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Hydrogeochemical Investigation of Surface Water and Groundwater Resources in Nnewi and Environs of Anambra Basin, Nigeria

Michael Emenike Egbunike Ephraim Ihenacho Okpoko
Department of Geology, Chukwuemeka Odumegwu Ojukwu University, P.M.B. 02, Uli, Anambra state, Nigeria

Abstract
The study area falls within the Anambra Basin in south eastern Nigeria. The lithostratigraphic units within the study area are Oligocene – Miocene Ogwashi-Asaba Formation and the Eocene Ameki Formation. This study investigates the hydrogeochemical analyses of the surface water and the groundwater discharge from the prolific Nanka sands reservoir. A total of twenty-four water samples were obtained from both groundwater and surface water sources from different locations within the study area and were analysed for their physico-chemical characteristics with the aim of assessing their quality and usability. Results of some physico-chemical parameters show average values of 4.85p^H, 18.18mg/l TDS, 6.47mg/l Ca^{2+}, 14.92mg/l Na^+, 8.46mg/l K^+, 0.67mg/l Mg^{2+}, 0.46mg/l HCO_3^-, 12.27mg/l Cl^-, 0.50mg/l Fe^{2+}, 1.87mg/l NO_3^- and 26.33µs/cm conductivity. The Total Hardness and Sodium Absorption Ratio are respectively 17.33mg/l and 1.82. The Total Hardness, Hydrogen bicarbonate, Calcium and conductivity are higher in the surface waters than in groundwater while Nitrate and Magnesium are comparatively higher in groundwater than in surface waters. Statistical analysis, using the product moment coefficient of correlation, indicates positive correlation between the following pairs of parameters: Total Hardness (TH) and TDS (r = 0.87); TDS and Ec (r = 0.97); Ca^{2+} and HCO_3^- (r = 0.31); Ca^{2+} and Mg^{2+} (r = 0.58). Negative correlation was obtained between p^H and Cl^- (r = -0.04) while very weak correlations were observed between p^H and TH (r = 0.18) and Na^+ and K^+ (r = 0.22). Seven water groups were identified based on characterization in the piper trilinear diagram. These include Na-SO_4, Ca-SO_4, Ca-Cl-SO_4, Na-Cl, Ca-Na-SO_4, Na-Mg-SO_4 and Na-Cl-SO_4. They reflect effect of different bedrock lithologies, base exchange processes, precipitation and weathering. In general, both water sources are acidic fresh water. The water samples are generally soft with low sodium content. The Sodium Absorption Ratio (SAR) and other related parameters such as p^H, NO_3^-, SO_4^{2-}, Cl^-, HCO_3^-, Ca^{2+}, Mg^{2+}, K^+, Ec, TH and TDS falling within the permissible limits for potable water. The sources are generally suitable for both domestic and agricultural uses requiring minor treatments.

Introduction
Water is an important part of the earth surface, covering about 75% of the Earth. It occurs as surface water in streams, rivers, lakes and worlds' seas and oceans as well as groundwater, and accumulates beneath the ground. Water is one of the three basic needs of man. Throughout the historical evolution of man, water has always played a key role in supporting life in various ways. Therefore, the quality of accessible water is an important index of the living standard (Elueze, et al., 2004). Water is readily available in the sedimentary rocks of the Anambra Basin but the major constraint is the quality of water. The quality of water is affected by the characteristics of the environment of circulation and occurrence; such sources are invariably exposed to anthropogenic and industrial pollutants. Okagbue (1988) suggested that a complete appraisal of available water resources in any area is commonly accomplished when aspects of water quality are included. Consequently, this study is borne out of the need to evaluate both the groundwater and surface water sources in the area. It particularly aims at determining the quality and usability of the water in addition to ascertaining possible pollutants and ways to ameliorate their effects.

Location and Geology of the Study Area
The study area falls within the Anambra basin. It lies within latitudes $6^0\ 00^1$N and $6^0\ 05^1$N and $6^0\ 50^1$E and $6^0\ 58^1$E (Fig.1). It covers an area of about 53.27km^2 with prominent settlements such as Oba, Ojoto, Oraifite, Nnobi, Alor, Awka Etiti and Nnewi.

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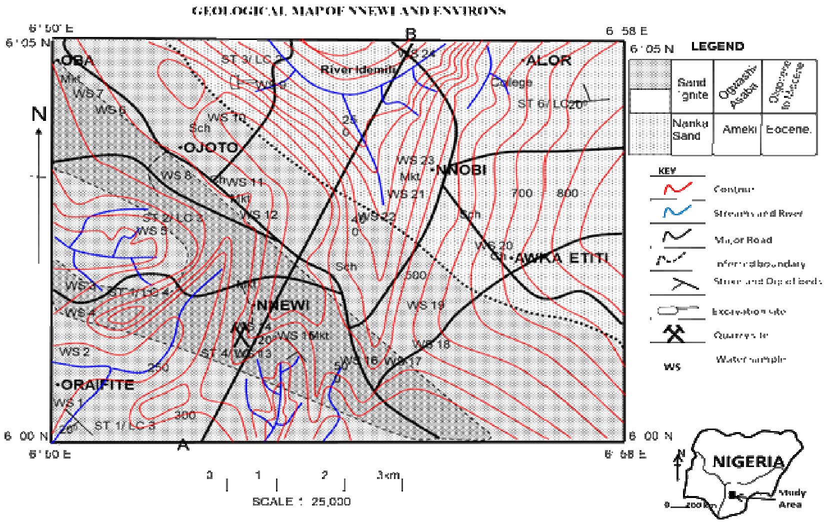

Fig.1: Geological map of Nnewi and environs.

