



Hydrogeochemical evaluation and geospatial distribution modeling of the major ion chemistry of groundwater and their suitability for drinking and irrigation in Lagelu, Southwestern Nigeria

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Abstract

Shallow groundwater is an essential resource for domestic, agricultural, and small-scale industrial uses in Lagelu in Oyo State, Southwestern Nigeria. A total of 20 representative groundwater samples were collected from different hand-dug wells and analyzed for the major cations, anions, and heavy metals to establish their suitability for drinking and irrigation. Geospatial variation maps of the major cations and anions were produced using the inverse distance weighted algorithm. The results of the respective concentrations of pH, TDS, EC, HCO_3^- , NO_3^- , SO_4^{2-} , Cl^- , PO_4^{2-} , Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Zn^{2+} , Cu^+ , Pb^{2+} , and As^+ except Fe^{2+} are within the recommended range set by the World Health Organization (WHO) and Nigerian Industrial Standards for Drinking Water Quality (NSDWQ). Based on the hydrogeochemical facies, the groundwater belongs to $\text{Na}^+ - \text{K}^+ - \text{Cl}^- - \text{SO}_4^{2-}$, and $\text{Ca}^{2+} - \text{Mg}^{2+} - \text{Cl}^- - \text{SO}_4^{2-}$ water types. Gibb's diagram shows that the interaction of rocks and water dominate the processes that control the ionic compositions of the groundwater due to rock weathering and dissolution. The correlation matrix that specifies the ion concentration relationship showed that TDS, K^+ , and Fe^{2+} strongly correlate positively with EC, Na^+ , and Ca^{2+} , respectively. CO_3^{2-} , Na^+ , and Cu moderately correlate positively with Cl^- , Mg^{2+} , and pH, respectively. The indices used to determine groundwater suitability for irrigation classified over 90% of the samples as suitable for irrigation.

Keywords Physico-chemical parameters · Geospatial mapping · Drinking water quality · Hydrogeochemical facies · Irrigation suitability

Introduction

Groundwater plays an essential role in the economic development of countries as it is utilized for domestic, industrial, and agricultural purposes (Reilly et al. 2008; Sefie et al. 2015). Groundwater occurs in basement rock complex terrains in fractured and weathered crystalline rock formations (Clark 1985; Jones 1985; Bala and Ike 2001). Hydrogeochemical classification of groundwater describes the type of water, source, and level of contamination of aquifers in an area (Aghazadeh et al. 2017; Brhane 2018). Processes such as rock-water interaction, weathering, and mineral dissolution make groundwater chemistry distinctive (Cerar and Urbanc 2013; Sidibé et al. 2019). Hence, the quality of groundwater can be assessed by analyzing its physicochemical properties (Oyegoke et al. 2012). In Lagelu, the study area, water scarcity has led a large population to depend on surface and shallow water sources for domestic, small-scale

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industrial and agricultural purposes. However, wastewater disposal, excessive use of chemical fertilizers, and pesticides pollute the soil and water in the area (John-Dewole 2012). The contamination of these water sources and the accompanying health issues remain the major challenges faced by the people. Consequently, it is pertinent to assess and monitor groundwater quality in order recommend suitable management strategy that can mitigate the possible health issues caused by the contaminants.

Recent studies have shown that anthropogenic activities such as excessive use of chemical fertilizers, urbanization, and industrialization are the main factors affecting groundwater quality. Elumalai et al. (2019) studied groundwater from fractured aquifers and established that the acidic proton nitric cycle and mineral weathering resulted from wastewater intrusion. Mineral dissolution, ion exchanges, rainfall, and evaporation are major factors that influence groundwater's chemical composition, which reflects their reliability for drinking and irrigation purposes (Jang et al. 2016; Mostaza-Colado et al. 2018; Chandrasekar et al. 2021; Karunanidhi et al. 2021; Panneerselvam et al. 2021). Some major cations are essential for crop growth and yields, but the excess concentration of some specific ions negatively influences groundwater use for irrigation (Aravindan and Shankar 2011; Şener et al. 2017; Balamurugan et al. 2020a, b; Soujanya Kamble et al. 2020; Haji et al. 2021). Gidey (2018) geospatially modeled the distribution of groundwater for domestic and agricultural purposes and established that groundwater composition is primarily influenced by modern agricultural practices, industrial wastes, and open landfills.

Emenike et al. (2018) investigated 21 groundwater samples in Abeokuta, Ogun State, Southwestern Nigeria. Their result reveals that 71% of the collected samples are within the slightly acidic range, indicating the dissolution of basement complex rocks. Olofinlade et al. (2018) studied groundwater samples from two contrasting geological formations of Ore and Okitipupa towns in Ondo State, Southwestern Nigeria. Ca^{2+} , Cl^- and HCO_3^- dominate the groundwater and the major cations and anions fall within the WHO permissible limits. Other studies in the Southwestern region reveal that major cations such as sodium, calcium, magnesium, and potassium influence groundwater quality for drinking and irrigation use. Hence, too much concentration of these ions alters the reliability of the groundwater for domestic and agricultural purposes. This excess ion concentration results primarily from too much use of chemical fertilizers and pesticides, wastewater, and industrial waste disposal (Phillips et al. 2010; Oyelami et al. 2013; Oni and Hassan 2013; Tijani et al. 2014; Adewumi et al. 2018; Talabi et al. 2020). However, no study combined both geospatial and hydrogeochemical analysis to evaluate the reliability of groundwater for domestic and agricultural use in Oyo state, southwestern Nigeria.

Geographic Information System (GIS) and IDW interpolation methods are essential tools for assessing and monitoring groundwater properties (Shankar et al. 2011; Magesh and Elango 2019; Karuppappan and Serre Kawo 2020; Panneerselvam et al. 2020; Soujanya Kamble et al. 2020). GIS serves as an effective method to evaluate the spatial distribution of water resources and associated contaminants (Selvam et al. 2013; Al-Rawabdeh et al. 2014; Hussain et al. 2017b). It is a cost-effective method that transforms data into spatial predictions to observe the trends and distributions of water resources and their physicochemical properties.

Shallow groundwater is an essential resource for domestic, agricultural, and small-scale industrial purposes in Lagelu. However, due to the increasing socio-economic development of the area, the pollution of surface water and the environment becomes increasingly severe. Therefore, this research aims to evaluate the physicochemical properties of shallow groundwater and assess its reliability for drinking and irrigation purposes using laboratory analysis, GIS interpolation technique, and statistical methods. This result will provide decision-makers with vital information regarding the groundwater's domestic, agricultural, and industrial usability.

Description of study area

Lagelu L.G.A. is one of the 33 LGA's in Oyo State, Southwestern Nigeria, covering 388 km². It is located on the coordinates 7° 25' N, 3° 55' E and 7° 37' N, 4° 9' E with an altitude that generally ranges from 185 to 270 m high above sea level (Fig. 1). The vegetation is of the guinea savannah, with a climate characterized primarily by the dry and rainy season having a yearly average temperature, precipitation, and relative humidity of 27.1 °C, 1300 mm, and 82.2%, respectively (Egbinola and Amobichukwu 2013).

Insert Fig. 1 here.

Geology and hydrogeology of the study area

The area belongs to the crystalline rocks of the Southwest basement complex of Nigeria (MacDonald et al. 2001). The basement rocks are primarily comprised of major and minor rock groups. The migmatite complex is the most common rock form, containing banded gneiss, augen gneiss, and magnetite. Pegmatites, granites, aplites, diorites, amphibolites, and xenolith comprise the minor rock group (Ajibade et al. 1987). Pegmatites are coarse-grained intrusive rocks that form joints and vein fillings and are easily weathered into clays and sands, acting as the regolith's aquifer system (Rahaman 1976).

