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Water Quality Index and Processes in Basement Complex Terrain of Southwestern, Nigeria

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Abstract

Groundwater Quality Index (WQI) was used in evaluating the water qualities of groundwater of the Southwestern part of Nigeria. The objective is to provide WQI reference values and pattern for this environment. A total of seventy-three water samples were taken and tested for TS, pH,temp , Conductivity, Total Dissolved Solids, nitrate, chloride, phosphate, bicarbonate, lead, copper, zinc, manganese, magnesium, potassium, and calcium determined in the water samples and were used for the data input. The results of the TDS ranged from 50-1930mg/l, and Electrical Conductivity ranged from 128-638μS/cm. The WQI results show that the value of the groundwater ranged from 12.01 to 143.43. The WQI results show that all the studied underground samples fall in the 'good' to 'excellent' water category indicating that its suitability except 12 water samples that fall in 'poor' category indicating that the water is unsuitable for human consumption unless treated. Gibbs plots identified rock–water interaction . Silicate weathering and dissolution of carbonate minerals were pointed as an other vital processes that influence the chemistry of studied water samples. Some studied water is unsuitable for human consumption and should be treated before usage.

Keywords: *Water Quality Index, Hydrochemical processes, Groundwater, Basement Complex, Nigeria*

Introduction

Groundwater had hugely become vital water supply in rural and urban areas ,underdeveloped and developed nations for industrial domestic and agricultural purposes [1]. Groundwater is a major source of water supply in Nigeria.The most prominent crisis of the twenty-first century is the shortage of drinkable water. Water resources are becoming more and more polluted, consequently declining water potability [2] . In the past decade,the need to ascertain water quality consumed by humans has turn out to be very intense [3]; [4]. The significance of the quality of water in human health has continually attracted a great deal of interest. In Nigeria, about 80% of all diseases are believed to be unswervingly linked to drinking of poor quality and unhygienic water [5];[6]. A great deal of recent alarm on environmental protection is focused on water because of its significance in maintaining the ecosystem and human health [7]. Potentially health and devastating environmental hazards are caused by poor management of materials from solid waste .Among health hazards that have resulted from the lack of an effective disposal system are periodic epidemic and communicable diseases. Communicable and periodic epidemic diseases are surrounded by health hazards that have resulted from the lack of effective waste disposal system. Groundwater processes in are basically controlled by the chemical and physical reactions that arise amid the groundwater and the aquifer materials [8].These are accountable for the spatial, temporal and seasonal variations chemistry and underground quality accordingly [9]. Water Quality Index (WQI) is a method of ranking that provides the composite influence of entity quality water parameters on the human consumption of overall quality [10] . One of the mainly efficient and effective tools used in 21st century to converse information on water quality for the management and assessment of water resources is Water quality index (WQI) [11] ; [12]. It is an dimension that estimate and expresses overall quality of water at a particular time and location based on the quality water parameters. According to [13];[14] , 2008 ,in recent years Water Quality Index is used to establish the suitability of the underground water for drinking purposes.Based on more than a few parameters of water quality, single number which descibes overall water quality at a definite time and location is provided [15]. It is calculated on the basis of the suitability of water quality for human usages. The aim is to assess water resources in Ogbomoso land with the specific objectives of evaluating the extent of

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contamination using contamination indices and appraising the water quality for domestic and agricultural use.

Study area

The area of study is located in Ogbomosoland Southwestern, Nigeria within the longitude $4^0 4^I$ E - $4^0 24^I$ E to latitudes $8^0 03^I$ N - $8^0 16^I$ N (Figure 1).It is characterised by high relative humidity and high temperature (averaging 28^0).

There are generally two seasons; rainy season regimes between the period of March to October and dry season regimes between April to September. The area of study area is composed predominantly of underlain by Quartz schist, Granite gneiss and Migmatite gneiss.Figure 2)[16].The major supply of water in the study area is majorly by underground water and surface water which are vulnerable to man –made point source through indiscriminately disposal of liquid and solid waste , use of pit latrines. Thereby add up to the incidence of widespread contamination in the studied area [17].

