Hydrochemical Analysis and Evaluation of Water Quality in Angwan Jeba and its Environs, Nasarawa State, Northcentral Nigeria

[1]G.K. Anudu, [1]S.E. Obrike, [2]L.N. Onuba and [3]A.E. Ikpokonte
[1]Department of Geology and Mining, Nasarawa State University, Keffi, Nigeria
[2]Department of Geology, Anambra State University, Uli, Nigeria
[3]Department of Geology, Ahmadu Bello University, Zaria, Nigeria

Abstract: Angwan Jeba and its environs lies within the Basement Complex of northcentral Nigeria and is underlain by migmatitic gneiss, biotite gneiss, biotite schist, muscovite schist and older granites with minor intrusions of pegmatite and quartz veins. The study involved the hydrochemical characterisation of waters of the area to ascertain their chemistry, quality and suitability for domestic, livestock and irrigation purposes. A total of eight hand-dug wells, four hand-pump boreholes, one stream and two rivers water samples were analysed for their cations and anions. Physical parameters such as temperature, pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured in the field. Results of the analysed chemical (cations and anions) parameters ranged as follows: Ca^{2+} (9.4-36.1 mg L^{-1}), Mg^{2+} (3.8-11.7 mg L^{-1}), Na^{+} (17.64-41.5 mg L^{-1}), K^{+} (4.36-18.14 mg L^{-1}), Fe (0.08-3.0 mg L^{-1}), Cu (<0.01-0.99 mg L^{-1}), HCO_3^{-} (84.08-134 mg L^{-1}), Cl^{-} (37.3-49.79 mg L^{-1}), SO_4^{2-} (13.2-23.4 mg L^{-1}) and NO_3^{-} (ND-0.96 mg L^{-1}). The Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Electrical Conductivity (EC) and Exchangeable Sodium Ratio (ESR) values varied between 0.73-1.59, -1.015-0.633 meq L^{-1}, 159-450 µS cm^{-1} and 0.333-1.187, respectively. Evaluation of the results revealed that the waters are fresh (130 ≤TDS≤304 mg L^{-1}), soft to moderately hard (39.12≤ TH≤128.85 mg L^{-1}), slightly acidic to slightly alkaline (6.85≤pH≤7.20) have low to medium Salinity Hazard (SH) and belong to four water facies types namely : Na-HCO_3-Cl, Na-Ca-HCO_3-Cl, Ca-Na-HCO_3-Cl and Ca-Mg-HCO_3-Cl. These waters have acquired their chemistry from the basement rocks, dissolution of silicate minerals and cation exchange reactions. All the analysed parameters were within the WHO Guidelines for drinking water and therefore are considered to be suitable for domestic, livestock and irrigation purposes.

Key words: Hydrochemical, angwan jeba, quality, chemistry, purposes, Nigeria

INTRODUCTION

In any hydrogeological setting, surface water and groundwater are main sources of water. Surface water includes water from rivers, streams and lakes whereas groundwater constitutes water from boreholes, hand-dug wells and springs. Both sources of water are prone to pollution and contamination hence the need for quality assessment. Okagbue (1988) stated that a complete appraisal of available sources of water in any area is commonly accomplished when aspects of water quality are included. It has been established that the quality of water is just as important as its quantity (Abimbola *et al.*, 1999; Adelana and Olasehinde, 2003; Adeyemi *et al.*, 2003). The quality required of groundwater supply depends on its purpose (Todd, 1980; Hamill and Bell, 1986; Ezeigbo, 1998; Anudu *et al.*, 2008). The basic purposes for which water is domestically required include drinking, bathing, cooking and general sanitation such as laundry, flushing of closets and other household chores, whereas for agricultural purposes it is essentially used for irrigation and livestock. Therefore an assured supply of water both qualitatively and quantitatively for these purposes greatly improves the social, economic and agricultural activities of the people.

In the study area, domestic usage of water accounts for a substantial part of the water consumption and due to the inability of government to meet the ever-increasing water demand, the inhabitants have had to look for alternative sources such as rivers, streams, hand-dug wells and hand-pump boreholes.

