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Hydrogeochemical Properties of Groundwater in Parts of Abakaliki City, Southeastern Nigeria

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This study is aimed at providing useful information about the hydrochemistry of some parts of Abakaliki city for proper understanding of the groundwater quality. Twelve representative groundwater samples from water boreholes/wells in the study area were analyzed for their hydrogeochemical properties : pH, Electrical Conductivity (EC), Turbidity, Total Dissolved Solids (TDS), Total Hardness (TH), COD, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, and CO_3^{2-}. Aquifers in the study environment were located in the fractured shales of Abakaliki Formation. The composition of the major ions outlined the relationships between the aquifer chemistry. Strong positive correlations exist between EC-TDS, Na^+-TDS, Mg^{2+}-SO_4^{2+} and Ca^{2+}-SO_4^{2+}. Piper trilinear diagram has also been utilized in data interpretation and to classify the hydrogeochemical facies. Majority of the analyzed samples were characterized by the dominance of Ca^{2+}, Mg^{2+}, SO_4^{2-} and Cl^- and the Piper trilinear diagram indicated two water types : Ca (Mg)-Cl and Ca-Mg-Na-Cl-SO_4 water types. Na/Cl ratio ranging from 0.12 to 0.73 (all below 1.0) with a mean of 0.55 inferred fresh water existence. Results of this study generally showed that the analyzed groundwater samples pose no threat to human consumption, health and environment since the concentrations of the physico-chemical parameters were within the WHO standards.

Key words : *Hydrogeochemical facies, groundwater quality, groundwater samples, physico-chemical parameters, Abakaliki formation*

Introduction

Water is an essential natural resource for sustaining life and environment that we have already thought to be available in abundance and free gift of nature [1, 2, 3]. Though groundwater contributes only 0.6% of the earth's total water resources (surface water and groundwater), it has strategically remained valuable as the major and preferred source of drinking water [4]. Groundwater quality problems are increasingly evoking considerable concern [5, 6, 7] as population expansion, unplanned urbanization and unrestricted exploration also imply more water demands. In the present state of Abakaliki city, the large urban and rural sector rely on groundwater for more than 95% of its water needs thereby constituting a great challenge to water supply.

The suitability of groundwater for drinking (domestic), industrial and irrigation (agricultural) purposes depends on its hydrogeochemical composition [8, 9]. With water as a universal solvent capable of dissolving virtually anything, the concentration of various hydrogeochemical contents is also dependent on the nature of the aquifer geology, contact time [10] and existing climate. There is little or no published data on the composition of the major ions of groundwater in Abakaliki city and adjoining areas close by except trace element data of sediments in the mineralized Abakaliki zones of Nigeria [11, 12].

To establish quality criteria - measures of chemical, physical and bacterial properties, we analyzed the hydrogeochemical properties of the twelve representative groundwater samples in the study area. The main aim of this research is to provide useful information about the hydrogeochemistry of some parts of Abakaliki city for proper understanding of the groundwater quality and pollution level. The quality of these groundwater samples was determined by measuring the concentration of the cations and anions. The existence of freshwater and characteristic water types in the environment was also evaluated.

Materials and methods

Groundwater sampling was carried out in the dry season periods (between November, 2007 and February, 2008). The samples were collected in plastic bottles which were pre-cleaned with concentrated hydrochloric acid followed by rinsing in tap and finally in distilled water [13]. This was also done to avoid unpredictable changes in characteristics as per the standard procedure [14]. The collected samples were analyzed for different hydrogeochemical properties such as

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pH, Electrical Conductivity, Turbidity, TDS, Total Hardness, COD, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, and CO_3^{2-}. And the results were compared with the standard specification [15] in order to assess how potable the water is.