Groundwater occurrence in Southwestern Nigeria is essentially semi-confined to unconfined aquifers due to the crystalline nature of the rock types. Nevertheless,

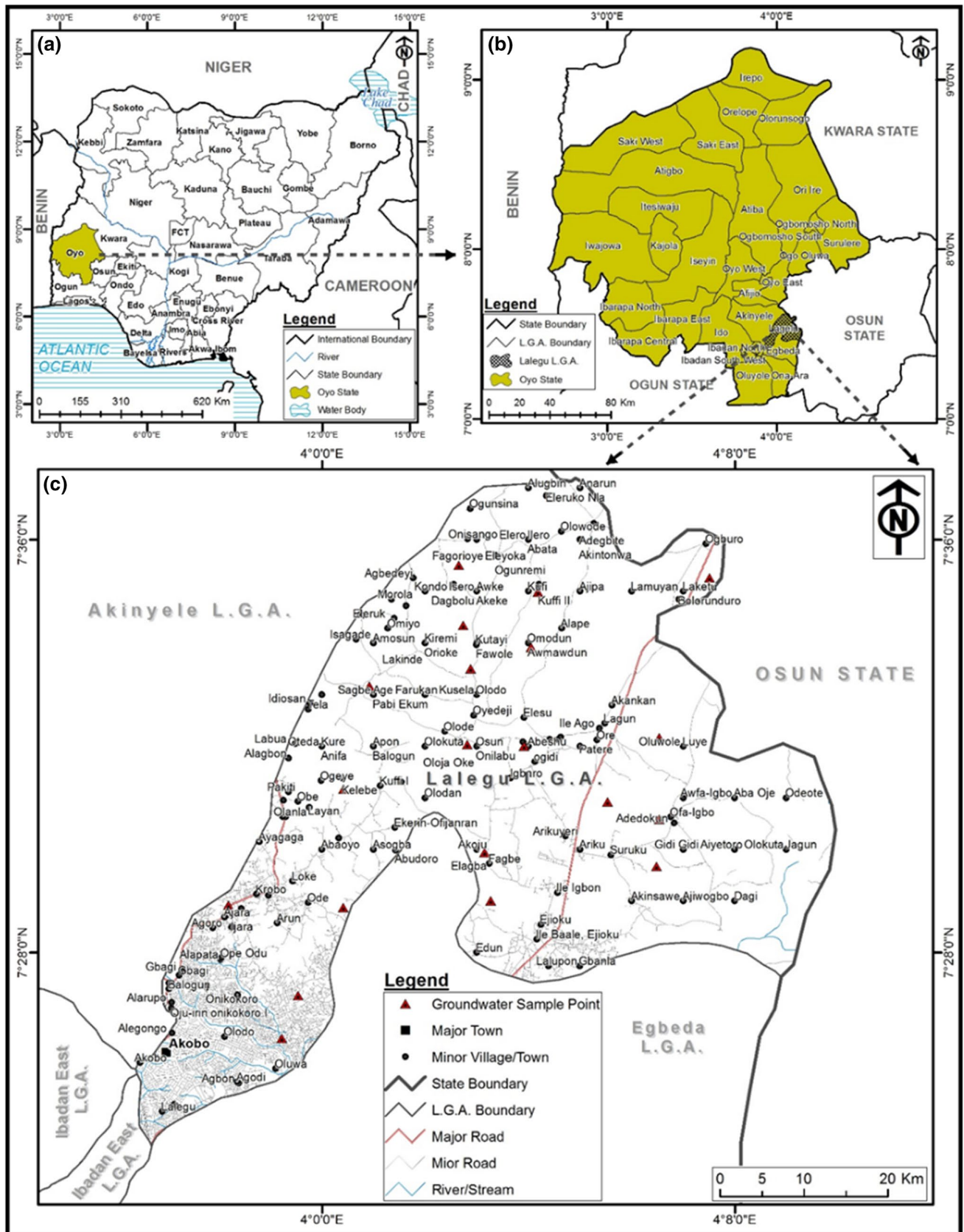


Fig. 1 Map of a Nigeria showing Oyo State, b Oyo State showing Lagelu and c Lagelu showing the groundwater sample points

considerable porosity and permeability develop through fracturing and weathering processes. Borehole lithological logs in the region revealed relatively deep weathering, and joints and rock fractures occur at depths between 30 and 68 m (Adelana et al. 2005). Boreholes in this region are designed to tap water from the weathered zone aquifer or the jointed/fractured basement rock aquifer Oteze (1981). Single-screened or multi-screened boreholes and open wells are drilled through fractured basement rocks yielding a significant quantity of water for the inhabitants. Most aquifers in this region occur within 40 m from the surface under unconfined conditions with a depth to water level rarely exceeding 24 m. Average boreholes water yields in this region are generally <2.5 l/s within estimated depths of 40–80 m with overburden thickness ranging between 3 and 24 m (Ehinola et al. 2006; Adelana et al. 2008). Borehole water yields between 1 and 2 l/s in this region are considered adequate to install motorized submersible pumps, while values of borehole yield <0.5 l/s are still suitable for hand-pumps (Adelana et al. 2008).

Materials and methods

Groundwater representative samples were taken from 20 hand-dug wells in the Lagelu Local Government Area (LGA) in Oyo State, Southwestern Nigeria. The latitudes and longitudes of the sampling points were recorded using GPS (Table 1). Before sampling, the sampling bottles (polyethylene) were

washed three times using the groundwater to be sampled. Then, the water samples were collected in the pre-cleaned polyethylene bottles, transferred to the laboratory, stored in a refrigerator at 4 °C, and analyzed within three (3) days of sampling. Electrical conductivity (EC), total dissolved solids (TDS), and pH were all measured in the field immediately after sampling using digital meters. The physicochemical properties of the cations (K^+ , Na^+ , Ca^{2+} , and Mg^{2+}), anions (HCO_3^- , SO_4^{2-} , NO_3^- , CO_3^- , Cl^- , and PO_4^{2-}) and heavy metals (Zn^{2+} , Cu^+ , Fe^{2+} , Pb^{2+} , and As^+) were analyzed in the laboratory adopting the standard procedure of the American Public Health Association (APHA, 2005). K^+ and Na^+ concentrations were determined by flame atomic absorption spectrophotometer (LS ASS PG-990). Ca^{2+} and Mg^{2+} were analyzed by the EDTA solution titrimetric method. Titrimetry was used for the anions; NO_3^- , CO_3^- , Cl^- , PO_4^{2-} , and HCO_3^- . SO_4^{2-} was analyzed using turbidimetry. The heavy metals were determined by the inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer Optima 3300DV). After ion concentrations analysis, the charge balance error (CBE) was calculated to certify the appropriately high quality, and the standard error for each sample was calculated using Eq. (1) (Wu et al. 2014). Acceptable CBE values with a limit of $\pm 5\%$ were considered (Li et al. 2014):

$$CBE = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100 \quad (1)$$

Table 1 Some physical properties of the groundwater samples measured in situ

Sample point	Elevation (m)	Latitude (N)	Longitude (E)	Appearance	Temperature (°C)
Kelebe	249.00	7° 28' 55"	3° 58' 11"	Turbid white	30.10
Araba	225.00	7° 31' 10"	4° 00' 25"	Clean	31.70
Aba Bale	222.00	7° 32' 02"	4° 02' 49"	Slightly brown	31.10
Farukan	213.00	7° 33' 10"	4° 00' 55"	Clean	31.90
Ayodeji	232.00	7° 33' 30"	4° 02' 53"	Turbid brown	30.10
Sagbe	244.00	7° 34' 20"	4° 02' 44"	Clean	30.60
Dogbolu	227.00	7° 35' 30"	4° 02' 39"	Clean	31.90
Adegbite	252.00	7° 34' 59"	4° 04' 11"	Clean	29.80
Molepin	246.00	7° 33' 55"	4° 04' 03"	Clean	30.00
Ore	228.00	7° 32' 00"	4° 03' 55"	Clean	29.80
Abudoro	210.00	7° 29' 45"	4° 02' 29"	Turbid brown	31.20
Ejioku	238.00	7° 29' 00"	4° 03' 16"	Turbid white	30.90
Onigbede	226.00	7° 28' 42"	4° 00' 47"	Clean	30.80
Sukuru	242.00	7° 30' 55"	4° 05' 32"	Turbid white	28.80
Offa-Igbo	228.00	7° 32' 10"	4° 76' 32"	Slightly brown	29.40
Aba-Ogo	230.00	7° 30' 35"	4° 26' 32"	Clean	30.80
Papa	237.00	7° 35' 05"	4° 70' 53"	Clean	31.10
Odo-Oba	258.00	7° 29' 40"	4° 06' 29"	Clean	29.00
Olodo	230.00	7° 27' 10"	3° 59' 32"	Slightly brown	28.70
Erunmu	220.00	7° 26' 20"	3° 59' 13"	Turbid white	29.10

We compare the physical and chemical constraints of the water samples to the recommended range for suitable drinking water quality set by the World Health Organization (WHO) and Nigerian Industrial Standards for Drinking Water Quality (NSDWQ). The Piper, Durov, and Gibbs diagrams are used to measure and classify the hydrogeochemical properties of groundwater samples.

The inverse distance weighted (IDW) interpolation is a deterministic method whose calculation is based on the closest known locations. The basic concept of this method is that more immediate things are similar to one another than things at a farther distance. Thus, more weights are given to the points closer to the sampling location than those farther. The IDW is an effective tool for the spatial estimation of groundwater quality parameters in unmeasured areas (Magesh et al. 2013; Sarfo and Karuppanan 2020).

