

## Hydrochemical study of shallow ground water in Ikot Abasi Coastal Aquifer

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**Abstract:** A hydrochemical study of shallow groundwater in Ikot Abasi coastal aquifer, Niger Delta, Nigeria, was undertaken, to assess the impact of incidences of oil bunkering, crude oil refining activities, burning of natural gas for power generation and aluminum smelting activities. Six groundwater samples were collected from existing boreholes at different stations, for dry and wet seasons respectively. The water samples were analyzed for temperature, pH, cations ( $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Mg}^{2+}$ ), anions (chloride, sulphate, nitrate and bicarbonate), total dissolved solids (TDS), electrical conductivity (EC), salinity, alkalinity and total hardness, bicarbonate ( $\text{HCO}_3^-$ ) and alkalinity, using standard analytical procedures by American Public Health Association. To establish the water types in the study area, the test results acquired for exchangeable cations and nutrients were subjected to Piper Plot, Durov Plot, and Gandha Plot for two seasons. The Piper Plot developed from experimental data revealed that water facies in Ikot Abasi aquifer are confined to only two types, with the majority of the samples having 67 percent plotted in the Ca-Mg-Cl water type, while 23 percent of the samples showed Na-Cl water type, which suggests freshness of the water with minor contribution from saline contribution. However, the Chandha plot for the groundwater indicated that within the study area 66.6 percent of the samples plot are within subfields-5, representing  $\text{Ca}^{2+}$  -  $\text{Mg}^{2+}$  -  $\text{HCO}_3^-$  water type, while 33 percent were of the samples plot within subfield -4, which is an indication of the presence of a significant concentration of acidic ions over weak anions, signifying strong acidic anions in the water exceeding weak acidic anions. Also, the observed pattern for the results of the Durov plot reveals that 66 percent of the samples plot are in the reverse ion exchange zone and

therefore suggest the occurrence of inverse/reverse ion exchange process occurring, due to the direct exchange of calcium ion and magnesium ions from the aquifer matrix in addition to sodium and potassium ions from the groundwater. While 33 percent of samples plot along the dissolution or mixing line. Based on the Lloyd and Heathcoat classification, the result can be aligned to recent fresh recharged of the water characterized by simple dissolution or mixing without the domination of major ions, and can be attributed to fresh recent recharged water exhibiting simple dissolution or mixing with no dominant major anions and cations. In spite of the shallow depth of the aquifer in the study area, there is no observed contamination of the water. Although the aquifer in Ikot Abasi has shallow depths of between 1.8m to 8.4 m, the concentrations of lead, cadmium, mercury, arsenic, zinc, and manganese are below the permissible limits of 0.05 mg/L, except iron content which has values above the permissible limit of 0.3 mg/L. The waters have mean salinity of 0.01 %, indicating no saltwater intrusion even though the study area is coastal. The calculated mean pollution index also suggests the absence of contamination from anthropogenic activities. The distribution of major anions, cations, and occurrence of different hydrochemical facies suggest that the composition of the groundwater is significantly influenced by water-rock interactions.

**Keywords:** Coastal aquifer, coastal plain sands, Groundwater, hydrochemical study, Ikot Abasi Coastal aquifer.

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**1.0 Introduction**

Groundwater is a key element in the hydrogeological cycle because its quality can be significantly altered by the extent of recharge from surface water deposits such as precipitation. The groundwater system can be seen as a static water storage reservoir that moves slowly beneath the earth. In spite of its location, the groundwater system is the major source of water to most cities in the world. Therefore, its quality may have a significant impact on the health of the ecosystem as well as the socio-economic status of a nation. Also, due to its slow-moving nature, its quality is critical in the water economy and the chemistry of water is very dynamic, as it percolates through soil formations (Khan *et al.*, 2012; Owamah *et al.*, 2013; Ukpong and Okon, 2013).

