Ajayi Crowther Journal of Pure and Applied Sciences (ACJPAS)
https://acjpas.acu.edu.ng

Ajayi Crowther J. Pure Appl. Sci. 2022, 1(1), pp.1-9
https://doi.org/10.56534/acjpas.2022.01.01.9

Article

Hydrogeochemical study of Shallow Groundwater of Oyo Town Southwestern Nigeria

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Article history: Received: Jun. 5, 2022 Revised: Jul. 10, 2022 Accepted: Aug. 1, 2022 Published: Dec. 13, 2022.

Abstract

Groundwater is the only reliable water **supply** for human population in Oyo Town, hence; studies of major ions concentrations and measurements of supplementary parameters were carried out in samples from twenty (20) hand dug wells across the area using flame photometry and spectrophotometry methods. The aim is to assess the quality of the water for human consumption. From well inventory, the depths of the hand-dug wells ranged between 6.6 and 26.5 m. The chemical analyses results showed that water samples from quartzite and quartz schist were more mineralized with TDS average of 612 mg/L than those from migmatised biotite gneiss and undifferentiated gneiss complex terrain with TDS of 530 mg/L and 133 mg/L respectively. Also, the measured water acidity/alkalinity is lower in terrains underlain by varieties of gneissic rocks than those from quartzite areas. The general range of major ions in mg/L were: Ca^{2+}10.9 – 126.5; Mg^{2+} 1.8 – 25.2; Na^{+} 6.5 – 76.2; K^{+} 0.9 – 80.0; HCO_3^- 58.0 – 434.0; Cl^- 2.0 – 62.6; SO_4^{2-} 3.0 – 81.0 and NO_3- 0.9 – 19.1. The dominant hydrochemical facies is the Ca- HCO_3^- water type. Considering the fact that the wells are shallow, nitrate concentrations can be said to be low with values between 0.9 and 19.1 mg/L, while chloride was between 2.0 and 62.6 mg/L. Though, the concentrations of all the ions are not worrisome; enrichment of nitrate and chloride in water often suggests human inputs. There is a strong and positive correlation between TDS and major ions, whereas nitrate and chloride have low relationships with the major ions suggesting possible anthropogenic source for the duo.

Keywords: Groundwater; hand dug wells; major-ions; ionic-association.

1. Introduction

The development of reliable water sources is a major concern for most people in many developing countries [1, 2]. This is due to unavailability of fresh water supply scheme [3] limited geographical distribution and high risk of contamination of surface water, whereby larger percentage of people rely on groundwater including Oyo town in southwestern Nigeria. However, occurrence of groundwater in areas underlain by intrusive crystalline rocks in Nigeria is shallow [4], and it is exploited for most domestic needs mainly through hand dug wells. Although, more often, the overlying soil unit may serve as natural filters for percolating water; but shallow aquifers are not completely immune from contamination from the surface environment and may be intolerable for domestic consumption. Even then, natural occurring elements may be present at unacceptable level in the crust and can also pose as treat to groundwater [5,6,7,8].

In this regard, water quality studies of shallow aquifers areas are as important just as the studies of its occurrence and distribution in basement areas of Nigeria. More so, since water is commonly referred to as 'universal' solvent, the chemical constituents of water are liable to abrupt changes due to dissolution along the flow pathways. Direct recharge, dissolution along the soil zone and enrichment from aquifer units may propel groundwater pollution, that affect and threaten groundwater usability [9,10]. This is more obvious in basement aquifers where groundwater occurs in shallow and in semi-confined condition making the enclosing water vulnerable to contamination [11,12,13]. This situation has necessitated the studies of the major ions and auxiliary parameters in the groundwater of Oyo, as a way of contributing to the water development scheme within this community that relies solely on groundwater being the only accessible water source in the area.