Terrain geology and hydrogeology

The study area (**Fig. 1**) is part of the Abakaliki shale formation which lies within the Albian Asu River Group. The area is mainly characterized by rather poorly bedded shale, occasionally sandy, splintery metamorphosed mudstone. Lenses of sandstone and sandy limestone are highly jointed and fractured. It has been noted that the influence of tectonic activities introduced the discordance dip between the Asu River Group and the overlying Turonian Eze-Aku formation (Afikpo Basin). Younger intrusive bodies in combination with numerous faults and joint systems have created the secondary porosity in the shale formation. The fracture systems which spread across Abakaliki anticlinorium and Afikpo syncline in the Benue rift during the deformational episode originated from vertical movement resulting from the rising and cooling of magma, which intruded the sediments in the Santonian time (A.C. Umeji, personal communication, 2005). Paleontologically, it is mainly characterised by species of *Mortoniceras* and *Elobiceras* [16]. *Pelecypods* and *Gastropods* are also relatively rare. The sediments are folded and fractured particularly in the country south of Abakaliki; the fold axes stretch NW – SE. Hydrogeologically, weathered rocks, alluvium and fractured zones form the aquifers in the study area. However, pockets of weathered and fractured rocks may form isolated groundwater reservoirs.

Results and discussion

The quality of analytical data is evaluated by computing the ionic balance (reaction rate percent) which is calculated by comparing the sum of the equivalents of the cations with the sum of the equivalents of the anion[17]. A positive number means that either there is excess cation or insufficient anion and vice versa. For fresh water, ionic balance is assumed to be good if it is ± 10% [18]. In this study, the ionic balance ranged from – 0.20% to + 0.19%. Ionic balance was also compared by generating the scatter plot between EC and sum of cations and sum of anions of the analyzed groundwater samples. **Fig. 2** shows that the sum of cations and sum of anions are equally balanced and linearly correlated.

Geochemistry

Table 1 depicts the results of the hydrogeochemical analysis of groundwater samples and **Table 2** gives the descriptive statistics of the analysed samples comparing with the World Health Organisation[15] standards. Drinking water standards are generally based on two main criteria[19]: (1) presence of objectionable taste, odour and colour and (2) presence of substances with adverse physiological (health effect) characteristics. According to [20], the most significant geohydraulic influence in groundwater chemistry arises from the source circulation of groundwater itself; regional geology plays a very significant role in determining the hydrogeochemistry of groundwater system. The erratic concentration of the four major cations may be ascribed to the fact that they are constantly involved in cation-exchange process and interaction with aquifer materials [21].

The distribution part of major ions showed compositional variation in groundwater samples. The general trend among cations showed Ca>Na>Mg>K. Similarly anions displayed SO_4>Cl>HCO_3>CO_3>NO_3 distribution pattern. The dispersion of ions in the groundwater of this terrain probably indicates nearly similar geochemical environment and climatic conditions [22].

The pH values of groundwater samples varied between 5.3 and 7.9. Turbidity of samples was found to be within the WHO permissible limits. The same trend was observed in the case of the TDS of various groundwater samples varying from 121 to 447 mg/L (within standard limits).

A good correlation was also inferred between EC and TDS (R^2 = 0.957) as shown in **Fig. 3**. The overall correlation as shown in **Table 3** suggests the relationship between the various aquifer chemistry parameters. Total Hardness (TH) indicates the trend in the correlation of Ca and Mg with value ranging from 11 mg/L to 108 mg/L. 66.7 % of the analyzed samples were found to be soft water, while the remaining 33.3 % (AC2, AC3, AC7, AC8) were moderately hard water. Calcium showed concentration between 2.8 and 25 mg/L while Bicarbonate ions showed distribution between 2.5 and 16.1 mg/L. Sulphate ions were inferred to be related with different probable gypsiferous shale units or remains [23]. Majority of the samples had average SO_4 concentration ranging from 0.8 to 84 mg/L. Chloride concentrations in groundwater samples were in the range 3 to 28.5 mg/L. The dominance of these ions was the best reflection of the bed rock chemistry.

Ionic composition and hydrogeochemical facies

In order to elaborate the composition of the groundwater, major ions are expressed in milliequivalents per litre (meq/L). The hydrogeochemical facies analysis reflected the chemical processes in certain lithological environment and under specific geochemical conditions. The general classification and trend of variation is shown by plotting the ionic concentrations of the major cations and anions in the Piper trilinear diagram (**Fig. 4**). The diagram shows the dominance of alkaline earth elements (Ca+Mg) over three alkali earth metals (Na + K). The area has high Cl + SO_4 in contrast to