Water, including groundwater, is an important natural resource especially for drinking, recreation, industrial and irrigation uses. Water quality assessment is essential for human health and the definition of water quality depends on the desired end-use and purposes of water (Adams *et al.*, 2001; Eddy *et al.*, 2004; Jain *et al.*, 2009). Therefore, different uses require different criteria for defining water quality and the standard methods for reporting and comparing results of water analysis (Singh *et al.*, 2004). The analysis of physicochemical properties of water is a significant approach to address the public health status of humans that depends on such water (Chen *et al.*, 2006; Palma *et al.*, 2010; Rizwan and Singh, 2009). Other water quality parameters such as heavy metal and nutrient content also have a significant environmental impact on the quality of the environment that is in contact with the water. Natural variations in groundwater hydrochemistry should be considered when

assessing water quality data from groundwater monitoring programs, as elevated concentrations for certain parameters might be influenced by the aquifer lithology (Kumar *et al.*, 2009). Therefore, to ensure that long-term sustainable groundwater resources are achieved, groundwater resource management is required through an assessment of anthropogenic pressures and the physical characteristics of the subsurface deposits, i.e. soil, subsoil, and aquifer type. The water quality assessment is mostly based on hydrochemical analysis and many organizations in different countries have developed and published the guidelines for drinking water to protect public health (American Groundwater Trust, 2012).

Water quality assessment is essential for human health and depends on the desired use of water.

According to Kumer *et al.*, 2013, natural variations in underground hydrochemistry should be considered when assessing water quality data from groundwater monitoring programs because elevated concentration for certain parameters might be influenced by aquifer lithology (Gundry *et al.*, 2003; WHO, 2006; Okorafor *et al.*, 2012; Srinivas *et al.*, 2014).

The hydrochemical properties of water depend on the water-rock interaction and other natural factors such as mixing between seawater and freshwater, anthropogenic factors and the type of groundwater circulation (Etesin *et al.*, 2013).

In this study, borehole waters from Ikot Abasi coastal aquifer were characterized by the determination of physicochemical parameters in order to establish the aquifer type in the area, the possibility of saline water intrusion and suitability of the water for different purposes. Therefore, the major objective of the study were to evaluate the hydrochemistry of the aquifer by subjecting the acquired data for Piper Plot modeling and comparative assessment of the water quality parameters with standard water guidelines and limits.