The study area

The study area is Oyo town and it lies within latitude 7⁰ 50′- 7⁰57′ N, and longitude 03⁰ 54′ - 03⁰ 57′ E (Figure 1) in the basement complex of southwestern Nigeria (SW). Oyo is a prominent ancient community in SW Nigeria. The area is within the transitional zone between the southern rain forest and the tropical savannah zone. The forest is mild with much grasses and scrubs at the northeastern part. The peak of the contour is 1000ft and the lowest is 900 ft showing that the area is undulated with few isolated rocks.

The relief influences the drainage pattern. The drainage pattern of the study area is sub-dendritic type. The rivers flow from the upland in Northwest and Southwest directions. The climate is tropical with two distinct seasons of wet and rainy season. The period of rainfall is between March and October and the dry season is from November to March. The annual rainfall ranges between 1200-1600mm while temperatures are relatively high (20 -36ºC) with a mean value about 26ºC.

The study area lies within the Pre-Cambrian Basement Complex of Southwestern Nigeria which in turn is part of the Pan African mobile belt lying east of the West African Craton [14]. The major rock unit in the study area include quartzite and quartz schist (QQS), migmatised undifferentiated biotite hornblende-gneiss (MBHG), undifferentiated gneiss complex (UGC), hornblende-biotite granite gneiss (HBGG), and biotite garnet schist/gneiss (BGSG) Figure 2.

