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Hydrogeochemical Assessment of Groundwater around Gauta, Central Nigeria

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ABSTRACT

The present study was aimed at assessing the hydrogeochemical characteristics of groundwater with a view to identifying key processes controlling groundwater chemistry and in so doing identify any quality concerns. A total of 30 water samples were analysed for concentrations of major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, HCO_3^{-}, CO_3^{-} and Cl^{-}); while *in-situ* measurements of pH, temperature, total dissolved solids TDS and electrical conductivity EC were made. Conventional graphical plots (Gibbs, Piper, and ionic ratios) of ionic concentrations in the groundwater were used to characterize water Facies and identify major processes responsible for the ionic assemblage. The study area is underlain by two main rock types, schist and gneiss. Dominance of cations is in the order: $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$; while that of the anions is in the order: $HCO_3^{-}>SO_4^{2-}> Cl^{-}>CO_3^{-}$. Groundwater in the study area is characterized by four types: Na-Cl type (33%); Mixed Ca-Mg-Cl type (30%); Mixed Ca-Na-HCO_3 type (27%) and Mg-HCO_3 type (10%). Gibbs plot indicated that the ions were mainly sourced from rock-water interaction through dissolution and leaching of the gneisses and schists of the study area. However, relatively high concentration of Cl may be due to anthropogenic activities, hence the Na-Cl water type. In terms of quality for domestic purposes, concentrations of analyzed ions and the physical parameters are within the permissible limits of both WHO and SON (NSDWQ, 2007), with the exception of a few locations that had high pH (up to 9.2) and another location with a high TDS concentration (1040mg/L). Assessment for irrigation purposes using indices such as SAR, PI, RSC and %Na show that most of the groundwater samples were suitable for use as source of water for irrigation.

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Introduction

To attain sustainable development, access to clean water remains a crucial factor; groundwater represents an excellent source of water due to its renewable nature and relatively higher quality than surface water. Getting adequate water supplies for drinking (domestic), industrial and agricultural purposes would not be possible without sufficient groundwater, which is the most reliable of all fresh water resources. The physical and chemical quality of groundwater determines its use for specific purposes most especially drinking purposes. Clean groundwater must therefore be devoid of harmful elements, excessive minerals, living and non living organisms which will impact on its quality. These substances may be sourced naturally through water – rock interaction or due to anthropogenic activities. The composition of aquifer framework impacts on groundwater chemistry through various hydrochemical mechanisms [1]. Point and non point sources of pollution due to anthropogenic activities can alter groundwater chemistry [2].

The study area, Gauta is a fast developing semi urban settlement that has witnessed population growth and hence an increase in the demand for water. The settlement is not connected to public water supply system and the streams that drain the area are in most parts seasonal; in addition to that anthropogenic activities along its course have lead to pollution of this resource. Groundwater in form of hand dug wells; hand pumped and motorized boreholes is the only source of water for domestic and industrial/agricultural use. It therefore becomes necessary to assess the resource in order to identify any quality concerns. The present study seeks to use major ion chemistry and physical parameters to assess hydrogeochemical properties and how they have determined the chemistry of groundwater. Physicochemical processes of groundwater have been explored in assessing groundwater quality where dominant hydrogeochemical processes as well as quality concerns were identified [3-8]. Factors such as population increase and pollution of surface water bodies by industrialization, agriculture and other human activities make the demand for groundwater on the rise.

Study Area description

The study area is a fast developing semi urban settlement that has witnessed population growth and expansion of industries. Agricultural activities mainly cattle rearing and farming are the main activities in this area; in addition to this a milling plant.

The study area is underlain by the Basement Complex rocks of North Central Nigeria and centred on the coordinates: E7°51′30″; and N8°48′30″ (figure 1). In the area, three main rock units constitute the geology i.e.: schist, gneiss and granite (figure 1), these intruded by pegmatite and quartzo-feldspathic veins. Schist covers about n 60% of the study area and is exposed mostly along stream channels. Granite occurs as a low lying outcrop around the eastern part of the study area covering about 20% of the study area. Gneiss was exposed as a low lying outcrop in the northern part of the study area. These rocks are poor aquifers as they are characterized by low matrix porosity with negligible permeability, resulting from their crystalline nature. Appreciable porosity and permeability may be developed through weathering and fracturing depending on the lithology and texture of the parent rock. The availability of groundwater would depend on the presence and extent of the weathered overburden regolith and the presence of faults and fractures in the underlying bedrock. The Regolith includes both the residual soil and the saprolite. The latter is derived from in-situ weathering while the residual soil usually develops from the underlying saprolite unit by further dissolution and leaching combined with other chemical, physical and biological processes [9].