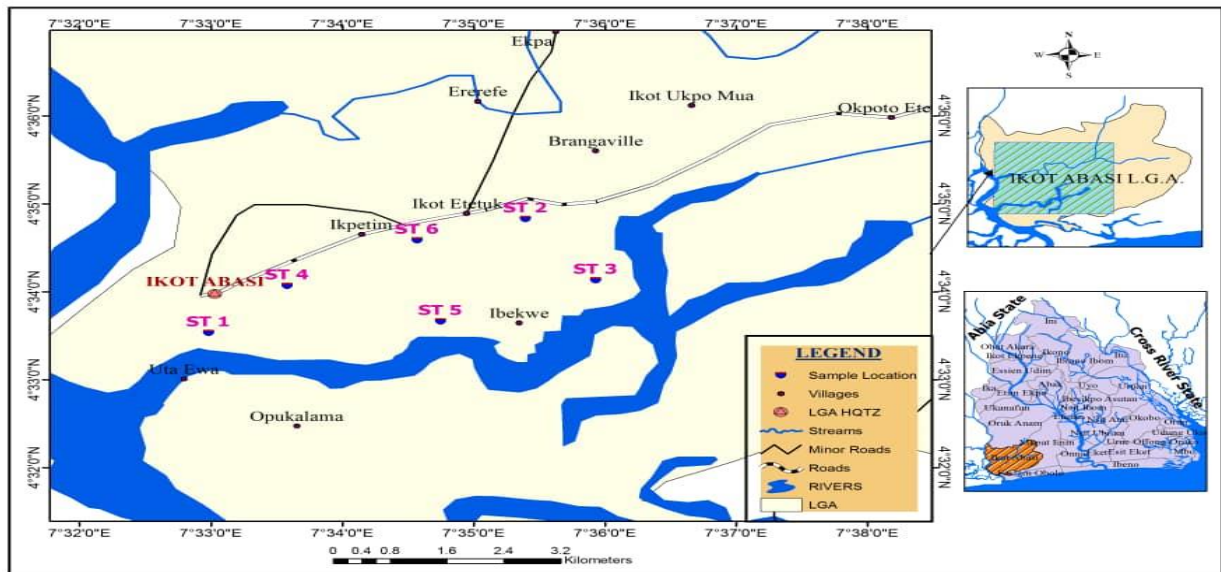


Fig. 1: Map of Ikot Abasi showing sampling locations

Table 1: Sample Locations

Sample Code	Location	Coordinates
ST 1	Utaewa Village	4.6058° N , 7.6244° E
ST 2	Ikot Etetuk Village	4.5831° N , 7.5992 ° E
ST 3	ALSCON Estate	4.5721° N , 7.5819° E
ST 4	Ikot Abasi Village	4.5739° N , 7.57789° E
ST 5	Ikot Obong Village	4.5908° N , 7.5940 ° E
ST 6	Ikpetim Village	4.5644° N , 7.5680 ° E

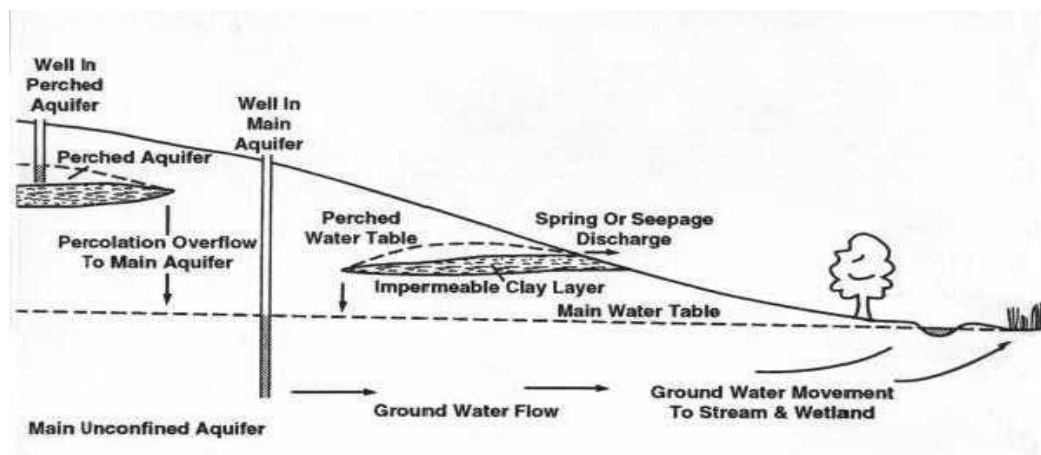


Fig 2: Sketch of groundwater flow

2.0 Materials and Methods

2.1 The study area

The study area, Ikot Abasi lies within the Niger Delta zone in Nigeria (Fig. 1). It is located between latitude 4.3111 ° and 4.4512 ° North and between longitude 7.5213 ° and 8.0219 ° East ( Ikot Abasi: The Aluminium Town, 1997) . Ikot Abasi is a local government in Akwa Ibom State that hosts

some major multinational companies, like Exxon Mobil, Aluminium Smelter Company of Nigeria (ALSCON), SEPTA gas station, Ibom Power Company Limited, Ikot Abasi and Oil Platforms close to Iko Town in Eastern Obolo.

The study area is underlain by the sedimentary formation of the Late Tertiary and Holocene ages (Udo *et al.*,2013).



Deposits of recent alluvium and beach ridge sands occurred along the coast and the estuaries of the Imo and Qua Iboe Rivers and also along flood plains of Uta Ewa creek (Magnus et al, 2012). The study area is made up of matured, coarse and moderately sorted coastal plain sands. overlies the Bende-Ameki formation and dips south westward (Enemugwem, 2009) . The landscape of the study area comprises of a low-lying plain and riverine areas with no portion exceeding 175 meters above mean sea level. The physiography of the area is that of a beach ridge complex characterized by a succession of sub-parallel sand ridges (Kumer, 2013). The physical relief of the study area is flat, though with some marshy river-washed soils around the banks of the Qua Iboe River (Etesin et al, 2013). Ikot Abasi Local Government Area falls within the tropical zone and its vegetation is the green foliage of trees/shrubs and the oil palm tree belt. The Local Government Area has two seasons: the wet season and the dry season. There are abundant deposits of crude oil and clay in the study area. Forest resources include mangroves, nipa palm, timber, palm produce while the area is also noted for seafood production. Farm crops range from yam, cassava, cocoyam, plantain to maize and vegetables (Akankpo and Igbokwe, 2011).