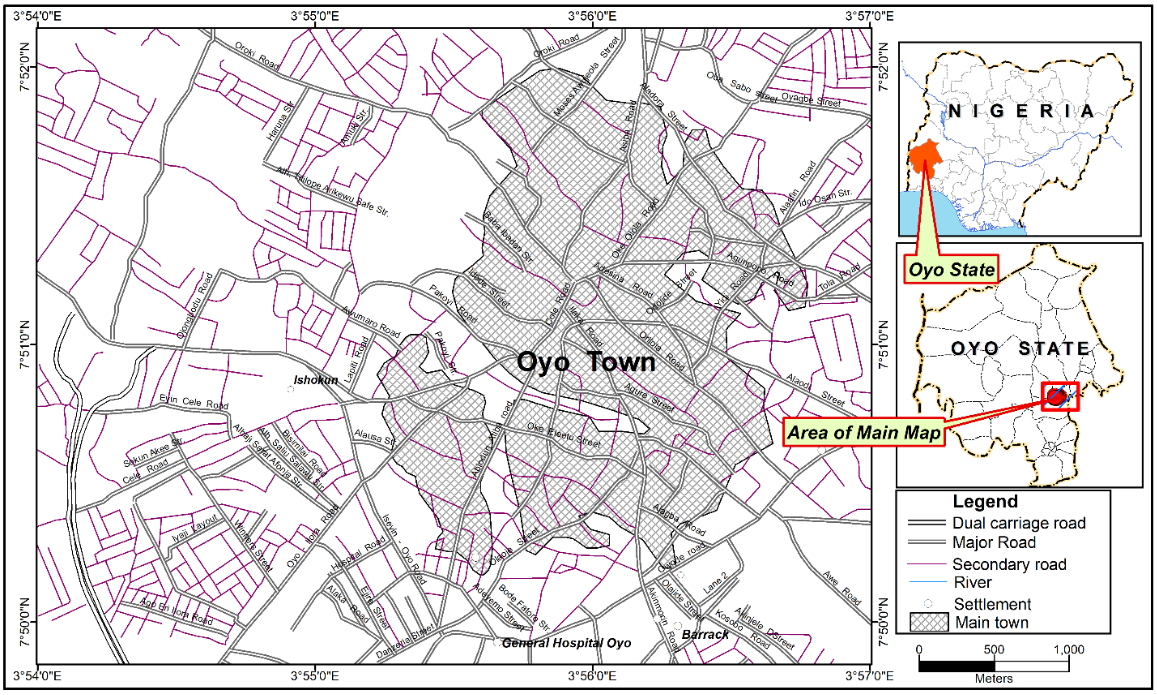

Fig. 1 Location map of the study area

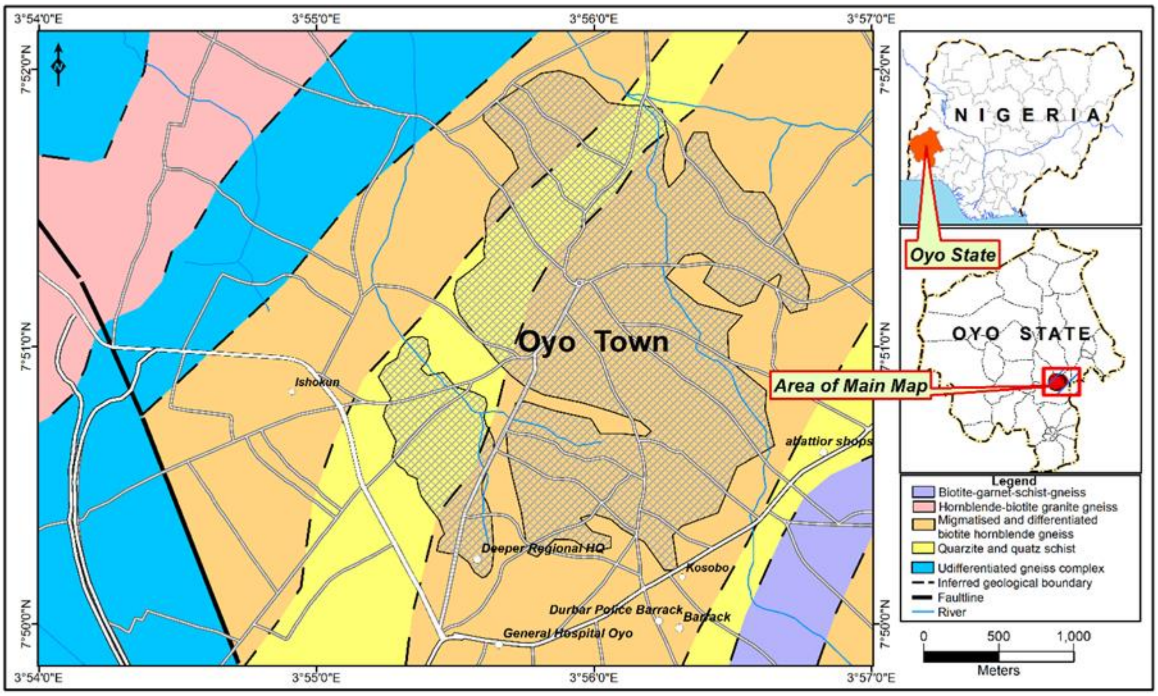

Fig. 2 Geological map of the study area.

The younger meta-sediments occur as quartzite and quartz schist (QQS), which form ridges and seems to be restricted to the centre of the southern part of the study area (Figure 2). The gneisses are leucocratic and medium to coarse grained, foliated and occur as migmatised undifferentiated biotite hornblende-gneiss (MBHG), hornblende-biotite granite gneiss (HBGG), undifferentiated gneiss complex (UGC), biotite garnet schist/gneiss (BGSG). MBHG covers about 50% of the study area, showing alteration of mafic and felsic minerals. The hornblende-biotite granite gneiss (HBGG) is found in the north-west and the outcropping sections are low lying and coarse grained. The undifferentiated gneiss complex (UGC) and biotite garnet schist (BGS) composed of feldspar and quartz with variable proportion of hornblende and biotite occurring as dark streaks and bands. The outcrops are melanocratic and are fine to medium grained. The quartzite and quartz schist form ridges and is restricted to the centre of the southern part of the study area (Figure 2). The outcrops of quartzite occur as disjointed units across the area.