This present study is borne-out of the need to evaluate both the surface water and groundwater sources in the area. It particularly aims at determining the drinking, domestic and agricultural (irrigation/livestock) usability of the water. This is imperative as there has not been any record on this aspect of research in the area. The area is relatively densely populated and essentially made up of

Corressponding Author: G.K. Anudu, Department of Geology and Mining, Nasarawa State University, Keffi, Nigeria

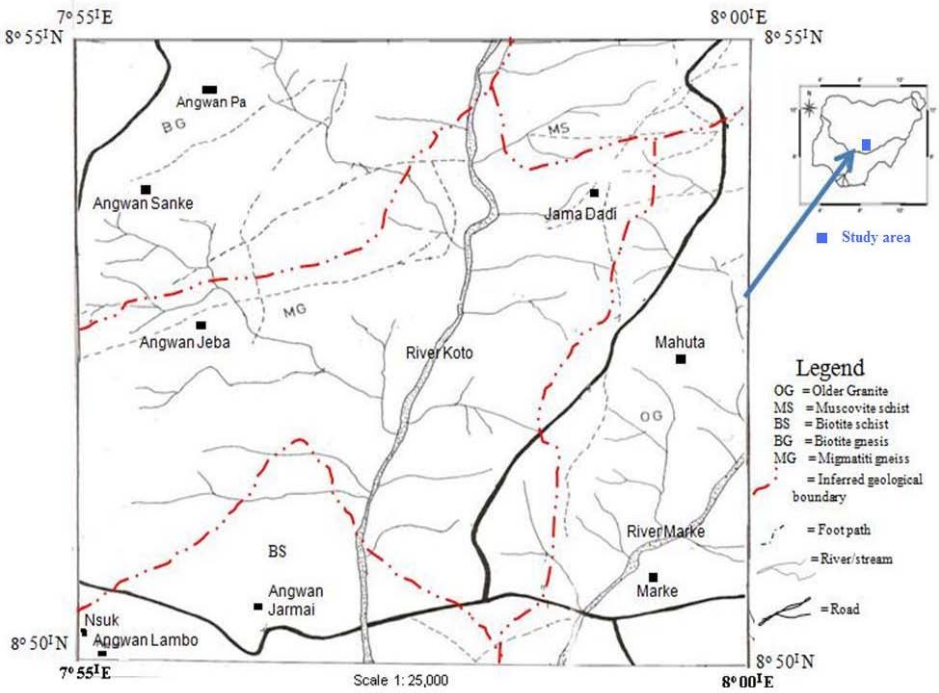


Fig. 1: Location and geological map of Angwan Jeba and environs; Map of Nigeria showing the study area (Angwan Jeba and environs)

various agrarian communities. The study area encompasses Angwan Jeba. Jama Dadi, Angwan Jarmai, Angwan Pa, Angwan Lambo, Angwan Sanke and Marke near Keffi town in Nasarawa state, northcentral Nigeria. They are located between latitudes 8°50 and 8°55'N and longitudes 7°55 and 8°00'E (Fig. 1). The area has a tropical climate which is characterized by two seasons: the rainy and dry seasons.

The rainy season lasts from April-October while the dry season lasts between November and March. Hamattan is usually experienced from November to February. The mean annual rainfall varies from 850-1150 mm and the mean annual temperature ranges between 28-29.5°C. Also it falls within the Guinea Savannah belt of Nigeria.

Angwan Jeba and its environs lies within the Basement Complex of northcentral Nigeria whose dominant rock types are migmatitic gneiss, biotite gneiss, biotite schist, muscovite schist and Older Granites with minor intrusions of pegmatite and quartz veins (Fig. 1). The surface water resources in the area consist of two rivers and several streams which flow southwards in dendritic pattern (Fig. 1).

The two rivers are Rivers Koto and Marke. Their flow directions are generally concordant to the strike of joints of the underlying basement rocks. The groundwater occurs within the weathered rock columns and fractured rock zones in the underlying basement rocks. Therefore two aquifer types present in the area are weathered zone aquifers and fractured zone aquifers. Majority of the hand-dug wells are tapping water from the weathered zone aquifers. Highest groundwater yields are obtained where the weathered rock columns overlies fracture zones in the underlying rocks.

MATERIALS AND METHODS

Fifteen water samples were collected which comprise 2 rivers, 1 stream, 8 hand-dug wells and 4 hand-pump boreholes. These constitute the main sources of water supply for the inhabitants. Sampling was conducted in December 2009 at the peak of dry season to avoid the effect of dilution that may result from precipitation during rainy season.

Parameters such as temperature, pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured in the field. Water samples were collected in new screw-cap, high-density polyethene bottles (1.5 L) which were first rinsed 2-3 times with the water to be sampled to avoid contamination. A pair of water samples was collected from each sample location for both cationic and anionic analyses. Samples for cationic analysis were acidified with dilute nitric acid at the point of collection. The samples were adequately labelled and were

immediately sent to the laboratory for analyses. The analyses were conducted at the National Geosciences Research Laboratories Centre Kaduna, Kaduna state northcentral Nigeria. Atomic absorption spectrometry (Model Young LIN AAS 5010) method was employed for determining the concentration of the following parameters: Ca^{2+}, Mg^{2+}, K^+, Na^+ and Fe^{2+} in the preserved water samples. SO_4^{2-}, HCO_3^- and Cl^- were determined by digital titration method whereas NO_3^- was determined using Hack-spectrophotometer. All analyses were carried out in accordance with the standard procedures specified in APHA and AWWA (1998).