## 2.2 Materials

Deionized water was used for the preparation of all reagents. All the chemicals used were of analytical grade (Analar). Six groundwater samples were collected monthly from boreholes at different locations during dry (November 2019 to March 2020) and wet (May 2020 to September 2020) seasons (Table 1). In situ measurements were carried out for pH, conductivity, salinity, redox potential, dissolved oxygen, total dissolved solids, turbidity and temperature while others were measured in the laboratory.

### 2.2.1 Total alkalinity and total hardness and calcium content

Total alkalinity was determined by the titrimetric method, according to method No.2320 B of APHA, AWWA.WEF (APHA, 2005). Total hardness and calcium content of

the waters were determined by EDTA titration, according to the method recommended by APHA, AWWA.WEF (APHA, 2005 )

### 2.2.2 Chloride content and total hydrocarbon

The chloride content of the water was determined by argentometric titration according to method No. 4500 - Cl-, B. of APHA, AWWA.WEF (APHA, 2005), while total hydrocarbon of the water samples from the study area was analyzed by gas chromatograph (AGILENT 7890), according to Method of APHA, AWWA, WEF (APHA, (2005).

### 2.2.3 Sulphate and nitrate contents

Sulphate content was determined by turbidimetric method, according to method No. 4500 SO<sub>4</sub><sup>2-</sup> E of APHA, AWWA.WEF (APHA,2005), while nitrate was determined by spectrophotometric method, according to method No. 4500 NO<sub>3</sub><sup>-</sup>, B of APHA, AWWA.WEF (APHA,2005).

### 2.2.4 Phosphate content

Phosphate content of the water was determined by spectrophotometric method, according to method No. 4500 - P, C of APHA, AWWA.WEF (APHA, 2005).

### 2.2.5 Dissolved oxygen

The dissolved oxygen content of the waters was determined in-situ at the field using a portable dissolved oxygen meter.

### 2.2.6 Redox potential

The redox potential of the waters was determined in-situ at the field by the use of a portable pH meter, calibrated according to the manufacturer's operational manual.

### 2.2.7 Carbonate, bicarbonate, and hydroxide alkalinity

Carbonate alkalinity, bicarbonate, and hydroxide alkalinity were determined by calculation after pH measurement, according to Method No. 4500 CO<sub>2</sub> D of APHA, AWWA.WEF (APHA, 2005).

### 2.2.8 Trace metals

Concentrations of cadmium, lead, zinc, copper and iron ions were determined by flame atomic absorption spectrometer (ATI,



Unicam 939) according to Method No 3111 A. of APHA, AWWA, WEF (APHA,2005).

### 2.2.9 pH and conductivity

The pH of the water samples was determined in-situ at the sampling locations by the use of a pre-calibrated pH meter while the conductivity of the water samples was determined in-situ at the sampling locations using a conductivity meter (APHA, AWWA, WEF (APHA,2005).

## 3.0 Results and Discussion

### 3.1 Physico-chemical parameters

Results obtained from physicochemical analysis of the water samples are presented in Table 2. These included the temperature, pH, electrical conductivity (EC), redox potential (RP), salinity, total dissolved solids (TDS) and dissolved oxygen of the water for both seasons. pH, electrical conductivity, TDS, range from 5.25 to 5.78 with a mean value of 5.60, 72 to 289  $\mu\text{S}/\text{cm}$  with a mean value of 193.6, 41.37 to 190.3 mg/L with a mean value of 123.4 mg/L respectively. Temperature and redox potential values were 26.6 to 27.4 °C with a mean of 26.98 °C and 78.4 to 98.0 mV with a mean of 82.0 mV respectively. Salinity