2. Materials and Methods

The scope of the work included groundwater sampling and measurement of well inventory from twenty hand-dug wells located within the populated zones. The geographical coordinates of each sampled well was adequately determined on the geological map with the aid of Etrex legend Global positioning system (GPS) device (Figure 3). The water sampling was carried out at the peak of dry season in the month of January when surface run-off and dilution are minimal. Sensitive parameters including pH and electrical conductivity (EC) that can change during transportation were measured onsite using Milwauker SMSOI pre-calibrated electrode and universal pH test paper respectively. Parameters analysed for were major cations- Na^+, Ca^{2+}, Mg^{2+}, K^+, and anions- NO^{3-}, Cl^-, CO_3^{2-}, HCO_3 and SO_4^{2-}. Flame photometer was employed for the measurement of cations while spectrophotometry method was used for measuring anions in water samples. The chemical analyses results in milligram per litre (mg/L) were converted to milli-equivalent per litre and plotted on trilinear diagram [15] to characterize the hydrochemical facies in water and the data were subjected to statistical analyses such as correlation analyses for evaluation of ionic-facies relationships in water.

3. Results and Discussion

The results of measured and analysed physical and chemical parameters, coordinates of the area locations and well depths (WD) are presented in Table 1. The statistical summary of these parameters as well as their permissible limits of WHO [16,17] are presented in Table 2.