Groundwater is primarily utilized for irrigation in the study area, and thus, it is essential to evaluate its reliability in agricultural uses. Sodium absorption ratio (SAR), percentage sodium (%Na), permeability index (PI), magnesium hazards (MH), residual sodium carbonate (RSC), Kelly ratio (KR), and potential salinity (PS) are the major indices to assess the quality of groundwater for irrigation purposes. The following formulas are used to calculate the index value:

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

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+} + Mg^{2+}]}{2}}} \tag{3}$$

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \tag{4}$$

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \tag{5}$$

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \tag{6}$$

$$PS = Cl^- + 0.5 \times SO_4^{2-} \tag{7}$$

$$r1 = \frac{(Na^+ - Cl^-)}{SO_4^{2-}} \tag{8}$$

$$r2 = \frac{[(K^+ + Na^+) - Cl^-]}{SO_4^{2-}} \tag{9}$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \tag{10}$$

Results and discussion

Physico-chemical analysis results

Tables 1 and 2 illustrate the summary of the samples' analyzed physical and chemical properties. The temperature ranges from 4.2 to 18.7 °C, averaged at 14.33 °C. The pH is neutral to alkaline, with values ranging from 6.28 to 8.03 with a mean of 7.41. TDS values varied in a wide range between 133 and 671 mg/L, with a mean of 334.36 mg/L. The EC ranged at 275 and 1368 μS/cm with an average value of 935.71 μS/cm. The higher concentrations of TDS and EC might be due to the water–rock interaction, such as the mineral dissolution and weathering. Among the anions, nitrate (NO₃⁻), bicarbonate (HCO₃⁻), carbonate (CO₃⁻), chlorine (Cl⁻), sulphate (SO₄²⁻) and phosphate (PO₄²⁻) shows concentration values varying between 1.44–22.02, 0.16–1.28, 0.14–0.73, 6.11–35.43, 1.02–32.15 and 4.00–26 mg/L, respectively. For the cations and heavy metals, the concentrations of magnesium (Mg²⁺), calcium (Ca²⁺), potassium (K⁺), sodium (Na⁺), iron (Fe²⁺), zinc (Zn²⁺), copper (Cu²⁺), lead (Pb²⁺) and arsenic (As⁺) varied between 1.03 and 21.62, 6.15 heavy metals, the concentrations of magnesium 45.29, 4.2–33.6, 4.62–34.02, 1.96–5.98, 0.001–0.57, 0.003–0.33, 0.001–0.003 and 0.0–0.001 mg/L in that order.

The drinking water harmless limit established by the (WHO, 2011) and (NSDQW, 2007) is summarized in Table 2. pH, EC, and TDS values fall within the allowable WHO and NSDQW range for water quality. The anions NO₃⁻, SO₄²⁻, and Cl⁻ have the highest values of 22.02, 32.15, 35.43, and 26 mg/L, which fall within the permissible limit for drinking water quality (NSDQW 2007; WHO 2011). However, there are no health limit values proposed for PO₄²⁻ and CO₃⁻. Similarly, the ion concentration values of the cations and heavy metals Mg²⁺, Ca²⁺, K⁺, Na⁺, Zn²⁺, Cu⁺, Pb²⁺, and As⁺ but Fe²⁺ of the samples are lower than the highest range of allowable values set by WHO and NSDQW for quality drinking water (Fig. 2).

Groundwater geospatial mapping

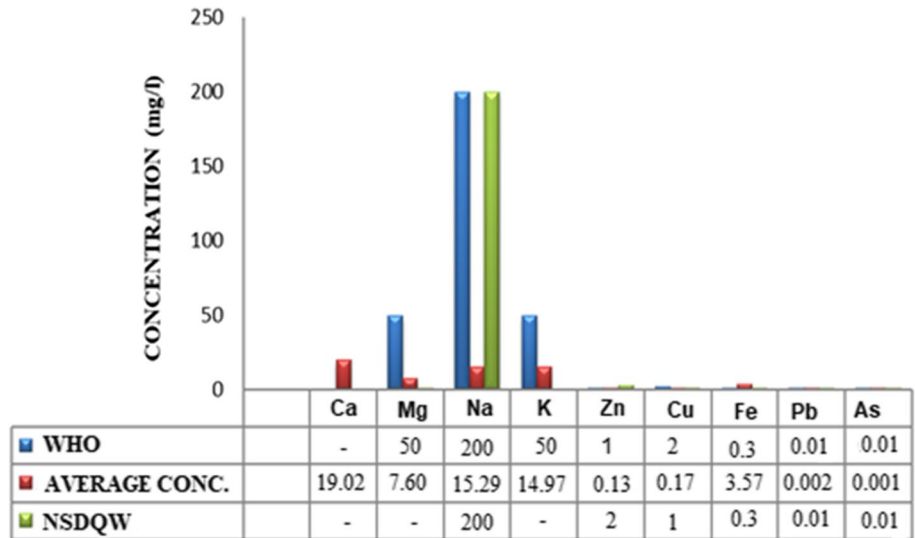
The IDW algorithm spatially interpolates and estimates values between data measurements as the weighted mean of close sample points. Hence, the groundwater spatial disparity maps of the main ionic compositions (cations and anions) of the unmeasured points are produced using this method. The spatial variation maps of Mg²⁺, Ca²⁺, K⁺, and Na⁺ are shown in (Fig. 3a–d). The study's interpolated

Table 2 Summary statistics of Physico-chemical quality parameters of groundwater samples

Parameters	Units	Min	Max	Mean	SD	Permissible limits (WHO, 2011) and (NSDQW, 2007)		
						WHO	NSDQW	Samples exceeding the permissible limit
pH		6.28	8.04	7.41	0.58	6.5–8.5	6.5–8.5	Nil
Turbidity	NTU	0.39	9.63	2.86	2.36	5.0	5.0	3
EC	µS/cm	275	1368	681.10	294.60	1250	1000	1
TDS	mg/L	133	671	334.36	144.92	1200	1000	Nil
SO ₄ ²⁻	mg/L	1.02	32.15	11.02	8.20	250	100	Nil
NO ₃ ⁻	mg/L	1.44	22.02	10.82	6.30	50	50	Nil
Cl ⁻	mg/L	6.11	35.43	16.71	7.81	100	250	Nil
CO ₃ ⁻	mg/L	0.16	1.28	0.53	0.27	NA	NA	NA
HCO ₃ ⁻	mg/L	0.14	0.73	0.32	0.17	NA	NA	NA
PO ₄ ²⁻	mg/L	4	26	13.65	5.56	NA	NA	NA
Ca ²⁺	mg/L	6.15	45.29	19.02	9.85	NA	NA	NA
Mg ²⁺	mg/L	1.39	21.62	7.60	5.91	50	NA	Nil
Na ⁺	mg/L	4.62	34.02	15.28	9.93	200	200	Nil
K ⁺	mg/L	4.2	33.6	14.96	8.20	50	50	Nil
Zn ²⁺	mg/L	0.01	0.57	0.13	0.12	1	2	Nil
Cu ⁺	mg/L	0.02	0.33	0.17	0.08	2	1	Nil
Fe ²⁺	mg/L	1.96	5.98	3.57	1.33	0.3	0.3	3
Pb ²⁺	mg/L	0.01	0.01	0.002	0	0.01	0.01	Nil
As ⁺	mg/L	0.01	0.01	0.001	0	0.01	0.01	Nil

NA No health-based guideline NTU Nephelometric Turbidity Unit µS/cm microSiemens/centimeter mg/L Milligram/ Liter

Fig. 2 Bar chart of the permissible limits standard for drinking water set by the WHO and NSDQW and the ion concentrations of the cations and heavy metals



spatial variation maps of ionic concentrations of Mg²⁺, Ca²⁺, K⁺, and Na⁺ have maximum values of 21.62, 45.29, 33.60, and 34.02 mg/L, respectively. These ionic concentrations are below the WHO and NSDQW groundwater acceptable standards (NSDQW 2007; WHO 2011). Likewise, the distribution of the major anions SO₄²⁻, CO₃⁻, Cl⁻, and HCO₃⁻ have the highest values of 32.15, 1.28, 35.43, and

0.73 mg/L, respectively (Fig. 4a–d). Also, the ionic concentration of the major anions in the area falls below the WHO and NSDQW allowable limits. The slightly high concentration of Mg²⁺ and Ca²⁺ (Fig. 3a and b) in the northeastern study area could be due to water–rock interaction. In (Fig. 3c and d), Na⁺ concentration is higher in the central region and K⁺ concentration is higher in the southwestern region due

Fig. 3 Spatial disparity maps of **a** Ca^{2+} , **b** Mg^{2+} , **c** K^+ and **d** Na^+