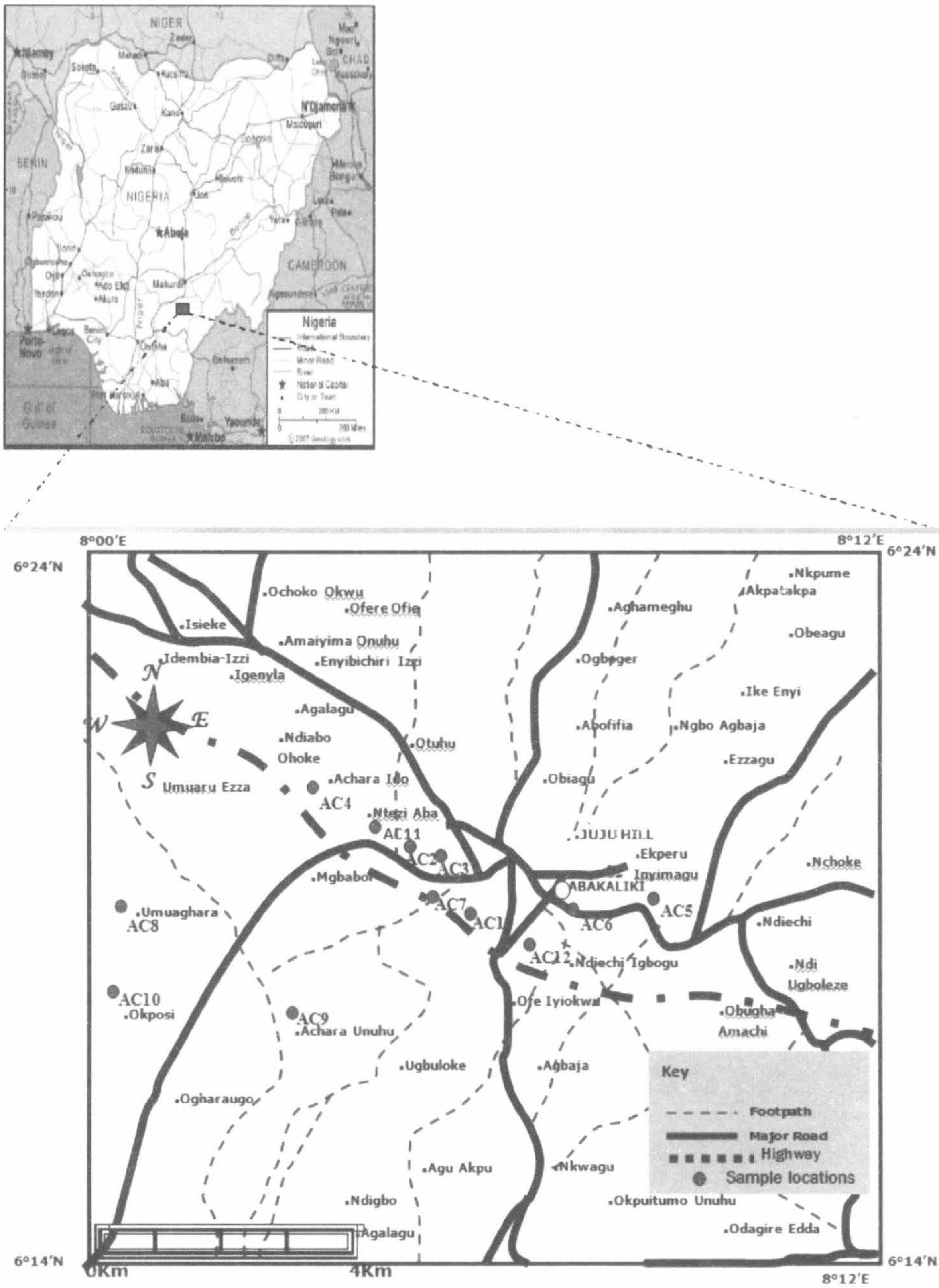

Fig. 1: Location map of the parts of Abakaliki city, southeastern Nigeria

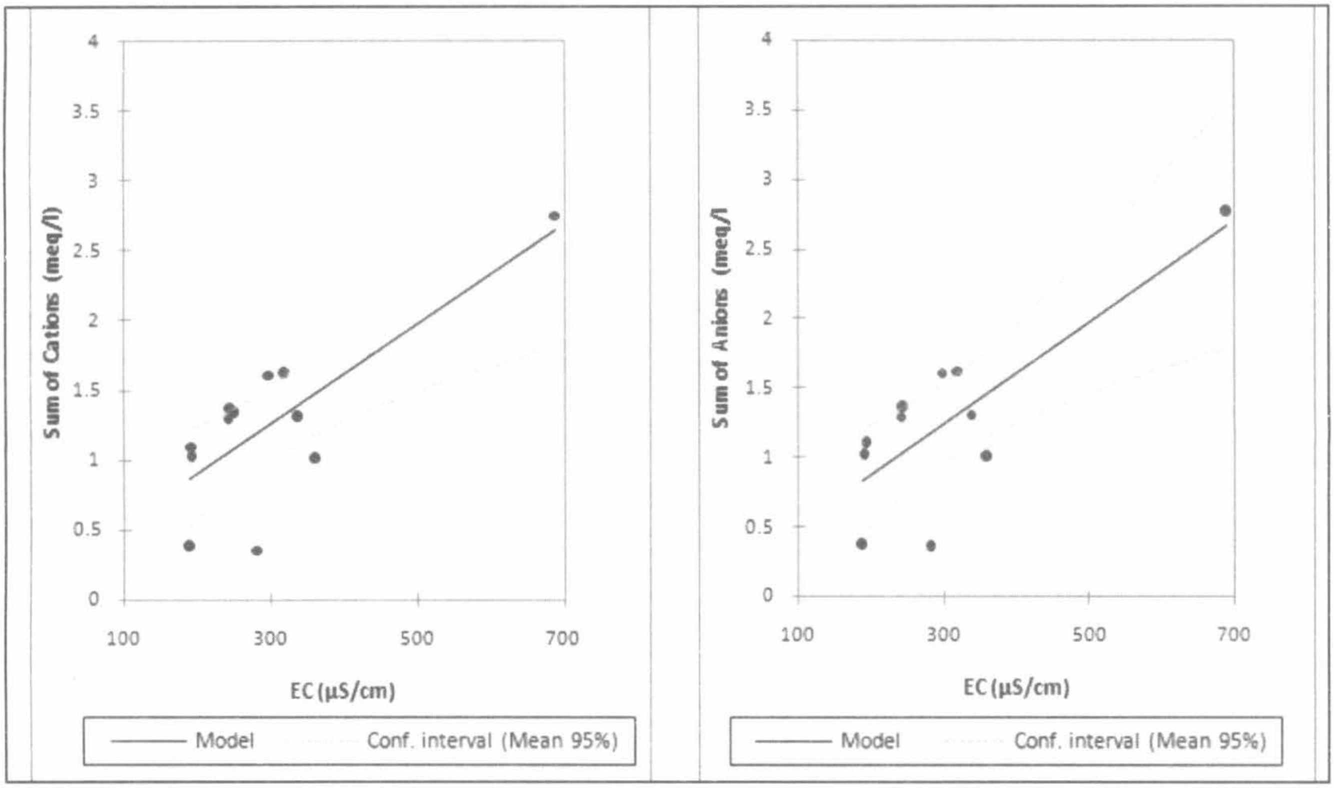

Fig. 2: Correlation between sum of cations (left – R^2=0.60) and sum of anions (right – R^2=0.62) with electrical conductivity

HCO_3 + CO_3; clearly suggesting a total deviation from the carbonate type of aquifer[24, 25]. In the cation triangle, majority of the samples were Ca-type and have Ca + Mg ranging from 59 to as high as 96 %. Only sample AC5 showed relatively high environment of Na (38%). The anion triangle reflected a Cl-type with SO_4>HCO_3 + CO_3. Out of the 12 groundwater samples from parts of Abakaliki city, 11 samples (91.7 %) falls in the plot 1 indicating that the chemical properties of