Dissolution of minerals and leaching tends to increase porosity, permeability and specific yield, but the decomposition of secondary clay minerals tends to reverse this process [10]. Schistose metamorphic rocks, and also zones of tectonic disturbances, are likely to promote deeper weathering and thicker regolith, although the presence of abundant Fe-Mg minerals (such as biotite), which readily weather to produce secondary products, is likely to further reduce permeability. Most hand-dug wells tap their water from the weathered regolith. The bedrock includes both fractured and fresh rock.

The area is characterized by two distinct climatic conditions marked in the area namely wet and dry season. Rainy season (April to October) and Dry season (November to March) are the two characterised climatic conditions with an annual rainfall and temperature range from 1300mm to 1500mm and 28°C-36°C, respectively. The vegetation is typical of the Guinea savannah belt characterized by predominance of tall grasses and few trees, except along the river channels where the trees predominate.

The area is gently undulating occasionally punctuated by hills measuring up to 333 m above sea level. The area is well drained by network of streams which flow southwards, in a dendritic pattern; the streams dry up during the long dry season.

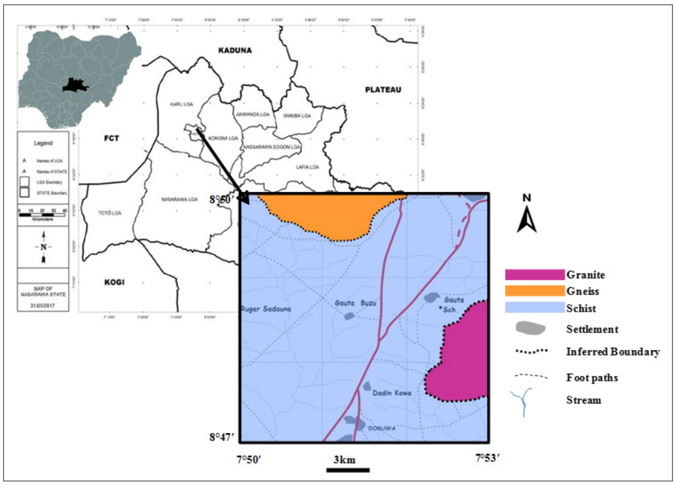

Figure 1: Location map of the Study Area showing the major geologic units and boundaries between them.

Methodology

To assess the hydrogeochemical properties of groundwater in the study area, thirty water points (boreholes, hand dug wells and streams) were identified. Water level was recorded where hand–dug wells were encountered and in the case of boreholes, owners were asked for the water levels if known. Samples were collected from 11 motorized boreholes, 13 hands dug wells, 4 hand pumps and 2 stream. In-situ measurements of temperature, pH, TDS and EC were done while water samples in each case were collected. For each water point, two samples were collected; one was acidified with nitric acid to preserve metals in solution. The samples were taken to the laboratory, where concentrations of major ions were determined. The species analysed for are: calcium, sodium, potassium and magnesium for the cations, while bicarbonate, sulphate, chloride and carbonate for the anions. Water level was recorded where hand –dug wells were encountered and in the case of boreholes, owners were asked for the water levels if known. A total of 29 water samples were collected; 10 boreholes, 13 hand dug wells, 4 hand pumps and 2 stream. The samples collected from the field were subjected to laboratory analyses specifically concentrations of major ions i.e: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} in order to achieve the objectives of the research. Anions were analyzed by titration, except for sulphate which was analyzed using a spectrophotometer. Sodium and potassium were analyzed using a flame photometer. Calcium and magnesium were determined by titration with EDTA.

Results and discussion

Groundwater Occurrence and Movement

Groundwater is the water that exists in pore spaces and fractures in rocks and sediments beneath the Earth’s surface. The area is underlain by rocks of the Basement Complex; these rocks have poor matrix porosity and permeability, porosity is concentrated around fractures zones. These zones will only be permeable if these fractures are interconnected.

The weathered zone in such areas may be porous and permeable depending on the weathering products; if clayey then permeability will be low. Groundwater occurrence in basement rocks is largely due to the development of secondary porosity and permeability by fracturing or weathering of these rocks. Hence groundwater exploration in such rocks is aimed at delineating fractures and/or thick weathered zones since they constitute aquifers in such terrains. Groundwater within the area occurs within the weathered and fractured/jointed basement rocks.

