50	Unsuitable	7	26.9
PI (Doneen, 1964)	14.157	76.739	37.360	12.968	> 75	Safe	1	3.8
					25 – 75	Moderate	23	88.5
					< 25	Unsafe	2	7.7
KR (Kelly, 1940)	0.168	1.679	0.591	0.367	< 1	Suitable	23	88.5
					> 1	Unsuitable	3	11.5
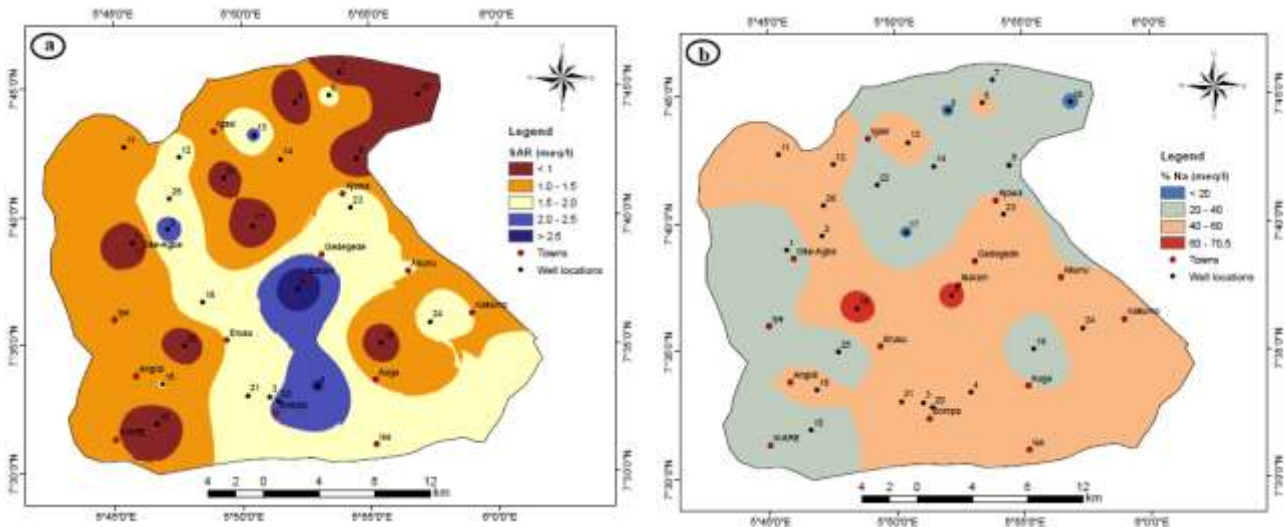
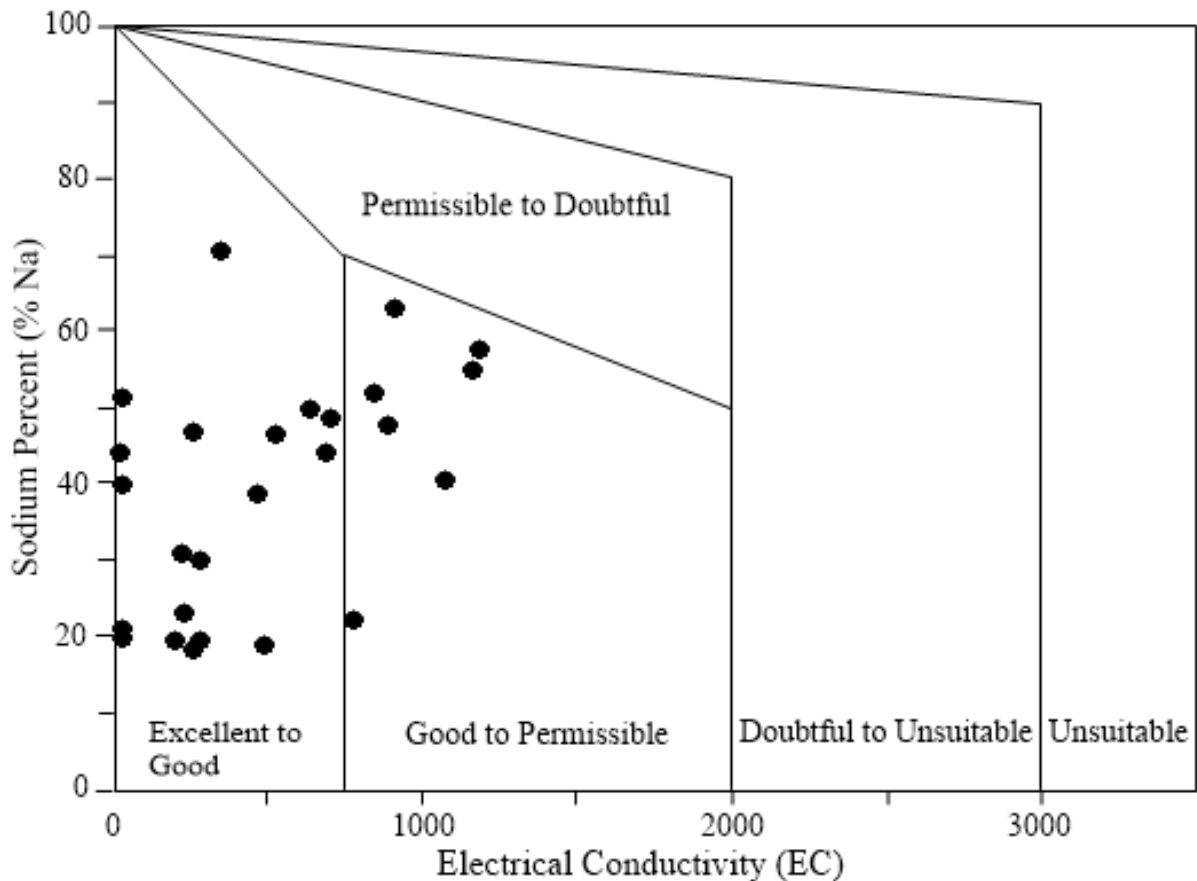**Fig. 8** Spatial variation map for (a) SAR (b) %Na

