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HYDROGEOCHEMISTRY AND QUALITY ASSESSMENT OF SHALLOW GROUNDWATER IN THE COASTAL AREA OF IGBOKODA, SOUTHWESTERN NIGERIA

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ABSTRACT

Hydrogeochemistry and quality assessment of shallow groundwater was carried out at Igbokoda coastal area, Southwestern Nigeria to ascertain its potability and suitability for agriculture. Twenty groundwater samples collected from the area were analyzed for cations and anions employing the Buck Scientific Model 210VGP Atomic Absorption Spectrophotometer and colorimetric method respectively. Temp (°C), pH and EC (µS.cm) were measured in-situ using multiparameter portable meter. Sodium absorption ratio, residual sodium bi-carbonate, permeability index, magnesium absorption ratio and Kelly ratio were estimated from the chemical data. Piper diagram, Principal component and correlation analyses were employed to reveal the hydrogeochemical characteristics of the shallow groundwater. The abundance of the major ions was; $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ and $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$. The major hydrochemical facieses were Na-Cl, Ca-Cl and mixed Ca–Mg–Cl types while precipitation and rock-water interaction constitute the major processes controlling the groundwater chemistry. All ionic concentrations were within approved standards for drinking water. However, 85% of the groundwater samples tested positive to e-coli counts. Evaluated irrigation parameters showed that the groundwater has a low to medium salinity hazard, low alkalinity hazard, magnesium absorption ratio, sodicity and Kelly ratio. This study revealed a non potable groundwater system that is suitable for agriculture.

Keywords: potability, irrigation quality, hydrochemical facieses, piper diagram, e-coli counts.

1. INTRODUCTION

Igbokoda is strategically located. It is the head quarter of the oil rich Ilaje local government and the gateway to other towns in the area. Igbokoda is famous as the hub of economic and commercial activities within Ondo State and beyond because it has the largest fish terminals in Nigeria in addition to oil palm production, alcohol distillery and palm wine tapping industries. The town is fluxed with migrants due to ongoing exploration for oil in the local government area. Igbokoda coastal zone is within the eastern part of Dahomey sedimentary basin and is endowed with abundant important raw materials including the high quality silica sand that is used in glass sheet production, crude oil that constitute the main source of revenue for Nigeria as well as large deposit of untapped bitumen. People in this area depend mainly on groundwater for drinking, agriculture and industrial uses. Groundwater is essential for continuity of life on earth and its occurrence is a function of different factors including geology, relief, type and amount of vegetative ground cover, seawater intrusion, anthropogenic activities and most importantly in recent time climate change [1]. In addition, the variation in the chemical composition of groundwater in coastal region depends on the nature of the hydrogeology, hydrometeorology, topography, drainage and other artificial conditions [2]. Climate change in combination with increased anthropogenic activities will affect coastal groundwater systems throughout the world [3].

Groundwater constitutes a portion of the hydrologic cycle. In the natural hydrologic cycle, human activities have induced many negative effects on the quality of groundwater resulting into artificial degradation of natural groundwater quality which can impair the use of water and create hazards to public health. The intensive use of natural resources and the large production of wastes in the study area often pose a threat to groundwater quality and could result into groundwater contamination. Igbokoda is densely populated because it has over the past decades, witnessed an unprecedented increase in the rate of development. Throughout the area, there are many human activities that have the potential to discharge pollutants into the environment which can then infiltrate into the groundwater resources. Indeed, groundwater withdrawal in the coastal area of Igbokoda beyond its renewable capability is not negotiable. The extensive exploitation of groundwater results in groundwater storage depletion, lowering of the water-table (drawdown), seawater intrusion and associated freshwater problems in the coastal region [4, 5]. Humans and plants existence and sustainability/continuity depend on water that has sufficient quality to serve as drinking water (potable water), an essential ingredient for good health and the socio-economic development of man [6]. Over large parts of the world, humans have inadequate access to potable water and use sources contaminated with disease vector, pathogens or unacceptable levels of toxins or suspended solids [7]. Such water is not wholesome and drinking or using such water in food preparation leads to widespread acute and chronic illness and constitute a major cause of death and misery in many countries [8].

Hence, this study examined the Hydrogeochemistry and groundwater quality of the coastal area of Igbokoda with a view to identify the mechanisms responsible for the chemical compositions of the shallow groundwater and to document water quality with respect to agricultural and approved drinking water standards.

2. LOCATION OF THE STUDY AREA

Igbokoda town extends from latitude 6˚ 20′ N to 6˚24′ N and longitude 4˚45′E to 4˚48′E (Figure-1) [9]. The town comprises of many quarters. It is about 24 km from the coast of Atlantic Ocean. The town is accessible through the existing road network that links it with the neighboring towns (Okitipupa, Aboto, Mahin, Igbo Nla etc). History revealed that the people of Igbokoda are Ilajes who in the course of searching for dry land to promote their economic activities and make contact with the people of upland areas, settled in the present Igbokoda town. The town is strategically located as a gateway to other towns in the riverine area apart from a modern market located within the town that serves as economic nerves to Ondo State, Nigeria [10]. Igbokoda is located on lowland area with elevation of <15m above sea level. The climate is of low land tropical rain forest type with mean monthly temperature of 27˚C and average annual rainfall that exceeds 2000mm. The study area is part of the sedimentary basin of Ondo state, Nigeria. The sedimentary basin of Ondo State is underlain by the Quaternary coastal alluvium, the coastal plain sands (Benin Formation), the Imo Shale, Upper coal measures and Nkporo shale. The Nkporo Shale is made up of shale, sandy clay and lenses of sand. The Upper coal measures consist of clay/sandy clay, sand, limestone and shale. The Imo shale group is composed of shale while the coastal plain sand has alternations of clay/sandy clay and clayey sand/sand. The Quarternary coastal alluvium is composed of an alternating sequence of sand and silt/clay [11].

