

Full Length Research Paper

Hydrogeochemistry of groundwater within the lateritic profiles over migmatite and pegmatized schist of Ibadan, Nigeria

Anthony Temidayo Bolarinwa

Department of Geology, University of Ibadan, Ibadan, Nigeria.

Received 15 September, 2016; Accepted 19 June, 2017

Groundwater compositions could be altered significantly due to geogenic and anthropogenic inputs from rock and human respectively. Such impacted water may be injurious to health if consumed. Studies of groundwater within the lateritic overburden on migmatite gneiss and pegmatized schist in Ibadan area were undertaken with the aim of determining their physico-chemical composition and portability. Groundwater within lateritic profiles over NE-SW trending migmatite and pegmatized schist were sampled. The temperature of the water ranged from 23.9 to 32.7°C, electrical conductivity from 60 to 580 $\mu\text{S}/\text{cm}$, pH from 5.5 to 7.3 and TDS from 55 to 422 mg/L. The concentrations of cations in mg/L ranged for Ca^{2+} (62.2-79.4), Mg^{2+} (7.5-15.3), Na^+ (28.2-54.3), and K^+ (55.0-85.1) while the anions are HCO_3^- (116.1-149.2), SO_4^{2-} (0.0-1.1), Cl^- (8.2-22.1) and NO_3^- (0.3-2.2) mg/L. These chemical data are characteristic of Na-(K)- HCO_3 water type. The cations, anions and the trace metals of the groundwater are generally within the WHO standards. The low level of chemical constituents in the groundwater reflects geogenic input arising from weathering of the basement rocks. The water is good for domestic, industrial and irrigation purposes.

Key words: Groundwater, water portability, migmatite, pegmatized schist, hydrochemistry.

INTRODUCTION

The provision of good quality water is crucial for sound human and environmental health, economic and sustainable development. Water is required for domestic, industrial and agricultural purposes. Provision of portable water is an essential ingredient in the achievement of the millennium development goals (MDGs). Government at various levels are making efforts to ensure adequate provision of good drinking water through the provision of solar powered boreholes drilled by government agents.

Previous efforts to supply drinking water to Ibadan metropolis through surface water at Asejire and Eleyele water works has become grossly inadequate, hence the need for individuals to complement government efforts through provision of water from motorized boreholes and hand dug wells.

Groundwater chemistry is altered as a result of the interaction between the subsurface materials or rocks and the percolating water. This brings about the need to

*Corresponding author. E-mail: atbola@yahoo.com.

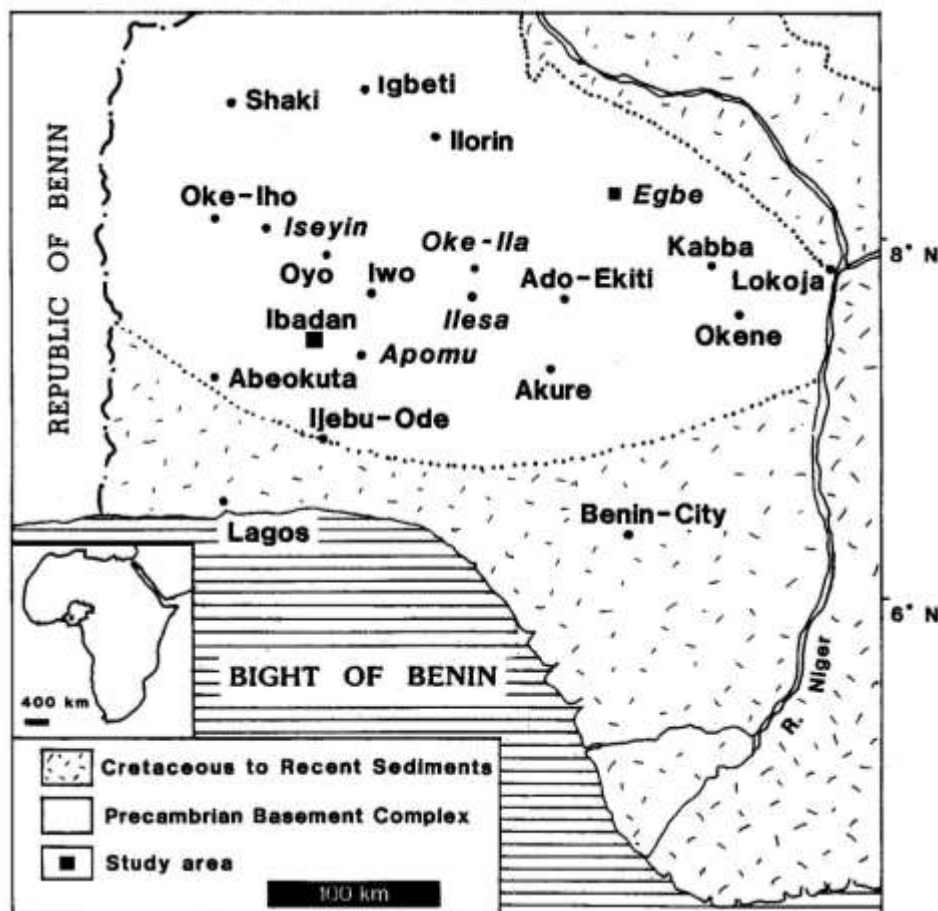


Figure 1. Map of southwestern Nigeria showing the location of Ibadan.

understand the influence of the bedrocks on the groundwater system of the study area. Apart from this geogenic influence, anthropogenic activity in the study area makes the groundwater system in the area prone to possibility of contamination. Therefore, a proper understanding of the groundwater and surface water in the study area is of paramount importance so as to maintain good quality water for drinking, irrigation and other domestic purposes.

Most of the previous work in Ibadan area are regional in nature and not detailed enough to address the peculiarity of the water bodies within the lateritic overburden on migmatites and pegmatized schist in Ibadan (Figure 1). The objectives of the investigation are to determine the physico-chemical characteristics, assess the geogenic and anthropogenic influence on the groundwater and evaluate the quality of the groundwater in terms of drinking, domestic, industrial and agricultural uses.

MATERIALS AND METHODS

Geological mapping of the study area was undertaken during this

investigation though regional studies of the rocks in Ibadan have been carried out by many workers including Jones and Hockey (1964), Grant (1970) and Bolarinwa (2001). The study area, which is the northeastern part of Ibadan, is located between latitudes $7^{\circ} 27'$ and $7^{\circ} 32'$, and longitudes $003^{\circ} 54'$ and $004^{\circ} 00'$ (Figure 2). It is a rapidly developing sub urban area north of Ibadan metropolis. Most of the rocks in this area are deeply weathered. Only few outcrops are available for mapping. Ibadan is within the polycyclic metamorphic terrain of the Precambrian Basement Complex of southwestern Nigeria. The rocks are generally poor aquifers, especially the migmatite, except where deeply weathered or fractured, thereby resulting in localized groundwater aquifers.