RESULTS AND DISCUSSION

The results of the physical and chemical parameters determined for the water samples are shown in Table 1 and 2, respectively.

Drinking and domestic water quality: Drinking and domestic water quality criteria for this study are based on World Health Organisation (WHO, 2006) Guidelines for drinking water. The results of the chemical (cations and anions) parameters (Table 3) show the following ranges: Ca^{2+} (9.4-36.1 mg L^{-1}), Mg^{2+} (3.8-11.7 mg L^{-1}), Na^+ (17.64-41.5 mg L^{-1}), K^+ (4.36-18.14 mg L^{-1}), Fe (0.08-3.0 mg L^{-1}), Cu (<0.01-0.99 mg L^{-1}), HCO_3^- (84.08-134 mg L), Cl^- (37.3-49.79 mg L^{-1}), SO_4^{2-} (13.2-23.4 mg L^{-1}) and NO_3^- (ND-0.96 mg L^{-1}). The mean concentration values of the cations is in the order $Na^+ > Ca^{2+} > K^+ > Mg^{2+} > Fe > Cu$, whereas that for anions is $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$. The Total Dissolved Solids (TDS) values range between 130-304 mg L^{-1} with a mean of 198.4 mg L^{-1} and Electrical Conductivity (EC) is between 159-450 µS cm^{-1} with a mean value of 274 µS cm^{-1}. The total hardness (T_H) values in all the water samples were calculated using Lloyd and Heathcote (1985) expression which is as follows: T_H ($CaCO_3$) mg L^{-1} = 2.497 (Ca^{2+})+4.118 (Mg^{2+}). The T_H values vary from 39.12-128.85 mg L^{-1} with a mean value of 87.40 mg L^{-1}. The pH values range from 6.85-7.20 and therefore depicting that the waters from the study area are slightly acidic to slightly alkaline.

All the physical and chemical parameters of the waters of the area fall within the WHO (2006) Guidelines for drinking water (Table 3) and are within the excellent to good class.

Livestock water quality: The Total Dissolved Solid (TDS) is the main parameter usually used to evaluate the suitability of any water for livestock farming. Based on the Australian and UNESCO standards for livestock water which stated that the TDS values between 0-2900 mg L^{-1} are suitable for all animals (Hamill and Bell, 1986), all the waters from the area are of best quality for livestock farming since the TDS values range from 130-304 mg L^{-1} (Table 3).

Irrigation water quality: The crop irrigation is the most extensively use of water (surface and groundwater) in the world and consequently, it is paramount to consider plant

Table 1: Physical parameters of the water samples of the study area

Sample location and sample source	Temp (°C)	pH (pH unit)	EC (µS cm^{-1})	TDS (mg L^{-1})	T_H (mg L^{-1})
Angwan Jeba (HDW 1)	26.7	6.88	334	230	70.35
Angwan Jeba (HDW 2)	26.8	6.87	305	180	69.05
Jama Dadi (HDW 1)	27.1	7.10	450	304	109.48
Jama Dadi (HDW 2)	27.0	7.15	272	185	128.03
Angwan Pa (HDW 1)	27.1	6.90	258	190	102.60
Angwan Pa (HDW 2)	27.1	7.10	250	178	95.07
Angwan Sanke (HDW 1)	27.5	7.20	301	210	87.46
Angwan Sanke (HDW 2)	27.5	7.15	296	220	77.54
NSUK (HP)	27.1	7.10	159	130	75.65
Angwan Lambo (HP 1)	26.5	6.90	230	150	45.67
Angwan Lambo (HP 2)	26.4	6.99	180	142	39.12
Mahuta (HP)	27.5	7.20	245	183	118.85
Angwan Jarmai (ST)	27.1	6.95	257	200	128.85
River Koto (RI)	27.3	6.85	248	210	98.62
Marke (RI)	27.6	6.90	325	264	64.65

EC = Electrical Conductivity; TDS = Total Dissolved Solids; T_H = Total hardness; HDW = Hand-Dug Well; HP = Hand-Pump; RI = River

Table 2: Chemical parameters (Cationic and Anionic) of the water samples of the study area