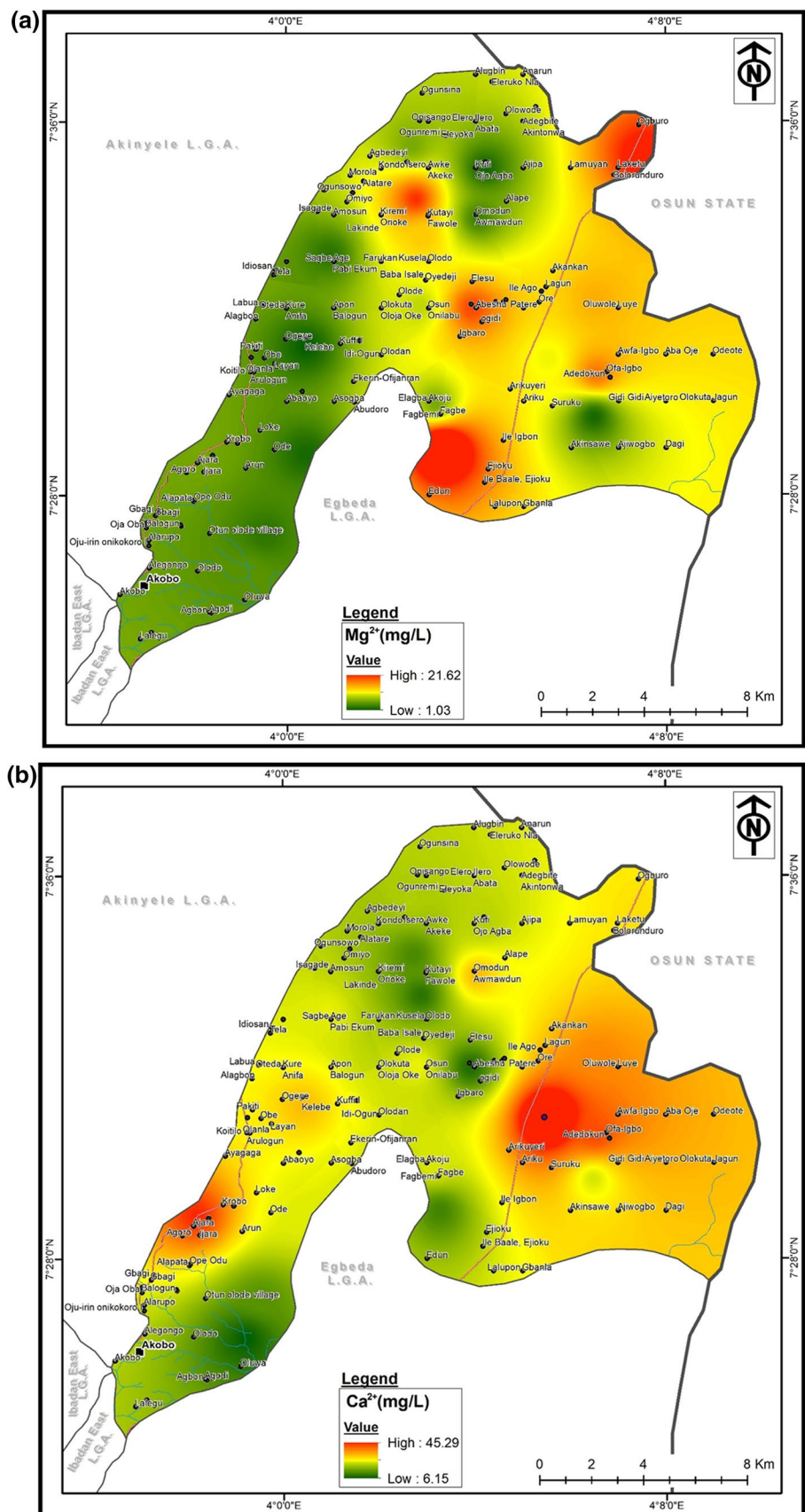


Fig. 3 (continued)

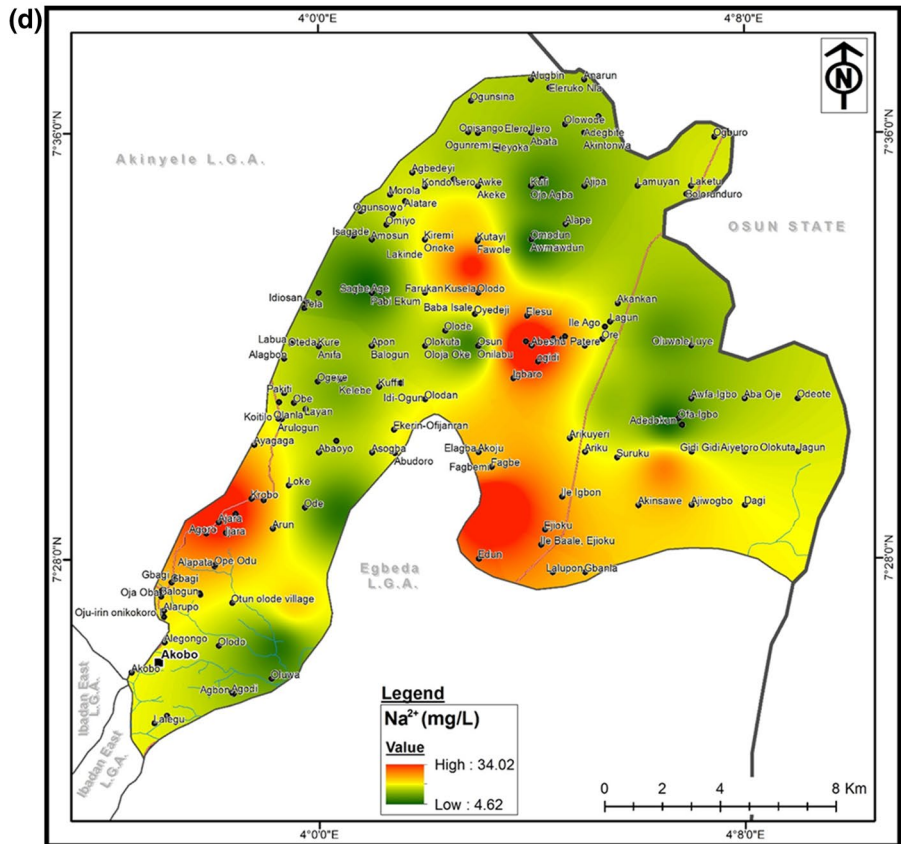
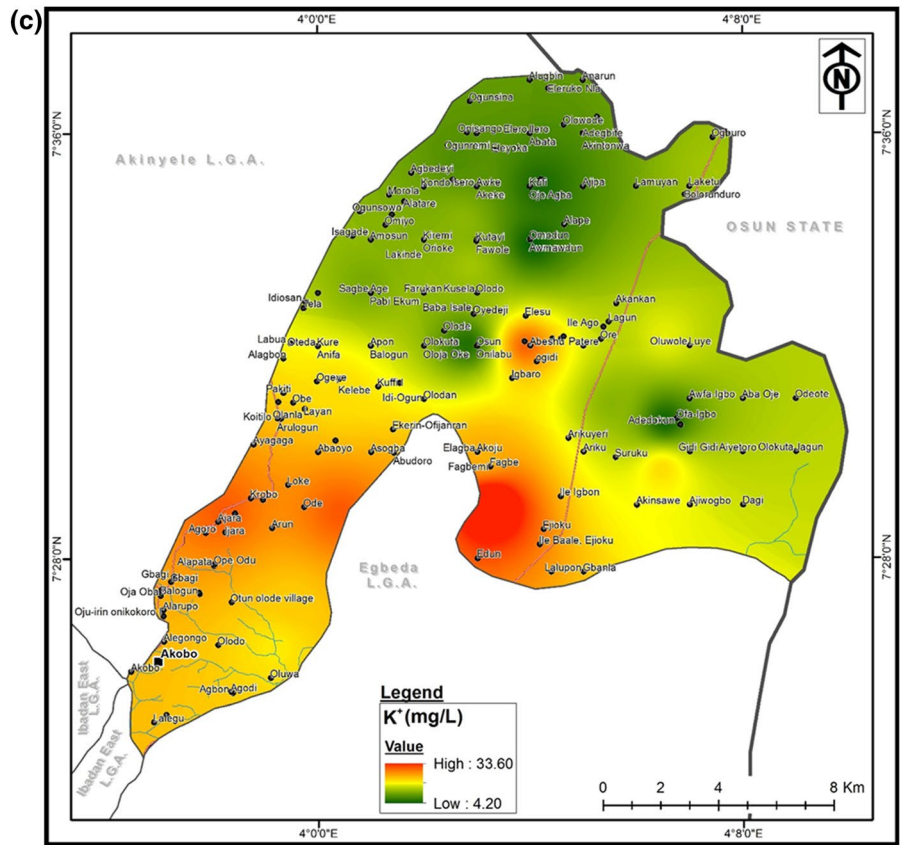


Fig. 4 Spatial disparity maps of **a** SO_4^{2-} , **b** CO_3^{2-} , **c** Cl^- , and **d** HCO_3^-