Fig. 9 Wilcox diagram for classification of groundwater based on EC and % Na

About 42% of the samples were moderately suitable for irrigation because they were in the medium salinity and low sodium hazard class (C2S1). Before they could be considered for irrigation, the remaining 27% of the samples with the high salinity but low sodium risk category (C3S1) required

salinity management (Selvakumar et al., 2017). The majority of the groundwater samples were excellent for irrigation purposes based on the information presented above (Kawo and Karuppannan, 2018).

Studies on the appropriateness of irrigation water sometimes include residual sodium carbonate (RSC), an expression of the relative proportion of excess sodium carbonate present in groundwater that impacts water and air circulation in soils. The average RSC result was -0.32722, ranging from -4.201 to 2.690 (Figure 11a). 22 samples (84.6%), 3 samples (11.5%), and only 1 sample (3.8%) were deemed good, doubtful, and inappropriate for irrigational usage, respectively, according to Raghunath (1987). Increased soil alkalinity, alterations to the soil's structure, and ultimately lower crop yields are the effects of too much magnesium (Elango et al., 2003; Chidambaram et al., 2013). With a mean value of 44.7, the magnesium adsorption ratio (MAR) for the study area ranged from 23.9 to 53.4 (Figure 11b). According to Paliwal (1972), 73% of the groundwater samples were deemed suitable for irrigation with MAR 50. The remaining 27% may not be suitable for irrigation since they surpassed the permitted limit.