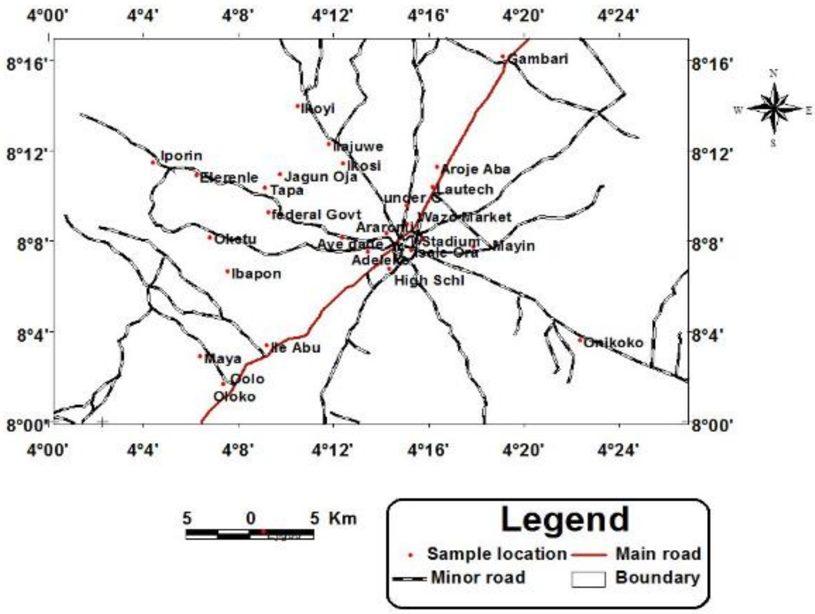

Figure 1: Description of the study area

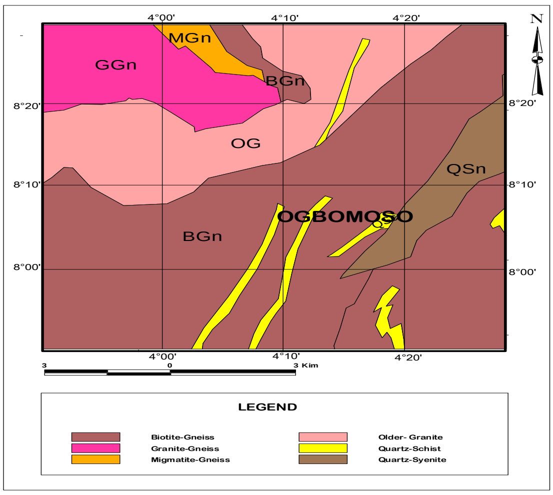

Figure 2: Geological Map of Ogbomoso (modified from [18])

Methodology

Hand-dug wells water samples were taken randomly within Ogbomosoland and analyzed for chemical analysis of major properties. Water samples were collected using a rubber and plastic water bailer and stored in a thoroughly washed polyethylene bottles, sealed and labelled for for the following parameters; pH,EC, TDS, Chloride (Cl^-), Sulphate (SO_4^{2-}), Bicarbonate (HCO_3^-), Zinc (Zn^+), Magnesium (Mg^{2+}), Manganese (Mn^-), Sodium (Na^+), Calcium (Ca^{2+}), Nitrate (NO_3^-),for analysis in the Laboratory. Calcium, Manganese, Sodium, and Magnesium, was determined using Atomic Absorption Spectrometer. The National Sanitation Foundation Water Quality Index, NSF-WQI, generally adopts this in the USA in calculating Water Quality Index. One combined numerical indicator consisting of nine parameters adopted in the development of Water Quality Index equation are pH, Temperature, DO, Fecal Coliforms, turbidity , BOD, No, PO, and Total solids. These parameters were aggregated using the equation below:

WQI = $\sum Wi * qi$ $n = 73$;Where, Wi is the important weight of the ith parameter and qi is the quality of the ith parameter.