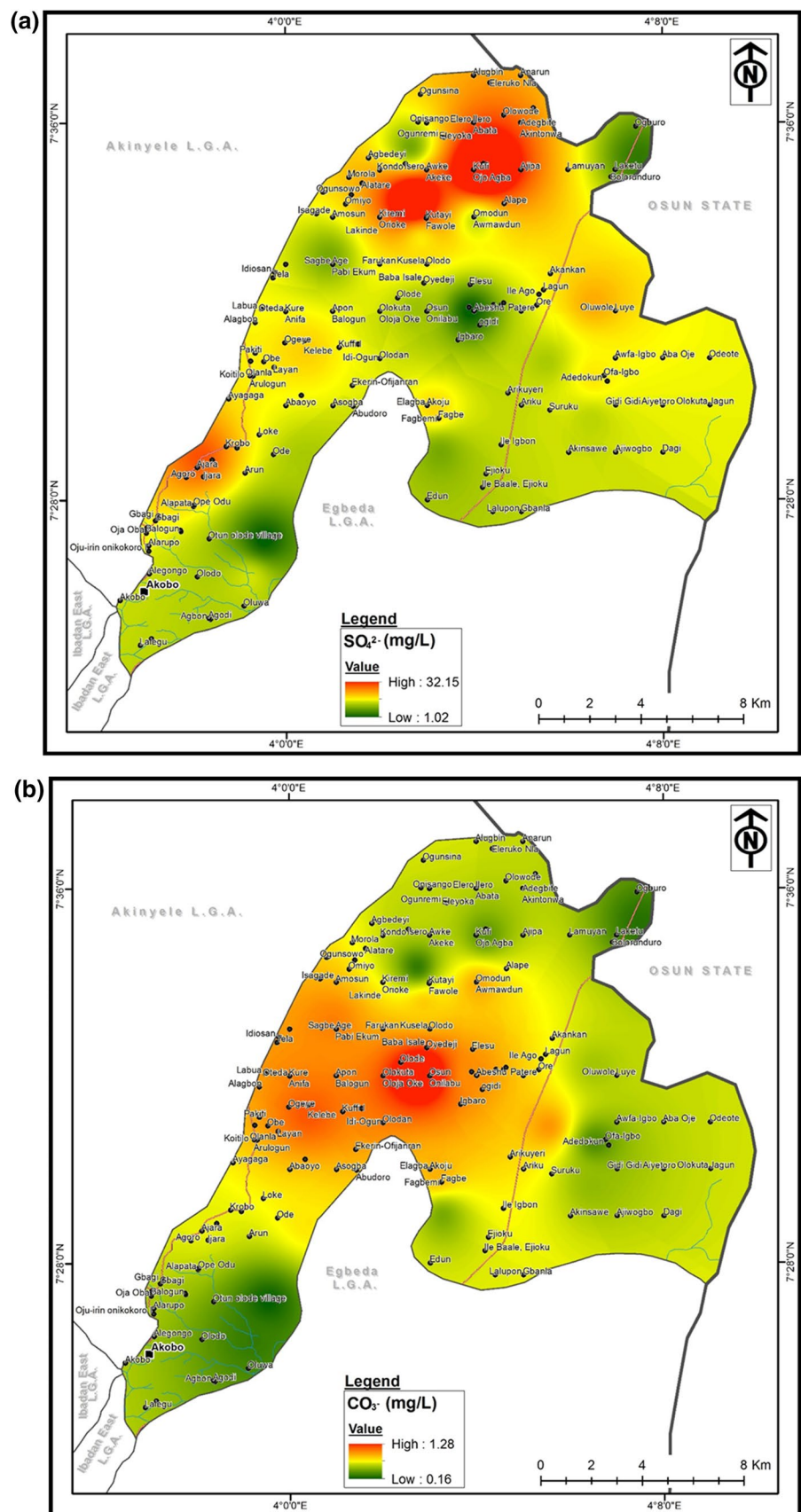
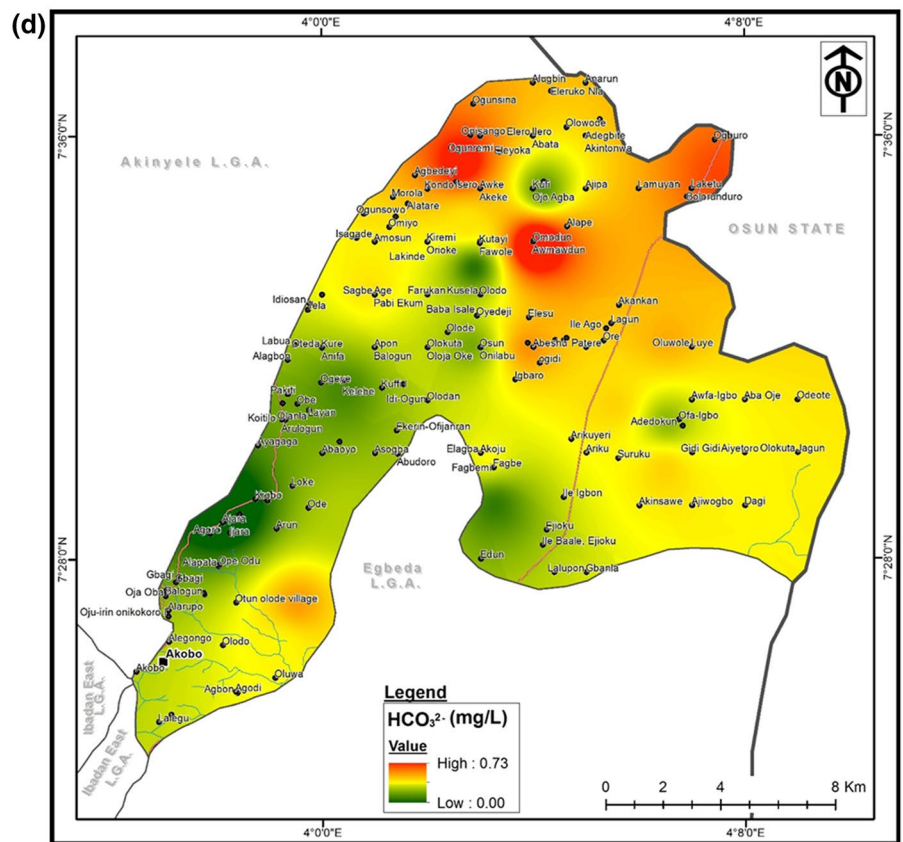
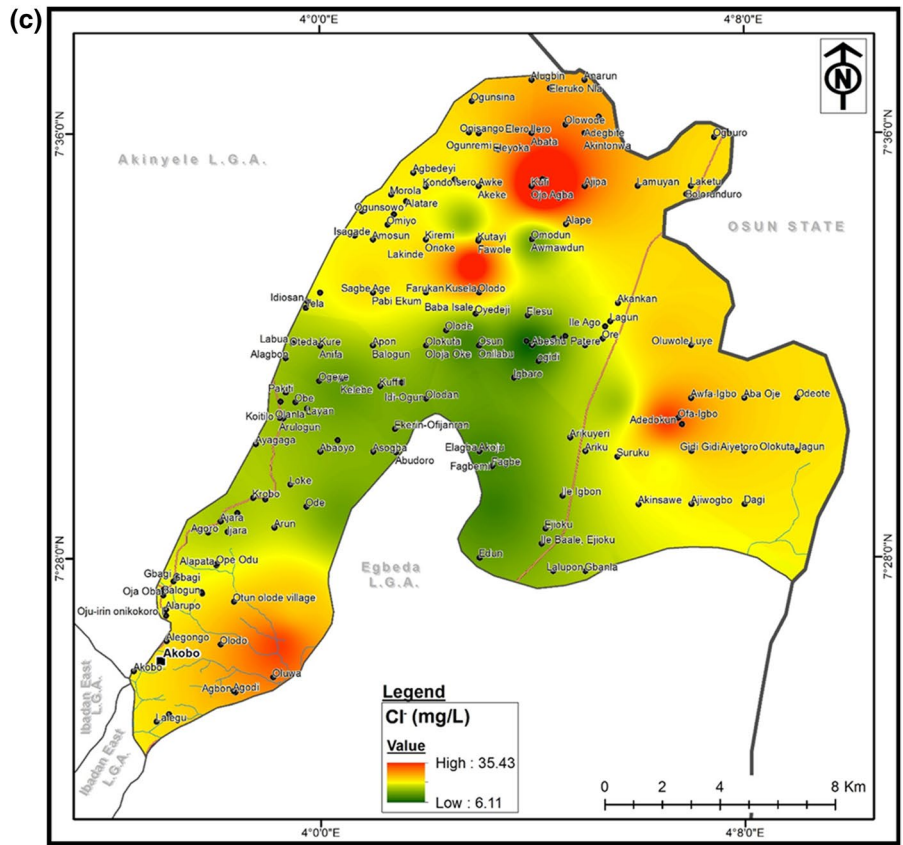


Fig. 4 (continued)



to cation exchanges (Adewumi et al. 2018). HCO_3^- slightly high concentration in the northern part could be due to chemical reactions between silicate minerals and groundwater (Oni and Hassan 2013). Higher concentrations of SO_4^{2-} and Cl^- in the northern region might be due to anthropogenic activities such as fertilizer use, waste disposal, and leaching (Oyelami et al. 2013).

Hydrogeochemical facies

Piper trilinear plot

The Piper trilinear plot is a graph that shows the relationship between variables. Based on the Piper trilinear diagram, most water samples (12 which make up 60%) belong to the $\text{Na}^+ - \text{K}^+ - \text{Cl}^- - \text{SO}_4^{2-}$ group in field II, and fewer samples (8, that form 40%) plotted under field I that belongs $\text{Ca}^{2+} - \text{Mg}^{2+} - \text{Cl}^- - \text{SO}_4^{2-}$ group. The fields are further

grouped into seven classes (A to G), as shown in (Fig. 5) (Langguth 1966). 5% of the samples belong to class C, corresponding to normal earth alkaline water with prevailing sulfate or chloride. 35% belongs to class E, the earth alkaline water with increased alkalis portions with prevailing sulfate and chloride. Class G (60%) is alkaline water with prevailing sulfate or chloride.