With a mean value of 37.36, the permeability index (PI) values ranged between 14.157 and 76.739 (Figure 11c). According to PI results, 3.8%, 88.5%, and 7.7% of the water samples were respectively safe, moderately safe, and unsafe for irrigational use (Doneen, 1964). The samples' computed Kelly ratios (KR) ranged from 0.168 to 1.679, with an average of 0.591 (Figure 11d).
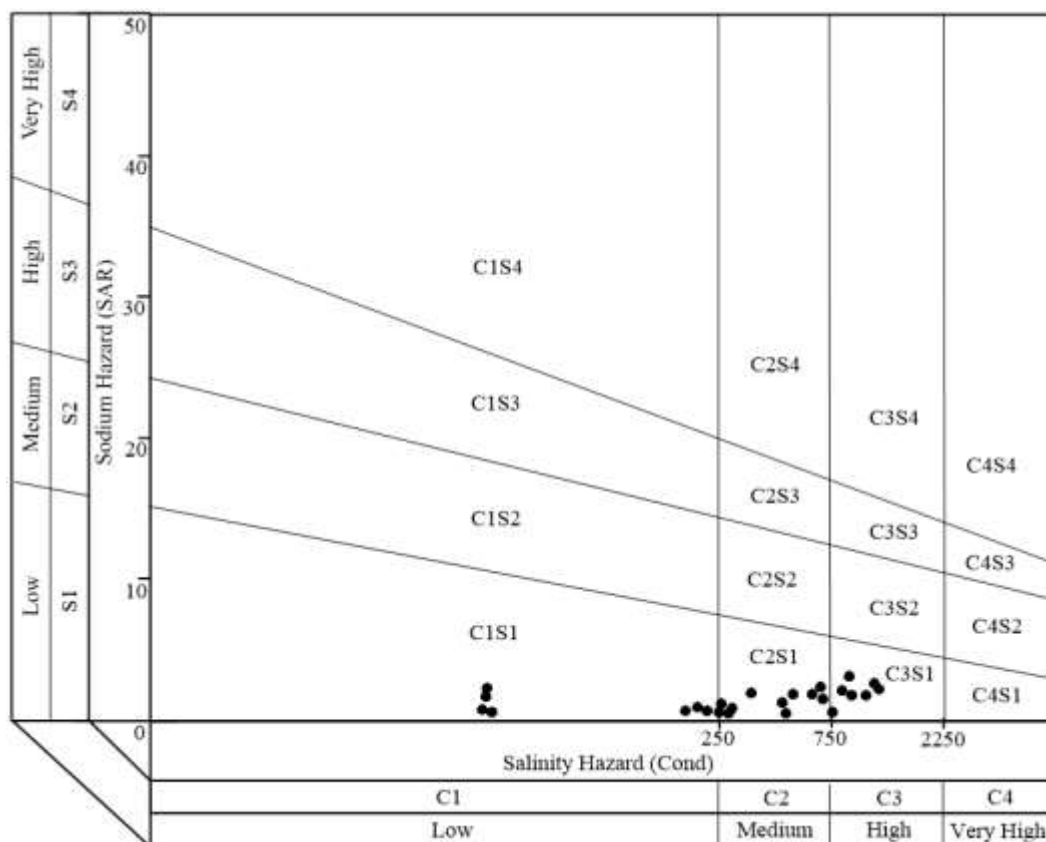