The lithostratigraphic units within the study area are the Oligocene-Miocene Ogwashi-Asaba Formation and the Eocene Ameki Formation. The Ogwashi-Asaba Formation (Oligocene-Miocene) overlies the Ameki Formation (Eocene). The Ogwashi-Asaba Formation (Oligocene-Miocene) consists of fine to coarse grained pebbly unconsolidated sandstone with thick beds of lignite and clay. Using pollen data, Okezie and Onuogu (1985) assigned the lignites to tropical and semi-tropical plants consisting of mainly palms. Short and Stauble (1967) inferred the depositional environment of Ogwashi-Asaba Formation as an Oligo-Miocene upper flood plain environment.

The Ameki Formation (Eocene) is made up of sandstone unit which is mainly coarse, pebbly sandstone with thin bands of clay at intervals. The pebble morpho-analysis and lithofacies changes suggest that the depositional environment ranges from beach to shallow marine.

Methods of Study

Twenty-four water samples were collected which comprised of sixteen (16) boreholes, four (4) springs, one (1) hand dug well , and three (3) streams. These constitute major sources of water supply for the inhabitants. Soil samples were observed visually for colour, texture and presence of fines while rock samples were obtained for petrography observation of the mineralogy. The water samples were collected in duplicate for every location in two litre white plastic containers. The samples were adequately labelled in the field. The sample meant for cations determinations were acidified with HNO_3 to prevent the ions from adhering to the surface of the container and to allow them remain in solution. The samples meant for anions determination were not acidified. The electrical conductivity, total dissolved solids (TDS), temperature were measured in the field using a digital conductivity meter WTWL 95 model. The analyses of the water samples were performed at the laboratory in Oyo state Ministry of Environment and Habitat, Ibadan.

Parameters that were analyzed for include Na^+, Ca^{2+}, Mg^{2+} and Fe^{2+} for cations, HCO_3^-, NO_3^-, Cl^- and SO_4^{2-} for anions. Also, hardness, salinity, p^H and alkalinity were determined using standard titrimetric, turbimetric and calorimetric methods. The results obtained from the various forms of analyses were statistically evaluated and interpreted to ascertain the hydrochemical character of the groundwater and surface water of the study area.

Discussion of Results

The data for physical and chemical parameters of both surface water and groundwater in the study area are presented in Tables 1 and 2. The summary of the various physical and chemical parameters and their mean values as compared to the values of World Health Organisation (WHO, 2006) standard for drinking water is shown in Table 3.

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Table 1: Results of physical characteristics of surface water and groundwater in the study area.

Sample No.	Water Source	P^H	Temp ^{0}c	EC	TH	TDS	SAR
WS 2	GW	5.70	26.80	33.50	24.00	21.78	1.06
WS 3	,,	4.60	27.20	17.29	10.00	11.00	0.96
WS 4	,,	4.52	28.30	18.26	10.00	12.32	1.51
WS 5	,,	4.83	28.10	13.56	10.00	8.62	2.89
WS 6	,,	4.66	27.70	13.85	10.00	9.12	1.56
WS 7	,,	5.72	27.40	98.00	54.00	63.70	1.11
WS 8	,,	4.46	28.60	11.55	8.00	10.12	1.54
WS 10	,,	4.71	28.60	12.49	8.00	8.12	1.85
WS 11	,,	4.74	26.30	17.19	16.00	11.17	1.99
WS 12	,,	4.59	28.30	70.80	42.00	46.02	0.47
WS 13	,,	4.33	27.20	18.49	12.00	12.00	2.70
WS 14	,,	4.46	28.00	62.90	50.00	40.88	1.61
WS 15	,,	4.17	27.40	42.60	30.00	27.69	1.03
WS 16	,,	4.85	28.00	7.62	6.00	4.95	2.13
WS 17	,,	4.54	28.30	10.52	8.00	8.77	1.54
WS 18	,,	5.11	26.30	12.62	10.00	8.62	1.70
WS 19	,,	5.41	28.00	14.55	4.00	29.58	3.05
WS 20	,,	5.14	27.60	19.79	8.00	12.86	5.41
WS 21	,,	4.48	28.90	21.90	16.00	14.24	1.11
WS 22	,,	4.63	28.70	18.68	10.00	12.41	2.20
WS 23	,,	4.83	28.60	15.24	10.00	9.90	1.79
WS 1	SW	5.05	28.40	34.80	14.00	22.62	1.42
WS 9	,,	5.02	27.8	20.40	18.00	13.26	2.50
WS 24	,,	5.62	27.20	25.30	28.00	16.58	0.57

TH = Total hardness, mg/l CaCO3; TDS = Total dissolved solids, mg/l
Ec = Electrical conductivity, µs/cm; SAR = Sodium absorption ratio;
GW = Groundwater; SW = Surface water

Table 2: Results of chemical characteristics of surface water and groundwater in the study area.