In the study area, hand dug wells and boreholes were sampled. Hand dug wells tap overburden aquifers and ranged in depth from 2m to 7.6m implying that overburden thickness in the area ranges from the ground surface to about 10m. Most hand dug wells are perennial as they had water in them during the fieldwork which was done at the peak of dry season (March-April 2020). Boreholes intercepted also were productive and had depths considerably deeper than the hand dug wells probably tapping water from fractured basement aquifers.

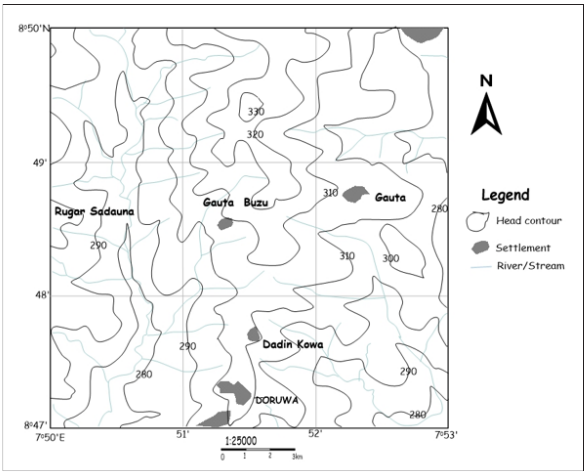

Figure 2: Groundwater elevation map showing most probable direction of groundwater movement

Hydrogeochemistry

Physical parameters

physical parameters measured in the field are: pH, Temperature, Electrical Conductivity EC and Total Dissolved Solids TDS. Groundwater samples had pH ranging from 6.2 to 9.2 most of the values fall within the permissible limit for drinking water with the exception of two samples from Gauta and Elkabir Estate which had values higher than the maximum permissible limit (figure 3a). Temperature in the water samples analyzed in this study ranges from 28.50C to 33.30C; all warmer than the permissible limits (figure 3b). TDS of groundwater in the study area ranges between 50mg/L to 510mg/L, with a mean value of 136.94mg/L; all values except that of a hand dug well in Dorowa are within the permissible limit for drinking water (figure 4a). EC values range from 110µS/cm to 1040 µS/cm with an average value of 269.66µS/cm; all values apart from that of Dorowa had EC values within permissible limits for drinking water (figure 4b)