A total of 20 water samples were collected from Ibadan area during the rainy season of July 2013. The well characteristics were noted and recorded. An HI 9813-6 pH/EC/TDS/ $^{\circ}$ C meter was used for in-situ measurement of temperature, pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS), while a clean rubber container and plastic bottles were used for water sampling. Samples for cation analyses were acidified with concentrated hydrogen trioxonitrate (v) acid in order to bring down the pH of the water and ensure that the metals are inert prior to analysis. Major cations, anions and trace metal contents of the water were determined according to the procedure of Brown et al. (1970). Results obtained from the hydrochemical analyses were presented graphically on the modified Piper (1944), Stiff (1951), Hemm (1983) diagrams using the Origin software. Descriptive statistics, correlation, factors and principal component analyses, Sodium

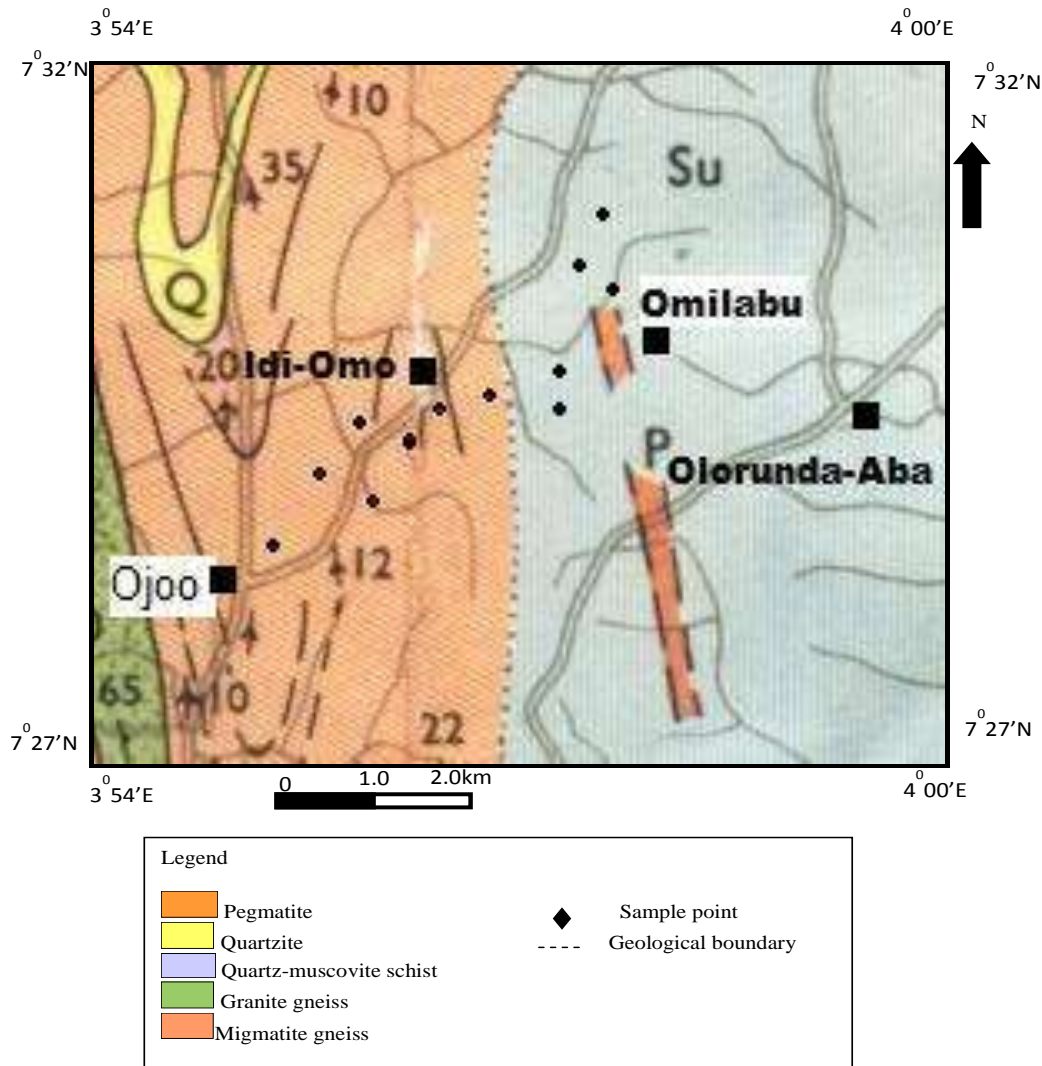


Figure 2. Geological map of Ibadan showing sample locations.

Absorption Ratio (SAR), Piper trilinear, Chadah and Stiff diagrams were used to interpret the results of the study.

RESULTS

Geology of the study area

The rock types mapped in the study area during the present investigation include migmatites, granite gneiss, pegmatized quartz muscovite schist and quartz veins (Figure 2). Migmatites occur linearly at the western part of the study area. They are low-lying rocks consisting of alternating light and dark bands of quartzo-feldspathic and ferromagnesian minerals. Together, the bands form planar, folded and contorted metamorphic layers (Figure 3). The banded varieties are very common. Parallel and cross-cutting veins and irregular pods of paleosomatic

(mafic) and neosomatic (felsic) compositions occur within the migmatites.

The granite gneiss in Ibadan is characterized by mineral lineations, weak foliations, irregular cross-cutting joints, pegmatite and quartz veins. They are composed dominantly of quartz, plagioclase feldspars, microcline, biotite and hornblende with subordinate muscovite. The quartzite bodies in the area are low-lying and have mica flakes in varying degrees along their parting planes often giving them a flaggy appearance. They also have some muscovite flakes within their main bulk apart from those in the parting planes. The quartz muscovite schist in the eastern side is intruded by northerly trending pegmatite dykes. This pegmatized quartz muscovite schist possesses large feldspar megacrysts (Figure 4). Smaller pegmatite veins cut across the migmatites, gneisses and the quartz muscovite schist. They are often conformable or cross-cut the main rock types. The pegmatite contains



Figure 3. A migmatite outcrop at Abutu showing mafic and felsic bands and concordant pegmatite dykes.



Figure 4. Pegmatized quartz muscovite schist showing feldspar megacrysts.

Large interlocking, euhedral, milky white quartz, plagioclase feldspar, microcline and large sheets of mica.

Table 1. Chemical compositions of the groundwater in Ibadan area.

No	Location	Sample code	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃ ⁻	Cl ⁻	Fe	Mn	Cu	Pb	Zn
			(mg/L)												
1	Ojoo Borehole	L1	67.1	8.43	37.5	55	124	0.2	0.3	12.5	0.3	0.002	0.2	0.02	0.5
2	Well	L2	71.2	10.4	44.8	65	132	0.7	2.2	22.1	0.5	0.05	0.4	0.06	0.8
3	Well	L3	65.6	7.5	42.0	55	150	0.5	1.0	16.0	0.4	0.06	0.4	0.05	0.5
4	Stream	L4	63.2	7.6	28.2	65	116	0.6	0.7	13.8	0.7	0.04	0.5	0.06	0.6
5	BLHMC Well	L5	79.4	13.0	48.8	65	158	1.1	2.0	20.6	0.5	0.06	0.4	0.06	0.8
6	BLHMC Well	L6	78.7	12.6	28.5	75	152	0.7	1.6	18.5	0.6	0.06	0.5	0.05	0.8
7	BLHMC Well	L7	72.3	15.3	52.1	70	197	0.4	0.8	8.6	0.5	0.04	0.4	0.04	0.4
8	BLHMC Well	L8	68.4	12.4	54.2	80	149	0.5	1.4	18.1	0.6	0.04	0.5	0.05	0.5
9	Omilabu Well	L9	62.2	10.4	40.2	60	120	1.0	1.8	21.6	0.5	0.03	0.3	0.04	0.5
10	Idi-Omo Well	L10	75.5	9.4	48.0	85	183	0.8	0.7	17.4	0.6	0.06	0.6	0.05	0.4
11	Well	L11	70.4	13.2	47.0	70	145	0.7	1.2	15.2	0.4	0.07	0.5	0.05	0.6

Table 2. Summary of the results of groundwater chemistry in Ibadan area.