Sample location and sample source	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	Fe^{2+}	Cu^{2+}
	(mg L^{-1})									
Angwan Jeba (HDW 1)	16.30	7.20	30.20	18.14	106.81	22.30	40.30	0.01	0.24	0.01
Angwan Jeba (HDW 2)	17.10	6.40	29.10	15.20	105.41	23.40	39.50	0.02	0.20	<0.01
Jama Dadi (HDW 1)	32.10	7.00	26.54	9.20	92.46	16.50	47.70	ND	1.09	0.30
Jama Dadi (HDW 2)	36.10	9.20	28.30	11.40	94.10	18.20	48.20	0.01	0.93	0.10
Angwan Pa (HDW 1)	27.40	8.30	32.98	7.96	102.64	21.40	37.32	ND	0.27	<0.01
Angwan Pa (HDW 2)	26.20	7.20	25.60	8.70	99.60	19.50	38.34	0.01	0.19	<0.01
Angwan Sanke (HDW 1)	18.70	9.90	30.22	9.03	98.20	22.00	39.68	0.02	0.22	<0.01
Angwan Sanke (HDW 2)	17.20	8.40	23.50	7.13	96.30	22.30	38.12	0.01	0.13	<0.01
NSUK (HP)	20.20	6.00	17.64	8.28	84.08	18.20	45.99	0.14	0.09	<0.01
Angwan Lambo (HP 1)	11.20	4.30	23.48	7.28	89.50	19.60	42.08	0.10	0.10	0.03
Angwan Lambo (HP 2)	9.40	3.80	21.34	8.56	86.30	18.20	40.76	ND	0.08	0.01
Mahuta (HP)	28.30	11.70	18.20	6.43	96.40	16.60	40.31	0.12	3.00	1.10
Angwan Jarmai (ST)	36.10	9.40	41.50	11.50	134.00	20.30	42.40	0.96	0.39	<0.01
River Koto (RI)	26.30	8.00	17.90	4.36	93.00	13.00	49.79	0.34	2.38	0.99
Marke (RI)	15.50	2.00	22.40	6.64	88.01	19.00	47.96	0.31	0.34	<0.01

HDW = Hand-dug well, HP = Hand-pump, ST = Stream, RI = River, ND = Not Detected

Table 3: Evaluation of physical and chemical parameters of waters of the study area for drinking and domestic purpose. Based mainly on the WHO (2006) Guidelines with some additions from EU standards

Physical and chemical parameters	WHO (2006) guidelines		Waters from the study area		
	Desirable limit	Permissible limit	Range	Mean	Evaluation for drinking
Temp (°C)	Variable	Variable	26.4-27.6	27.09	Good
pH (pH unit)	7.0-8.5	6.5-9.2	6.85-7.20	7.02	Slightly acidic to slightly alkaline
EC ($\mu S\ cm^{-1}$)	<250	<1480	159-450	274.00	Excellent to good
TDS ($mg\ L^{-1}$)	<500	<1000	130-304	198.40	Excellent
T_H ($mg\ L^{-1}$)	<150	<500	39.12-128.85	87.40	Excellent
Ca^{2+} ($mg\ L^{-1}$)	<75	<200	9.4-36.1	22.57	Excellent
Mg^{2+} ($mg\ L^{-1}$)	<50	<150	3.8-11.7	7.54	Excellent
Na^{+} ($mg\ L^{-1}$)	<120	<400	17.64-41.5	25.93	Excellent
K^{+} ($mg\ L^{-1}$)	-	-	4.36-18.14	9.33	Excellent
HCO_3^{-} ($mg\ L^{-1}$)	Variable	Variable	84.08-134	97.79	Excellent
Cl^{-} ($mg\ L^{-1}$)	<250	<500	37.3-49.79	42.56	Excellent
SO_4^{2-} ($mg\ L^{-1}$)	<200	<400	13.2-23.4	19.38	Excellent
NO_3^{-} ($mg\ L^{-1}$)	<10	<45	ND-0.96	0.14	Excellent
Fe ($mg\ L^{-1}$)	<0.3	<1.0	0.08-3.0	0.64	Good?
Cu ($mg\ L^{-1}$)	<0.05	<1.0	<0.01-0.99	<0.18	Good?