Fig. 10 Classification of irrigation water based on US Salinity diagram
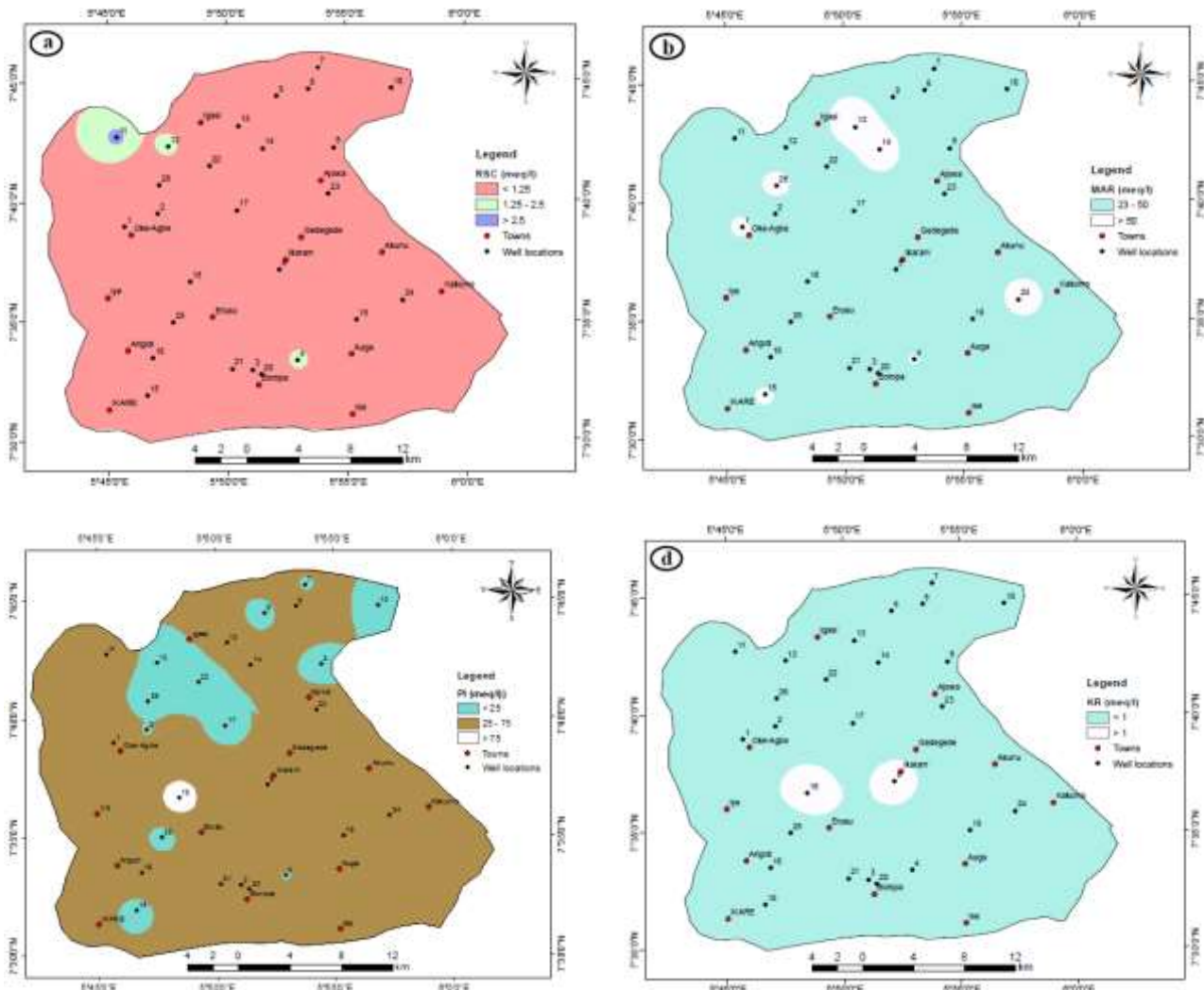
Fig. 11 Spatial variation map for (a) Residual Sodium Carbonate (RSC) (b) Magnesium Adsorption Ratio (MAR) (c) Permeability Index (PI) (d) Kelly Ratio (KR)

In total, 23 samples (88.5%) with KR 1 were deemed suitable for irrigation, while the remaining three samples (11.5%) with KR > 1 may not be (Kelly, 1940).

Groundwater suitability

Drinking water quality index (DWQI)
The allocated weights and computed relative weights for the drinking water quality index (DWQI) computation are displayed in Table 7. In the research area, the DWQI computation yielded values ranging from 32.15 to 87.93 (Table 8). Sahu and Sikdar (2008) indicated that out of the twenty-six groundwater samples, eleven (42.31%) could be categorized as exceptional water and the remaining fifteen (57.69%) as good water. Figure 12 illustrates the regional variance of the DWQI in Akoko and its surroundings.

Table 7 Weights and relative weights for the DWQI parameters

Parameters	DWQI weight	
	Weight (w_i)	Relative weight (W_i)
pH	4	0.111
EC (µS/cm)	4	0.111
TDS (mg/l)	5	0.139
TH (mg/l)	3	0.083
Cl^- (mg/l)	1	0.028
HCO_3^- (mg/l)	3	0.083
SO_4^{2-} (mg/l)	3	0.083
NO_3^- (mg/l)	5	0.139
Ca^{2+} (mg/l)	2	0.056
Mg^{2+} (mg/l)	2	0.056
Na^+ (mg/l)	3	0.083
K^+ (mg/l)	1	0.028