Table 1: Results of the hydrogeochemical analysis of the groundwater samples

Water quality parameters	Sample codes											
	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	AC9	AC10	AC11	AC12
PH	7.3	5.8	7.2	6.9	7.1	7.4	7.4	7.3	6.4	7.5	7.5	7.8
TDS (mg/L)	163	447	197	231	181	157	144	157	219	130	123	121
EC (µS/cm)	250	689	297	360	281	241	319	245	337	190	192	189
Total Hardness	35	108	72	36	11	59	66	63	54	48	51	14
Total Coliform	0.7	4	2	4	2.5	4.0	0.2	3.5	3.5	7	3	0.8
Turbidity (NTU)	1.7	6.5	5.8	10.2	7.5	5.1	7.3	2.6	5.5	5.3	3.5	2.4
COD	8.4	9.2	12.8	16.7	10.1	12.8	11.3	8.3	5	7.9	11	6
Ca^{2+}(mg/L)	16	25	20.1	6	4.07	20	18	18	12.3	13.8	12	2.8
Mg^{2+}(mg/L)	4.8	11	5.3	5	0.1	2.1	5	4.5	5.7	3.4	5.2	1.6
Na^{+}(mg/L)	3	13.5	3.2	5.8	3.1	2	4.2	1.8	4.5	1	1.2	1.5
K^{+}(mg/L)	0.6	0.5	1.8	1.5	0.4	1.5	5	0.7	0.9	0.2	0.8	1.5
HCO_3^-(mg/L)	10.4	12.1	15	15	2.8	2.8	16.1	11	9.41	14.61	2.5	5
SO_4^{2-}(mg/L)	42	84	53	15	0.8	41	60.5	33.5	32.3	26	30	9.5
Cl^-(mg/L)	10	28.5	9.2	15	9.6	13.5	3.2	15	15.6	7.5	15	3
NO_3^-(mg/L)	0.8	0.8	0.2	1.2	1.5	0.9	0.7	3.8	2.5	1.5	0.9	0.6
CO_3^{2-}(mg/L)	0.14	0.07	0.13	0.12	0.01	0.05	0.09	0.06	0.05	0.05	0.04	0.04
Na/Cl (meq/L)	0.46	0.73	0.54	0.60	0.5	0.23	2.03	0.19	0.45	0.21	0.12	0.5

Table 2: Descriptive statistics of analyzed samples compared with the World Health Organisation standards

Parameter	No. of samples	Min.	Max.	Mean	SD	WHO (1984) Maximum Permissible Limit
pH	12	5.8	7.8	7.13	0.55	6.5 – 8.5
TDS (mg/L)	12	121.00	447.00	189.17	88.71	1000
EC (μS/cm)	12	189.00	689.00	299.17	135.55	1400
TH	12	11.00	108.00	51.42	26.27	500
Turbidity	12	1.70	10.20	5.28	2.46	5
COD	12	5.00	16.70	9.96	3.23	—
Ca^{2+}(mg/L)	12	2.80	25.00	14.01	6.91	75
Mg^{2+}(mg/L)	12	0.10	11.00	4.48	2.70	50
Na^{+}(mg/L)	12	1.00	13.50	3.73	3.40	200
K^{+}(mg/L)	12	0.20	5.00	1.28	1.28	55
HCO_3^-(mg/L)	12	2.50	16.10	9.73	5.21	—
SO_4^{2-}(mg/L)	12	0.80	84.00	35.63	22.94	400
Cl^-(mg/L)	12	3.00	28.50	12.09	6.81	250
NO_3^-(mg/L)	12	0.20	3.80	1.28	0.98	50
CO_3^{2-}(mg/L)	12	0.01	0.14	0.07	0.04	—
Total Coliform	12	0.20	7.00	2.93	1.87	0/100 (MPN/100 mL)

groundwater are dominated by alkaline earths (Ca^{2+}, Mg^{2+}) and strong acids (SO_4^{2-}, Cl^-) and only sample AC5 constituting only 8.3 % falls in quarter 3 indicating that no cation-anion pair dominated by alkalies (Na^+, K^+) and weak acids (HCO_3^-, CO_3^{2-}) exceed 10 %. Thus the majority of the analyzed samples are characterized by the dominance of Ca^{2+}, Mg^{2+}, SO_4^{2-} and Cl^- and the Piper trilinear diagram indicated two water types [26] : Ca (Mg)-Cl and Ca-Mg-Na-Cl-SO_4 water types.