Parameters	Minimum	Maximum	Mean	WHO (2004)	SON (2007)
Temp (°C)	23.9	32.7	28.3	-	-
pH	5.5	7.3	6.5	6.5 – 8.5	6.5 – 8.5
EC (µS/cm)	60	580	282.8	1000	1000
TDS (mg/L)	55	422	229.6	-	500
Ca (mg/L)	62.2	79.4	70.4	75	75
Mg (mg/L)	7.5	15.3	10.9	50	50
Na (mg/L)	28.2	54.3	42.9	200	-
K (mg/L)	55.0	85.1	67.8	-	-
HCO ₃ ⁻ (mg/L)	116.1	149.3	147.8	-	-
SO ₄ ²⁻ (mg/L)	0.0	1.1	0.6	250	100
Cl ⁻ (mg/L)	8.6	22.1	16.8	250	100
NO ₃ ⁻ (mg/L)	0.3	2.2	1.2	50	50
Fe (µg/L)	300	700	509.1	300	300
Mn (µg/L)	20	70	48.2	500	500
Cu (µg/L)	200	600	427.3	2000	2000
Pb (µg/L)	20	60	48.2	10	10
Zn (µg/L)	400	800	581.8	300	300

Hydrochemical profiles

The results of the chemical analyses are presented in Table 1. Table 2 shows the summary of results of groundwater chemistry irrespective of rock types. The range and mean values for the study area are displayed alongside World Health Organization (WHO) and Standard Organization of Nigeria (SON) standards. Detailed results indicating well inventory, in-situ measurement, as well as, the physicochemical and trace element parameters are presented in Table 3.

The concentrations of the major cations are in the order Na⁺>Ca²⁺>K⁺>Mg²⁺ with average value of 42.9, 70.4, 67.8 and 10.93 mg/L respectively, while the order of the

major anions concentration is HCO₃⁻>Cl⁻>NO₃⁻>SO₄²⁻ with average values of 147.8, 16.8, 1.2 and 0.6 mg/L. From the results of the chemical analysis in Table 1, it was observed that eight major constituents which are Ca²⁺, K⁺, Mg²⁺, Na⁺, HCO₃⁻, Cl⁻, NO₃⁻ and SO₄²⁻ make up 99.5% of the solute of the groundwater in the study area. All the water samples have Lead (Pb) concentrations higher than the WHO 0.01 mg/L recommended standard value for drinking water with the minimum concentration of 0.02 mg/L in Location 1 and maximum concentration of 0.06 mg/L in locations 2, 4 and 5. Similarly, Zn concentration of 0.4 to 0.8 mg/L is higher than the WHO 0.3 mg/L permissible limit for drinking water. The Fe concentrations range from 0.3 to 0.7 mg/L, which

Table 3. Physical parameters, well and stream inventory of Groundwater from Ibadan.

Code	Location	GPS Reading	Elev. (m)	Water level (m)	Water depth (m)	Temp (°C)	pH	EC (µS/cm)	TDS (mg/L)	Remark
L1	Ojoo Borehole	N07°28'.333" E03 ° 55'.163"	252	ND	ND	25.5	6.3	230	175	Deep borehole, 40 m deep, on pegmatite within migmatite.
L2	Abutu well	N07°29'.818" E03 ° 56'.153"	224	5.5	12.0	28.6	6.8	280	208	Well lined, covered, within a fenced clean compound with concrete cement floor.
L3	Alapata well, south of a factory	N07°29'.960" E03 ° 56'.292"	219	4.0	8.0	28.7	6.4	500	360	Well lined, covered, within a fenced clean compound with concrete cement floor.
L4	Stream	N07°29'.914" E03 ° 56'.298"	210	Stream	Stream	23.9	6.8	240	179	Oily stream water flowing from East to West in the southern part of a factory.
L5	BLHMC well 1	N07°30'.134" E03 ° 57'.578"	236	2.5	6.0	27.9	5.9	60	55	Well is shallow, hit the basement rock. Caving on the sides. Not lined but partially covered with planks.
L6	BLHMC well 2	N07°30'.051" E03 ° 57'.598"	238	4.0	8.0	29.2	6.3	250	187	Well lined, covered and locked. Water chlorinated.
L7	BLHMC Omilabu stream	N07°29'.925" E03 ° 57'.379"	228	Stream	Stream	24.6	6.7	200	154	Clear stream water flowing from East to West.
L8	Well 50 m outside BLHMC	N07°30'.464" E03 ° 57'.335"	242	3.5	8.0	30.4	6.5	280	213	Well lined and covered in front of a building without a fence but with concrete cement floor.
L9	Omilabu area well	N07°30'.058" E03 ° 57'.229"	241	11.0	15.5	29.3	6.7	580	422	Well lined, covered and locked. Outside a compound without a fence.
L10	Idi-Omo well	N07°30'.304" E03 ° 57'.120"	253	12.0	16.0	30.0	5.5	420	303	Well lined, cover removed. Not too far from main road.
L11	Well north of a factory	N07°30'.030" E03 ° 56'.422"	233	6.0	10.0	32.7	7.3	370	269	Well lined, covered, within a fenced clean compound with concrete cement floor.

generally exceeded the WHO approved standard value of 0.3 mg/L. These may affect the taste or color of the well water. Although Fe does not pose a health risk at levels normally found in drinking water, its presence in concentration above the recommended limit can indicate deteriorating groundwater quality. Trace elements concentrations are in the order Zn>Fe>Cu>Pb>Mn with average value of 0.6, 0.5, 0.4, 0.05 and 0.04 mg/L respectively.

The summary of the results of the physical

parameters presented in Table 3 indicates that the pH of the water in the area varies from 5.5 to 7.3. Values slightly lower than the permissible limit were recorded in five wells. However, pH values of 5.5 and 5.9 in locations 5 and 10 calls for vigilance. This is because at low pH clay minerals may dissolve and release silica into the water. The EC values of the water samples (60 to 580 µS/cm) are far less than 1000 µS/cm recommended by WHO (2004) and SON (2007) indicating that the water in the study area is safe

for drinking purposes. The temperature of the water in the area varies between 23.9 to 32.7°C while the TDS in the area varies from 55 to 422 mg/L. The water samples fall within the freshwater category and the TDS values are below the 500 mg/L standard for drinking water.