Table 8 DWQI for groundwater samples in the study area

Sample code	DWQI	Type of water
S1	53.70	Good water
S2	87.93	Good water
S3	79.47	Good water
S4	84.76	Good water
S5	78.63	Good water
S6	51.96	Good water
S7	37.70	Excellent water
S8	49.47	Excellent water
S9	45.44	Excellent water
S10	45.60	Excellent water
S11	33.40	Excellent water
S12	70.29	Good water
S13	67.90	Good water
S14	57.83	Good water
S15	37.24	Excellent water
S16	53.69	Good water
S17	52.44	Good water
S18	32.15	Excellent water
S19	34.04	Excellent water
S20	78.27	Good water
S21	58.04	Good water
S22	49.30	Excellent water
S23	39.48	Excellent water
S24	50.64	Good water
S25	39.37	Excellent water
S26	59.00	Good water

Irrigation water quality index (IWQI)

Table 9 provides the irrigation water standards (FAO, 1994), allocated weights, and relative weights used in the derivation of the irrigation water quality index (IWQI). According to the IWQI results for the research area, values ranged from 25.16 to 248.90 (Table 10). Twenty-six groundwater samples had excellent, good, bad, and very poor water, respectively, in six (23.08%), twelve (46.15%), six (23.08%), and two (7.69%) (Table 11). No sample was unfit for irrigation purpose. Figure 13 depicts the IWQI's spatial variance within the research area.

Conclusion

In order to improve food security and ensure water security, rain-fed agriculture, which is defined by seasonal rainfall patterns, must be integrated with more sustainable irrigated agriculture in Nigeria's Akoko senatorial region. The current study used a combination of analytical, statistical, and geospatial tools to identify the hydrogeochemical processes influencing groundwater quality variation.
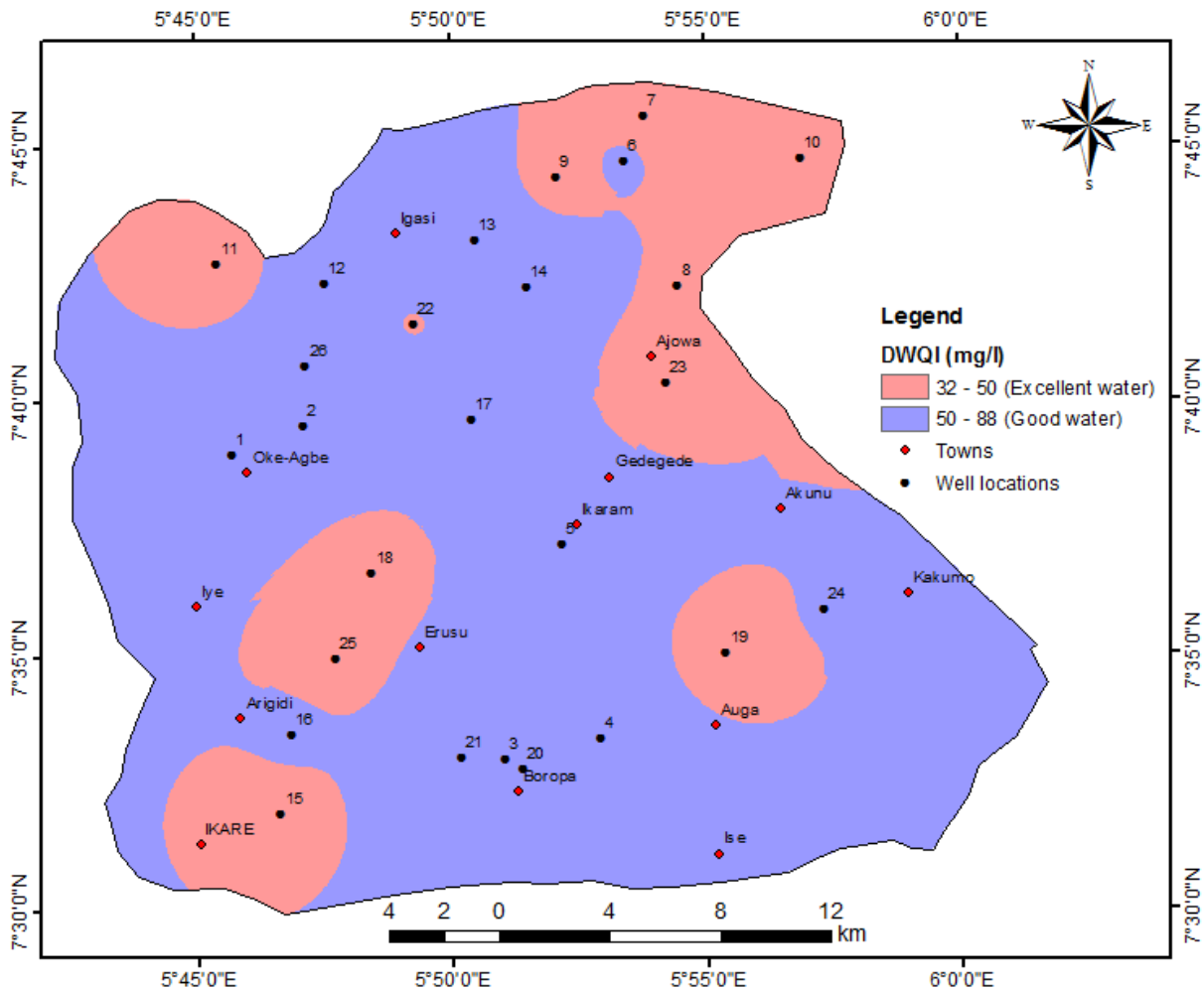