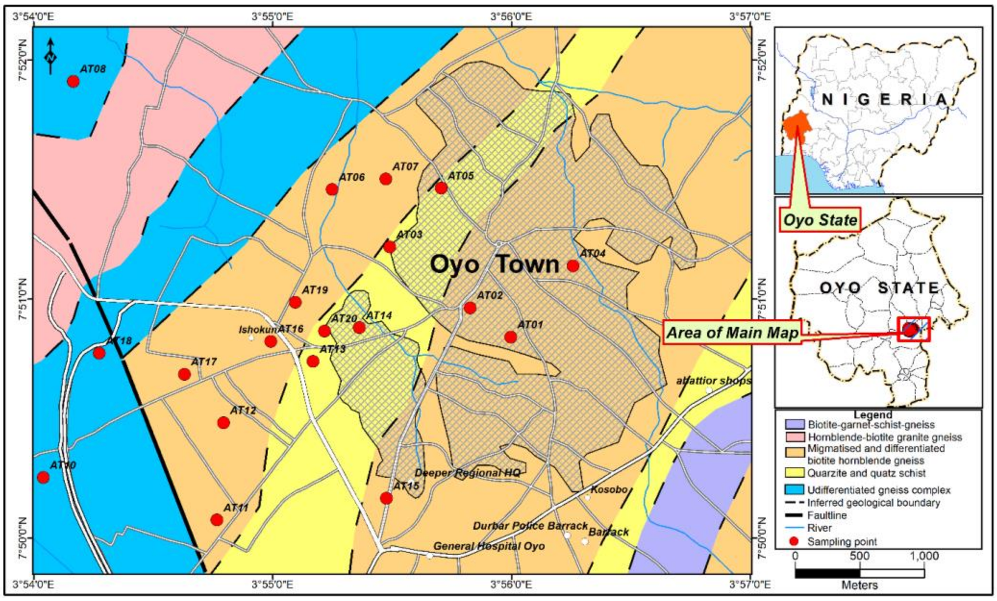

Fig. 3 Location of sampled hand-dug wells on geological map of the study area

Table 1: Well inventory and physico-chemical parameters

Well No	Location Area	Coordinates		pH	TDS Mg/l	EC (µS/cm)	WD (m)	Bedrock
		Latitude	Longitude					
HD01	Baago	N07 50 55.2	E 03 56 29.2	6.5	580	1000	6.6	MBHG[1]
HD02	Adikuta	N 07 51 02.2	E03 56 21.6	7.0	560	1130	8.0	MBHG
HD03	Lagbodoko	N 07 51 17.7	E03 56 05.4	6.5	500	1020	10.8	QQS[2]
HD04	Aladade	N 07 51 12.2	E03 56 38.8	6.0	630	1260	21.7	MBHG
HD05	Iyalamu	N 07 57 34.5	E03 56 12.2	7.0	630	1290	18.0	QQS
HD06	Koko-Ogi	N 07 51 32.5	E03 55 53.1	6.5	930	1870	26.5	MBHG
HD07	Ile-Abutu	N 07 51 34.6	E03 56 03.8	6.2	690	1380	20.0	MBHG
HD08	Ayelagbe	N 07 52 00.1	E03 55 03.9	6.0	100	220	19.6	UGC[3]
HD09	Oroki	N 07 57 34.5	E03 57 11.9	6.0	100	210	20.0	MBHG
HD10	Alagbon	N 07 50 19.6	E03 54 55.7	6.5	200	425	19.8	UGC
HD11	Lamlatu	N 07 50 09.2	E03 55 31.9	7.0	445	920	17.7	MBHG
HD12	Ladindi	N 07 50 33.3	E03 55 32.1	7.0	350	720	23.6	MBHG
HD13	Olusami	N 07 50 49.2	E03 55 50.3	6.5	490	980	15.4	QQS
HD14	Ilaka	N 07 50 57.8	E03 56 0.2	7.0	760	1480	21.4	QQS
HD15	Are-Ago	N 07 50 14.5	E03 56 06.0	6.0	595	965	26.2	MBHG
HD16	Ile Oniyun	N 07 50 54.9	E03 55 41.0	7.0	680	1350	23.2	MBHG
HD17	Ojongbodu	N 07 50 45.3	E03 55 24.2	7.0	400	830	16.5	MBHG
HD18	Isokun	N 07 50 50.9	E03 55 06.6	6.5	100	200	26.4	UGC
HD19	Akesan 1	N 07 51 04.7	E03 55 46.4	6.0	400	830	17.7	MBHG
HD20	Akesan 2	N 07 50 57.2	E03 55 52.3	6.5	680	1360	26.2	QQS

[1]Migmatised undifferentiated biotite hornblende gneiss

[2]Quartzite and quartz schist

[3] Undifferentiated gneiss complex

Table 2: Summary of parameters of groundwater in different bedrock settings

Parameters	UNDERLYING BEDROCKS						
	MBHG		**UGC**		**QQS**		WHO [16,17] Guidelines (mg/L)
	n=12		n=3		n=5		
	Range	Mean	Range	Mean	Range	Mean	
pH	6.0 -7.0	6.5	6.0-6.5	6.3	6.5 – 7.0	6.7	6.5-8.5
EC (μS/cm)	210-1870	1038.8	200-425	281.7	980 - 1480	1226	1500
TDS (mg/L)	100-930	530	100-200	133.3	490 - 760	612	600
Well Depth (m)	6.6 – 26.5	19.0	19.6 – 26.4	21.9	10.8 – 26.2	18.4	-
Ca^{2+} (mg/L)	15.6-102.2	69.1	10.9-41.0	30.6	83.8-126.5	97.4	2500
Mg^{2+} (mg/L)	1.8-20.8	12.3	2.4-9.7	5.4	10.5-25.2	15.5	250 - 350
Na^{+}(mg/L)	7.6-46.0	30.6	6.5-10.5	8.8	24.8-76.2	48.9	NHC*
K^{+} (mg/L)	0.9-58.5	23.7	2.6-11.2	5.5	9.5-80.0	43	NHC
HCO_3^{-} (mg/L)	58-428	253.6	66-156	115.3	202 - 434	288	100
CL^{-} (mg/L)	4.0 – 57.6	36.6	2.0-14.1	6.7	13.1-62.6	40.1	NHC
SO_4^{2+} (mg/L)	5.0- 81	32.8	3.0-12.0	6.0	31.0-80.0	50.8	NHC
NO_3^{-} (mg/L)	1.1-19.1	11.2	0.9-6.7	3.4	2.5-18.0	12.1	50
CO_3^{2-} (mg/L)	Nil	-	-	-	42.7-89.2	60.8	NHC