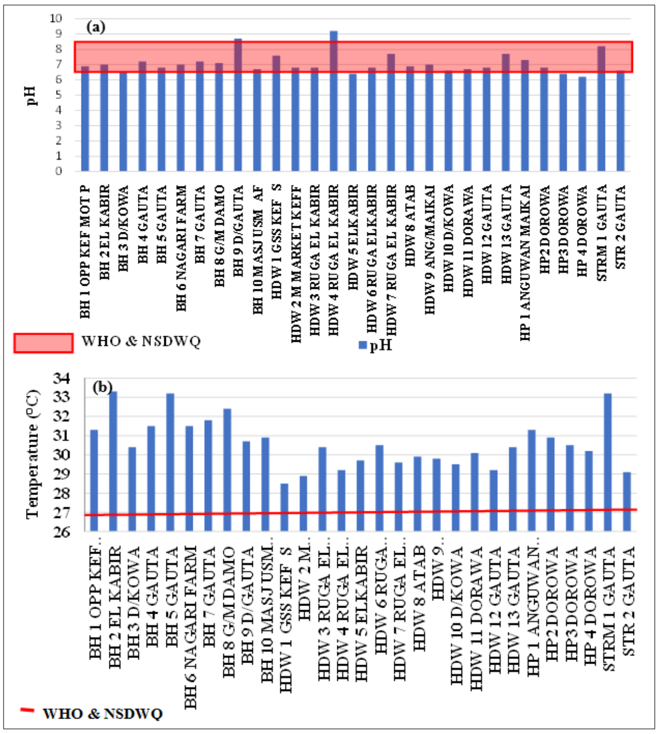

Figure 3: pH (a) and temperature (b) of groundwater within the Study Area

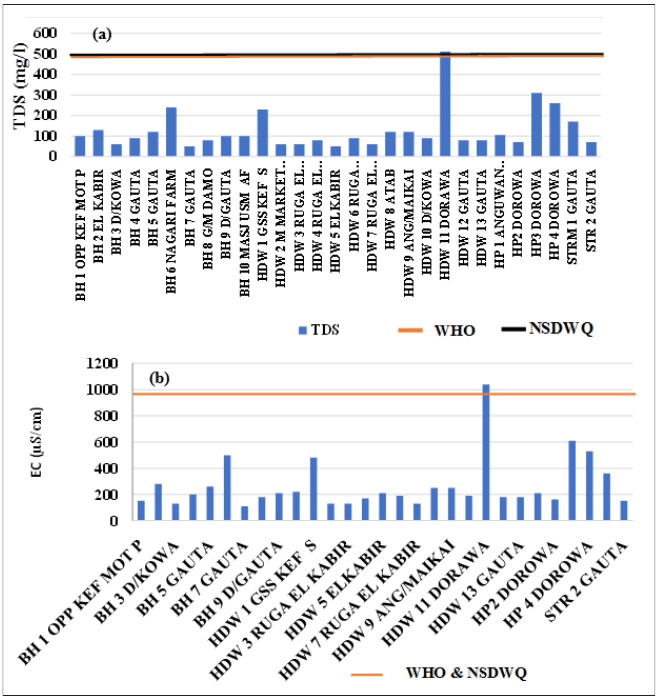

Figure 4: TDS (a) and EC (b) of groundwater within the Study Area

Major ion concentration

dominance of cations is in the order: $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$. Sodium is the most abundant cation with a mean concentration of 13.31mg/L ±8.32s.d; Ca^{2+} has a mean concentration of 6.23mg/L ±6.56s.d; Mg^{2+} has a mean concentration of 3.96mg/L ±2.15s.d; K^{+} has a mean concentration of 1.82mg/L ±4.63s.d.

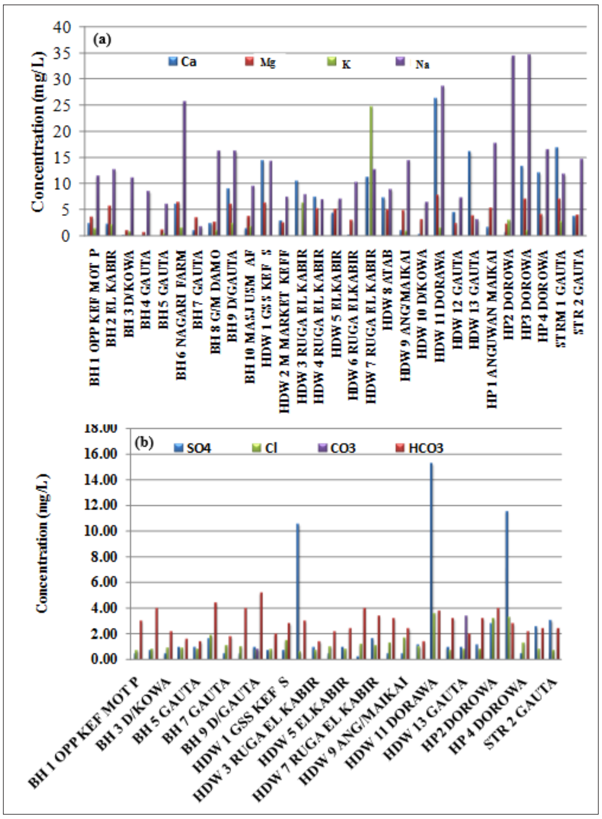

Figure 5: Relative abundance of major cations (a) and anions (b) in groundwater samples of the Study Area.

With the exception of 3 locations; dominance of anions is in the order: HCO_3^->SO_4^{2-}> Cl^->CO_3^-. Groundwater samples in these locations had higher concentration of SO_4^{2-} relative to other cations. HCO_3^- has a mean concentration of 0.98mg/L ±2.82s.d; SO_4^{2-} has a mean concentration of 2.21mg/L ±3.67s.d; Cl^- has a mean concentration of 1.23mg/L ±0.80; CO_3^- has a mean concentration of 0.14mg/L ±0.64s.d. Concentrations of these major ions are all within permissible limits for drinking water.