Sample No.	Water	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe^+	HCO_3	Cl^-	SO_4^{2-}	NO_3^-
WS 2	GW	8.80	0.56	12.00	5.00	0.37	2.00	3.90	23.00	0.03
WS 3	,,	4.00	0.00	7.00	2.00	0.08	Nd	53.32	56.00	0.00
WS 4	,,	4.00	0.00	11.00	4.00	0.03	Nd	0.26	10.00	0.00
WS 5	,,	4.00	0.00	21.00	6.00	2.37	Nd	24.99	24.00	0.00
WS 6	,,	3.20	0.36	11.00	4.00	0.19	Nd	23.33	25.00	0.00
WS 7	,,	20.00	11.20	25.00	7.00	0.05	3.00	18.33	65.00	0.00
WS 8	,,	3.21	0.00	10.00	3.00	0.05	Nd	10.09	9.00	0.02
WS 10	,,	3.20	0.00	12.00	0.00	2.35	Nd	1.67	31.00	0.00
WS 11	,,	5.60	0.35	18.00	8.00	0.00	Nd	8.33	123.00	0.01
WS 12	,,	16.00	0.36	7.00	3.00	0.27	Nd	3.33	45.00	0.00
WS 13	,,	4.00	0.36	21.00	34.00	0.92	Nd	2.09	19.00	0.09
WS 14	,,	19.20	0.36	26.00	11.00	0.07	Nd	37.49	56.00	0.00
WS 15	,,	12.00	0.00	13.00	9.00	0.34	Nd	2.09	27.00	16.72
WS 16	,,	2.40	0.00	12.00	1.00	0.29	Nd	4.09	15.00	4.84
WS 17	,,	3.20	0.00	10.00	3.00	0.34	Nd	11.66	64.00	2.20
WS 18	,,	3.20	0.36	12.00	50.00	0.04	Nd	0.00	12.00	13.20
WS 19	,,	1.60	0.00	14.00	11.00	0.27	1.00	3.33	70.00	1.22
WS 20	,,	2.40	0.36	34.00	9.00	0.05	3.00	29.99	70.00	3.52
WS 21	,,	5.60	0.36	10.00	8.00	0.00	Nd	0.34	12.00	1.09
WS 22	,,	4.00	0.00	16.00	7.00	0.14	Nd	24.99	6.00	1.76
WS 23	,,	4.00	0.00	13.00	5.00	0.23	Nd	1.90	3.00	0.09
WS 1	SW	4.80	0.36	12.00	5.00	0.12	Nd	1.21	10.00	0.03
WS 9	,,	6.40	0.36	24.00	8.00	0.29	Nd	14.33	66.00	0.00
WS 24	,,	10.40	0.56	6.98	0.00	3.06	2.00	13.50	14.00	0.00

All parameters in mg/l; GW = groundwater;
SW = Surface water; Nd = Not detected

Table 3: Summary of physico-chemical parameters of the water samples, WHO (2006, 2011) guidelines and NSDWQ (2007) standards for drinking water.

Measured Parameter	Range	GW*	SW*	Overall mean	WHO (2006, 2011) Guidelines	NSDWQ (2007) Standards
Temp (^{0}c)	26.30-28.90	27.82	27.80	27.82	25	Ambient
P^H (P^H unit)	4.17-5.72	4.78	5.23	4.84		
Ec (µs/cm)	7.62-98.00	26.26	26.83	26.33	500	1000
TH (mg/l)	4.00-54.00	16.95	20.00	17.33	500	150
TDS (mg/l)	4.95-63.70	18.28	17.49	18.18	1000	500
SAR (mg/l)	0.47-5.41	1.87	1.50	1.82		
Ca^{2+}(mg/l)	1.60-20.00	6.36	7.20	6.47	200	75
Mg^{2+} (mg/l)	0.00-11.20	0.70	0.43	0.67	150	0.20
Na^+ (mg/l)	6.98-34.00	15.00	14.33	14.92		
K^+ (mg/l)	0.00-50.00	9.05	4.33	8.46	15	NG
Fe^+ (mg/l)	0.00-3.06	0.40	1.16	0.50	0.3	0.3
HCO_3 (mg/l)	0.00-3.00	0.43	0.67	0.46	500	NG
Cl^- (mg/l)	0.00-53.32	12.64	9.68	12.27	250	250
SO_4^{2-} (mg/l)	3.00-123.00	36.43	30.00	35.63	400	100
NO_3 (mg/l)	0.00-16.72	2.13	0.01	1.87	10	50

GW* = groundwater, SW* = Surface water (mean concentration) for each group, NG = Not Given

The p^H ranges from 4.17-5.72, indicating a strongly to weakly acid fresh water. Temperature varies between 26.30^{0}C-28.90^{0}C while the electrical conductivity (Ec) values ranges from 7.62µs/cm-98.00µs/cm (Table1). Total hardness (total hardness as $CaCO_3$) is from 4.00mg/l-54.00mg/l while sodium absorption ratio (SAR) and total dissolved solids (TDS) range respectively from 0.47-5.41 and 4.95mg/l-63.70mg/l (Table1).