Gibbs's diagram is widely used to assess the source of dissolved chemical constituents, such as, precipitation dominance (dilution), rock dominance (weathering) and evaporation dominance (evaporation). The plot of the

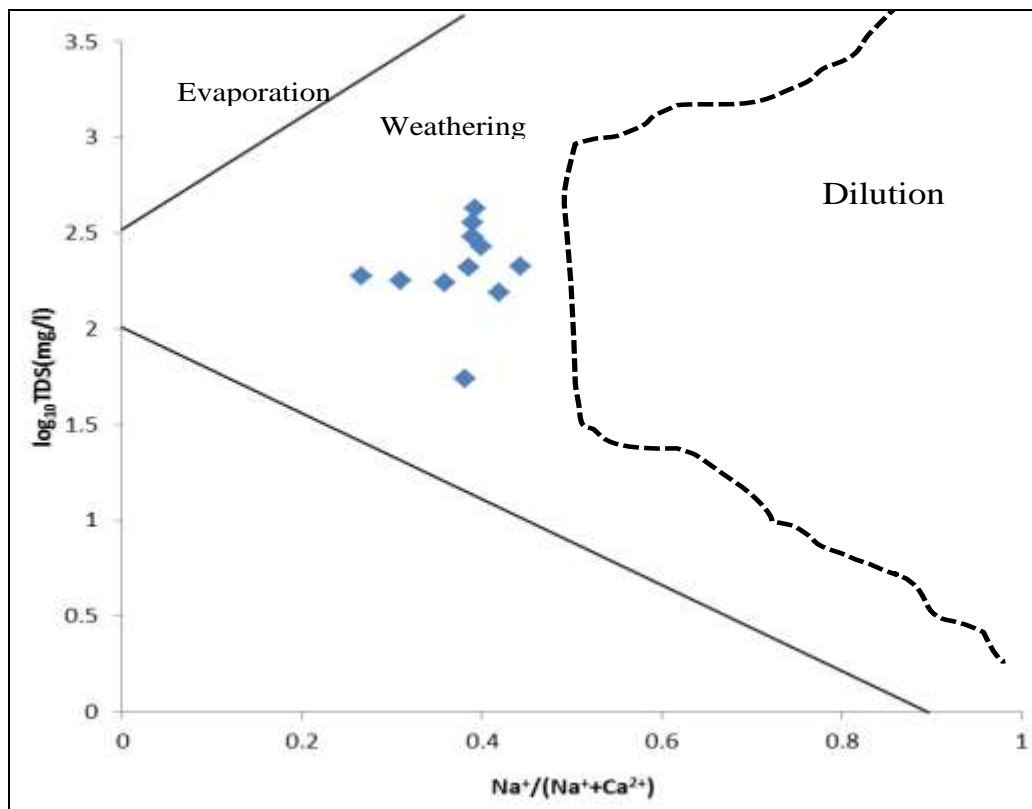


Figure 5. Gibbs (1970) diagram showing groundwater evolution.

Table 4. Results of major ionic parameters (in mg/L) of groundwater from the study area based on rock types.

Rock type		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	NO ₃ ⁻
Migmatite	Min	62.2	7.5	37.5	55.0	120.1	0	12.5	0.3
	Max	75.5	10.4	48.0	85.1	183.0	1.0	22.1	2.2
	Mean	68.3	9.2	42.5	64.0	141.8	0.6	17.9	1.2
Pegmatized schist	Min	63.2	7.6	28.2	65.1	116.1	0.4	8.6	0.7
	Max	79.4	15.3	54.3	80.2	197.2	1.1	20.6	2.0
	Mean	72.7	12.35	43.2	70.8	152.8	0.7	15.8	1.3

analytical data on Gibbs diagram (Figure 5) show that the groundwater samples clustered at the region of rock dominance (weathering). It indicates that the water chemistry have been modified through weathering of the underlying rocks. In order to establish the effects of bedrock units on the groundwater system of the study area, the hydrochemistry were further presented based on the two major rock units in the area, namely, migmatite and pegmatized schist. Summary of the major ions in the water from weathering profiles on both rock types are presented in Table 4 and Figures 6 and 7. The chemical compositions of the groundwater for the two rock units are quite similar due to the fact that the rocks

are closely associated and interrelated. An evidence of this is the presence of pegmatite veins and dykes in the migmatite outcrop as shown in Figure 3. This could be responsible for the high Na⁺ content in the well water within both migmatite and pegmatite bedrocks. Weathering of the bedrock as a result of chemical decomposition of sodic feldspar, such as oligoclase and albite present in the migmatite and pegmatite respectively commonly release Na into the environment which may eventually end up in the water bodies.

Correlation analysis between the various parameters of the shallow groundwater in the study area was carried out. The result is presented in Table 5. Statistical

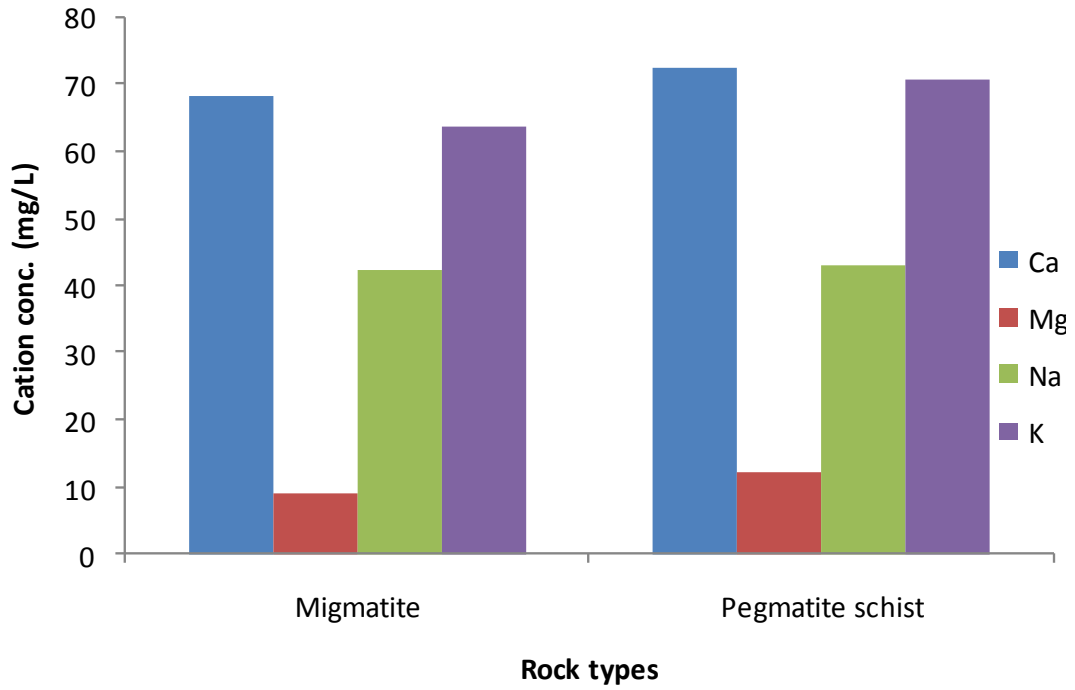


Figure 6. Mean concentrations of major cations based on rock types.