Groundwater classification

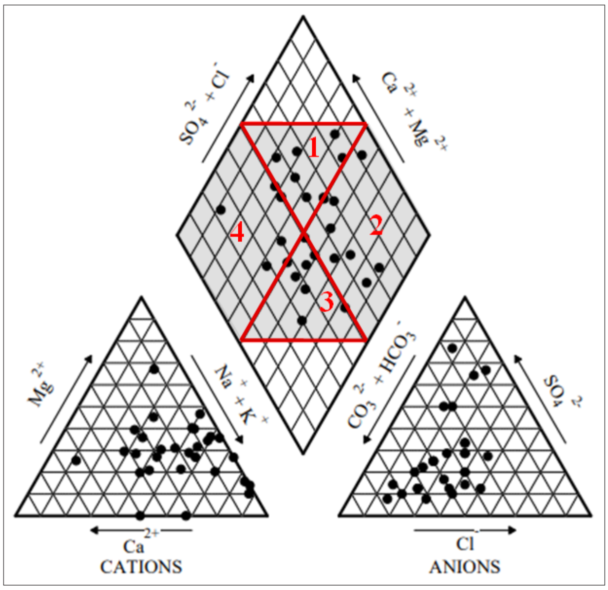

Figure 6: Piper diagram showing groundwater types in the Study Area

The geochemical origin of groundwater and hence the water type can be unraveled by plotting the concentration of major cations and anions in the Piper (1944) trilinear diagram. Analyzed concentrations of cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (HCO3 - , SO_4^{2-} , CO_3^- and Cl-) are expressed in percentages of their meq/l and subsequently plotted on the Piper diagram. This diagram shows the similarities and differences in groundwater samples because those with similar qualities will tend to plot together as groups (Todd, 2001; Selvakumar et al., 2014). The plot (figure 6) shows that groundwater in the study area is characterized by four types: Na-Cl type (33%); Mixed Ca-Mg-Cl type (30%); Mixed Ca-Na-HCO_3 type (27%) and Mg-HCO_3 type (10%). Na-Cl type predominates, followed by Mixed Ca-Mg-Cl and together they represent 63% of the water type; while the other two types i.e.: Mixed Ca-Na-HCO_3 and Mg-Cl types represent 37%.

Hydrogeochemical processes

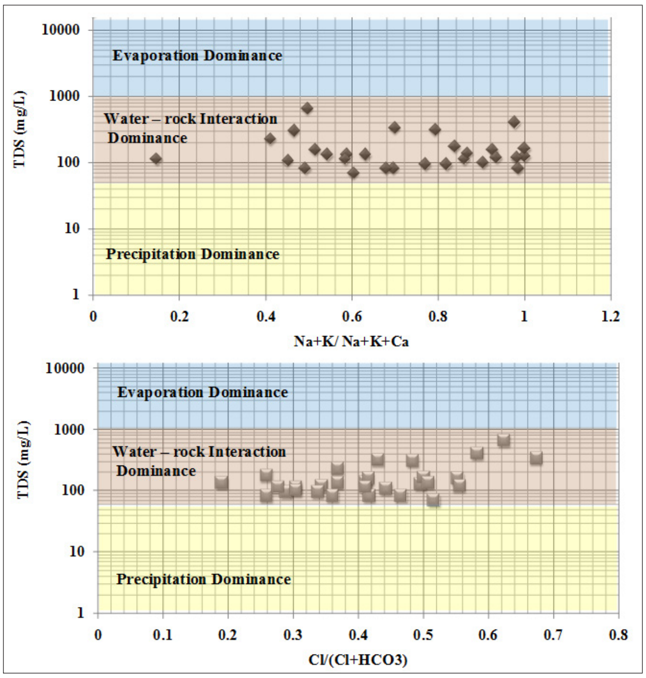

Figure 7: Gibbs classification of major hydrogeochemical processes of groundwater; groundwater samples from the Study Area plot within the water–rock interaction domain

In the region of the study area; common hydrogeochemical processes are: precipitation, evaporation and water – rock interaction. The groundwater chemistry of the study area will therefore be dependent on a combination of these processes.

A generalized classification to identify the dominant process contributing to the groundwater chemistry is possible by plotting a Gibbs (1970) diagram. Gibbs diagram for groundwater in the study area is shown in figure 7. All the groundwater samples plot in the field for water-rock interaction; this implies only that the main hydrogeochemical process in operation to determine groundwater chemistry is its interaction with bedrock. This implies that silicate weathering plays an important role in determining groundwater chemistry; although the other processes may contribute to the observed chemistry of the groundwater especially precipitation since it is ultimately the main source of recharge into a groundwater system. Evaporation could be a factor since the samples were collected at the peak of the dry season in the Study Area.