The ranges of the chemical parameters in mg/l are as follows: Ca^{2+} (1.60-20.00); Mg^{2+} (0.00-11.20); Na^+ (6.98-34.00); K^+ (0.00-50.00); Fe^{2+} (0.00-3.06) while others are HCO_3^- (0.00-3.00); Cl^- (0.00-53.32); SO_4^{2-} (3.00-123.00) and NO_3^-(0.00-16.72) (Table 2). The mean concentration of the cations therefore is in the order $Na^+ > K^+ > Ca^{2+} > Mg^{2+} > Fe^{2+}$ while for the anions, it is $SO_4^{2-} > Cl^- > NO_3^- > HCO_3^-$ (Table 2).

Statistical correlation using product moment coefficient of correlation indicates positive correlation between some pairs of parameters (Table 4). There are relatively strong correlation between TH and TDS (r = 0.87), TDS and Ec (r = 0.97), Ca and Mg (r = 0.58). Weaker correlation were obtained between Ca and HCO_3^- (r = 0.31). Very weak correlations were observed between Na and K (r = 0.22) and p^H and TH (r = 0.18). Also, very weak negative correlation was observed between p^H and Cl (r = -0.04).

Table 4: Correlations between some of the Hydrochemical parameters.

Variable	Correlation co-efficient
TH and TDS	0.87
Na and K	0.22
TDS and Ec	0.97
Ca and $HC0_3^-$	0.31
Ca and Mg	0.58
P^H and TH	0.18
P^H and Cl	- 0.04

A plot of the TDS against $Na/(Na+Ca)$ ratio (Fig.2), indicate that the waters may have modified their chemistry from the weathered materials derived from the underlying rocks. The majority of the samples plot in the Gibbs (1970) diagram showed that weathering is the main pollutant in the area. This study showed that sodium ion (Na^+) has the highest cation mean value of 14.92mg/l in the mapped area. Sodium must have entered the groundwater system through natural system i.e. rainwater (Spears, 1976).

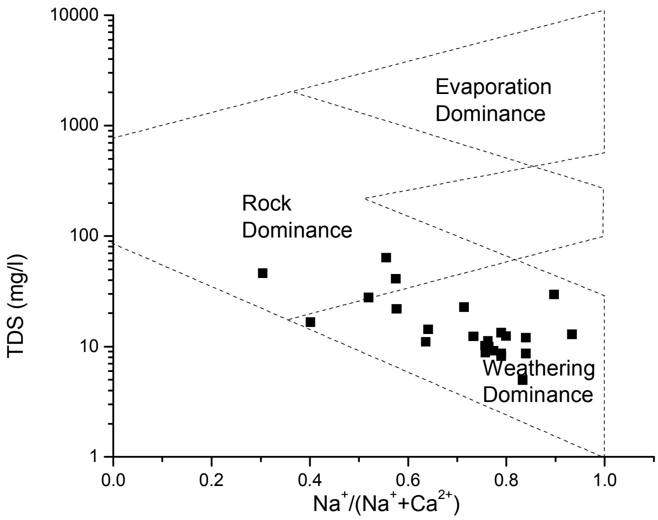

Fig.2. Plot of TDS against the $\left(Na / Na + Ca \right)$ ratio (after Gibbs 1970).

Another contributory factor is as an impurity in the cementing material where sodium ion (Na^+) and potassium ion ion (K^+) substitute for calcium ion (Ca^{2+}) in the carbonate lattice (Hem, 1970). Other natural sources include weathering of feldspars (albite) and leaching of clay minerals according to (Spears and Reeves, 1975; Ogbukagu, 1976; Todd, 1980). Ogbukagu (1976) suggested that the high sodium ion (Na^+) in the Nanka sand is probably due to the chemical breakdown of feldspar flakes. Though this is feasible, but due to the insufficiency and unreactive nature of these minerals, with respect to the p^H condition, the ion-exchange phenomenon must be invoked to explain the high sodium ion (Na^+) concentration. The major source of sulphate ion (SO_4^{2-}) in the area with mean concentration of 35.63mg/l in the sample may result from gypsum and oxidation of sulphide ores. The mean chloride ion (Cl^-) concentration of 12.27mg/l are generally low because of the fact that chloride does not show any correlation with the components of pore water derived from mineral breakdown (Spears and Reeves, 1975) and because of the fact in sedimentary rocks the major source of chloride in groundwater is due to evaporite (Hem, 1970). The concentration of rainwater by evapotranspiration may be an important source of chloride in the area. The potassium ion (K^+) with the mean concentration of 8.46mg/l may be as a result of the presence of natural sources such as feldspars (orthoclase and microcline), feldspathoids, some micas, and clay minerals.