Results and Discussion

Hydrogeochemistry

The summary of results of underground water in the studied area are shown in Table 1. The sampled water have pH values ranging between 5.9 - 7.3 which are within the [19] Standard. Conductivity measures the ability of a solution to carry electric current. Its ability is dependent on the presence of ions in solution .The Conductivity values range between 128 mho/cm - 638mho/cm with a mean value 335.97 mho/cm . All studied water samples has electrical conductivity below [19] standard limits of 1000ucm^{-1} except well points at Agric. Settlement and had a corresponding high conductivity of 638 mho /cm.High values of Electrical Conductivity were recorded from well close to septic tank in an Agric Settlement. This agrees with the work of [20]. High conductivity affects taste of water [21].Total Dissolved Solids (TDS) is the major representation of the amount of ions in water quality . In studied samples , TDS value ranged between 50-1930 mg/l with the mean value of 329.3 . High TDS values do pose a health risks. All studied water fell within the allowable limit for TDS of 500mg/l [19] signifying fresh water except the highest TDS value of 1930mg/l recorded in Agric. Settlement . High TDS is ascribed to addition of ions by leaching and weathering of minerals from rocks . Rock weathering contributes to some level of TDS in groundwater. Total hardness ranges between 32.7mg/l - 75.2mg/l making the groundwater to be classified as soft to moderately hard using [22] hardness classification standard. (Table 2).The Potassium values in the studied samples ranged between 4.8 mg/l and 18 mg/l with mean of 11.10mg/l, these values fell within the [19] permissible limit. In most waters, turbidity is due to colloidal and extremely fine dispersions. The turbidity values for Under G, Ibapon, Oketu and Elerenle were 2.5, 2.5, 2.5 and 3 respectively though slightly higher than other sampling points, hardness values varied from 32.67 mg/L to 75.2 mg/L with a mean value of 50.78mg/l. Turbidity and hardness fell within the permissible limit [19].Turbidity can provide shelter for opportunistic microorganisms and pathogens [23]. The prescribed value for total alkalinity by [19] is 50 mg/l. The values for all the investigated samples ranged from 0.2-2.4 with a mean value of 0.89 and were found to be lesser than the value prescribed by [19]. Sodium is derived geologically from decomposition of various minerals. Na concentration ranges between 32mg/l to 66mg/l (Table 1), the concentrations that falls within the acceptable limit of [19] standard . Sodium and Potassium are transported possibly in solution as base exchange of clay minerals. The values of Nitrate in the studied water samples ranges between 0.00mg/l to 76.2mg/l with mean of 39.1mg/l (Table 1). All water samples are within the permissible limit given by [19] except those from Abattoirs, dumpsites that have high nitrate concentration High nitrate concentration in water causes cyanosis in infants under two years old [24];[2];[25] ,also a probable factor in stomach cancer development [2]. Contaminations level will increase with increased industrial growth and probable influence from farm pesticide and fertilizer commonly use by farmers in the area [26];[27].The sulphate values ranges between 0 mg/l and 0.6 mg/l. with mean of 0.05 mg/l. The sulphate values are less than the [19] maximum permissible level. The phosphate content in the studied water was found in the range of 0 mg/l to 2 mg/l and a mean value of 0.02 mg/l the values were found to be within the [19] permissible limit. The concentration of the total iron for the study area ranges from 0.00 – 0.4mg/l (Table 1). It was observed that only areas like Olojo has value of 0.4mg/l; Atenda 0.4 mg/l; 0.3 mg/l in Ayedade; 0.44 mg/l in Aroje-Aba; 0.41mg/l in Orile Igbon are above the permissible level of 0.3mg/l was recommended by [19]. High Iron concentration in water may have been sourced from weathering rock minerals or infiltration of leachates .Iron content in water pose both aesthetics and health problems. The Lead (Pb^{2+}) concentration varies from 0.0 to 0.3mg/l,with mean of 0.01 these values fall within the [19] recommended drinking water standard that has the highest desirable level 0f 200mg/l. Chloride values for all the studied groundwater samples ranged between 2.5 to 12.5 mg/l with a mean of 7.01mg/l. A high value of 250mg/l and maximum permissible level of 100mg/l is being recommended by [19] for drinking water. All studied samples are suitable for drinking and industrial processes with the level of chloride content.