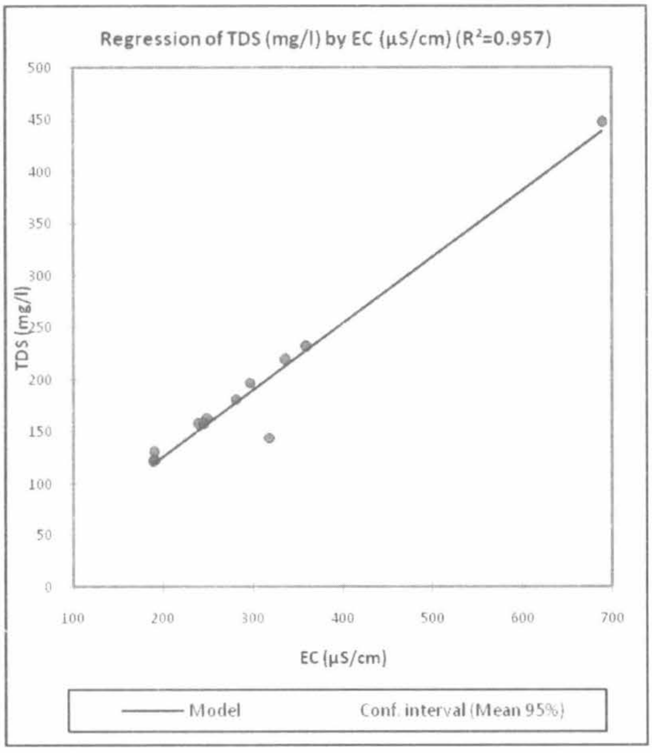

Fig. 3 : Correlation between Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

In order to determine salinization, Na/Cl ratio in milliequivalents per litre was valuable. Na/Cl below 1.0 indicates fresh water existence. In the study area, the collected groundwater samples have Na/Cl ranging from 0.12 to 0.73 with a mean of 0.55 inferring fresh water. Na/Cl ratio more than 1.0 suggests evaporation and concentration [27].

Conclusions

Conclusively, the groundwater quality of the studied water wells/ boreholes in parts of Abakaliki city poses no threat to human consumptions. Except in few cases where the Turbidity was exceptionally higher than what is obtainable in other studied sites due to industrial (pyroclastic quarrying) and rice mill activities, weathering and bed rock erosion/clay suspensions. The groundwater nature is explained by the Piper trilinear diagram which indicates that most of the groundwater samples fall in the Ca (Mg)-Cl and Ca-Mg-Na-Cl-SO_4 water types. Among the 12 analysed samples, cations are clustered within the area of 30 – 77 % Ca, 2- 41% Mg and 4 – 41 % Na + K while anions fall within the range of 6 -76 % Cl, 5 – 77% SO_4 and 4 – 24 % HCO_3 + CO_3. This study therefore compliments the massive awareness campaign among the people to maintain groundwater at their highest quality and purity levels.

Table 3: Correlation matrix for the various hydrogeochemical properties of the groundwater samples

Water quality parameters	pH	TDS (mg/L)	EC (µS/cm)	TH	Turbidity	COD	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	HCO_3^- (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	CO_3^{2-} (mg/L)
pH	1														
TDS (mg/L)	-0.931	1													
EC (µS/cm)	-0.910	0.978	1												
TH	-0.584	0.642	0.676	1											
Turbidity (NTU)	-0.412	0.383	0.442	0.111	1										
COD	0.043	0.071	0.103	0.102	0.626	1									
Ca^{2+}(mg/L)	-0.371	0.435	0.465	0.905	-0.108	0.071	1								
Mg^{2+}(mg/L)	-0.739	0.774	0.792	0.838	0.120	0.021	0.651	1							
Na^{+}(mg/L)	-0.894	0.972	0.994	0.625	0.440	0.108	0.408	0.789	1						
K^{+}(mg/L)	0.227	-0.200	-0.010	0.146	0.290	0.304	0.138	0.006	-0.011	1					
HCO_3^-(mg/L)	-0.237	0.257	0.327	0.431	0.362	0.195	0.359	0.489	0.323	0.361	1				
SO_4^{2-}(mg/L)	-0.501	0.592	0.660	0.920	0.009	0.055	0.915	0.809	0.630	0.300	0.441	1			
Cl^-(mg/L)	-0.824	0.823	0.752	0.629	0.165	0.083	0.455	0.722	0.733	-0.462	-0.024	0.460	1		
NO_3^-(mg/L)	-0.126	-0.076	-0.108	-0.012	-0.161	-0.363	-0.035	-0.054	-0.156	-0.321	-0.006	-0.238	0.214	1	
CO_3^{2-}(mg/L)	-0.079	0.149	0.175	0.249	0.090	0.419	0.343	0.399	0.200	0.281	0.673	0.407	-0.017	-0.323	1