2.1. Geology and hydrology of study area

The area is covered mainly by Quaternary alluvium deposits underlain virtually in all places by the Quaternary coastal plain sands (Figure-1). The coastal plain sands constitute the major shallow hydrogeological units and adequate annual recharge is guaranteed considering the high annual rainfall and other favourable climatic conditions. Within the coastal alluvium and coastal plain sands, the aquifer units identified are predominantly sands with high porosity and permeability. The aquifer system is a multi-storey type. Maximum of four aquifer units have been delineated within the coastal alluvium/coastal plain sands. The depths to top and aquifer thicknesses are 5 - 23 m (7 - 26 m); 7 - 80 m (6 - 67 m); 63 - 188 m (20 - 143 m) and 245 - 261 m (61 - 117 m) for the first, second, third and fourth aquifer units respectively. Based on the aforementioned, the groundwater potential of the Coastal Alluvium/Coastal Plain Sands can be rated high. The Imo Shale Group contains thick layers of porous but impermeable shale thus making the groundwater yielding capacity to be of a very low rating. However, limited groundwater yield could be obtained from lenses of sand/sandstone within the shale. Within the Upper Coal Measures, lenses of sand, dissolved or fractured limestone constitute the aquifer units. Limited groundwater yield is expected from the lenses of sand. Groundwater potential is also adjudged low. The Nkporo Shale has lenses of sand as its aquifer unit. Within the Nkporo Shale, thin layers of sand constitute the aquifer units with consequently low groundwater potential [12].

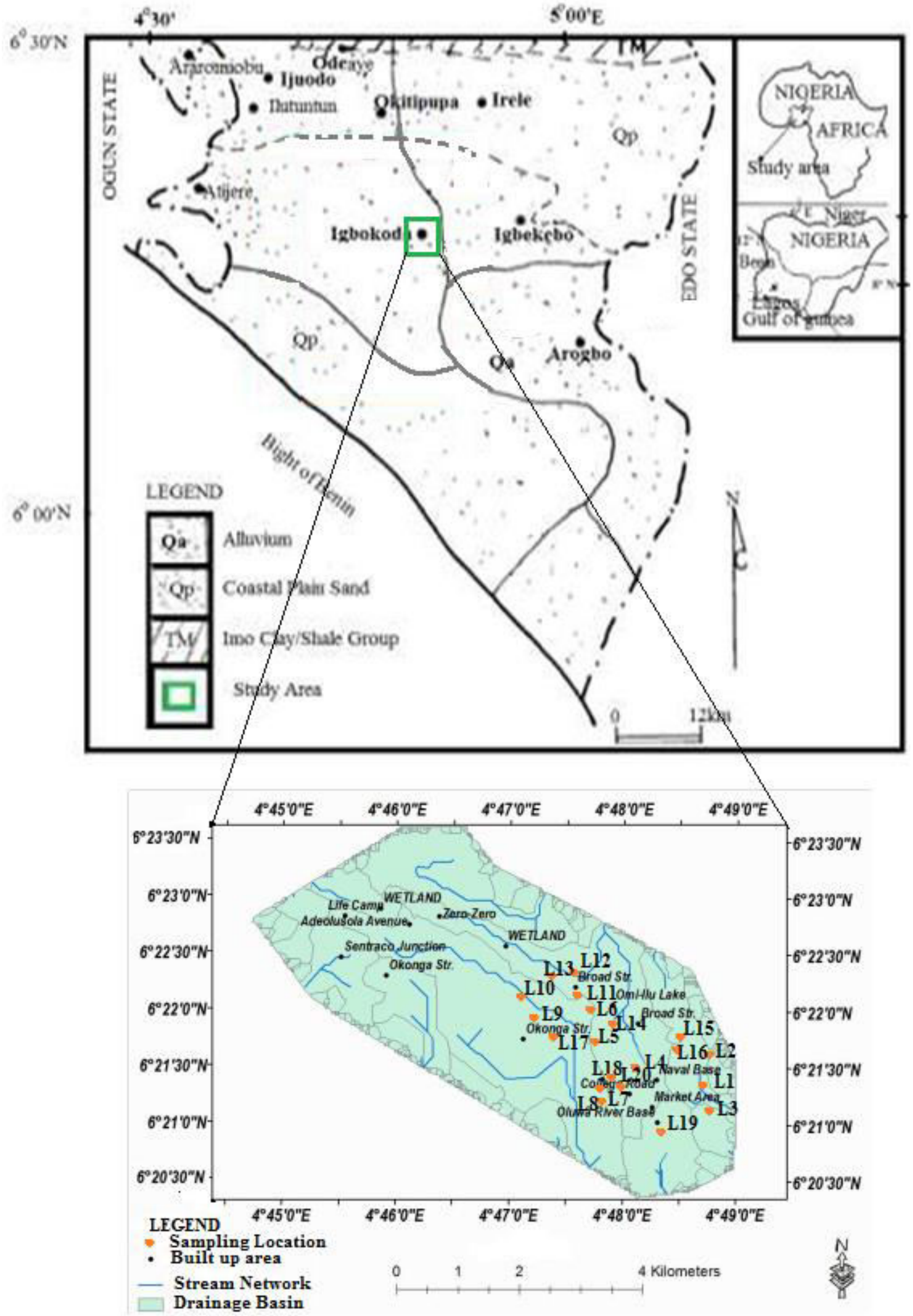

Figure-1. Location and geology map of study area (modified after Talabi *et al.*, 2012).