The values of studied groundwater samples were calculated with respect to WQI equation to give water quality index (WQI) data. Table 3. The computed WQI values are usually classified into five categories (Table 4): excellent, good, poor, very poor and unfit for human consumption. The values of WQI for studied underground water samples ranged between 12.01 to 146.43 . All studied underground water samples was considered excellent (WQI value < 50) (Table 5) except 12 sample sites that had poor-quality drinking water (WQI value > 100) and the. Poor quality water in Atenda abbatoir, Otte , Gambari, Arada, Kaara and Sabo was classify as unsuitable for human consumption . Adiatu well point displayed an good water class as WQI less than 50 .

Table 1 The values of Nitrate in the studied water samples ranges between 0.00mg/l to 76.2mg/l with mean of 39.1mg/l

Parameters	Range	Mean	SD	WHO (2011)
PH	5.9-7.3	6.8	6.5	NS
EC	85-638	341.3	134.3	500
TDS	50-1930	329.3	253.6	500
Cl^-	2.5-12.5	6.9	2.29	250
SO_4^{2-}	0-0.6	0.05	0.1	250
Fe^-	0-0.4	0.12	0.09	0.3
NO^{3-}	0-76.2	39.1	0.11	50
HCO_3^-	0-0.2	0.02	0.03	NS
Ca^{2+}	28.7-66.1	45.1	7.24	7.5
Na^+	32-66	50.43	8.95	200
Mg^{2+}	2.8-8	5.55	1.01	20
K^+	4.5-18	10.95	3.11	55
PO_4^{3-}	0-2.0	0.28	0.31	0.1
Mn^-	0-0.2	0.02	0.02	0.1
SiO_2^-	0-0.3	0.01	0.04	NS
Zn^-	0.01-2.0	0.05	0.23	0.5
Cu^-	0-0.4	0.18	0.01	0.5
Pb^-	0-0.03	0.01	0.01	0.1

Table 2: Classification of Water Hardness [22]

Hardness ($Ca+MgCO_3$)mg/l	Water Classification
0-75	Soft
75-150	Moderately hard
150-300	Hard
>300	Very hard

Microbiological Analysis

The results on biochemical test, total viable and total coliform of bacteria isolates are presented in Table 6 in which total viable count ranged between 1.8 X 10^5 - 6.0 x10^5 and total coliform ranged between 7.6×10^5 - 5.0×10^3 respectively. A total of 6 bacteria were isolated from all the samples gotten from the wells in Ogbomoso and its environs . Based on the morphological and cultural characteristics , isolates were selected for microbiological test. The isolates were identified to be *Bacillus Sp., Pseudomonas Sp., Flavobacterium Sp., Enterobacterium Sp., Aeromonas Sp.* and *Proteus sp.* it was clearly evident from the results of total coliform count and total viable count that the studied water samples were highly polluted possibly due to high bacterial contamination level. From the results obtained in this study, it was evidenced that the microbial load and the status of the microorganisms isolated from water samples in Ogbomoso and its environs showed the level of contamination, an indication that the presence of domestic and faecal wastes in any waterbody would make it highly polluted with different species of microorganisms.

Accumulation of microbes inside water meant for human consumption could cause diseases such as cholera, typhoid fever, dysentery, skin diseases, pneumonia, and cutaneous infections. Faecal contamination in water is usually demonstrated by the detection of specific bacteria that are present in very large numbers in the intestines [28]. Also from the results it can be deduced based on the report of [19] that the water from the upstream, mid-stream , downstream and well water were not portable since they were higher than the safe limits of [19]. The water was highly contaminated because it has high coliform count, indicating human faecal materials and other contaminants. Hence it can be deduced that the water is not safe for human consumption and domestic purpose unless given primary, secondary and tertiary treatments.