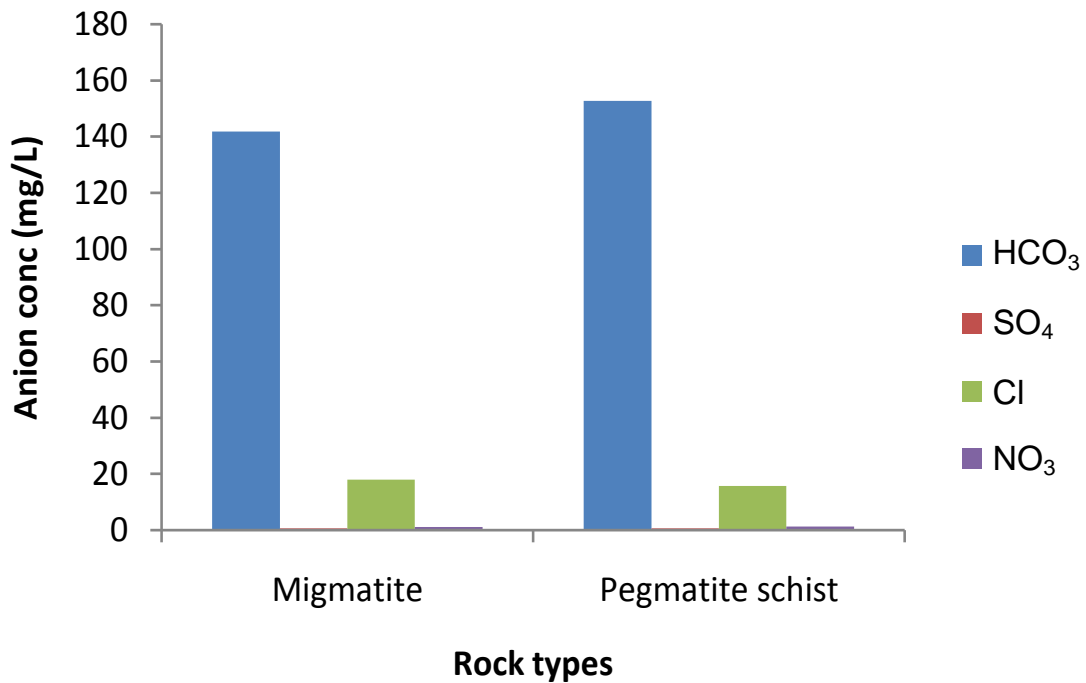


Figure 7. Mean concentration of major anions based on rock type.

correlation using product moment coefficient of correlation indicates positive correlation between some pairs of parameters. A plot of TDS against EC (Figure 8a) indicated coefficient of correlation of 1.000. This shows

that the dissolved ions in the groundwater are responsible for the EC. The correlation between pH and bicarbonate ion (Figure 8b) shows a combination of direct and inverse relationship. The pH values are mostly in the

Table 5. Correlation coefficient of chemical parameters of groundwater in Ibadan area.

Ions	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	TDS	EC	pH	Temp p	Elev.
Ca ²⁺	1												
Mg ²⁺	0.556	1											
Na ⁺	0.210	0.506	1										
K ⁺	0.517	0.421	0.328	1									
HCO ₃ ⁻	0.519	0.565	0.579	0.557	1								
Cl ⁻	-0.158	-0.092	-0.003	0.070	-0.339	1							
NO ₃ ⁻	0.290	0.347	0.146	0.028	-0.149	0.830	1						
SO ₄ ²⁻	0.315	0.221	0.093	0.242	0.049	0.710	0.709	1					
TDS	-0.560	-0.397	-0.045	-0.113	-0.194	0.222	-0.039	0.126	1				
EC	-0.553	-0.404	-0.051	-0.110	-0.189	0.219	-0.045	0.128	1.00	1			
pH	-0.506	-0.180	-0.092	-0.306	-0.407	-0.179	0.117	-0.159	-0.143	0.139	1		
Temp	0.211	0.216	0.342	0.389	0.064	0.538	0.415	0.418	0.438	0.441	0.048	1	
Elev.	0.313	-0.158	0.273	0.342	0.205	0.137	-0.117	-0.053	0.073	0.086	-0.528	0.351	1

Elev. – Elevation. Correlation is significant at the 0.051.

range of 6 and 7 which means that the water is slightly acidic to neutral. The source of bicarbonate in the samples can therefore be attributed to CO₂ charge - recharge. The CO₂ charged precipitation makes the groundwater mildly acidic, which subsequently dissociates to produce hydrogen and bicarbonate ions. The major exchangeable ions, notably Na⁺, Ca²⁺ and Mg²⁺ correlate positively with HCO₃⁻ (Figure 8c). However, Na⁺ and Cl⁻ have a very weak and inverse relationship of -0.003 (Figure 8d). This shows that sodium can be derived from other sources, such as, dissolution of plagioclase and ion exchange other than halite dissolution.

Principal Component (PC) analysis was performed on the groundwater data for better understanding of their interrelationships, probable source of the major ions and to explore the reduction of the experimental variables. Table 6 shows the principal components, Eigen values and associated variance explained in the physico-chemical data. The four extracted Factors in Table 7 explained 81.4% of the data set variance. Factor 1 explained 29.7% of the total variance, Factor 2 explains 24.2%, Factor 3 explains 15.8% while Factor 4 explains 11.7%. Factor 1 has the highest factor loadings of Ca²⁺, Mg⁺, Na⁺, K⁺ and HCO₃⁻. This strongly suggests that PC1 may represent geogenic variables from influence of bedrock geology on groundwater. Factor 2 has the highest (positive) factor loadings of Cl⁻, NO₃⁻ and SO₄²⁻ and low (negative) factor loadings for other major ions and can be considered as anthropogenic factor. High factor loadings of Cl⁻ could be as a result of addition of a chlorine-based disinfectant popularly known as water guard in the wells to reduce or eliminate germs. Also, NO₃⁻ and SO₄²⁻ factor loading are moderate and may not suggest contamination of the wells. Factor 3 has the

highest (positive) factor loadings of TDS and EC while Factor 4 has the highest (positive) factor loadings of pH. These components (PC3 and PC4) are related to natural chemical weathering of rocks and dissolution of rock forming minerals in the area.

DISCUSSION

Drinking water quality assessment

The chemical character of any water determines its quality and utilization. The quality of water is a function of the physical, chemical and biological parameters which could be subjective since the expected quality depends on the intended use (Olayinka et al., 1999; Hussein 2012). There are different water quality standards based on various water uses (WHO, 1984). Drinking water standards are generally based on two main criteria. These include the presence of objectionable taste, odour and colour plus the presence of substances with adverse physiological (health) effects. Water quality assessment includes those for domestic, agriculture/irrigation and industrial application. It is therefore important to determine groundwater suitability for different uses based on different chemical indices. Hydrochemical parameters of groundwater in the study area are compared with the specifications of WHO (2004) and SON (2007) earlier presented in Table 2.

The TDS in the water samples fall within the fresh water category (<500 mg/L). Spatial distribution of TDS demarcated on the basis of excellent (>055 mg/L) to poor (422 mg/L) indicates that the study area has low TDS, indicating that the water is safe for drinking and domestic purposes. The groundwater pH of 5.5 - 7.3 is very close to the WHO permissible limits of 6.5 to 8.5. The slight