3. MATERIALS AND METHODS

Groundwater samples were collected from 20 shallow water wells distributed over the study area in March, 2017 (Figure-1). The samples were collected into new pre cleansed dry-washed polyethylene bottles that were rinsed three times with the water sample before filling it to capacity and then labeled accordingly. The samples were stored at a temperature below 4°C at the Ace Microlab Services Limited, Ibadan Nigeria prior to analysis. For collection, preservation and analyses of the samples, the standard method [13] was adopted. In-situ parameters (Temp. (°C), EC (μS/cm) and pH of water samples were measured in the field immediately after the collection of the samples using multiparameter portable meter (Testr^{Tm} 35 series). Field measurements of EC (µS/cm) reflect the amount of total dissolved solids (TDS (mg/L)) in natural water with an approximate relationship given by an equation; TDS (mg/L) ≈ 0.67× EC (µS/cm) [14]. This relationship was adopted in this research to estimate TDS. Total Hardness (TH) was also estimated employing; TH = $2.5Ca^{2+} + 4.1Mg^{2+}$ [15]. Cation concentrations were measured by the Buck Scientific Model 210VGP Atomic Absorption Spectrophotometer (AAS) while the anions were analyzed using colorimetric method.

The irrigation quality assessment was carried out using the following under listed estimated irrigation indices in which all ionic concentrations are in millequivalent per litre:

a) Sodium Absorption Ratio (SAR) $SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$ [16] (1)

b) Residual Sodium Bicarbonate (RSBC) = $HCO_3 - Ca$ [17] (2)

c) Permeability Index (PI) = $\frac{Na + \sqrt{HCO3} \times 100}{Ca + Mg + Na}$ [18] (3)

d) Magnesium Absorption Ratio (MAR) = $\frac{Mg*100}{Ca + Mg}$ [19] (4)

e) Kelly Ratio (KR) = $\frac{Na}{Ca + Mg}$ [20] (5)

f) Sodium Percentage (%Na) = $\frac{Na + K}{Ca + Mg + Na + K}$ [19] (6)

As part of data evaluation, chemical values were compared with [21] and [22] standards while statistical analysis was carried out using the Microsoft Excel 2007 version. Graphical plots (Gibb's plot, Piper and Schoeler diagrams) were employed to unravel the hydrochemical characteristics and evolution of the groundwater. The Piper diagram was plotted employing concentration values for three cations (calcium, magnesium and alkali metals- sodium and potassium) and three anions (bicarbonate, chloride and sulfate) relative to one another. These ions are generally the most common constituents in unpolluted groundwater.

4. RESULTS

4.1. Groundwater chemistry

Water is a highly reactive substance having a great capacity to dissolve solids, liquids and gases. Physical and chemical characteristics of natural waters depend on several factors such as the lithology of the geological strata in which groundwater is flowing (i.e. the aquifer), time of residence of water in the aquifer, and environmental conditions [23]. The results of the physical and chemical parameters evaluated in respect of shallow wells water in Igbokoda coastal area are presented along with the [21] and [22] standards in Tables 1 and 2 respectively. Results (Table 1) revealed that pH ranged from 6.9 - 8.2 (av. 7.72), EC (µS/cm) from 32 – 719 (av. 307.5), TDS from 24 - 539.25 (av. 230.63) and TH (mg/L) from 4.4 - 171.24 (av. 77.29). pH is a measure of the acidity or alkalinity of groundwater. Groundwater with pH 7 has equal numbers of hydrogen (H^+) and hydronium (OH^-) ions and is termed neutral. Generally, acidic groundwater is corrosive in nature while alkaline groundwater tends to be incrusting. Either of the situations requires treatment before consumption by humans. pH controls many of the chemical reactions involving groundwater including the amount of dissolved CO_2, carbonate and bicarbonate and is a very important indicator of its quality [24].The pH values in this research signified neutral to alkaline water and are within [21] and [22] approved standards (6.5 - 8.5) for drinking water with neither corrosion nor incrustation. The abundance of the major ions in the groundwater of the study area was in the following order: $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ and $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$ (Table 2). Sodium, calcium and potasium were dominant cations which vary between 0.47 and 57.36 mg/ L, 3.01 and 75.53 and 0.93 and 35.34mg/ L respectively. Magnesium concentration was generally low ranging between 0.72 and 10.57mg/L. The concentrations of major cations such as Na^+, Ca^{2+}, K^+ and Mg^{2+} in Igbokoda groundwater were far below the recommended maximum concentrations of 200, 75, 20 and 50 mg/ L, respectively[21, 22]. Following similar trend, the major anions have low concentrations that were within the approved standards. However, as indicated in Table-1, only 3 groundwater samples (15%) satisfied the recommended value (0cfu/100ml) for e-coli count. In addition, visual observation during field operations revealed that most of the groundwater had green to light yellowish coloration. Thus the water in the study area is not potable and must be treated before consumption.

4.2. Water hardness

Hard water results from high levels of calcium and magnesium. Hard water makes it difficult for domestic water users to form lather when washing and can cause the build up of scale in boilers when it evaporates.

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Table-1. Physical parameters and coliform counts of shallow groundwater at Igbokoda.