*NHC Not of health concern at levels found in natural water

The pH of the shallow groundwater samples was between 6.0 and 7.0. Based on mean values, groundwater in slightly acidic, more so in UGC bedrock with 6.3 value. The TDS is generally less than 1000mg/l with values ranging from 100 to 930mg/l. Mineral solubility is higher in QQS with an average value of 612 mg/L compared to other bedrocks in which case the average dissolved solids values were between 133 and 530 mg/L. However, the highest TDS value of 930 mg/L was obtained at Koko-Igi (HD06) in MBHG bedrock. Based on mineral dissolution in water, the TDS in thirteen samples representing 65% of the total sampled wells were below the guildeline limit of 600 mg/L (Table 2) for drinking water, however; long term intake of water with TDS >500 mg/L may lead to health issue such as causing kidney stone [5]. The mean values of EC were between 281.7 and 1226 μS/cm. The low water conductivity was obtained in samples within areas underlain by UGC. In addition, areas underlain by UGC are characterized by deeper wells with the range of 19.6 – 26.4 m and mean value of 21.9 m, compared to wells in MBHG and QQS having average well depths of 19 and 18.4 m respectively.

Based on the average values of major ions concentrations, the cationic dominance is $Ca^{2+} > Na^{+} > K^{+} > Mg^{2+}$ and this is similar in all bedrock terrains. This is also similar for cationic dominance in terrains underlain by MBHG and UGC which is $HCO_3^{-} > CI^{-} > SO_4^{2-} > NO_3^{-}$, whereas the order is $HCO_3^{-} > SO_4^{2-}$ $CI^{-} > NO_3^{-}$ in QQS where sulphate concentration is more dominant than chloride. Among the cations, calcium is the most dominant with concentration ranges from 10.9-126.5 mg/l and a mean of 70.4mg/l. Calcium is readily mobile in the hydrosphere and the possible sources of calcium are from the weathered product of minerals such as feldspars, amphibole and pyroxene groups in groundwater system of basement terrains. Magnesium is the least dominant cation with a range of 1.8 to 25.2 mg/L. the lowest value of 1.8 mg/L obtained at Akesan underlain by MBHG. Magnesium aids protein synthesis and regulation of body temperature and it is one of the essential elements needed for good body metabolism. Sodium concentrations generally ranged between 6.5 and 76.2 mg/L. it is more dominant in QQS bedrock with an average value of 48.9 mg/L and least occurred in UGC with just 8.8 mg/L. Sodium belongs to the metal group called alkali metals, it is mostly found in significant quantity in natural water, and its occurrence reflects geochemical interactions of transported foreign material with those occurring locally in the area. Possible natural sources of sodium in groundwater are from weathered plagioclase feldspars, exchangeable sodium from clay and atmospheric dust washed down by rain. Potassium is the third most abundant cation in the groundwater of the area with concentrations of 0.9 - 80.0 mg/L. Potassium is much more abundant in QQS with an average of 43 mg/L while it was 5.5 and 23.7 mg/L in UGC and MBHG respectively.

Bicarbonate is the most dominant anions in all the bedrock terrains. It ranges from 58 to 428 mg/L in water. Based on average values, bicarbonate is most dominant in QQS with a mean value of 288 mg/L. For other two bedrocks the values were 253.6 and 115.3 mg/L in MBHG and UGC respectively. Chloride is the second most enriched anion in the water samples. The concentration level of chloride was generally between 2.0 and 62.6mg/l (av. 31.5mg/l). Sources of chloride in fresh water could from both natural and anthropogenic inputs. The natural sources commonly involved sea precipitation, dissolution of rock salts such as halite and sea water intrusion. From field investigation, wells that have high values of chloride are those that are occasionally treated with chlorine for biological contaminations. Aside this, other anthropogenic sources of high concentrations of chloride in groundwater are from sewage, agricultural and industrial inputs [18]. Water that contains less than 150 mg/L chloride is satisfactory for most purposes. A chloride content of more than 250mg/l is generally objectionable for a municipal water supply, and water containing more than 350 mg/l is objectionable for most irrigation and industrial uses. Sulphate is more enriched in QQS with an average value of 50.8 mg/L compared to 32.8 and 6 mg/L in MBHG and UGC samples. Nitrate ion is the least abundant anion. The concentration level ranged from 0.8-18.0 mg/l and its mean value is 10.24 mg/L. in contrast to other elements in groundwater, nitrate is not derived primarily from the minerals in rocks that make up the groundwater reservoir. The low NO_3^- (mean) value indicates that the groundwater in the study area has not been influenced greatly by human activities. Even then, occurrence of nitrate in water is a concern and evidence of contamination from household and agricultural sources. Nitrate concentration is very low in groundwater samples in UGC terrain with a mean value of 3.4 mg/L compared to other bedrock areas where the mean values were 12.1 and 11.2 mg/L in QQS and MBHG terrains respectively. Lastly, carbonate only occur in few locations in QQS terrain.