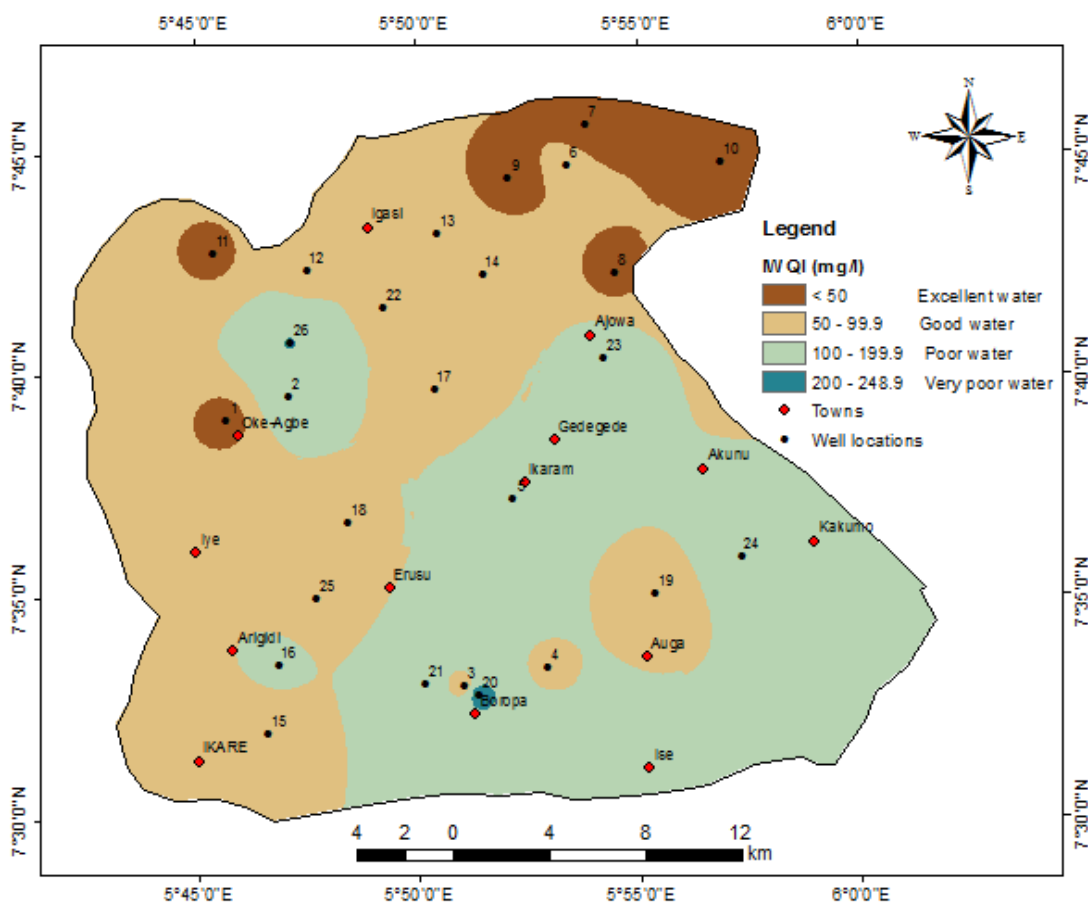**Fig. 12** Spatial variation map of DWQI