Code	Northing	Easting	Temp.	pH	EC (µS/cm)	TDS (mg/L)	TH	E-coli (cfu/100ml)
IGB - 1	6° 21′ 7″	4° 48′ 21″	30.6	8.2	480	321.6	131.15	0
IGB - 2	6° 21′ 8.6″	4° 48′ 20.6″	30.8	7.8	646	432.82	171.24	4
IGB – 3	6° 21′ 02.3″	4° 48′ 2.9″	32.4	8.2	32	21.44	4.74	20
IGB - 4	6° 21′ 31.3″	4° 48′ 8″	31.6	7.6	299	200.33	53.98	6
IGB - 5	6° 21′ 38.9″	4° 47′ 48″	30.7	7.5	103	69.01	27.84	4
IGB - 6	6° 21′ 52.9″	4° 47′ 23.2″	29.7	7.6	263	176.21	64.86	2
IGB- 7	6° 21′ 23″	4° 48′ 1.1″	31	8	510	341.7	140.77	10
IGB - 8	6° 21′ 26.2″	4° 47′ 42.5″	30.5	7.8	263	176.21	62.93	0
IGB - 9	6° 21′ 48.4″	4° 47′ 0.5″	30.3	7.8	450	301.5	162.63	6
IGB - 10	6° 22′ 21″	4° 47′ 13.3″	29.9	6.9	88	58.96	9.23	8
IGB - 11	6° 22′ 13.1″	4° 47′ 31.7″	30.5	8	237	158.79	92.93	4
IGB - 12	6° 22′ 14.6″	4° 47′ 32″	30.4	8	520	348.4	130.02	0
IGB - 13	6° 22′ 31.1″	4° 47′ 10.2″	30.6	7.7	144	96.48	8.77	10
IGB - 14	6° 21′ 56″	4° 48′ 2.9″	29.7	7.5	235	157.45	62.83	8
IGB - 15	6° 21′ 27.9″	4° 48′ 18.7″	30	7.3	37	24.79	7.41	6
IGB - 16	6° 21′ 18.3″	4° 48′ 12.3″	29.6	7.1	209	140.03	26.05	0
IGB - 17	6° 21′20.4″	4°47′ 29.9″	29.7	7.4	32	21.44	4.44	4
IGB - 18	6° 21′ 16″	4° 47′ 41.8″	28	7.7	719	481.73	147.85	6
IGB - 19	6° 21′ 10.2″	4° 48′ 11.5″	28.9	8.2	477	319.59	133.73	7
IGB - 20	6° 21′ 19.4″	4° 47′ 56.6″	29.3	8	406	272.02	102.36	5
Min			28	6.9	32	21.44	4.44	0
Max			32.4	8.2	719	481.73	171.24	10
Mean			30.21	7.72	307.5	206.03	77.29	5.5
Stdev			0.95	0.36	208.28	139.55	58.86	4.64
WHO (2011)			-	6.5-8.5	1500	1000	500	0
SON (2007)			-	6.5-8.5	1000	500	150	0

Hardness is defined as the concentration of calcium and magnesium in water expressed as the equivalent of calcium carbonate ($CaCO_3$). General guidelines for classification of waters hardness are: 0 to 60 mg/L as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard [25]. Eight (40%) out of the twenty groundwater samples fell into the soft water category, five (25%) in moderate category while remaining 7 samples (35%) were in the hard group. The hardness is consequent of the geology of the study area as well as the erosion characteristics that contributed to Ca and Mg contents of the groundwater. Hardness of the water is objectionable from the viewpoint of water use.

4.3. Correlation of Igbokoda shallow groundwater parameters

The correlation (Table-3) revealed that the major cations contributed to the increased TDS as they are positively correlated with the TDS (r>0.8) while only Cl^- has appreciable correlation with TDS as regards major anion (r>0.7). All the ions were negatively correlated with NO_3^- while SO_4^{2-} and PO_4^- were equally negatively correlated with HCO_3^-. The trends observed in the correlation analysis revealed geogenic source for the cations and Cl^- anions.

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Table-2. Chemical parameters of shallow groundwater of Igbokoda coastal area.

Code	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)
IGB - 1	44.52	4.76	39.75	26.04	1.98	6.88	0.42	0.00	1.08
IGB - 2	57.36	6.68	51.75	34.41	0.43	8.73	26.58	2.37	6.21
IGB – 3	0.69	0.72	4.50	1.86	0.36	0.86	0.15	4.11	4.18
IGB - 4	18.42	1.90	31.50	12.09	1.95	5.63	0.77	0.00	3.23
IGB - 5	9.51	0.98	3.01	1.86	1.63	1.97	0.99	0.00	1.67
IGB - 6	21.74	2.52	20.25	7.44	0.81	7.43	1.95	0.81	5.62
IGB- 7	46.98	5.60	46.50	22.32	1.45	10.76	1.34	0.00	0.84
IGB - 8	21.32	2.31	25.50	9.30	1.74	6.89	0.92	0.00	1.67
IGB - 9	54.23	6.49	34.50	16.74	1.79	19.14	1.61	0.00	4.06
IGB - 10	2.14	0.93	7.50	6.51	nil	1.26	0.73	2.06	3.11
IGB - 11	31.62	3.33	6.75	8.37	1.18	11.28	2.03	0.00	5.85
IGB - 12	44.47	4.52	29.25	16.74	1.44	15.11	1.68	0.00	3.23
IGB - 13	2.07	0.86	12.11	8.37	nil	3.97	1.45	1.74	4.78
IGB - 14	22.13	1.80	17.25	11.16	1.86	8.02	0.65	0.00	4.66
IGB - 15	0.85	1.27	3.01	1.86	0.29	0.49	0.50	0.94	3.11
IGB - 16	2.11	4.99	24.14	16.74	nil	10.14	3.33	3.72	4.90
IGB - 17	0.470	0.78	4.50	0.93	nil	0.74	0.69	2.15	2.27
IGB - 18	41.52	10.57	75.53	17.67	1.36	16.51	0.77	0.00	4.78
IGB - 19	44.78	5.23	32.85	35.34	1.41	10.92	1.11	0.00	3.94
IGB - 20	35.86	3.05	32.31	21.39	1.82	12.18	1.53	0.00	3.58
Min	0.47	0.72	3.01	0.93	0.29	0.49	0.15	0.00	0.84
Max	57.36	10.57	75.53	35.34	1.98	19.14	26.58	4.11	6.21
Mean	25.14	3.47	25.12	13.86	1.34	7.94	2.46	0.90	3.64
Stdev	20.04	2.61	19.07	10.23	0.57	5.44	5.72	1.33	1.56
WHO-2011	200	150	200	200	600	600	600	50	-
SON-2007	-	0.2	200	-	-	250	100	50	