Graphical Representations

Graphical representations are useful for comparing analyses, and illustrating similarities and differences. They can be used in detecting the mixing of water of different compositions as well as identifying chemical processes during groundwater movement (Todd and Mays, 2005). Graphical illustrations can be illustrated by use of Stiff pattern diagrams, Schoeller (semi logarithmic) diagram, piper (trilinear) diagram and Durov trilinear diagram.

Stiff Pattern:

Graphic representation by Stiff pattern proposed by Stiff 1951 form an irregular polygonal shape thus giving a distinctive shape to waters of a similar quality. Four parallel horizontal axes are created from four parallel horizontal axes extending on either side of a vertical zero axes. Concentrations in milliequivalents per litre are plotted on the left of the zero axis one on each horizontal plane, and anions are plotted to the right. A rapid visual comparison between waters from different sources can be made by Stiff patterns. The water types can be known from the projections inferred for water samples (WS 1-24).

Radial Diagram

Lines for cations and anions emanate from a central point and are projected out. The concentration of the constituents is marked out as points on the radial lines. These are connected and visual inspection indicates type water of groundwater analyzed for water samples (WS 1-24).

Schoeller Semilogarithmic Diagram

The use of semilogarithmic graph paper to plot the concentrations of anions and cations was proposed by Schoeller (1955). The concentrations are plotted in meq/l. The diagram enables us to make a visual comparison of the compositions of different water (Fig. 3).

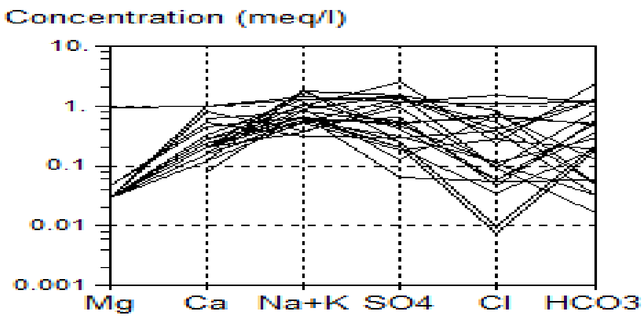

Fig.3: Scholler semi-logarithmic diagram showing relative abundance of cations and anions in the study area.

Water Types

Figs. 4 (a-c) show diagrams for cations and anions made by Stiff pattern. Water samples from WS 2, WS 4, WS 9, WS 11, WS 13, WS 16, WS 17, WS 18, WS 19, WS 20, and WS 21 indicate water types to be sodium sulphate and constitute the major type water in the study area. Additional water types found are Ca-SO_4, Ca-Cl-SO_4, Na-Cl, Ca-Na-SO_4, Na-Mg-SO_4 and Na-Cl-SO_4. Radial diagram is also used to display the composition of cations and anions in the study area as shown in Figs. 5 (a-c). Sodium sulphate (Na-SO_4) is the major water type accounting for more than fifty percent (50%) of the water type in the study area. Na-Cl, Na-Cl-SO_4 are additional water types found in the area and constitute twenty-three percent (23%) and eighteen percent (18%) respectively. Ca-SO_4, Ca-Na-SO_4, Ca-Cl-SO_4 and Na-Mg-SO_4 are less than nine percent (9%) each in composition. Common source of sodium is from feldspars and clay minerals in rocks whereas calcium and magnesium concentrations are obtained from natural sources such as amphiboles, feldspars, dolomite and clay minerals. Sulphate is obtained from sulphide ores and gypsum. Base Exchange and chemical reduction are the principal chemical processes involved in the occurrence in the water types occurring in the area. Source of sulphate and chloride in groundwater are due to leacheates and damaged septic tanks (Todd and Mays, 2005).

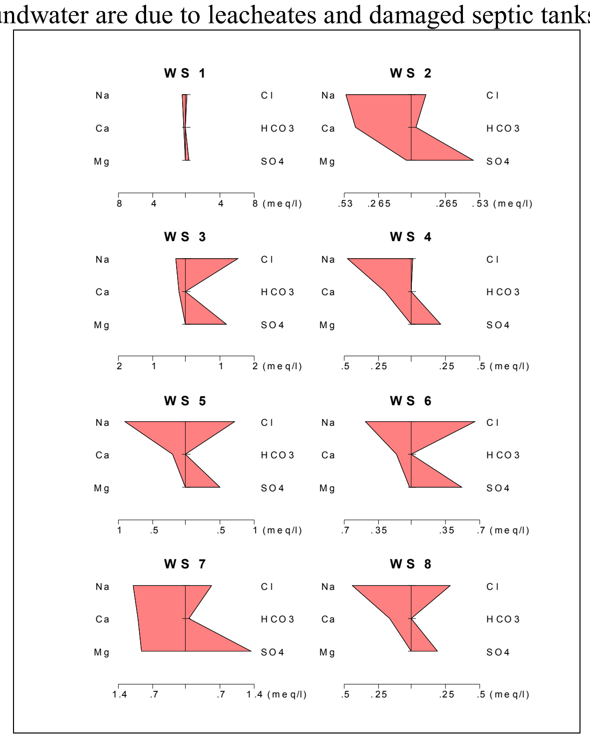

Fig.4a.The stiff diagrams of the water samples (1 – 8) in the study area.