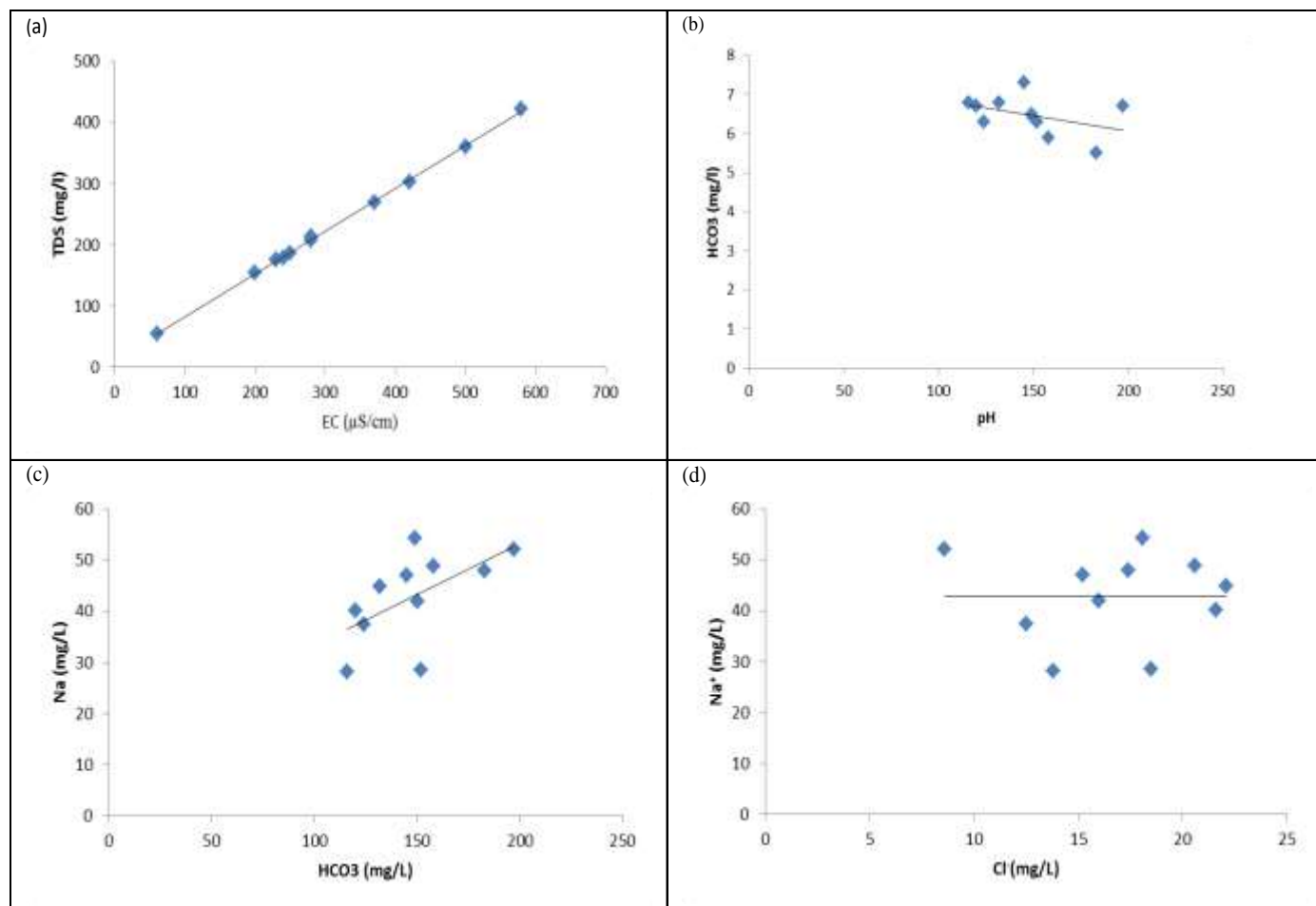


Figure 8. Scatter plots of (a) TDS vs EC (b) HCO₃⁻ vs pH (c) Na⁺ vs HCO₃⁻ and (d) Na⁺ vs Cl⁻.

acidity recorded in some of the locations may be due human contamination. The wells involved were not properly covered. The physico-chemical profiles of the water are within the permissible limits of WHO (2004) and SON (2007).

Irrigation quality assessment

Sodium Absorption Ratio (SAR) was used to assess the quality of the water bodies for irrigation. According to the modified Wilcox (1950) classification (Table 8), irrigation water can be classified as excellent, good, permissible and doubtful. The effect on the irrigated soil and crops depend on the soil type and crop variety, relative proportion of sodium ions to other cations and the climate of the area. The SAR, EC, soil type, plant variety and the amounts of irrigation water used determine the class of irrigation water to be used. Sodium concentration is important because it reacts with soil to harden and reduce its permeability. The SAR for all samples was calculated and plotted against EC to determine the

suitability of the water for irrigation purposes (Figure 9). Water containing SAR of 0 to 10 can be used to irrigate all agricultural soils while those having SAR range of 18 to 26 may produce harmful effects. Water with SAR range of 26-100 is generally unsuitable for irrigational purposes. Based on this Table, the SAR of the water samples shows that the water has low sodium content and therefore can be used to irrigate most plants and soils (Kelly, 1963; Leeden, 1990).

Groundwater characterization

The overall chemical character of groundwater was interpreted using the Piper trilinear diagram (Figure 10). The water falls within the Na-K-HCO₃ water type. This water type with appreciable amounts of Na+K indicates cation exchange reaction in groundwater. The HCO₃⁻ concentration in the water is higher than the available alkaline-earth metal ions. Therefore, when the excess bicarbonate ions present in the water reacts with cation exchangers, such as, clay minerals and other related

Table 6. Factors and component analysis.

Parameters/ Variables	Component			
	1	2	3	4
Ca ²⁺	0.880	-0.148	-0.142	-0.237
Mg ²⁺	0.730	-0.134	-0.149	0.546
Na ⁺	0.562	0.040	0.314	0.457
K ⁺	0.695	0.039	0.320	0.024
HCO ₃ ⁻	0.705	-0.321	0.403	0.193
Cl ⁻	0.223	0.835	-0.332	-0.312
NO ₃ ⁻	0.378	0.640	-0.610	0.091
SO ₄ ²⁻	0.424	0.665	-0.331	-0.082
TDS	-0.434	0.673	0.540	0.129
EC	-0.434	0.671	0.542	0.124
pH	-0.439	0.074	-0.314	0.778
Temp	0.367	0.731	0.265	0.198
Elevation	0.417	0.097	0.555	-0.362

Component Matrix (a). Extraction Method: Principal Component Analysis.

Table 7. Summary of loading parameters.

Factor	C1	C2	C3	C4
Range of Assigned Factor Loading	-0.439 to +0.880	-0.321 to +0.835	-0.610 to +0.555	-0.362 to +0.778
Extracted Factor	22.9 and 29.7	24.2 and 53.9	15.8 and 69.7	11.7 and 81.4
Controlling Variables	Ca ²⁺ , Mg ²⁺ , Na ⁺ , K ⁺ and HCO ₃ ⁻	Cl ⁻ , NO ₃ ⁻ , SO ₄ ²⁻ , TDS and EC	TDS and EC	pH

Table/ 8. Modified Wilcox (1950) quality classification of irrigation water.

Water class	EC (mS/cm)	Salinity hazard	SAR
Excellent	<250	Low	0-10
Good	250-750	Medium	10-18
Permissible	750-2000	High	18-26
Doubtful	2000-3000	Very high	26-30

SAR - Sodium absorption ratio.

aquifer materials, alkali ions (usually Na⁺ and K⁺) are released into the solution by exchange reaction. Thus, the water is enriched in Na⁺ and K⁺ ions. In the Chaddah (1999) diagram (Figure 11) majority of the samples are confined to field 3 characterised by Base Exchange reaction. By implication 75% of the samples plotted in the field representing the Na-K-HCO₃ water type. This is similar to the results obtained from the Piper (1944) plot. The major anions and cations were plotted on the Stiff (1951) diagram. This data is expressed in milli-equivalent per litre (meq/l). The diagrams presented in Figures 12 and 13 indicated that Ca-HCO₃ and (Na+K)-HCO₃ are the dominant water facies in the area.