However, SO_4^{2-} and PO_4^- have mainly anthropogenic source since most sources of NO_3^- in groundwater have been attributed to anthropogenic activities [26]. Correlation of Ca^{2+} and Mg^{2+} with TH are high (r>0.9) since hardness is an approximate measure of Ca^{2+} and Mg^{2+} as $CaHCO_3$ equivalent in water. The sources of ions in the groundwater of Igbokoda coastal area was further substantiated by Gibb's plot [27], which revealed precipitation and weathering of rocks as the main source of ions in the groundwater of the area (Figure-2). Erosion has been prominent in the area in view of the increased built up areas and anthropogenic activities [27]. In order to establish the source of Ca^{2+} and Mg^{2+} in the groundwater of the area, scatter diagram of Ca^{2+}/Mg^{2+} was plotted (Figure-3). The ratio of Ca^{2+}/Mg^{2+} has been employed to establish the sources of Ca^{2+} and Mg^{2+} ions in groundwater [28]. Ratio (r) of Ca^{2+}/Mg^{2+} = 1 signifies dissolution of dolomite and when r>2, reflects contribution of Ca^{2+} and Mg^{2+} from the weathering of silicate minerals of the parent rocks [29]. Fourteen samples (70%) fell into the category of r>2, 2 samples (10%) had 1< r <2 while 4 samples (20%) had r <1 (Figure-3). This observation showed that very few samples fell below 1 (r<1), indicating low ion exchange process as source of ions to the groundwater of the area. However, as earlier shown by Gibbs plot, rock- water interactions (effects of silicate minerals weathering) was dominant as source of Ca^{2+} and Mg^{2+} in the groundwater with majority of samples having r>2.

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Table-3. Correlation analysis of major ions from Igbokoda groundwater.

Parameters	TDS	TH	Ca	Mg	Na	K	HCO3	Cl	SO4	NO3	PO4
TDS	1.000	-	-	-	-	-	-	-	-	-	-
TH	0.936	1.000	-	-	-	-	-	-	-	-	-
Ca	0.903	0.979	1.000	-	-	-	-	-	-	-	-
Mg	0.879	0.913	0.859	1.000	-	-	-	-	-	-	-
Na	0.925	0.871	0.831	0.856	1.000	-	-	-	-	-	-
K	0.876	0.837	0.845	0.846	0.914	1.000	-	-	-	-	-
HCO3	0.498	0.498	0.542	0.306	0.444	0.448	1.000	-	-	-	-
Cl	0.772	0.817	0.776	0.823	0.693	0.705	0.372	1.000	-	-	-
SO4	0.400	0.454	0.424	0.522	0.297	0.357	-0.131	0.606	1.000	-	-
NO3	-0.541	-0.547	-0.563	-0.384	-0.384	-0.401	-0.829	-0.537	-0.010	1.000	-
PO4	0.095	0.151	0.086	0.233	0.075	0.100	-0.335	0.346	0.542	0.323	1.000

4.4. Principal Component Analysis (PCA)

Principal Component Analysis is a means by which the regularity and order in phenomena can be discerned. Measurements and qualitative observations are resolved into distinct patterns of occurrence. In this study, the total variance explained by each PC and the loading matrix of PCs are presented in Table-4. Three PCs with eigen values greater than 1 were extracted, accounting for 99.79 % of the total variance (Table-4).

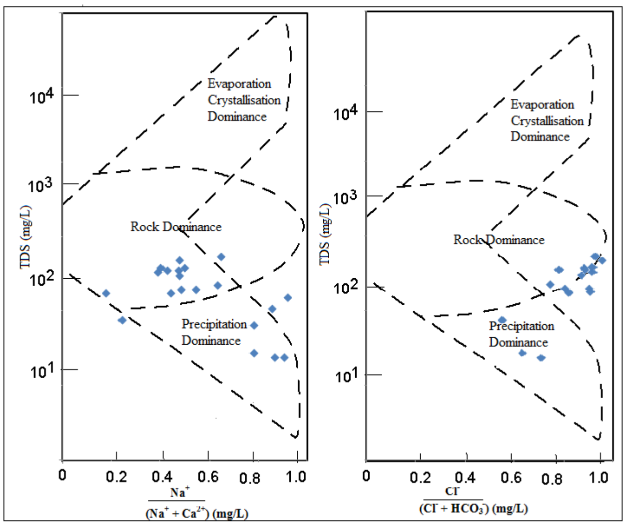

Figure-2. Gibb's plot.

The first two PCs explain 97.90 and 1.68 % of the variance respectively. PC1 accounts for most of the variance in the original dataset. Principal component three (PC3) explains only 0.18 % of the total variance. PC1 has significant loadings by TDS, TH, Ca and Na, which suggests that PC1 represents the dissolution/precipitation processes of alumino-silicate minerals. Ca and Na are the major ions constituting important components of TDS and TH in this research. PC2 has positive loadings TH and Ca and a negative loading by TDS and Na representing cation exchange between Na and Ca.

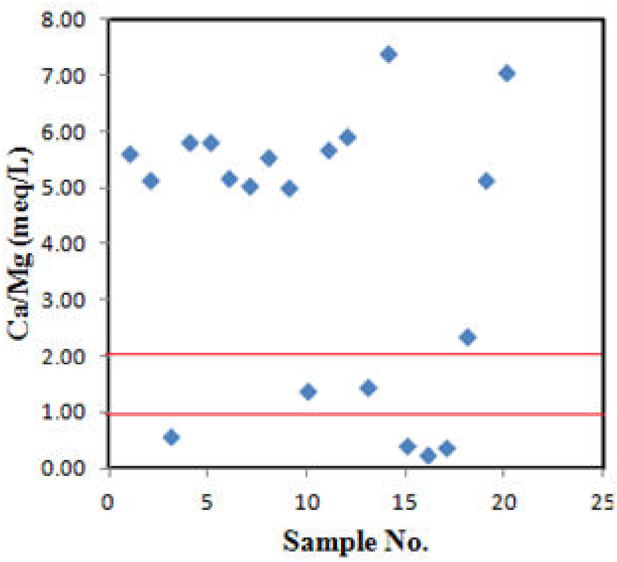

Figure-3. Major ion relationship: Scatter diagram of Ca^{2+}/Mg^{2+}.