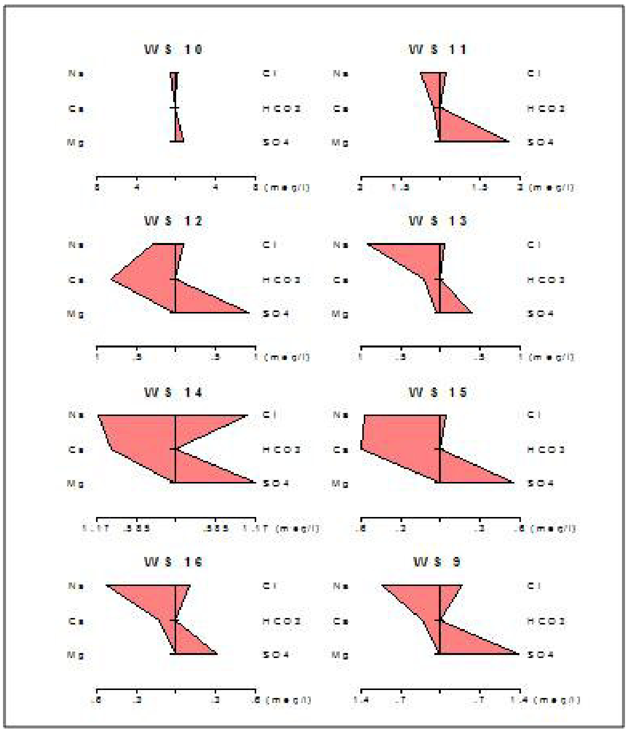

Fig.4b.The stiff diagrams of the water samples (9 – 16) in the study area.

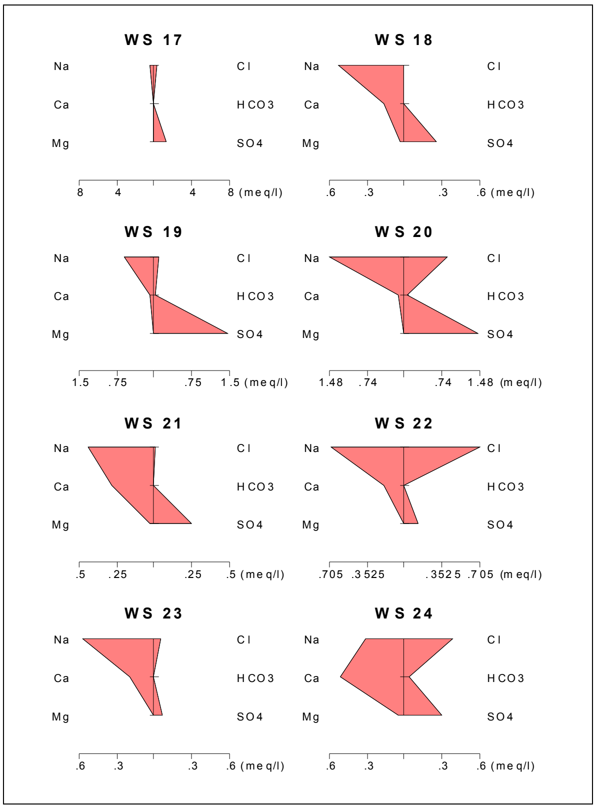

Fig. 4c.The stiff diagrams of the water samples (17 – 24) in the study area.