Durov plot

Sixty percent of the samples plot in the dissolution or mixing field, according to the data on the Durov diagram (Fig. 6). Field 5 (Lloyd and Heathcote 1985) describes that the water dissolves or mixes easily with no major dominant ions. Ca^{2+} and HCO_3^- ions are prevalent in 35% of the groundwater samples. The remaining sample (5%) shows predominantly SO_4^{2-} and Na^+ ions, signifying possible mixing or rare dissolution effects.

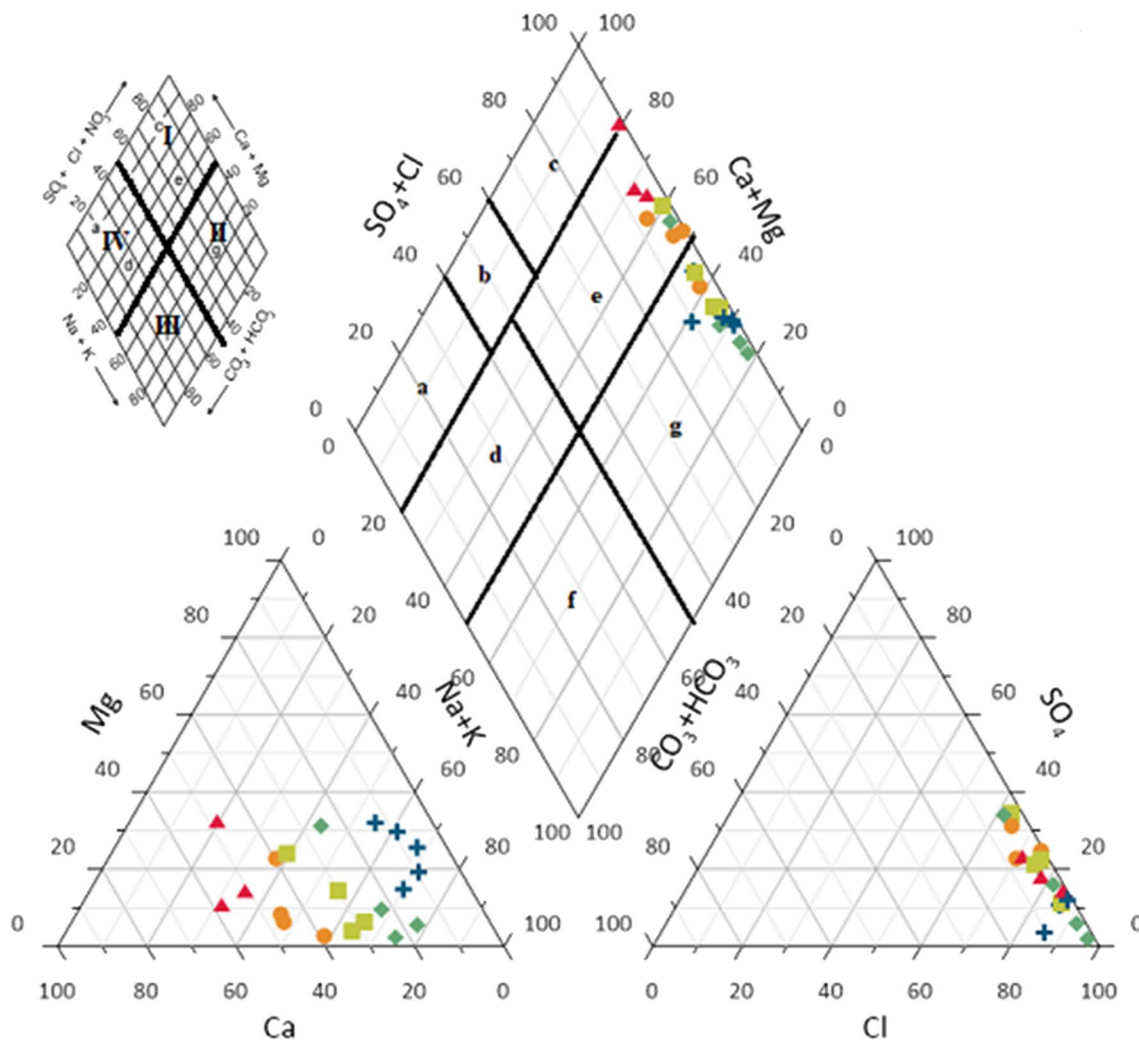
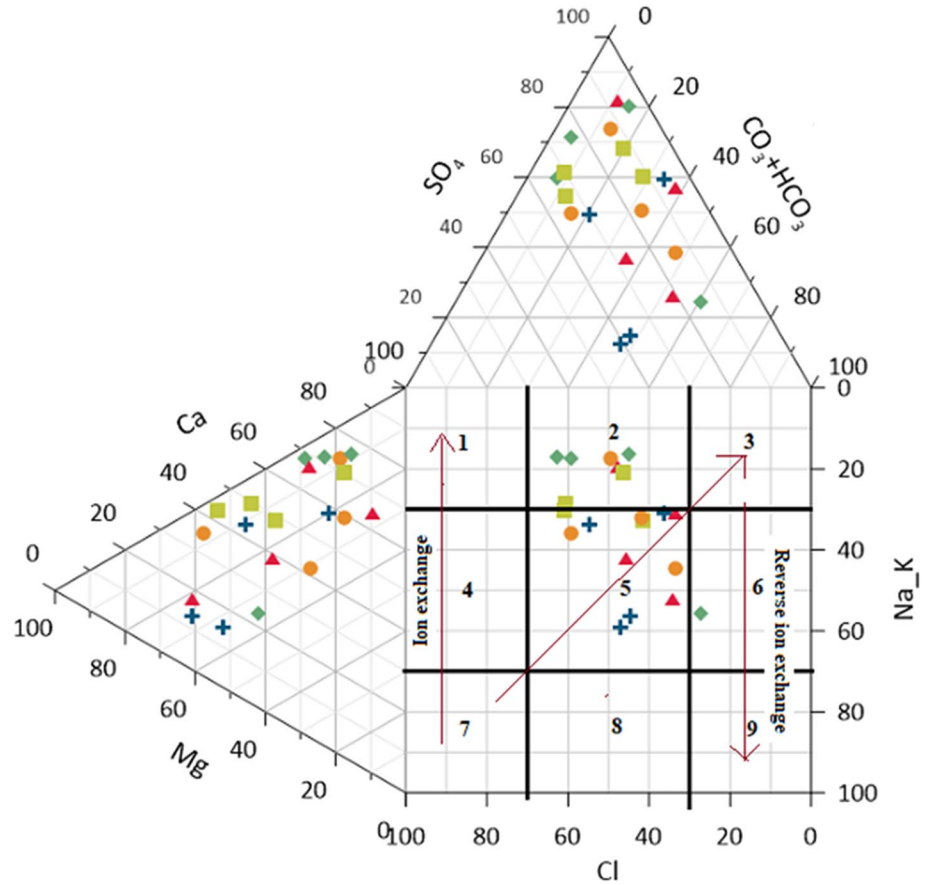


Fig. 5 Piper diagram for groundwater samples (Langguth, 1966)

Fig. 6 Durov diagram for groundwater samples (Lloyd and Heathcote, 1985)



Gibbs plot

The groundwater chemistry regulation mechanisms are analyzed using Gibb's diagram. To identify the dominance of samples due to precipitation, rock, and evaporate, the graph plots $\text{Na}^+(\text{Na}^+ + \text{Ca}^{2+})$ and $\text{Cl}^-(\text{Cl}^- + \text{HCO}_3^-)$ as a feature of TDS. The plotted diagram (Fig. 7) associates 90% of the samples to the rock dominance (RD) zone and 10% to the evaporation zone, signifying that the rock-water interaction majorly influences the primary ion composition. Thus, rock weathering and dissolution are the primary influences of geochemical reactions in the study area.

Chloro alkaline indices (CAI)

Ion exchange indices provide a good understanding of the groundwater composition and rock interactions (Schoeller 1965). Two chloro-alkaline indices (CAI I and II) were computed using Eqs. (11) and (12) to investigate cation exchange effects on the evolution of groundwater.

$$\text{CAI I} = \frac{\text{Cl} - (\text{Na} + \text{K})}{\text{Cl}} \quad (11)$$

$$\text{CAI II} = \frac{\text{Cl} - (\text{Na} + \text{K})}{(\text{SO}_4 + \text{HCO}_3 + \text{NO}_3)} \quad (12)$$

(all measurements are in meq/l).