Table 3: Results of Water Quality Index (WQI) of the Study Area

SAMPLE NO	CODE	WQI	Quality		SAMPLE NO	CODE	WQI	QUALITY
1	IK	32.85	Excellent		38	ID	33.91	Excellent
2	KAR	132.48	Poor		39	OLJ	32.94	Excellent
3	OO	32.94	Excellent		40	RA	12.21	Excellent
4	MY	33.33	Excellent		41	AS	21.67	Excellent
5	UDG	31.58	Excellent		42	AD	12.45	Excellent
6	LAUT	33.80	Excellent		43	AS 2	13.14	Excellent
7	ORI	142.52	Poor		44	ARM	22.45	Excellent
8	ISOR	21.89	Excellent		45	AO	22.12	Excellent
9	OJT	22.36	Excellent		46	KU	21.71	Excellent
10	AR	142.43	Poor		47	SU	32.39	Excellent
11	GAB	32.68	Excellent		48	EYE	33.27	Excellent
12	ON	32.44	Excellent		49	IAD	32.61	Excellent
13	OWD	142.23	Poor		50	IAP	33.42	Excellent
14	HSC	21.76	Excellent		51	AS	34.05	Excellent
15	OO	23.42	Excellent		52	AR	22.20	Excellent
16	IBP	21.19	Excellent		53	IW	22.48	Excellent
17	ST	32.23	Excellent		54	LC	31.53	Excellent
18	AN	31.93	Excellent		55	OD	22.83	Excellent
19	YOA	32.44	Excellent		56	IL	132.89	Poor
20	IKY	32.12	Excellent		57	IK	142.77	Poor
21	FGV	31.65	Excellent		58	AG	23.50	Excellent
22	OO,2	132.23	Poor		59	LA	12.01	Excellent
23	IP1	33.13	Excellent		60	OA	31.22	Excellent
24	JO	33.02	Excellent		61	AT	32.64	Excellent
25	AYD	32.54	Excellent		62	FA	142.38	Poor
26	AD	33.46	Excellent		63	JA	33.02	Excellent
27	OKT	23.52	Excellent		64	NI	143.11	Poor
28	ELE	33.90	Excellent		65	ON	32.19	Excellent
29	ONK	32.21	Excellent		66	AP	33.42	Excellent
30	WAM	33.24	Excellent		67	TE	142.94	Poor
31	OLO	32.23	Excellent		68	TA	32.81	Excellent
32	IB	33.55	Excellent		69	OK	141.09	Poor
33	TA	22.86	Excellent		70	AN	32.88	Excellent
34	EJI	32.39	Excellent		71	OK	31.06	Excellent
35	ILA	31.44	Excellent		72	AD	52.21	Good water
36	MAY	22.75	Excellent		73	OL	146.43	Poor
37	ARM	21.96	Excellent					

Table 4: Summary values of Computed Water Quality Index for the Study Area

Parameters	Ci	Si	Wi	qi	Wiqi
pH	6.8	6.5-8.5	0.13	90.67	12.09
EC	341.3	500	0.002	68.26	0.14
TDS	329.3	500	0.002	65.86	0.13
$SO4_{2-}$	0.05	250	0.004	0.02	0.00
Cl-	6.9	250	0.004	2.76	0.01
Fe-	0.12	0.3	3.33	40	133.33
NO3	0.12	50	0.02	0.24	0.005
HCO_{3-}	0.02	100	0.01	0.02	0.0002
Ca2+	45.1	7.5	0.13	601.33	80.18
Na+	50.43	200	0.005	25.22	0.13
Mg2+	5.55	20	0.05	27.75	1.39
K+	10.95	55	0.02	19.91	0.36
PO43-	0.28	0.1	10	280	2800
Mn-	0.02	0.1	10	20	200
Zn-	0.05	0.5	2	10	20
Cu-	0.18	0.5	2	36	72
Pb-	0.01	0.1	10	10	100

EC- Electrical Conductivity; TDS- Total Dissolved Solid
Value for WQI= 37.72, Over all WQI= 90.67

Table 5: Quality Classification Based on Water Quality Index Values

WQI	Quality	Samples (%)
<50	Excellent	86%
50-100	Good Water	2%
100-200	poor water	12%
200-300	very poor water	0%
>300	unsuitable for drinking	0%

Hydrogeochemical Processes

To ascertain main sources affecting groundwater quality, it is important to Identify the hydrogeochemical processes controlling its chemistry. Quality of Water is determined by reactions between aquifer minerals and groundwater which can be used to understand the origin of the groundwater. To distinguish and understand between the influences of evaporation , precipitation , rock-water interaction, dilution and on chemistry of water, Gibbs plot is employed in this study [29]. The ion exchange chemistry between groundwater and the surrounding environment is a major hydrogeochemical process that affects distribution and occurrence of ions in groundwater and this process can be evaluated using the Chloro-Alkaline Indices (CAI).