Further investigation in the area should include determination of the microbial load and isotopic analyses.

These will reveal further the suitability of the water and shed light on the origin, residence time and evolution of the ground water. It is recommended that wells should be lined inside with prefabricated concrete rings to prevent seepage of contaminated water and that wells should be sited at least six meters from roads, pit latrines and soak away.

Conclusions

Hydrochemical evaluation of groundwater from Ibadan area was carried out. The wells from which the water was obtained were dug on two major rock types, namely, migmatites and pegmatized schist. Hydrochemical data

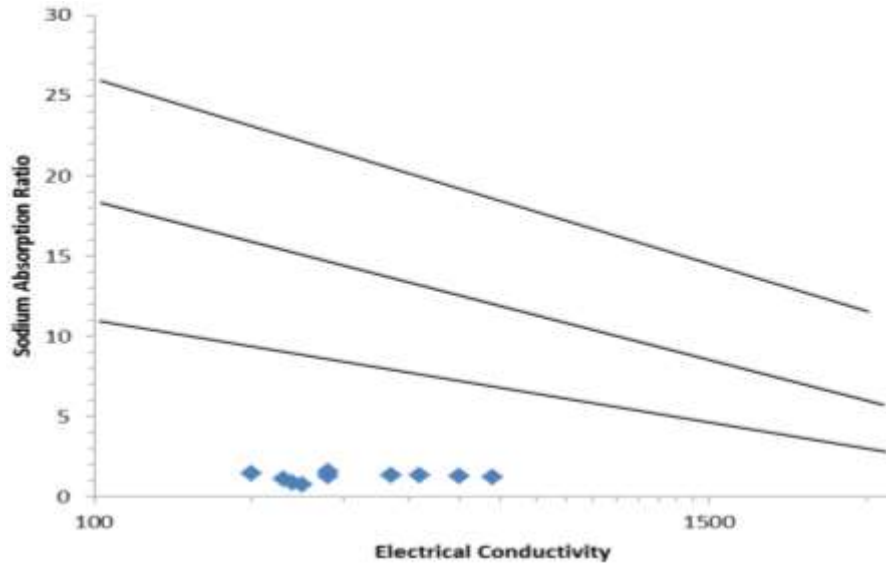


Figure 9. Wilcox diagram showing classification of groundwater for irrigation uses.

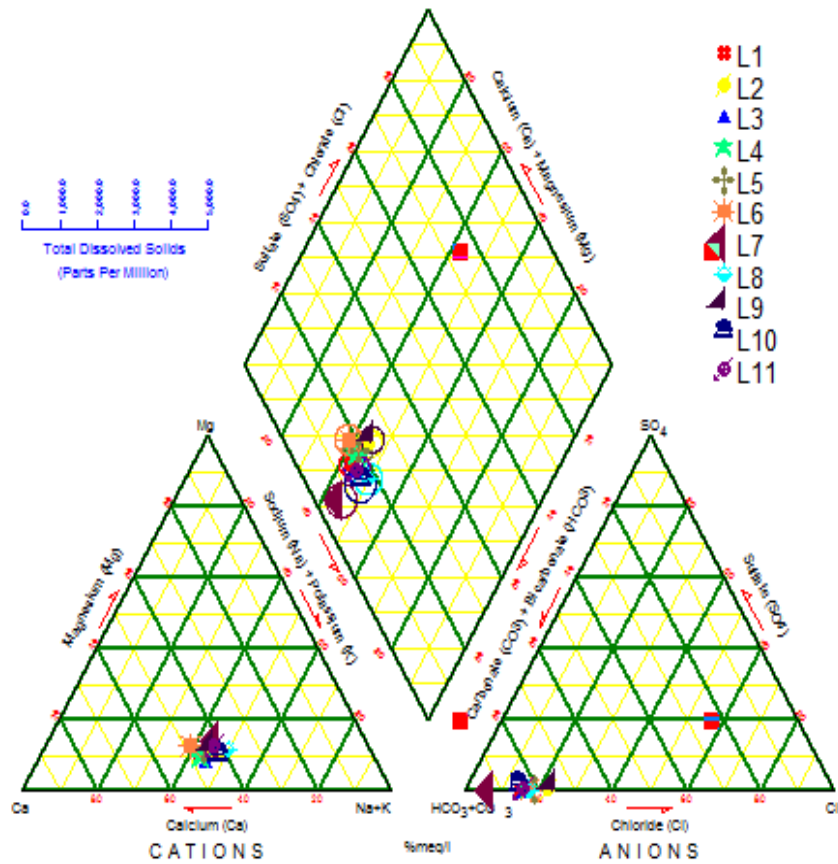


Figure 10. Diagram showing the hydrochemical facies of groundwater of Ibadan area. Source: Piper (1944)

of both surface and groundwater in the area showed that the water is slightly acidic with Na+K-HCO₃ water facies.

Hydrochemical analysis using Gibbs (1970) approach indicates that weathering is responsible for the evolution

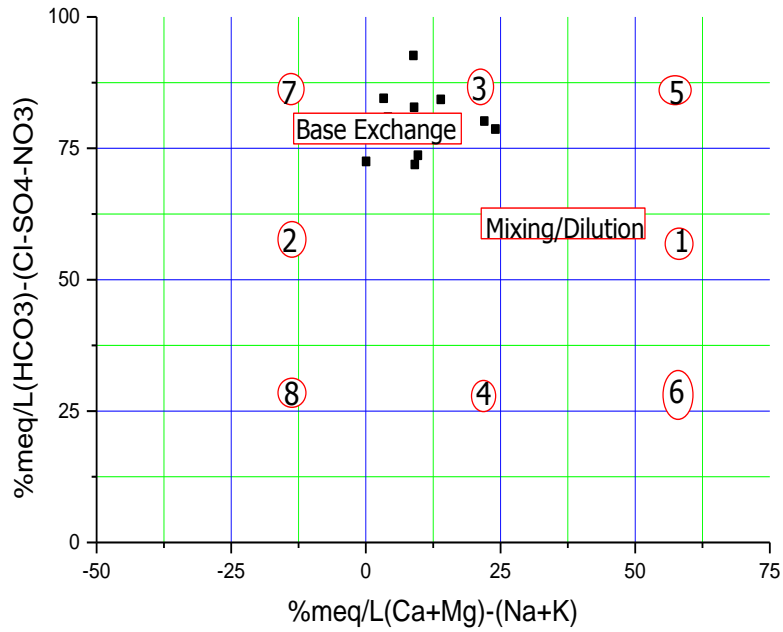


Figure 11. Diagram for groundwater of Ibadan area.
Source: Chadah (1999)