Fig. 13 Spatial variation map of IWQI

Table 9 Standards, weight and relative weight for the IWQI parameters

Parameters	FAO (1994) Standards	IWQI weight	
	Max. desirable	Weight (w_i)	Relative weight (W_i)
pH	8.5	3	0.073
EC (µS/cm)	3000	5	0.122
TDS (mg/l)	2000	5	0.122
Cl^- (mg/l)	1063	5	0.122
HCO_3^- (mg/l)	610	1	0.024
SO_4^{2-} (mg/l)	960	5	0.122
NO_3^- (mg/l)	10	5	0.122
Ca^{2+} (mg/l)	400	3	0.073
Mg^{2+} (mg/l)	60	3	0.073
Na^+ (mg/l)	919	4	0.098
K^+ (mg/l)	2	2	0.049
			$\Sigma = 1.000$

The groundwater under investigation is mildly acidic to alkaline. The suggested safe limits are not exceeded for any anionic concentrations (SON, 2007; WHO, 2011). Similar to this, K^+ has values that are above the allowable limits in 57.7% of the groundwater samples, but all other cationic concentrations are much below the permitted limits for drinking water.

Table 10 IWQI for groundwater samples in the study area

Sample code	IWQI	Type of water
S1	25.85	Excellent
S2	139.70	Poor
S3	53.53	Good
S4	86.68	Good
S5	155.28	Poor
S6	59.59	Good
S7	34.31	Excellent
S8	33.30	Excellent
S9	25.16	Excellent
S10	32.16	Excellent
S11	35.43	Excellent
S12	76.51	Good
S13	76.13	Good
S14	80.94	Good
S15	51.50	Good
S16	114.22	Poor
S17	60.94	Good
S18	80.78	Good
S19	61.78	Good
S20	248.90	Very poor
S21	142.30	Poor
S22	87.43	Good
S23	151.06	Poor
S24	139.09	Poor
S25	62.50	Good
S26	202.91	Very poor

The area had a mostly $Ca\text{-}HCO_3$ water type, which was supported by PCA and DWQI and indicated silicate minerals were dissolving due to water-rock interactions. Cl^-, SO_4^{2-}, Na^+, K^+, EC, TDS, and other water-rock interaction-related variables have a significant impact on DWQI. In the majority (about 77%) of the samples, alkali earth metals ($Ca^{2+} + Mg^{2+}$) predominated over alkali metals ($Na^+ + K^+$), while $CO_3^- + HCO_3^-$ (about 75%) exceeded $SO_4^{2-} + Cl^-$ (about 25%) to indicate a continental environment that is predicted inland.

There were signs of Na^+ depletion against Cl^-, the presence of weathering processes, and the predominance of the exchange of $Na^+ + K^+$ in the aquifer by $Ca^{2+} + Mg^{2+}$ in groundwater. Other significant positive correlations indicate that seasonal fluctuations and evaporation may have an effect on the chemistry of groundwater.

Table 11 Range of IWQI and classification of groundwater samples (Abbasnia *et al.,* 2018)

IWQI Range	Type of groundwater	Number of samples	% Samples
< 50	Excellent water	6	23.08
50 – 99.99	Good water	12	46.15
100 – 199.99	Poor water	6	23.08
200 – 299.99	Very poor water	2	7.69
≥ 300	Unsuitable water	Nill	Nill

The majority of the groundwater in the research area might be deemed appropriate for irrigated agriculture, while the minority would need salinity management. The study's findings generally established the potability of groundwater. Additionally, in the Akoko senatorial district of southwest Nigeria, efficient policies for the sustainable management of groundwater resources had to be developed to improve water security for various water users, guarantee an appropriate supply of safe drinking water, and assure food security through irrigated agriculture.

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