Hydrochemical facies

From the trilinear diagram in Figure 4, calcium and bicarbonate are the dominant ions. The diamond shaped field revealed two major water types; while the dominant one is the $Ca-HCO_3$, sample HD19 from hand-dug well at Akesan market plotted in Na-Cl water type. Calcium, sodium and bicarbonate enrichment in groundwater are commonly attributed to dissolution of aluminosilicate minerals of mostly feldspar rich bedrocks by CO_2 stimulated groundwater [12]. Chloride enrichment is attributable to household contaminants. The plot of sample HD19 from hand-dug well located in Akesan area within the vicinity of the major market in the area on Na-Cl water type field corroborates this insinuation.

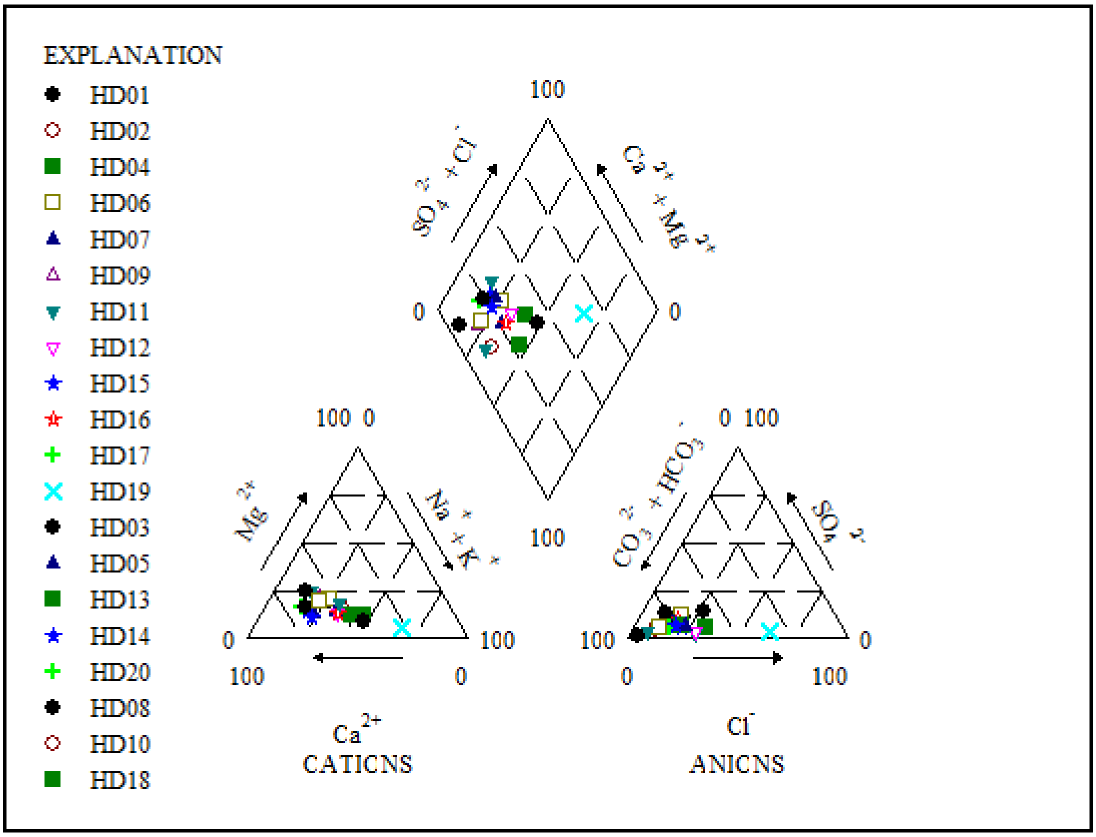

Fig. 4 Trilinear diagram of chemical data for all sampled wells

Correlation analyses

The results of correlation analyses are presented in Table 3. It shows that the relationships between TDS and EC as well as with the major elements are strong and direct. This is an indication that the ionic parameters are the major contributary factor to the total dissolved solids in water. However, the correlation between well depth (WD) and TDS is insignificant (0.05). This means that the depth of the wells has little or no bearing on water mineralization enrichment. In the light of this, it can be deduced that the dissolved solids in water are not necessarily from the bedrock region alone but may also be from direct recharge and/or dissolution along the soil zone. This confirmed the vulnerability of shallow aquifer to contamination and it is evidence of vulnerability of the overlying weathered – regolith units to transmit water directly to the underlying bedrock aquifers. This is further corroborated by insignificant values obtained between WD and major ions and the contrariwise significant and strong relationships that existed between TDS and the latter (Table 3).

Nitrate has weak relationships with most major ions with the coefficients of relationship (R) values ranging from 0.12 with Mg and 0.35 with Ca. In a similar but at lower extent; the relationships that occur in Cl and other ions are also low with the exception of univalent ions, Cl/Na and Cl/K where the associations are quite strong to moderate with R equals to 0.73 and 0.56 respectively. However, the association between nitrate and chloride is moderately significant with R = 0.45. in the light of this, it is deduced that the affinity of nitrate and chloride is stronger compared to other major ions; hence nitrate and chloride may likely be from similar source(s).