PC3 has positive loadings of K and SO_4 with negative loadings of TH, Na and Cl represents the dissolution of halite and orthoclase/ other K and SO_4 rich minerals because it has a strong loading by K and SO_4. PCA revealed that water-rock interactions were the main factor influencing the major ion concentrations in the area as earlier indicated by Gibb's plot.

Table-4. Total variance explained by each PC and the loading matrix of PCs.

Parameters	PC 1	Components PC 2	PC 3	Communialities
TDS	0.911	-0.348	-	0.95
TH	0.369	0.822	-0.101	0.82
Ca	0.122	0.351	-	0.14
Mg	-	-	-	-
Na	0.116	-0.276	-0.218	0.14
K	-	-	0.697	0.49
HCO3	-	-	-	-
Cl	-	-	-0.250	0.06
SO4	-	-	0.613	0.38
NO3	-	-	-	-
PO4	-	-	-	-
Variance (%)	97.90	1.68	0.18	
CVariance (%)	97.90	99.58	99.79	
Range of assigned factor	0.116 - +0.911	-0.351 - +0.822	0.250 - +0.697	
Loading extracted factor	97.90 – 97.90	1.68 – 99.58	0.18 – 99.79	
Controlling variable	TDS, TH, Ca and Na	TDS, TH, Ca and Na	TH, Na, K, Cl and SO4	

4.5. Geochemical classification

The geochemical classification was carried out employing Schoeller diagram and Trilinear plotting systems [30]. Variations of the chemical parameters concentrations (SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+) and the ratio among them are represented by Schoeller diagram in fig.4. [31, 32]. The Schoeller diagram indicated Cl^- as the more dominant anion while NO_3^- was least. As for the cations, Na^+ was dominant while Mg^{2+} was least. Furthermore, the dispersion of ions was represented using Piper diagram (Figure-5). The fundamental interpretations of the chemical nature of water samples in the Piper diagram are based on the location of the sample ion values. Determining the nature and distribution of hydrochemical facies can provide insight into how groundwater quality changes within and between aquifers. The Piper Trilinear diagram has been applied by several Researchers to understand the hydrogeochemical processes [33, 34, 35 36].

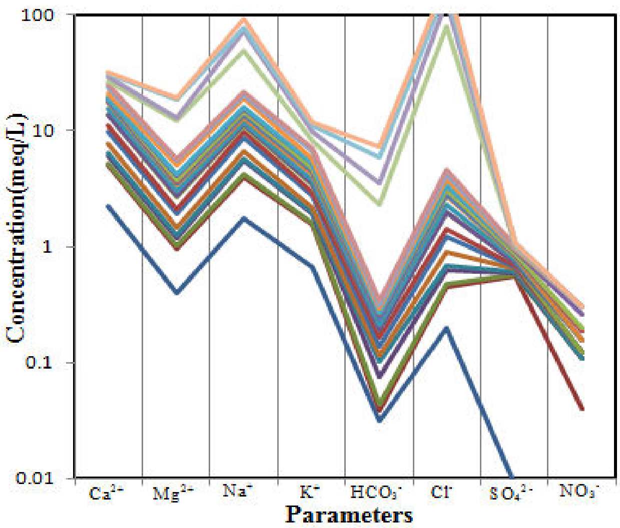

Figure-4. Schoeller diagram.

Distinct zones within aquifers having defined water chemistry properties are referred to as hydrochemical facies [37]. In this study, largest anion dispersion was represented by Cl^- concentration while the Na^+ concentration had the largest cation dispersion. The dominant water type was Na-Cl water representing 50% of the groundwater samples while Ca-Cl and mixed Ca-Mg-Cl water types had 30% and 20% representations respectively. The hydrochemical facies signified that the hydrochemistry of the groundwater samples was characterized by alkali metals which exceeded alkaline

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earths [38]. The dominant water types are in the order of NaCl >CaCl>mixed CaMgCl suggesting the mixing of high salinity water caused from surface contamination sources, domestic wastewater and septic tank effluents with existing water followed by ion exchange reactions [39].

4.6. Irrigation quality assessment

All waters used for irrigation contain varying amount of salts. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. The suitability of the water can be assessed using total salt content (salinity), pH, sodicity (SAR), Kelly Ratio (KR), Magnesium absorption ratio (MAR) and Permeability index (PI) amongst others. pH is a term used universally to express the intensity of the acid or alkaline condition of a solution.

The pH values of the groundwater samples from the study area ranged between 6.9 and 8.2 (av. 7.72) (Table-1). All the water samples fell in the safe limit of pH standard (6-8.5) for irrigation purpose [40]. Electrical Conductivity (EC) reflects to a greater extent, the total salt content of irrigation water. EC in this study ranged from 32-719(μS/cm). Twelve (60%) of the groundwater samples had EC<250(μS/cm) and fell into low salinity zone while the remaining 8 samples (40%) with $250 \geq EC \leq 750$ (μS/cm) were in the class of medium salinity zone [41]. The groundwater posts no risk to irrigation based on EC concentrations. The Sodicity (sodium or alkali hazard limit for irrigation) is determined by the sodium absorption ratio (SAR) which represents the absolute and relative concentration of cations in the irrigation water.