Positive CAI corresponds to the replacement of Na^+ and K^+ by Ca^{2+} and Mg^{2+} in groundwater, commonly referred to as the reverse ion exchange process. In contrast, negative CAI indicates the exchange of Ca^{2+} and Mg^{2+} with K^+ and Na^+ in groundwater, denoting the ion exchange process. CAI value of 0 implies a state of equilibrium between the groundwater chemical composition and its surrounding materials. 90% of the computed CAI-I and CAI-II are negative, whereas 10% are positive. This implies that 90% of the groundwater samples exchange Ca^{2+} and Mg^{2+} with K^+ and Na^+ , increasing the K^+ and Na^+ ion concentrations.

Statistical analysis

The interrelationship of the groundwater physicochemical variables was analyzed using a correlation matrix (Wu et al. 2014). The interpretation guidelines adopted indicate that variables with r values greater than 0.7 correlate strongly, and r ranging from 0.5 to 0.7 moderately correlate. Table 3

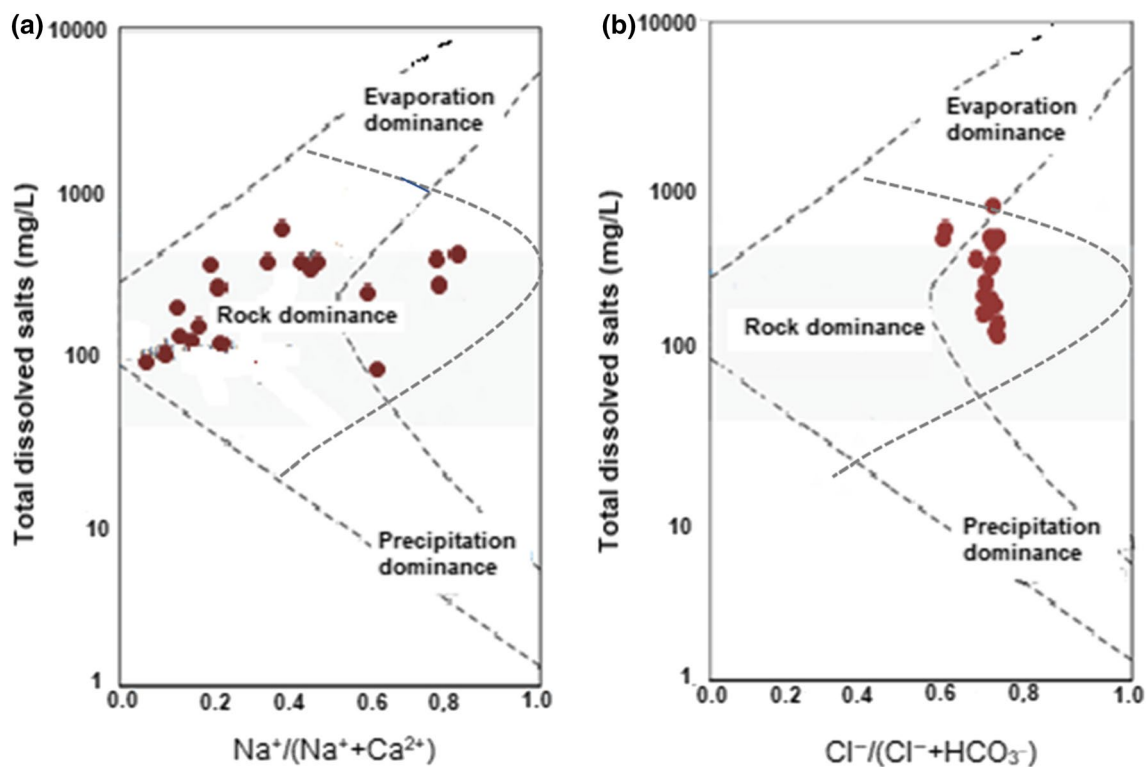


Fig. 7 Gibbs diagrams indicating the groundwater natural evolution mechanisms; **a** TDS vs. $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$ and **b** TDS vs. $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$

shows the correlations between the analyzed parameters of the groundwater samples.

TDS strongly correlates positively with EC and CO_3^{2-} moderately correlates positively with Cl^- . Na^+ exhibits a moderate negative and positive correlation with NO_3^- and Mg^{2+} . K^+ exhibits a strong and moderate negative correlation with NO_3^- and Cl^- , respectively. It also strongly correlates positively with Na^+ . Cu^+ positively correlates with pH, and Fe^{2+} exhibits a high and moderate positive relationship with Ca^{2+} and Zn^+ , respectively. The poor correlation between NO_3^- and Ca^{2+} and the negative correlation between NO_3^- and Na^+ and K^+ show the source of NO_3^- could be from excessive use of chemical fertilizers (Wu et al. 2014).

Suitability for irrigation

Percent sodium (%Na)

%Na is used to assess the suitability of groundwater for irrigation purposes (Kawo and Karuppanan 2018). Excess Na^+ in water reduces soil permeability and limits air and water circulation, hindering plant growth (Wilcox 1955; Todd 1980; Ayers and Westcot 1985). In addition, a base-exchange reaction replaces high sodium in water with Ca^{2+}

and Mg^{2+} ions, impacting soil structural form, aeration, and permeation (Naseem et al. 2010; Kawo and Karuppanan 2018). Using the Wilcox classification, 10%, 40%, and 50% of the samples have excellent, good, and permissible percent sodium for irrigation, respectively (Table 4).

Sodium adsorption ratio (SAR)

SAR estimates the quantity of Na^+ relative to Ca^{2+} and Mg^{2+} in water. The substitution of Ca^{2+} and Mg^{2+} ions in soils through the exchange of bases due to increased sodium causes soil compaction that impacts soil structure and water movement (Karanth 1987; Tahmasebi et al. 2018). Thus, soils with large SAR values reflect high clay percentage, low permeability, and poor soil structure, which becomes hazardous to crops. All the samples will be harmless when used for irrigation (Ravikumar et al. 2011) (Table 4).

Salinity and sodium hazard

The SAR is plotted against EC as the indices of sodium (alkali) and salinity hazard to determine the suitability of groundwater (US Salinity Laboratory, 1954). The USSL diagram categorizes salinity and sodium hazards into the C-class (C1, C2, C3, C4, and C5) and S-class (S1, S2, S3, and S4). 50% of the samples are of medium salinity and low

Table 3 Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
pH	r	1															
Turbidity (NTU)	r	-0.416	1														
Electrical Conductivity (µS/cm)	r	0.370	0.148	1													
TDS (ppm)	r	0.373	0.148	1.000**	1												
SO ₄ ²⁻ mg/L	r	-0.005	-0.086	-0.276	-0.271	1											
NO ₃ ⁻ mg/L	r	-0.082	-0.166	-0.164	-0.170	-0.055	1										
Cl ⁻ mg/L	r	0.008	-0.050	0.016	0.020	0.355	0.251	1									
CO ₃ ⁻ mg/L	r	0.193	0.162	0.069	0.071	-0.204	0.295	-0.486*	1								
PO ₄ ²⁻ mg/L	r	-0.226	-0.215	-0.166	-0.168	0.168	0.179	0.113	-0.108	1							
Ca ²⁺ mg/L	r	0.138	-0.023	-0.305	-0.306	0.075	0.193	-0.100	.213	0.027	1						
Mg ²⁺ mg/L	r	0.247	0.005	0.092	0.087	-0.076	-0.112	-0.158	-0.245	0.074	-0.125	1					
Na ⁺ mg/L	r	0.120	0.161	0.401	0.400	-0.120	-0.519*	-0.284	-0.086	-0.159	-0.321	0.465*	1				
K ⁺ mg/L	r	-0.248	0.156	0.142	0.144	-0.254	-0.610**	-0.101	-0.101	-0.044	-0.251	0.206	0.664**	1			
Zn ²⁺ mg/L	r	0.116	0.183	0.228	0.223	-0.123	-0.109	-0.134	0.065	0.232	0.274	0.047	-0.081	1			
Cu ⁺ mg/L	r	0.528*	0.295	0.316	0.325	-0.010	-0.248	0.035	-0.391	-0.112	0.248	0.294	-0.061	0.243	1		
Fe ²⁺ mg/L	r	0.016	-0.120	-0.264	-0.266	-0.073	-0.016	-0.022	0.145	0.685**	-0.055	-0.230	-0.050	0.547*	-0.063	1	

*Correlation is significant at the 0.05 level(2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Table 4 Summary of the classification of groundwater for irrigation based on different parameters