Gibb's Plot

The plot of TDS versus [Na^+ / (Na^+ + Cl^-)] and [Cl^-/(Cl^- +HCO_3^-)] were developed by [29] gives a apparent clue of the mechanisms that control the chemistry of groundwater, in view of dilution, precipitation, evaporation and weathering processes. Based on this plot, 92% of the studied samples fell solely on the rock weathering dominance field while the remaining 8% were plotted on the evaporation dominance field (Figure 3 and 4). This evidently showed that weathering is the principal processes that controls the groundwater chemistry. Weathering gives rise to different products such as muscovite,ferromag,quartz and feldspar , and these are made up of clay minerals [30]. Clay minerals are the major natural sources of dominant cations, such as Na, K, Mg, Ca, Fe [31]. Dominant cations are in considerable quantities in the water chemistry data of Ogbomoso and its environs [32].

Ion Exchange

This entails replacement of dominant cations absorbed on the surface of fine-grained materials in aquifers [31]. An important information anticipated by [33] regarding ion exchange reactions between underground water and the aquifer materials is offered by Chloro-alkaline Indices (CAI). This was used to categorize the ion exchange processes controlling the groundwater chemistry.

Ion exchange in underground water and aquifer can be evaluated by chloro-alkaline indices (CAI) using corresponding concentrations of SO_4 , HCO_3 ,Cl^-, Na^+, K^+ and NO (CAI-1 and CAI-2) exchange linking Na and K in the aquifer with Ca and Mg in an underground water will give rise to a negative index indicating ion exchange while the one resulting to positive index indicates reverse ion exchange.

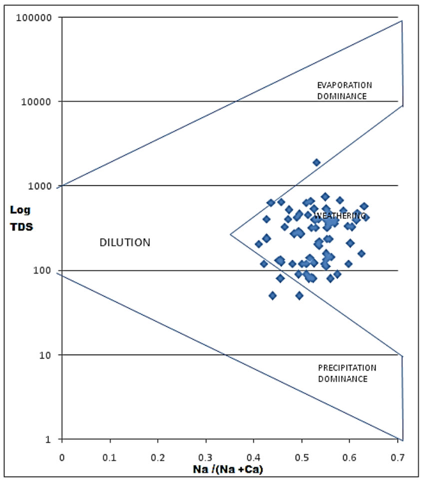

Figure 3: Gibbs Diagram of the Water Sample.

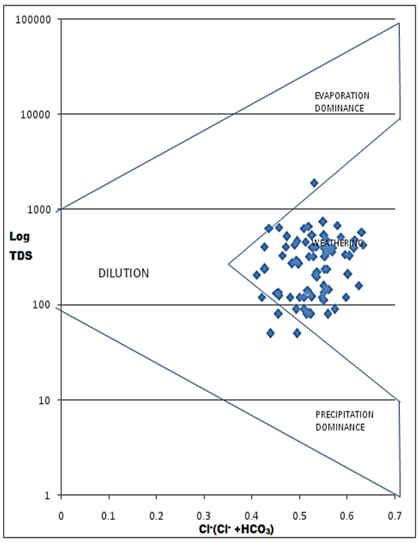

Figure 4: Gibbs Diagram of the Water Sample

The values of chloro-alkaline indices CAI in the studied areas ranges between -26.92 to -5.56 (Figure 5) showing negative indices values . This chloro-alkaline indices CAI results revealed that fact that ion exchange is the dominant hydrogeochemical processes controlling the groundwater chemistry in the study area. This is cause of permeability reduction and deflocculating in the physical properties of soils is as result of Ion exchange reactions [2].