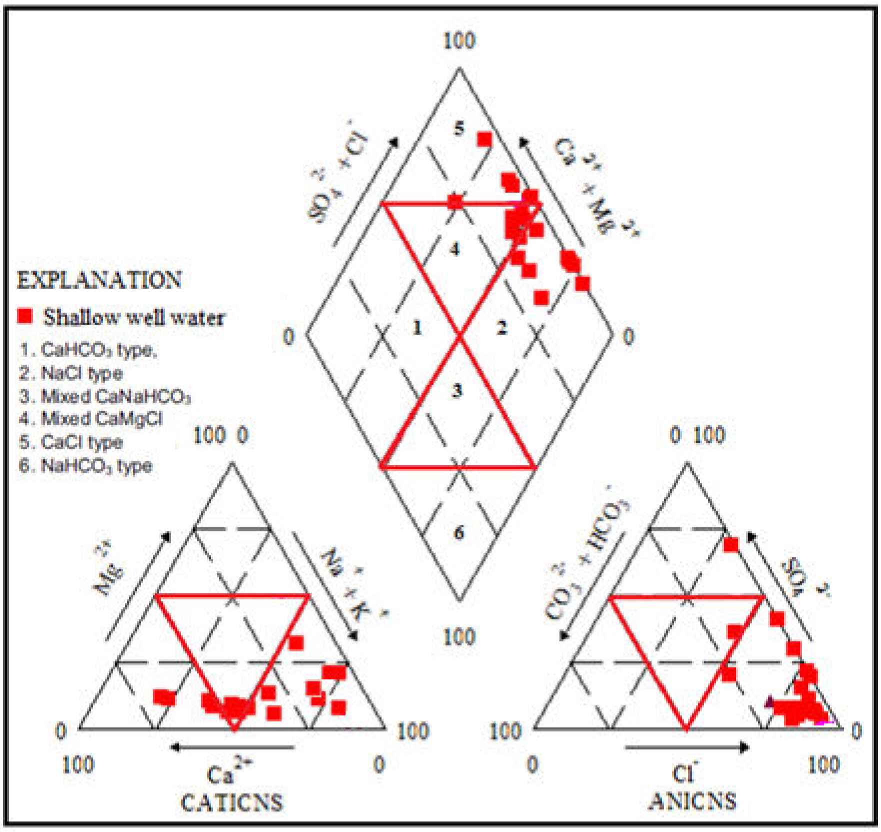

Figure-5. Piper trilinear diagram.

There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If groundwater used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles [42]. Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. Calculated SAR in this research ranged from 0.25 - 2.7 (Table-5).

A very low SAR (less than 2) indicates no danger from sodium, low SAR (2 to 10) indicates little danger from sodium; medium hazards are indicated between 10 and 18; high hazards from 18 to 26 and very high hazards more than that [42]. Eighteen (90%) out of the 20 groundwater samples had SAR<2 signifying no danger from sodium while the remaining 2 samples (10%) were in the low SAR category. The groundwater is suitable for irrigation based on calculated SAR.

Another method for determination of groundwater suitability for agricultural use is by calculating Na^+ percentage [43], because Na^+ concentration reacts with soil to reduce its permeability [44]. The calculated sodium percentage varied from 21.47

- 80.88 (Table-5). The maximum recommended sodium percentage for irrigation water is 60 [20]. Fourteen (70%) out of the 20 groundwater samples had %Na<60 while the remaining 6 samples (30%) had values slightly above 60. Thus the groundwater in the study area is good for irrigation purpose. Plot of Sodium percentage and electrical conductivity [43], for classification of groundwater for irrigation uses (Figure-6) also confirmed that Igbokoda groundwater is good for irrigation as all the groundwater samples fell into excellent to good irrigation class.

Magnesium absorption ratio represents the excess of magnesium over calcium whereas calcium and magnesium maintain a state of equilibrium in most waters [18]. Excess of Mg in water affects the quality of soil which invariably results into poor crops yield. From Table-4, it is seen that the magnesium ratio varied from 11.94 to 79.76 with an average value of 29.81. In this study, most of the groundwater samples (80%) have Magnesium absorption ratio <50% approved standard for irrigation water [45] which confirmed the suitability of Igbokoda groundwater water for irrigation as the few samples with MAR>50% might be consequent of localized anthropogenic contamination.

Table-5. Irrigation parameters of Igbokoda coastal groundwater.

Location	SAR	RSBC	KR	MAR	PI	%Na
IGB - 1	1.51	-2.19	0.66	15.12	43.80	47.74
IGB - 2	1.72	-2.86	0.66	16.25	41.11	47.77
IGB – 3	0.90	-0.03	2.07	63.49	93.48	72.03
IGB - 4	1.86	-0.89	1.27	14.67	63.11	60.88
IGB - 5	0.25	-0.45	0.23	14.66	42.40	24.27
IGB - 6	1.09	-1.07	0.68	16.19	45.64	45.23
IGB- 7	1.70	-2.33	0.72	16.57	44.93	47.95
IGB - 8	1.40	-1.04	0.88	15.30	53.86	51.70
IGB - 9	1.18	-2.68	0.46	16.63	35.11	37.23
IGB - 10	1.07	-1.60	1.77	42.01	35.30	72.77
IGB - 11	0.30	-1.56	0.16	14.93	20.00	21.47
IGB - 12	1.12	-2.20	0.49	14.49	36.75	39.55
IGB - 13	1.78	-2.12	3.01	40.91	44.80	80.88
IGB - 14	0.95	-1.08	0.60	11.94	45.94	45.19
IGB - 15	0.48	-0.04	0.88	71.35	71.17	54.62
IGB - 16	2.06	-0.05	2.01	79.76	54.60	73.94
IGB - 17	0.93	-2.14	2.21	73.45	24.20	71.27
IGB - 18	2.70	-2.05	1.11	29.79	54.97	55.83
IGB - 19	1.24	-2.22	0.53	16.29	38.46	46.60
IGB - 20	1.39	-1.76	0.69	12.42	45.62	48.83
Min	0.25	-2.86	0.16	11.94	20.00	21.47
Max	2.70	-0.03	3.01	79.76	93.48	80.88
Mean	1.28	-1.52	1.05	29.81	46.76	52.29
Stdev	0.60	0.89	0.76	23.39	16.15	16.02

The RSBC of Igbokoda groundwater ranged between -2.86 and -0.03 (meq/L) (Table-5). The RSBC values were less than approved maximum value of 1.25 indicating that the water is suitable for irrigation [46].