Table 3 Results of correlation analyses of physico-chemical parameters in groundwater

	TDS	pH	EC	WD	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-
TDS	1											
PH	0.25	1										
EC	0.99	0.30	1									
WD	0.05	-0.18	0.06	1								
Ca^{2+}	0.78	0.56	0.77	-0.14	1							
Mg^{2+}	0.69	0.61	0.70	-0.18	0.88	1						
Na^{+}	0.69	0.31	0.72	0.00	0.56	0.40	1					
K^{+}	0.63	0.34	0.66	0.01	0.51	0.38	0.93	1				
HCO_3^-	0.69	0.63	0.68	-0.19	0.92	0.89	0.41	0.41	1			
SO_4^{2-}	0.76	0.13	0.76	0.01	0.66	0.50	0.63	0.55	0.52	1		
Cl^-	0.64	0.24	0.64	0.03	0.38	0.28	0.73	0.56	0.29	0.36	1	
NO_3^-	0.59	0.02	0.59	0.53	0.35	0.12	0.30	0.24	0.25	0.32	0.45	1

4. Conclusion

From this study, the TDS of 65% of sampled hand dug wells are < 600 mg/L, which is the recommended standard for drinking that is generally satisfactory for other domestic and industrial use. Likewise, the concentrations of major ions occurred at levels that were normally regarded as not of health concern. The dominant ions in the groundwater are Ca-Na-HCO_3-Cl. Dissolved solids in the groundwater are from rock/mineral dissolutions, as revealed from direct and strong associations occurring between the major ions and TDS.

Well depth bears insignificant affinity with the major ions, except with nitrate where the relationship is moderately positive, an indication of well depth influence on nitrate concentrations. Though, nitrate occurred far below the guideline limit of 50 mg/L in all the wells, the moderate positive relationship occurring between nitrate and chloride may depicts human inputs into the shallow groundwater. For a complete quality assessment of the groundwater in the area, further studies including bacterial counts and trace element assessment should be carried out. Meanwhile, it is recommended that the hand dug wells be properly cased and the water be treated appropriately before consumption.

Funding: Not applicable

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest

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Cite article as:

Akanbi, O.A., Falana O.A. and Gabriel S. (2022). Hydrogeochemical study of Shallow Groundwater of Oyo Town Southwestern Nigeria. *Ajayi Crowther J. Pure Appl. Sci.* 1(1): 1-9. doi.: https://doi.org/10.56534/acjpas.2022.01.01.9