Ionic plots

To understand further the hydrogeochemical processes in operation major ion chemistry and the geology need to be considered. Ionic plots are presented in figure 8. A correlation between Na and Cl is shown in figure 8a; most of the samples plot in the region of Na implying a Na: Cl ratio much greater than 1, meaning the cations are sourced from different processes. It also is indicative of silicate weathering (Kumar and James, 2016). The study area is underlain by rocks of the Nigerian Basement Complex enriched with minerals like Na-Ca-K feldspars and micas; these minerals will weather to produce free Na and K for groundwater to carry in solution. In figure 8b, a correlation between Ca+Mg and total cations is shown; in this case all points fall within the field of total cations showing the dominance of Na relative to Ca and Mg, and silicate weathering processes. To assess the influence of evaporation on the groundwater chemistry observed, the ratio of Na/Cl versus EC is used; evaporation leads to an increase in TDS (EC) with a constant Na/Cl ratio (Subramani et al., 2010). In figure 8c, the samples do not present a constant Na/Cl ratio with increase in EC, indicating that evaporation is not a prominent process in determining the chemistry of groundwater in the study area.

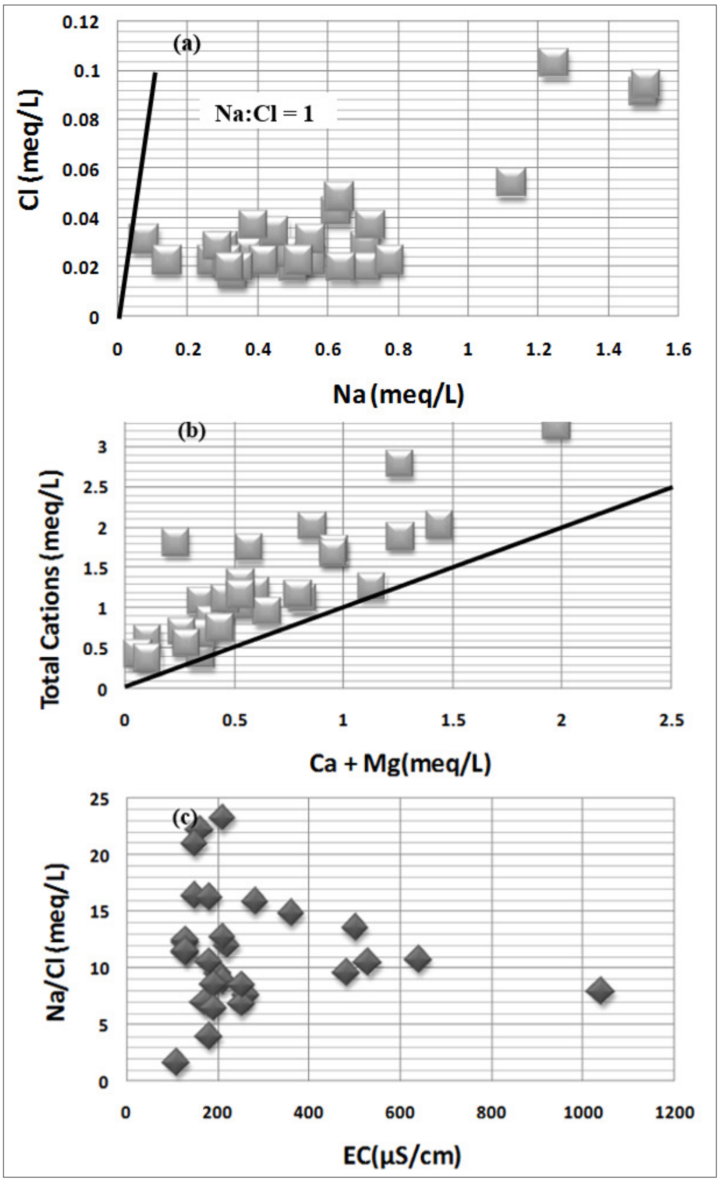

Figure 8: Relationship between EC and Na/Cl ratio

Correlation between physicochemical properties of groundwater

The relationship between ions and the TDS is shown in the correlation matrix in table 1. This was used as an indicator for assessing contributions from anthropogenic activities such as chemical fertilizers, infiltration of organic matter, synthetic fertilizers, runoff from agricultural fields, and wastewater effluents. Strong positive correlations of TDS/EC with the ions: Na^+, $SO_4{}^{2-}$ and especially with Cl- are indicative of contributions from anthropogenic activities in addition to contributions water –rock interaction. The correlation between Na^+, and Cl- and $SO_4{}^{2-}$ and Cl- suggests that they may have originated from the same source.