Table 4: Irrigation water parameters for the study area

Sample location and sample source	EC ($\mu S\ cm^{-1}$)	SH	SAR	ESR	RSC ($meq\ L^{-1}$)
Angwan Jeba (HDW 1)	334	Medium	1.56	0.932	0.346
Angwan Jeba (HDW 2)	305	Medium	1.52	0.917	0.136
Jama Dadi (HDW 1)	450	Medium	1.10	0.528	-0.670
Jama Dadi (HDW 2)	272	Medium	1.09	0.481	-1.015
Angwan Pa (HDW 1)	258	Medium	1.41	0.700	-0.371
Angwan Pa (HDW 2)	250	Medium	1.14	0.586	-0.269
Angwan Sanke (HDW 1)	301	Medium	1.40	0.752	-0.139
Angwan Sanke (HDW 2)	296	Medium	1.16	0.660	0.030
NSUK (HP)	159	Low	0.88	0.508	-0.136
Angwan Lambo (HP 1)	230	Low	1.51	1.119	0.554
Angwan Lambo (HP 2)	180	Low	1.48	1.187	0.633
Mahuta (HP)	245	Low	0.73	0.333	-0.793
Angwan Jarmai (ST)	257	Medium	1.59	0.701	-0.378
River Koto (RI)	248	Low	0.78	0.395	-0.444
Marke (RI)	325	Medium	1.21	0.754	0.151
	159-450	Low-medium	0.73-1.59	0.333-1.187	-1.015-0.633

TDS = Total Dissolved Solids; SH = Salinity Hazard; SAR = Sodium Adsorption Ratio; ESR = Exchangeable Sodium Ratio; RSC = Residual Sodium Carbonate

Table 5: Modified Wilcox quality classification of irrigation water (Todd, 1980)

Water class	EC ($\mu S\ cm^{-1}$)	Salinity Hazard (SH) class	Percentage of water samples
Excellent	<250	Low (C1)	33.33
Good	250-750	Medium (C2)	66.67
Permissible	750-2250	High (C3)	-
Doubtful	>2250	Very high (C4)	-

requirements with regards to water quality. The following parameters were used to judge the suitability of the water for irrigating crops: Salinity Hazard (SH), Sodium Adsorption Ratio (SAR), Exchangeable Sodium Ratio (ESR) and Residual Sodium Carbonate (RSC) (Table 4).

The Salinity Hazard (SH) relates to accumulation of excessive soluble salts. It restricts the plants roots from absorbing water even if the field appears to have sufficient moisture and therefore results to physiological drought condition (Hiscock, 2005). The Salinity Hazard (SH) Expressed as Electrical conductivity (EC) varies from 159-450 $\mu S\ cm^{-1}$ (Table 4) and hence categorising most of them are within the best quality class. Using the modified Wilcox (1955) model shown in Table 5 and Fig. 2, 33.33% of the water samples are within the excellent water class whereas the remaining 66.67% fall within the good water class. Therefore all the water samples from the study area are within the excellent to good irrigation water class with low to medium salinity hazard and are suitable for most crops on most soils with little likelihood that salinity problem will develop. The sodium hazard relates to accumulation of excessive sodium. It usually brings about a reduction in soil permeability and cause the soil to harden. Both effects are due to cation exchange of calcium and magnesium ions by sodium ions on clay minerals and colloids (Hamill and Bell, 1986). The sodium hazard of irrigation water is estimated by the Sodium Adsorption Ratio (SAR) which relates the proportion of Na^{+} to Ca^{2+} and Mg^{2+} in the waters as follows:

$$SAR = \frac{Na^{+}}{\sqrt{\left\{\frac{Ca^{2+} + Mg^{2+}}{2}\right\}}}$$

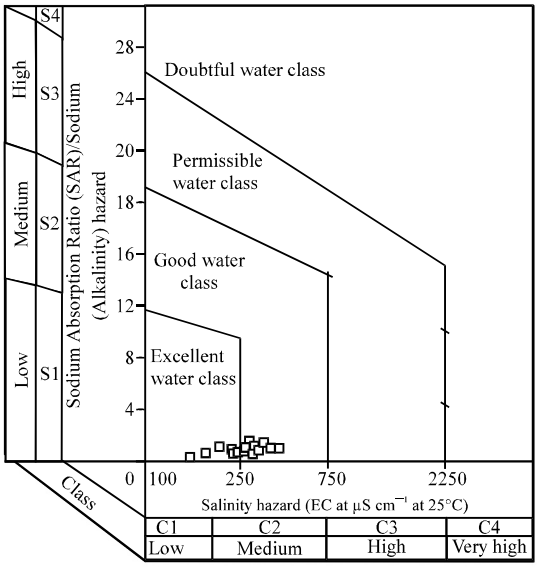


Fig. 2: Diagram for classification of irrigation waters (Wilcox, 1955)