The soil permeability is affected by long term use of irrigation water. It is influenced by sodium, calcium, magnesium and bicarbonate contents of soil. PI values of groundwater samples in this study ranged from 20.00 to 93.48 with an average value of 46.46 (Table-5). Analytical data of PI values plotted on Doneen diagram [47] revealed that 70% of the groundwater samples fall in Class I (very good to good) (Figure-7) while 25% and 5% fell into classes II (good to hazardous) and III (hazardous to very hazardous), respectively. Majority of the groundwater samples fell under Classes I in the Doneen diagram and are generally good for irrigation purposes.

The hazardous effect of sodium on water quality for irrigation usage was also determined [48]. A Kelly's ratio of more than one indicates excessive sodium in water. Therefore, water with a KR<1 are suitable for irrigation while those with a KR>1 are unsuitable. The KR in this study varied from 0.16 t0 3.01 (av. 1.05) (Table 5). Thirteen of the groundwater samples (65%) had KR<1 while the remaining seven samples (35%) had KR>1. Kelly ratio of majority of the groundwater samples indicated suitability for irrigation.

5. CONCLUSIONS

The groundwater resources in the coastal area of Igbokoda were evaluated for their chemical composition and suitability for irrigation. The abundance of the major ions is as follows: $Ca^{2+}>K^{+}>Mg^{2+}$ and $Cl^{-}>SO_4^{2-}>HCO_3^{-}>NO_3^{-}$. Precipitation and rock-water interaction are the main sources of ions in the groundwater of the study area. The major hydrochemical facieses were Na-Cl, Ca-Cl and mixed Ca–Mg–Cl types. All ionic concentrations were within approved [20] and [21] standards for drinking water.

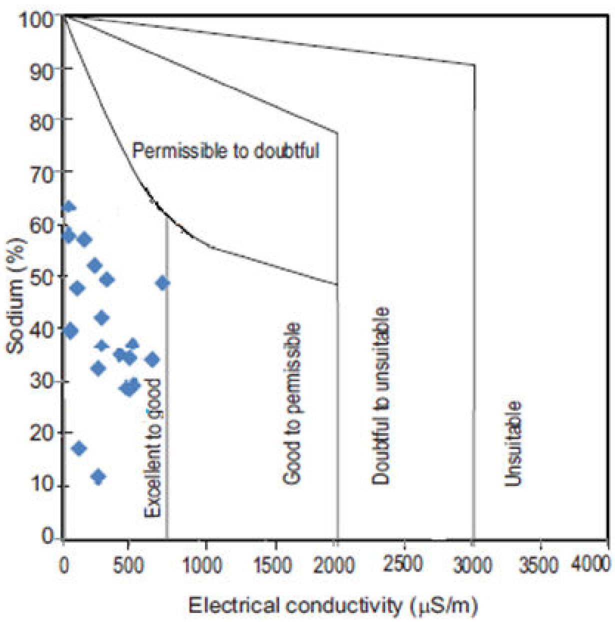

Figure-6. Wilcox's diagram for classification of groundwater quality in the coastal area of Igbokoda.

However, 85% of the groundwater samples tested positive to e-coli counts. The groundwater was chemically potable but contaminated by bacterial. The results also showed that the surveyed groundwater for irrigation purposes have a low to medium salinity hazard, low alkalinity hazard due to low concentration of HCO_3^- and low magnesium absorption ratio, low sodicity and low Kelly ratio. Evaluated irrigation parameters revealed that the groundwater is excellently suitable for irrigation except in few situations that the groundwater could be hazardous. Based on the results of this study, the quality of the groundwater is suitable for irrigation. Groundwater in Igbokoda coastal area is not potable but suitable for irrigation.

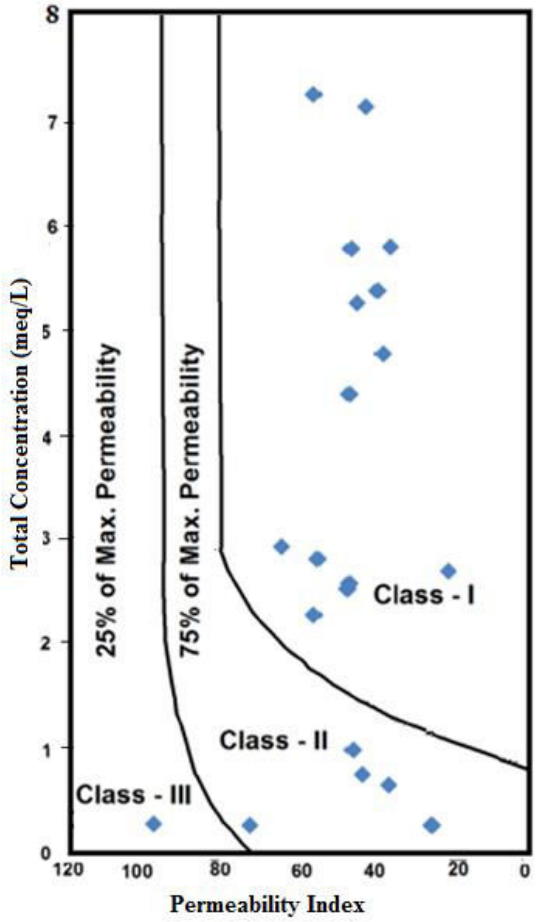

Figure-7. Doneen's diagram for classification of groundwater quality in Igbokoda coastal area.

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