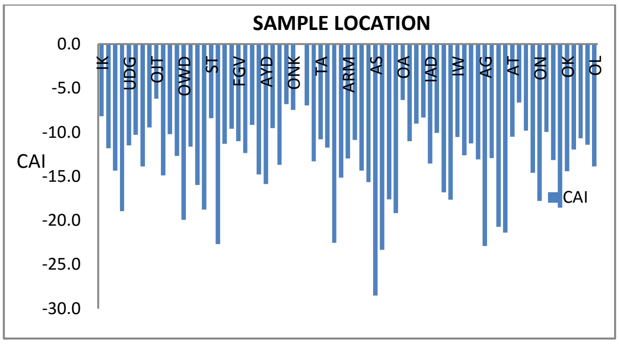

Figure 5: Chloro-Alkaline Index (CAI) Indicating Ion Exchange Process

Evaporation

The plot of Na^+/Cl^- versus EC is used to classify the evaporation process in the chemistry of underground water . Evaporation will raise the concentration of total dissolved solids in groundwater.

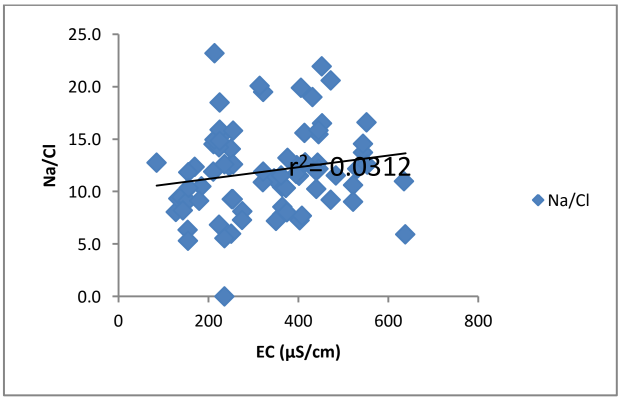

Figure 6: Relation between EC and Na/Cl in the Groundwater

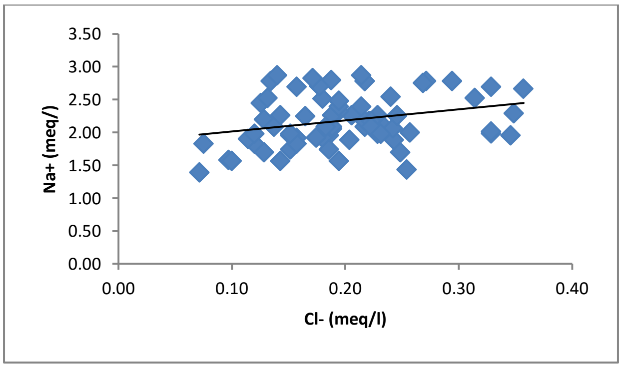

Figure 7: Scatter plot of Na^+ versus Cl^- obtained from the hydrogeochemical data

The scatter plot of EC versus Na/Cl of the groundwater samples in the studied area (Figure 6 and 7) showed that the trend line is inclined indicating a decreasing Na/Cl ratio with the increasing salinity ,the influence of evaporation on 8% of the groundwater chemistry of the studied area cannot be overemphasized. The sampled water collected at shallow depths may be due to Cl enrichment in some part of the study area. As Cl enrichment can be attributed to anthropogenic sources such as leachate from solid waste disposal and irrigation inflows.

Conclusion

Quality status of some groundwaters were investigated with an objective to classify the processes affecting the groundwater chemistry in Basement Complex Terrain of Southwestern, Nigeria. pH values revealed slightly acidic to slightly basic in the studied groundwater . 90% of the studied water fall in permissible limits except for some parameters such as the pH, TDS and Fe in some locations. The WQI results show that all the studied underground samples fall in the 'good' to 'excellent' water category indicating that its suitability except 12 water samples that fall in 'poor' category indicating that the water is unsuitable for human consumption unless treated.It was evidenced that the microbial load and the status of the microorganisms isolated from water samples in Ogbomoso and its environs showed the level of contamination, an indication that the presence of domestic and faecal wastes in any waterbody would make it highly polluted with different species of microorganisms.The anthropogenic factors comprise of indiscriminate disposal of solid and abattoir wastes, application of phosphate fertilizers which will further declines in groundwater quality .The geogenic factors are dissolution of minerals and ion exchange processes. Gibbs plots identified rock–water interaction as an important hydrochemical processes in the study area. Silicate weathering and dissolution of carbonate minerals were pointed as an other vital processes that influence the chemistry of studied water samples. Some studied water is unsuitable for human consumption and should be treated before usage ,Hence,underground water should be constructed with non-corrosive materials.

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