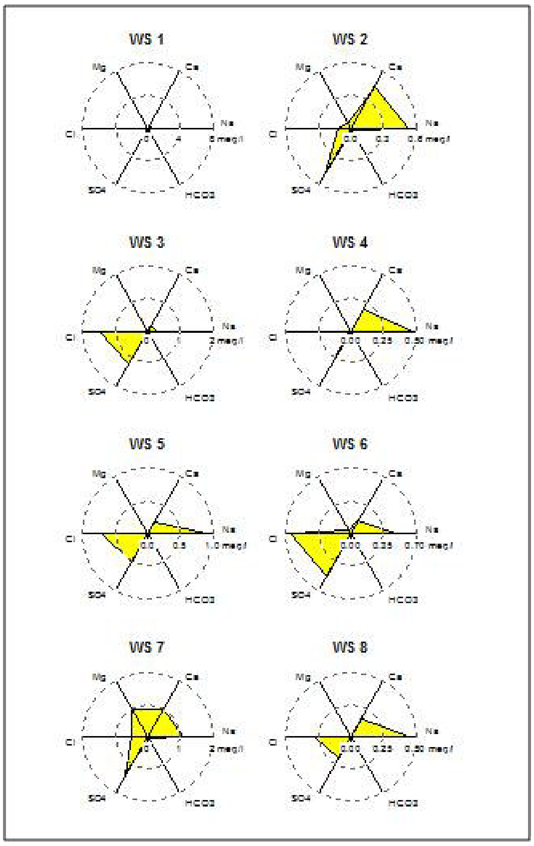

Fig. 5a.The radial diagrams of the water samples (1 – 8) in the study area

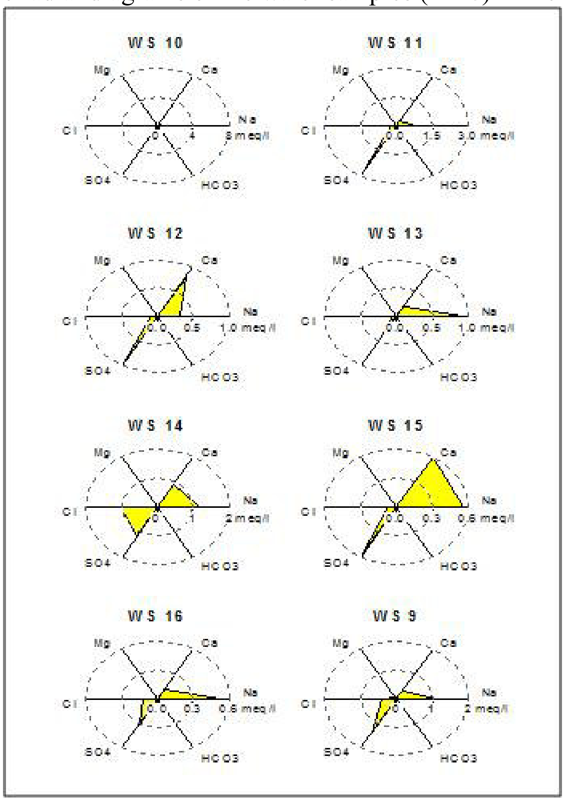

Fig. 5b.The radial diagrams of the water samples (9 – 16) in the study area

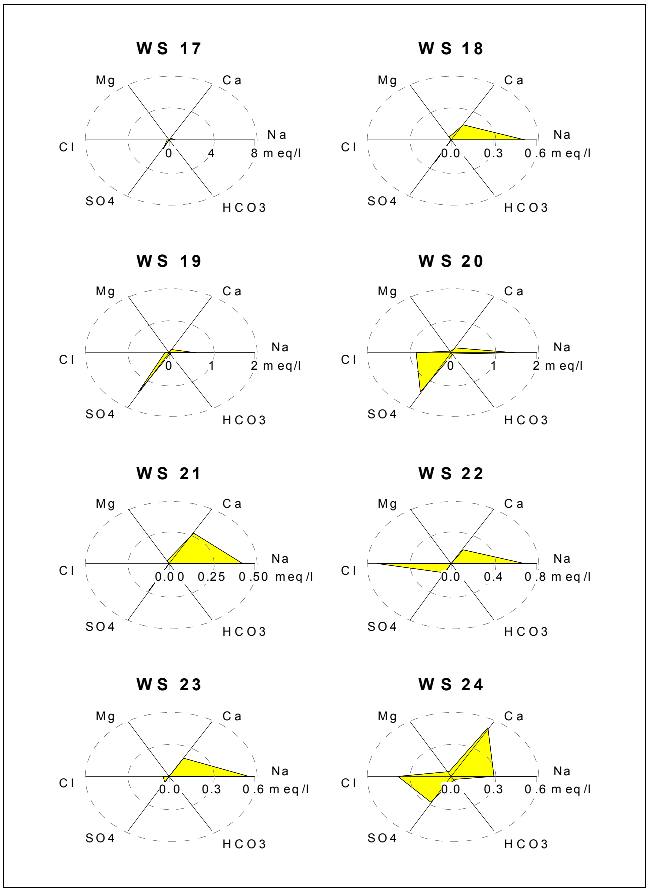

Fig. 5c.The radial diagrams of the water samples (17 – 24) in the study area

Water quality and usability

The chemical character of any water determines its quality and utilization. The water quality is a function of the physical, chemical and biological parameters and could be subjective since it depends on a particular intended use (Tijani, 1994). The World Health Organization (2006, 2011) prescribed the quality of drinking water worldwide. Comparing the various analyses with the prescribed standards, most of the water samples are within the specified standards. The physical parameters such as p^H, Ec, TDS are within the acceptable limit of the WHO (2006, 2011) guidelines (Table 3). The water samples in the study area are classified as fresh water based on the proportion of Total Dissolved Solids (TDS) which falls between 0 – 1000mg/l (Caroll, 1962).

According to Mandel and Shiftan (1991), water containing Sodium Absorption Ratio (SAR) of 0 to 10 can be applicable on all agricultural soils while, that having SAR range from18 to 26 may produce harmful effects and require good soil management. Sodium Absorption Ratio range of 26 – 100 is unsuitable for irrigational purposes. Based on the above, the Total Hardness (TH) and Sodium Absorption Ratio (SAR) (Richardson, 1954; Sawyer and McCarthy, 1967) shows that the water is soft, and has low sodium content. On the other hand, irrigation water criteria are dependent on water conductivity (Ec), Sodium Absorption Ratio (SAR), type of plants, and amounts of irrigation water used, soil and climate. Using Wilcox model (Table 5), both the surface water and groundwater are excellent with very low saline content.

Table 5: Modified Wilcox quality classification of irrigation water.