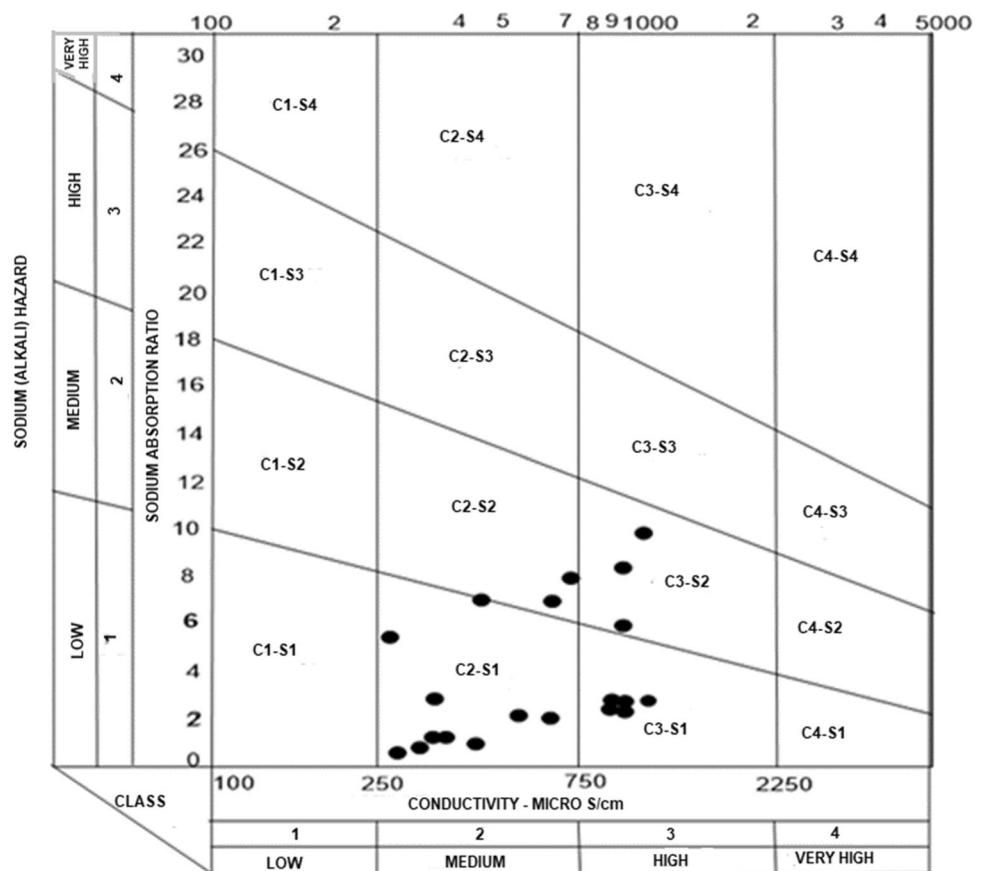
Parameters	Units	Classification	Range	No. of samples (Percent)
%Na	meq/L	Excellent	<20	2 (10%)
		Good	20–40	8 (40%)
		Permissible	40–60	10 (50%)
		Doubtful	60–80	Nil
		Unsuitable	> 80	Nil
SAR	meq/L	Excellent	< 10	20 (100%)
		Good	10–18	Nil
		Doubtful	18–26	Nil
		Unsuitable	> 26	Nil
		RSC	meq/L	Good
Doubtful	1.25–2.5	Nil		
Unsuitable	> 2.5	Nil		
MH	meq/L	Suitable	<50	15 (75%)
		Unsuitable	> 50	5 (25%)
PI	meq/L	Suitable (Class I)	> 75	Nil
		Suitable Class II	25–75	13 (65%)
		Unsuitable (Class III)	< 25	7 (35%)
PS	meq/L	Excellent to good	< 3	20 (100%)
		Good to Injurious	3–5	Nil
		Injurious to Unsatisfactory	> 5	Nil
KR	meq/L	Suitable	< 1	20 (100%)
		Unsuitable	> 1	Nil

alkalinity belonging to the C2-S1 type. 10% are classified as C2-S2, which denotes medium salinity and alkalinity. Also, 25% are of the C3-S1 type, matching high salinity and low alkalinity, and 15% as C3-S2, corresponding to high salinity and medium alkalinity. Therefore, 60% are good, and 40% are doubtful for irrigation (Fig. 8). However, 40% of the water samples can still be used to irrigate salt-tolerant crops under good drainage conditions which control salinity (Kawo and Karuppanan 2018).

Residual sodium carbonate (RSC)

The RSC guide is evaluated by subtracting calcium and magnesium ion compositions from the bicarbonate and carbonate ion concentrations. The irrigation suitability of water depends on the abundance of sodium content, excess bicarbonate, and carbonates to alkaline earth. Since adequate calcium and magnesium are present over the carbonates, an unlikely accumulation of sodium results in a negative value of RSC. Conversely, the likelihood of sodium accumulation will produce a positive value of RSC, and a high RSC (> 2.5 meq/l) shows that sodium accumulation in the soil is imminent. Therefore, high RSC increases soil salinity and reduces the soil structure by blocking pore spaces, impeding air and water movement, directly harmful to crops (Eaton

Fig. 8 USSL diagram for classifying groundwater for irrigation (U.S. Salinity Laboratory, 1954)



1950; Raghunath 1987; Naseem et al. 2010). The groundwater samples' RSC values ranged from -2.24 to -0.71 , making it 100% good for irrigation based on this classification (Table 4).

Magnesium hazard (MH)

Mg^{2+} high percentage in groundwater increases soil alkalinity. The magnesium and clay particles impede water infiltration in the soil, thereby causing harm to crops (Ravikumar et al. 2011; Hussain et al. 2017a; Khalid 2019). Therefore, MH specifies the degree of soil structure damage caused by Mg^{2+} in water (Tahmasebi et al. 2018). A value of $MH > 50$ and $MH < 50$ in groundwater indicates unsuitable and suitable groundwater for irrigation, respectively (Abdulhussein 2018). The sample's MH ranged between 6.57 and 78.82%, with 15 (75%) suitable and 5 (25%) unsuitable for irrigation.

Permeability index (PI)

The variable PI is essential in the irrigation potential classification of water (Singh et al. 2008). It ascertains the amount of Ca^{2+} , Mg^{2+} , Na^+ , and HCO_3^- in groundwater in which their prolonged use for irrigation can reduce soil aeration and hinder the growth of seedlings (Khalid 2019). PI is categorized as class I, II, and III with values of ($> 75\%$), ($25-75\%$), and ($< 25\%$), which corresponds to suitable, good, and unsuitable groundwater for irrigation (Doneen 1964; Raju 2007). Analyzed PI values ranged from 9.23 to 51.77%, with 13 (65%) belonging to class II (suitable) and 7 (35%) to class III (unsuitable) for irrigation (Table 4).

Potential salinity (PS)

PS is also a variable used to establish the irrigation potential of groundwater (Tahmasebi et al. 2018). Based on (Doneen 1962) classification (Table 4), we rate all groundwater samples as excellent to fine and ideal for irrigation.

Soltan classification

(Soltan 1999) established that groundwater for irrigation can be from base-exchange indices ($r1$) and meteoric genesis indices ($r2$). Groundwater with $r1 < 1$ and $r1 > 1$ corresponds to $Na^+-SO_4^{2-}$ and $Na^+-HCO_3^-$ sources, while $r2 < 1$ and $r2 > 1$ corresponds to deep meteoric and shallow meteoric types. The study area's samples have been categorized into; 12 and 8 samples corresponding to $Na^+-SO_4^{2-}$ and $Na^+-HCO_3^-$ sources, while 7 and 13 samples correspond to deep meteoric and shallow meteoric types.

Kelly's ratio (KR)

KR determines sodium quantity in water and acts as an alkali hazard indicator (Kelley 1940; Li et al. 2016). The values $KR < 1$ and $KR > 1$ are suitable and unsuitable for irrigation, respectively (Krishnakumar et al. 2014). The samples' KR varied between 0.31 and 0.89, and thus, all analyzed samples are suitable for irrigation (Table 4).

Conclusion

Groundwater is an essential resource for domestic, agricultural, and small-scale industrial purposes. Hence, to evaluate the suitability of groundwater for drinking and irrigation purposes, 20 groundwater samples were collected from hand-dug wells and analyzed for the major cations, anions, and heavy metals. Spatial variation maps of the major cations and anions were produced using IDW interpolation technique.

The piper trilinear diagram categorizes the hydrogeochemical groundwater facies into $Na^+-K^+-Cl^- - SO_4^{2-}$ and $Ca^{2+}-Mg^{2+}-Cl^- - SO_4^{2-}$ groups. Durov plot shows that Ca^{2+} and HCO_3^- ions are prevalent in the groundwater.

Gibb's diagram reveals that rock weathering and dissolution are the primary influences of geochemical reactions because the interaction of rocks and water dominate the processes controlling the primary ion composition.

Based on the USSL diagram, 50% of the samples are of medium salinity and low alkalinity (C2-S1). 10% belongs to the medium salinity and alkalinity (C2-S2), 25% shows high salinity and low alkalinity (C3-S1). 15% corresponds to high salinity and medium alkalinity (C3-S2).

Based on the irrigation indices, %Na, SAR, RSC, PS, and KR the groundwater is suitable for irrigation. However, some groundwater samples need management for irrigation because of a few high concentrations of MH, PI, and salinity hazards.

Generally, geogenic processes, wastewater disposal, and excess use of chemical fertilizers for agricultural purposes affect the area's groundwater chemistry. Hence, the result of this study will be helpful to decision-makers in managing groundwater resources and mitigating their contamination.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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