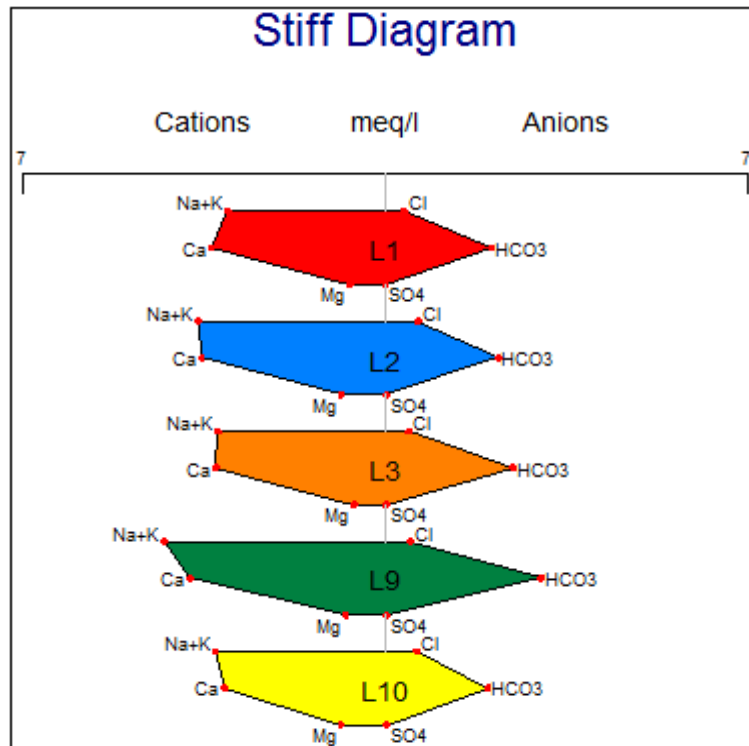


Figure 12. Plot of groundwater samples on migmatite bedrock.
Source: Stiff (1951)

of the groundwater in the study area. High Cl^- content of the water was hinged on addition of chlorine-base

disinfectant to the wells to reduce or eliminate germs. Computed values of Sodium Absorption Ratio indicate

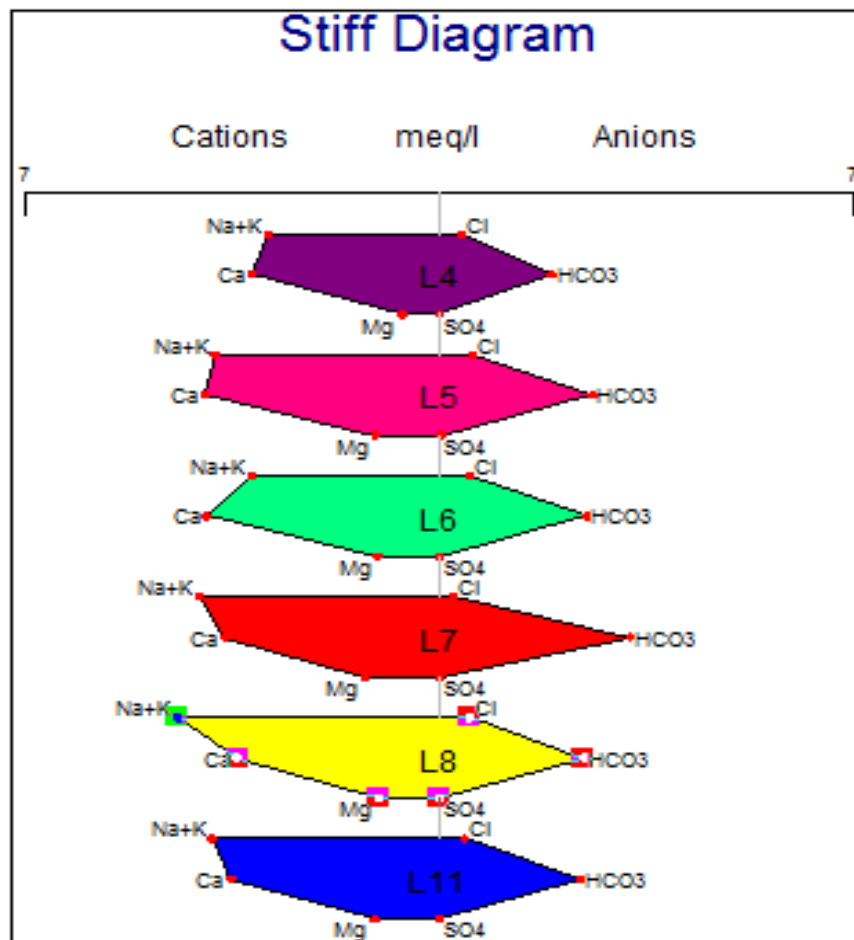


Figure 13. Plot of groundwater samples on pegmatite-schist of Ibadan area.
Source: Stiff (1951)

that the water has low sodium content and can therefore be used to irrigate most soils and plants. The hydrochemical parameters of the water satisfy the WHO (2004) and SON (2007) standards for domestic, agricultural and other industrial uses.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

- Bolarinwa AT (2001). Compositional characteristics and economic potentials of lateritic profiles over basement and sedimentary rocks in Ibadan – Abeokuta area southwestern Nigeria. Unpublished Ph.D. Thesis, University of Ibadan, Nigeria, 255 p.
- Brown E, Skougstad MW, Fishman MJ (1970). Methods for collection and analysis of water samples for dissolved minerals and gases. US Geological Survey Techniques of water Resources Investigations, Book 5, Chapter A-1.
- Chaddah DK (1999). A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. *Hydrogeol. J.* (5):431-439
- Grant NK (1970). Geochronology of Precambrian basement rocks from Ibadan, Southwestern Nigeria. *Earth Planet Sci. Lett.* 10:29-38.
- Gibbs RJ (1970). Mechanisms controlling world water chemistry. *Science* 17:1088-1090
- Hemm JD (1983). Study and interpretation of the chemical characteristics of natural water. US Geological Survey Water-supply Paper 2254.
- Hussein AY (2012). Hydrogeological mapping of Ibadan and environ. Nigerian Geological Survey Agency Occasional Paper 19:72p.
- Jones HA, Hockey RD (1964). The geology of Part of southwestern Nigeria. *Geol. Surv. Niger. Bull.* 31:101.
- Kelly WP (1963). Use of Saline Irrigation Water. *Soil Sci.* 95(4):355-391.
- Leeden V (1990). *The Water Encyclopedia. A Compendium of useful Information on Water resources*, Lewis Publishers, Inc., 2nd edition. P 824.
- Olayinka AI, Abimbola AF, Isibor AR (1999). A geoelectrical – hydrogeochemical investigation of shallow groundwater occurrence in Ibadan, S.W. Nigeria. *Environ. Geol.* 34(1,2):31-39.
- Piper AM (1944). A graphic procedure in the geochemical interpretation of water analyses. *Trans. Am. Geophys. Union* 25:914-928.
- SON (2007). Nigerian Standards for Drinking Water Quality. Standard Organization of Nigeria (SON) Publ. NIS. 554:30.
- Stiff HAJ (1951). The interpretation of chemical water analysis by means of patterns. *J. Pet. Technol.* pp. 15-17.
- World Health Organization (WHO) (1984). *Guidelines for drinking-water quality Vol. 1, Recommendations*. Geneva. Switzerland, WHO

Publishers.

World Health Organization (WHO), (1984). Guidelines for drinking – water quality, Vol. 2 – Health criteria and other Supporting Information: Geneva, WHO Publishers, 335 p.

World Health Organization (WHO), (2004). Guidelines for drinking-water quality. Vol .1, Recommendations (3rd edn). Geneva. Switzerland, WHO Publishers.

Wilcox LV (1950). Classification and use of irrigation waters. United States Department of Agriculture. Circular no 696, Washington DC. 16 p.