Table 1: Pearson's bivariate correlation matrix of physicochemical properties of groundwater samples from the Study Area

	TDS	EC	Ca^{2+}	Mg^{2+}	K^+	Na^+	So_4^{2-}	Co_3^-	HCO_3^-	Cl^-
TDS	1.00									
EC	1.00	1.00								
Ca^{2+}	0.57	0.57	1.00							
Mg^{2+}	0.54	0.54	0.49	1.00						
K^+	-0.06	-0.06	0.20	-0.36	1.00					
Na^+	0.75	0.75	0.08	0.42	0.07	1.00				
So_4^{2-}	0.65	0.65	0.51	0.35	-0.01	0.53	1.00			
Co_3^-	-0.10	-0.10	0.30	0.04	-0.07	-0.21	-0.08	1.00		
HCO_3^-	0.35	0.35	0.12	0.37	0.15	0.54	0.17	-0.05	1.00	
Cl^-	0.88	0.88	0.41	0.39	0.01	0.64	0.64	-0.13	0.30	1.00

Assessment of Groundwater quality

The concentrations of the analyzed ions and the physical parameters are within the permissible limits of both WHO and SON (NSDWQ, 2007), with the exception of a few locations that had high pH (up to 9.2) and another location with a high TDS concentration (1040mg/L). Land use is predominantly for agricultural purposes as such an assessment of the suitability of the water for irrigation purposes needs to be done. Suitability of groundwater for agricultural purposes has been determined by calculating indices such as sodium absorption ratio SAR; percentage sodium %Na; residual sodium carbonate RSC; permeability index PI [7,8,11,12]. These indices are determined using equations 1 to 4.

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad (1)$$

(Richards, 1954)

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

(Wilcox, 1955)

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \qquad (3)$$

(Eaton, 1950)

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^+} \qquad (4)$$

(Doneen, 1964)

Table 2: Groundwater quality assessment for irrigation purposes

Index	Range	Classification	Samples (%)
SAR	0-10	Excellent	86
	10-18	Good	3
	18-25	Doubtful	8
	>26	Unsuitable	3
%Na	0-20	Excellent	7
	20-40	Good	21
	40-60	Permissible	48
	60-80	Doubtful	14
	80-100	Unsuitable	10
RSC	0-1.25	Good	100
	1.25-2.5	Medium	0
	>2.5	Bad	0
PI	0-25	Unsuitable	7
	25-75	Good	83
	≥75	Excellent	10

Assessment of SAR

Sodium absorption ratio is important since sodium will always participate in cation exchange (with Ca and Mg) thereby sorbing unto soil particles the net effect of this is a reduction in permeability of soils. A high SAR therefore is hazardous to plant growth due to excess Na. according to the classification by Richards shown in table 2; 86% of groundwater samples fall within the excellent region, having SAR values between 0 and 10 [13].

Assessment of % Na

Percentage sodium is crucial in determining groundwater quality for irrigation. Excess Na is water leads to reduction in permeability of soils since it will readily participate in ion exchange thereby sorbing onto soil particles. Sodium can react with carbonates present in soils to increase the alkalinity of soils; it can also react chloride to increase salinity of soils. Majority of groundwater samples have %Na values within permissible range i.e. 66% (permissible to excellent, table 2), while 24% of groundwater samples are based on this index not suitable for irrigation purposes.

Assessment of RSC

Residual sodium carbonate influences ground water quality for irrigation purposes. When CO3- and HCO3- ions exceed the concentration Ca and Mg content RSC exists and the tendency for the formation of sodium bicarbonate then increases. All groundwater samples have excellent RSC values for irrigation purposes as shown in table 2 and according to the classification by Eaton [14].

Assessment of PI

Permeability index has to do with permeability of soils i.e. the ease with which water will move for optimum crop production. It is influenced by the relative proportions of Na, Ca, Mg and HCO3. Based on the classification by Doneen majority of the groundwater samples (83%) have good permeability indices suitable for irrigation purposes, while 10% had excellent indices [15].

Conclusion

Hydrogeochemical assessment of groundwater in the study area using physical parameters and major ion concentration showed that the groundwater chemistry and hence quality is predominantly determined by water-rock interaction. Groundwater in the study area is characterized by four types: predominantly Na-Cl type (33%); Mixed Ca-Mg-Cl type (30%); Mixed Ca-Na-HCO3 type (27%) and Mg-HCO3 type (10%). Major Hydrogeochemical processes are associated with dissolution and leaching of constituents from the aquifer framework which in this case is weathered and fractured basement rocks specifically gneisses and schists. Anthropogenic effects are also seen as depicted by the strong correlation between TDS/EC with the ions: Na+, SO4 2- and especially with Cl-.