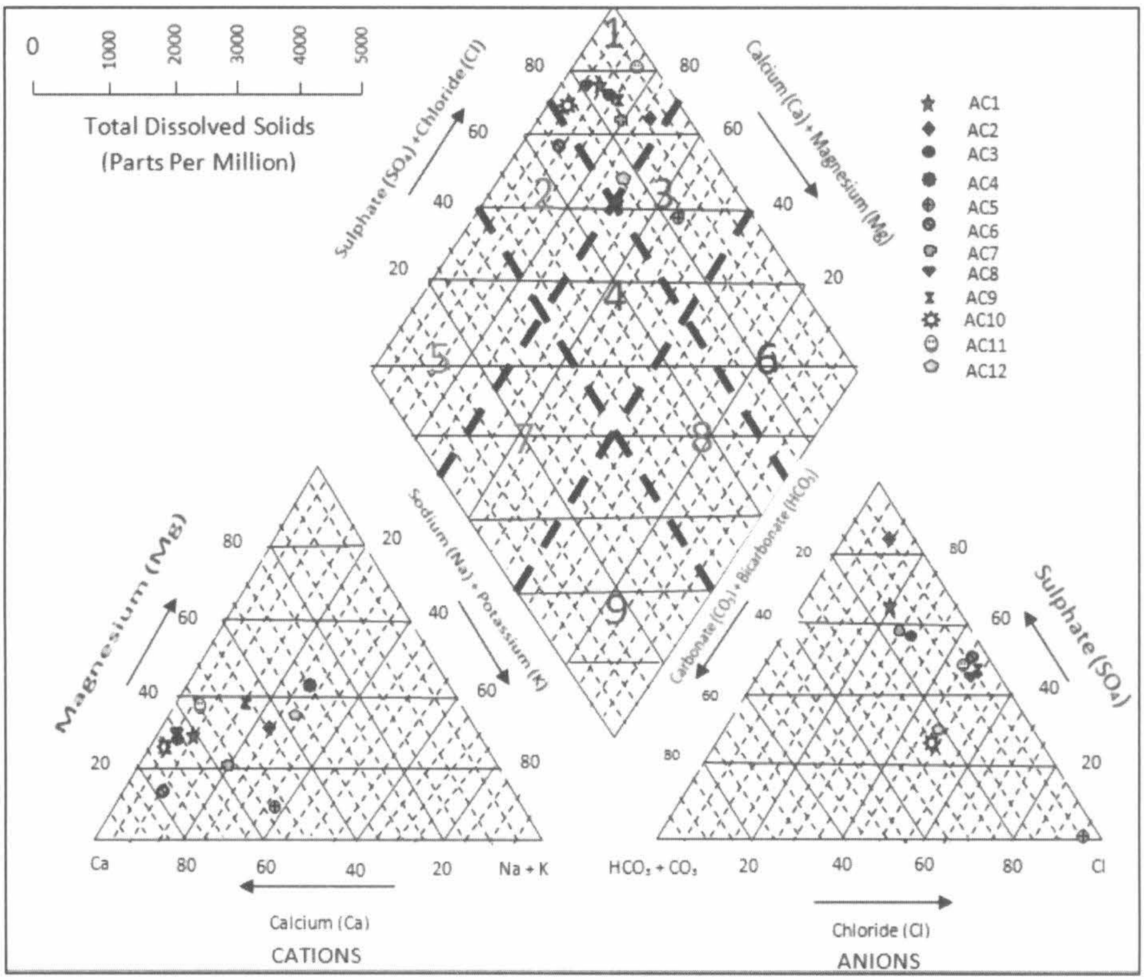

Fig. 4: Piper trilinear diagram for the studied groundwater samples

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