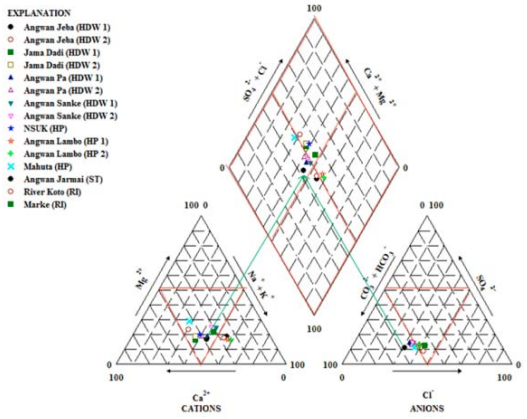


Fig. 3: Piper trilinear diagram of major ion analyses of water from the study area (Piper, 1944); Cation percentages in meq L^{-1} plotted on the left triangle and anion percentages in meq L^{-1} plotted on the right triangle. The information on the two triangles is transferred onto the diamond-shaped plot by constructing a line through the point on the cation triangle (e.g., point ●), parallel to the Magnesium (Mg) axis and another line is constructed through the corresponding point ● on the anion triangle parallel to the Sulfate (SO_4) axis. The intersection of these two lines yields the location of the point to be plotted on the diamond-shaped part of the Piper diagram

with the ionic concentrations expressed in meq L^{-1}. The Sodium Adsorption Ratio (SAR) values computed vary from 0.73-1.59 (Table 4) and hence are within the low (S1) sodium hazard class (Fig. 2). Using the modified Wilcox model (Table 5) and Mandel and Shiftan (1991), all the water samples from the study area are within the excellent to good water class and can be used for irrigation on almost all soils, since they fall within the SAR range of 0-10. The Exchangeable Sodium Ratio (ESR) is calculated according to the formulae:

$$ESR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

with the ionic concentrations expressed in meq L^{-1}. The Exchangeable Sodium Ratio (ESR) values calculated range from 0.333-1.187 and can be used in all classes of soils.

In waters having high concentration of bicarbonate and carbonate, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated and as a result the amount of sodium in the water is increased in the form of sodium carbonate. The Residual Sodium Carbonate (RSC) is calculated using the formulae:

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

with the ionic concentrations expressed in meq L^{-1}. According to the California Fertilizer Committee (1975), waters having <1.25 meq L^{-1} of Residual Sodium Carbonate (RSC) are safe for irrigation. The RSC values of the water samples vary from 1.015-0.633 meq L^{-1} (Table 4) and hence are within the safe water for irrigation in all soils.

Water classification: Plots of the hydrochemical parameters of the waters on the Piper (1944) trilinear diagram (Fig. 3) based on the water classification scheme of Furtak and Langguth show that 73.33% of the waters are earth alkaline water with higher alkaline proportion whereas the remaining 26.67% belong to alkaline water. Furthermore the waters were classified into hydrochemical facies representing water types based on the subdivisions of the Piper trilinear diagram in manner suggested by Back (1961) and Hanshaw (1965). These subdivisions are shown in Fig. 4.

Using the aforementioned water classification scheme, the waters of the study area are classified into four water types namely Na-HCO_3-Cl, Na-Ca-HCO_3-Cl, Ca-Na-HCO_3-Cl and Ca-Mg-HCO_3-Cl. In addition the plots of

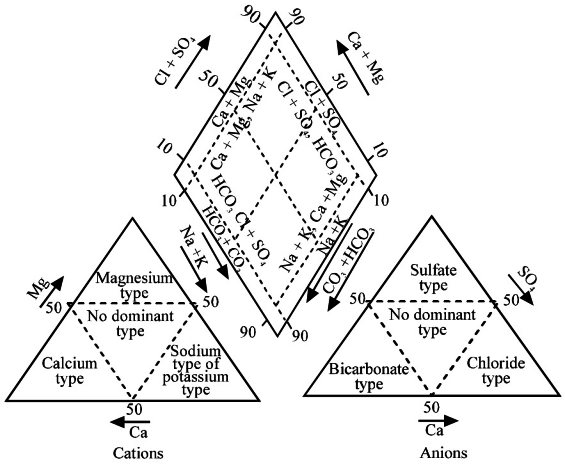


Fig. 4: Water type classification using the Piper trilinear diagram. Water types are designated according to the domain in which they occur on the diagram segments (Back, 1961; Hanshaw, 1965)

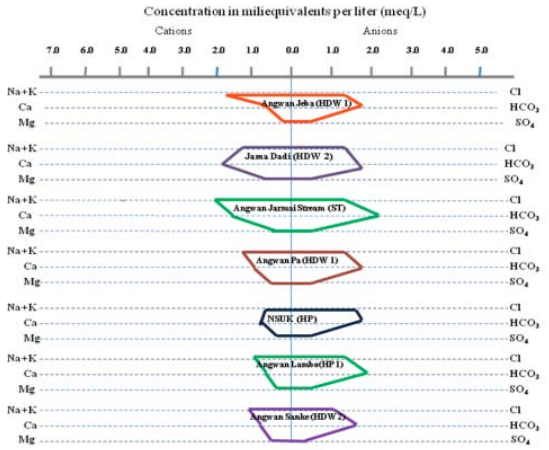


Fig. 5: Stiff diagram of major ion analyses of water from the study area (Stiff, 1951). Cations are plotted on the left of the axes and anions are plotted on the right in units of milliequivalents per liter (meq L^{-1})