Assessment of groundwater for domestic purposes showed that concentrations of the analyzed ions and the physical parameters are within the desirable limits of both WHO and SON with the exception of a few locations that had high pH (up to 9.2) and another location with a high TDS concentration (1040mg/L) [16]. Assessment for irrigation purposes using indices such as SAR, PI, RSC and %Na show that most of the groundwater samples were suitable for use as source of water for irrigation [17-23].

References

1. Rajmohan N and Elango L (2004) Identification and evolution of hydrogeochemical processes in groundwater environment in an area of the Palar and Cheyyar River Basins, Southern India. Environmental Geology 46: 47-61.
2. Brindha K and Elango L (2014) Cross comparison of five popular groundwater pollution vulnerability index approaches. Journal of hydrology 524: 597-613.
3. Rajmohan N and Elango L (2006) Hydrogeochemistry and its relation to groundwater level fluctuation in the Palar and Cheyyar river basins, southern India. Hydrological Processes 20: 2415-2427.
4. Cloutier V, Lefebvre R, Therrien R, Savard MM (2008) Multivariate statistical analysis of geochemical data as indicative of the hydrogeochemical evolution of groundwater in a sedimentary rock aquifer system. Journal of hydrology 353: 294-313.
5. Sajil Kumar PJ and James EJ (2016) Identification of hydrogeochemical processes in the Combatore district, Tamil Nadu, India. Hydrological Sciences Journal 61: 719-731.
6. Baghvand A, Nasrabadi T, Bidhendi N, Vosoogh A, Karbassi A, et al. (2010) Groundwater quality degradation of an aquifer in Iran central desert. Desalination 260: 264-275.
7. Sunitha V and Sudharshan RY (2019) Hydrogeochemical evaluation of groundwater in and around Lekkireddipalli and Ramapuram, Y.S.R District, Andhra Pradesh, India. Hydroresearch, 2: 85-96.
8. Abdelshafey M, Saber M, Abdelhaleem A, Abdelrazek SM, Saleem EM (2019) Hydrogeochemical processes and evaluation of groundwater aquifer at Sohag city, Egypt. Scientific African 6: 1-15.
9. Olorunfemi MO, Fasuyi SA (1993) Aquifer Types and the Geoelectric/Hydrogeologic Characteristics of Part of Central Basement Terrain of Nigeria (Niger State). Journal of African Earth Sciences 16: 309-317.
10. Tijani MN (1994) Hydrogeochemical assessment of groundwater in Moro area, Kwara State, Nigeria. Environmental Geolog, 24: 194-202.
11. Papazotos P, Koumantakis I, Vasileiou E (2019). Hydrogeochemical assessment and suitability of groundwater in a typical Mediterranean coastal area: A case study of the Marathon Basin, NE Attica, Greece. Hydroresearch 2: 49-59.
12. Brindha K, Pavelic P, Sotoukee T, Douangsavanh S, Elango L

(2016) Geochemical characteristics and groundwater quality in theVientiane Plain, Laos. Exposure and Health 9: 89-104.

13. Richards LA (1954) Diagnosis and improvement of alkaline soils. US Departments of Agriculture handbook, Washington DC160.
14. Eaton FM (1950) Significance of carbonates in irrigated waters. Soil Science 69: 127-128.
15. Doneen LD (1964) Water Quality for Agriculture. University of California, Davis, Department of Irrigation.
16. SON (2007) Nigerian Standards for Drinking Water Quality NSDWQ. Standard Organization of Nigeria (SON) Publ. NIS-554
17. SON (2007) Nigerian Standards for Drinking Water Quality NSDWQ. Standard Organization of Nigeria (SON) Publ. NIS-554
18. Piper AM (1944) A graphical procedure in geochemical interpretation of water analysis. Transactions of American Geophysical Union 25: 914-923.
19. Shanyengana ES, Seely MK, Sanderson RD (2004) Major ion chemistry and groundwater salinization in ephemeral floodplains in some arid regions of Namibia. Journal of Arid Environments 57: 211-223.
20. Subramani T (2014) Groundwater geochemistry and identification of hydrogeochemical processes in a hard rock region Southern India. Environmental Monitoring and Assessment 162: 123-137.
21. Tijani MN, Abimbola AF (2003) Groundwater chemistry and isotope studies of weathered basement aquifer: a case study of Oke-Ogun area, SW Nigeria. African Geosciences Review 10: 373-387.
22. Todd DK (1959) Groundwater Hydrology. John Wiley and Sons. Inc, pp. 277-294.
23. Wilcox LV (1955) Classification and use of irrigation water. US Department of Agriculture, Washington DC (Circular Number 969:19).