Water class	Electrical conductivity	Salinity harzard	SAR
Excellent	< 250	Low	0 – 10
Good	250 – 750	Medium	10 – 18
Permissible	750 – 2000	High	18 – 26
doubtfull	2000 – 3000	Very high	26 – 30

However, two principal effects of sodium are a reduction in soil permeability and a hardening of the soil. This study showed that such effects are ruled out because of low Sodium Absorption Ratio (SAR). Hence, it can be used to irrigate most plants (crops) and on most soils (Hem, 1985; Leeden et al., 1990). Based on the work of Leeden et al., (1990), the ranges of additional parameters such as Sodium Absorption Ratio (SAR), Total Hardness (TH), etc. are consistent with domestic supplies, recreation, wildlife propagation, irrigation and most industrial requirements.

Conclusion

The results of hydrochemical studies of both surface waters and groundwater in the area shows that the water is generally acidic fresh water. Sodium Sulphate (Na-SO_4) constitutes the major water type in the study area, accounting for more than fifty percent (50%) of the water type in the study area. Na-Cl, Na-Cl-SO_4 is additional water types found in the area and constitute 23% and 18% respectively. Ca-SO_4, Ca-Na-SO_4, Ca-Cl-SO_4 and Na-Mg-SO_4 are less than 9% each in composition. These may reflect contribution of diversity of bedrock types and consequently also, the product of weathering. Computed values of Total Hardness and Sodium Absorption Ratio indicate that the water is generally soft with low sodium content. The quality of both the groundwater and surface waters are good and satisfy the World Health Organisation (WHO) guidelines and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) for domestic, agricultural and other industrial uses. It is recommended that both water sources be developed to supplement the existing ones. Further studies should include microbial investigation, heavy metal and isotopic composition, so as to ascertain other quality parameters hence the prescription of necessary treatment measures.

References

Carrol, D. (1962). Rainwater as a chemical agent of geologic processes – A review. U.S. Geological survey water supply paper 1535 – G, p.18.

Elueze, A. A., Omidiran, J.O. and Nton, M.E. (2004). Hydrogeochemical investigation of surface water and groundwater around Ibokun, Ilesha area, southwestern Nigeria. Journal of Mining and Geology, vol. 40(1), pp.57-64.

Gibbs, R. J. (1970). Mechanism controlling world water chemistry. Science v.170, pp.1088 – 1090.

Hem, J. D. (1970). "Study and Interpretation of Chemical Characteristics of Natural Water". Paper No. 1473. U.S. Geological Survey: Washington, DC.

Leeden, F. V. D., Troise, F. L. and Todd, D. K. (1990). The water encyclopedia. Geraphly and Miller groundwater series, Lewis Publishers. Inc. U.S.A. p.417 – 493.

Mandel, S. and Shiftan, Z. I. (1991). Groundwater Resources Investigation and Development, Academic Press Inc.

NSDWQ (2007). Nigeria Standard for Drinking Water Quality, Nigeria Industrial Standard, Approve by Standard Organization of Nigeria Governing Council. ICS 13.060.20: 15-19.

Ogbukagu, IK. N. (1976). "Soil Erosion in the Northern Parts of Awka-Orlu Uplands". Journal of Mining and Geology, v. 13, pp.16-19.

Okezie, C. N. and Onuogu, S. A. (1985). The lignites of southeastern Nigeria. Geol. Survey of Nigeria Occassional paper, No. 10, p.28.

Richards, L. A. (1954). Diagnosis and improvement of saline and alkali soils. Agric. Handbook 60, U. S. Dept. of Agric. Washington, D. C. p.160.

Sawyer, C. N. and McCarthy, P. L. (1967). Chemistry for Sanitary engineers, 2nd ed. McGraw – Hill, New York, p.518.

Schoeller, H.(1955). Geochemie des e'aux souterraines. Revue de L'Institute Francais du Petrole. 10:230-244.

Short, K. C. and Stauble, A. J. (1967). Outline of Geology of the Niger Delta. AAPG Bull., v.51, p.761-779.

Spears, D. A. (1976). "Information on Groundwater Composition Obtain from a Laboratory Study of Sediment-Water. Q.J. Engng. Geol., v.9, pp. 25-36.

Spears, D.A. and Reeves, M. J. (1975). "The Influence of Superficial Deposit on Groundwater Quality in the Vale York". Q. J. Engng. Geol. v.8, pp. 255-270.

Stiff, A. A. (1951). The Interpretation of chemical water analysis by means of patterns. Journal of Petroleum Technology, v.3, No.10, pp. 15-17.

Tijani, M. N. (1994). Hydrogeochemical assessment of groundwater in Moro area, Kwara state, Nigeria. Environmental Geology, vol.24, pp.194 – 202.

Todd, D. K.and Mays, L. W. (2005). Groundwater Hydrology. 3rd Edition. John Wiley and sons, New York. p.636.

Todd, D.K. (1980). Groundwater Hydrology. John Wiley, New York.

WHO (2006). Guidelines for drinking water quality. First Addendum to 3rd Ed., vol. 1. Recommendations. Geneva. p.405.

WHO (2011). Guidelines for drinking water quality.4th Edition, p.504.