the water parameters on the Stiff (1951) diagram (Fig. 5) agreed with the above-mentioned four water facies types. The Na-HCO_3-Cl, Na-Ca-HCO_3-Cl, Ca-Na-HCO_3-Cl water types are referred to as cation exchange waters (Tijani, 1994; Elueze *et al.*, 2004) and it is an indication of more HCO_3 ions compared to available earth alkaline metal ions (Ca^{2+} and Mg^{2+}) in equivalent concentrations. These excess HCO_3^- ions then cause the release of alkaline ions usually Na^+ into the solution by exchange reaction with the cation exchangers such as clay

Table 6: Hardness classification of water from the study area (Sawyer and McCarty, 1967)

Hardness ($Ca+MgCO_3$) (mg L^{-1})	Water classification	Results of study (%)
0-75	Soft	33.33
75-150	Moderately hard	66.67
150-300	Hard	-
>300	Very hard	-

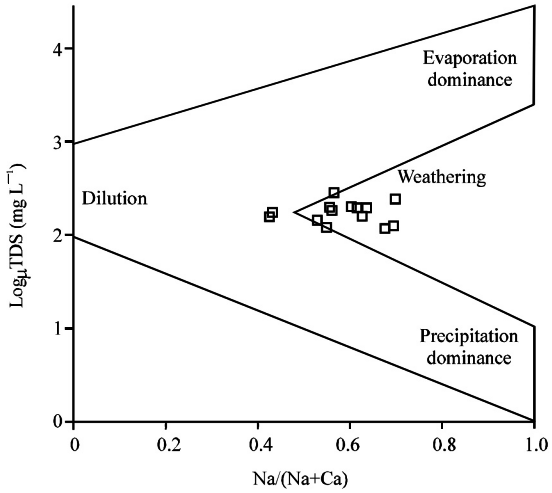


Fig. 6: Plot of TDS versus Na/(Na+Ca) ratio. Points denote the chemical data of waters of the study area (Gibbs, 1970)

minerals and other related minerals that form part of the aquifer materials, thereby enriching these waters with Na-HCO_3. In addition, the relative high Cl ions concentration in these waters might be due to the alteration of biotite in the weathered and fractured zones of the underlying biotite-rich basement rocks (biotite gneisses, migmatitic gneisses, biotite schists, biotite granites).

Employing the Sawyer and McCarty (1967) total hardness classification scheme (Table 6), 33.33% of the waters are soft and the remaining 66.67% are moderately hard. Also based on the Total Dissolved Solids (TDS) content after Todd (1980), all the waters in the study area are classified as fresh water (TDS<1000 mg L^{-1}).

Mechanism controlling the water chemistry (or Functional sources of ions in the waters): The plot of TDS against $Na^+/(Na^+ + Ca^{2+})$ ratio referred to as Gibbs plot assesses the functional sources of dissolved ions in waters as evaporation dominance, rock dominance (dilution and weathering) and precipitation dominance which controls the water chemistry (Gibbs, 1970). The chemical data of the waters from the study area plotted mainly around the weathering zone (Fig. 6) and therefore

indicate that the chemical compositions of these waters are controlled primarily by rock dominance (weathering reactions). The Gibbs plot (Fig. 6) also depicts that the waters of the study area have their chemistry modified from the weathered materials derived from the underlying biotite gneisses, migmatitic gneisses, biotite schists and granites as well as from dissolution of silicate minerals from them.

CONCLUSION

This study has thrown light on the hydrochemistry, quality and suitability of waters from Angwan Jeba and its environs. The physical and chemical parameters of all the waters fall within the WHO (2006) Guidelines for drinking water and depict that the waters are within the excellent to good class. Evaluation of the results showed that the waters are fresh ($130 \leq TDS \leq 304$ mg L^{-1}), soft to moderately hard ($39.12 \leq TH \leq 128.85$ mg L^{-1}) and slightly acidic to slightly alkaline ($6.85 \leq pH \leq 7.20$). Characterisation of the waters using Piper trilinear and Stiff diagrams has indicated four water facies types, namely: Na-HCO_3-Cl, Na-Ca-HCO_3-Cl, Ca-Na-HCO_3-Cl and Ca-Mg-HCO_3-Cl. In addition, all the waters from the area are within the excellent to good irrigation water class with low to medium salinity hazard and are suitable for most crops on most soils. The Gibbs plot depicted that the chemistry of waters were modified by the weathered products derived from the underlying basement rocks as well as from dissolution of silicate minerals.

RECOMMENDATIONS

It is however, recommended that further studies should include microbial investigation, isotopic and detailed trace elements compositions to further ascertain the water quality and recommend necessary treatment measures.

REFERENCES

APHA and AWWA, 1998. Standard Methods for Examination of Water and Wastewater. 20th Edn., American Public Health Association, Washington, DC.

Abimbola, A.F., M.N. Tijani and S.I. Nurudeen, 1999. Some aspects of groundwater quality in Abeokuta and its environs southwestern Nigeria. Water Resour. J. Nig. Asssoc. Hydrogeologists, 10: 6-11.

Adelana, S.M.A. and P.I. Olasehinde, 2003. High nitrate in water supply in Nigeria: Implications for human health. Water Resour. J. Nig. Assoc. Hydrogeologists, 14: 1-11.

Adeyemi, G.O., A.O. Adesile and O.B. Obayomi, 2003. Chemical characteristics of some wells in Ikire southwestern Nigeria. Water Resour. J. Nig. Assoc. Hydrogeologists, 14: 12-18.

Anudu, G. K., S.E. Obrike and L.N. Onuba, 2008. Physico-chemical quality of groundwater in Abagana and its environs, Anambra Basin, Southeastern Nigeria. Int. J. Chem. Sci., 1: 296-301.

Back, W., 1961. Techniques for mapping of hydrochemical facies. US Geological Survey Professional Paper, 424-D, pp: 380-382.

California Fertilizer Committee, 1975. Western Fertilizer Handbook. 5th Edn., The Interstate Printers and Publishers, Danville, Illinois, ISBN-13: 9780813417363, pp: 250.

Elueze, A.A., J.O. Omidiran and M.E. Nton, 2004. Hydrochemical investigation of surface water and geoundwater around Ibokun, Ilesha area, Southwestern Nigeria. J. Mining Geol., 40: 57-64.

Ezeigbo, H.I., 1998. Geological and hydrogeological influences on the Nigerian environment. J. Nig. Assoc. Hydrogeologists, 1: 38-39.

Gibbs, R.J., 1970. Mechanisms controlling world water chemistry. Science, 170: 1088-1090.

Hamill, L. and F.G. Bell, 1986. Groundwater Resource Development. Butterworth Publishers, Stoneham Massachusetts, ISBN-13: 9780408014090, pp: 344.

Hanshaw, B.B., 1965. Chemical Geohydrology. In: Advances in Hydroscience, V. te Chow (Ed.). Vol. 2, Academic Press, New York, pp: 49-109.

Hiscock, K.M., 2005. Hydrogeology: Principles and Practice. John Wiley and Sons, New York, ISBN-13: 9780632057634, pp: 389.

Lloyd, J.W. and J.A. Heathcote, 1985. Natural Inorganic Hydrochemistry in Relation to Groundwater: An introduction. Clarendon Press, Oxford, ISBN-13: 9780198544227, pp: 296.

Mandel, S. and Z.L. Shiftan, 1991. Groundwater Resources Investigation and Development. Academic Press, Inc., New York.

Okagbue, C.O., 1988. Hydrology and Chemical Characteristics of Surface and Ground Water Resources of the Okigwe Area and Environs., Imo-State, Nigeria. In: Groundwater and Mineral Resources of Nigeria (Earth Evolution Science Series), Ofoegbu, C.O. (Ed.). Viewing, Germany.

Piper, A.M., 1944. A graphic procedure in the geochemical interpretation of water analysis. Trans. Am. Geophys. Union, 25: 914-923.

Sawyer, C.N. and P.L. McCarty, 1967. Chemistry for Sanitary Engineers. 2nd Edn., McGraw-Hill, New York, pp: 518.

Stiff, Jr. H.A., 1951. The interpretation of chemical water analysis by means of patterns. J. Petrol. Technol., 3: 15-17.

Tijani, M.N., 1994. Hydrochemical assessment of groundwater in Moro area, Kwara State, Nigeria. Environ. Geology, 12: 194-202.

Todd, D.K., 1980. Groundwater Hydrology. 2nd Edn., John Wiley and Sons, New York, USA., pp: 267-315.

WHO, 2006. World Health Organisation Guidelines for Drinking Water Quality. 3rd Edn., Vol. 1, World Health Organisation of the United Nations, Rome, Italy, pp: 68.

Wilcox, L.V., 1955. Classification and Use of Irrigation Waters. 1st Edn., United States Department of Agriculture, Washington, DC., pp: 19.