has a value of less than 0.001 ‰. Dissolved oxygen content ranged from 5.6 to 6.37 mg/L with a mean of 5.92 mg/L during the dry season (Table 2). The results of the physicochemical parameters were all below the WHO limits (WHO,2006). The temperature has values of 26.5 to 27.6°C with a mean of 26.95 °C, pH has values of 5.48 to 6.19 with a mean of 5.89, electrical conductivity has values of 59.22 to 274.1  $\mu\text{S}/\text{cm}$  with a mean of 140.9, redox potential has values of 76.19 to 89.3 mV with mean of 79.75. Values of total dissolved solids ranged from 24.74 to 237.5 mg/L with a mean value of 199.5, while the salinity of the water was less than 0.001‰. The dissolved oxygen of the water sample ranged from 4.98 to 5.98 mg/L with a wet season mean concentration of 5.68 mg/L. Measured physicochemical parameters for the wet season are within WHO and FEPA standards except for pH that was mildly acidic than the WHO minimum of 6.5.(Standards of Nigeria, 2007; WHO, 2011).

**Table 2: Physicochemical parameters of underground water from different sampling stations**

Sampling station	T (oC)	pH	EC. ( $\mu\text{S}/\text{m}$ )	RP (mV)	TDS (mg/l)	DO (mg/L)	TH (mg/L)	TA (mg/L)	THardness (mg/L)
ST1	27.4	5.2	259.00	83.00	179.00	5.60	1.77	160.7	130.6
ST2	26.9	5.72	270.00	79.80	168.00	5.89	2.09	158.2	137.1
ST3	27.2	5.64	120.00	81.00	87.24	5.83	1.62	115.3	63.82
ST4	26.7	5.54	289.00	89.00	190.30	6.13	3.06	41.96	67.35
ST5	27.2	5.69	151.70	80.80	72.93	6.37	3.92	92.04	45.06
ST 6	26.5	5.78	72.01	78.40	41.37	6.04	2.96	40.03	17.54
ST1*	26.9	6.07	131.80	77.65	24.74	5.31	0.17	16.95	18.22
ST2*	26.5	6.05	125.20	80.05	79.99	5.82	0.41	15.07	90.14
ST3*	27.4	5.73	132.00	78.90	42.07	4.98	2.06	118.5	71.93
ST4*	27.6	5.48	274.10	89.30	237.50	6.23	0.096	17.95	69.93
ST5*	26.5	6.19	122.80	76.40	234.10	5.98	0.075	28.71	11.07
ST6*	26.8	5.79	59.22	76.19	83.96	5.73	1.044	16.95	10.83
<b>Dry season mean</b>	26.98	5.60	193.62	82.00	123.14	5.98	2.57	101.37	76.91
<b>Wet season mean</b>	26.95	5.89	140.85	79.75	117.06	5.68	0.64	35.69	45.35
<b>WHO limit</b>	< 40	6.5-8.5	<2000		<500	>5	<0.003	<500	80-100

\* indicates wet season data



Nutrient contents of underground water from the various sampling stations are shown in Table 3. The nutrient is a significant quality parameter because of its potentials to initiate eutrophication, which is a condition that is characterized by an algal bloom, the release of toxins to the water and depletion of the dissolve oxygen content of the water. However, the effect of nutrients on underground water may be less impactful compared to surface water except for the objectionable taste and threat to public health (Domerech and Sauri, 2011). Measured concentration of nitrate ions (during dry season) ranged from 0.26 to 0.53 mg/L, (mean = 0.413 mg/L). Dry season concentration of

sulphate ions ranged from 3.54 to 5.22 mg/L (mean =4.082 mg/L). Also the range of dry season concentrations of chloride and phosphates were 0.02 to 0.05 mg/L respectively. The respective mean concentrations were 4.082 and 0.032 mg/L. (Table 2). In the wet season, measured concentrations of nitrate, sulphate, chloride and sulphate were in the following ranges, 3.96 to 5.21 mg/L, 2.94 to 11.42 mg/L 22.96 to 130.1 mg/L and 0.052 to 0.091 mg/L respectively while the mean concentrations were 4.46, 7.58, 60.26 and 0.067 mg/L In both seasons, mean concentrations of analyzed nutrients were within the WHO safety range ( Adekola et al, 2015).

**Table 3: Concentrations of nitrate, chloride, phosphate and sulphates in underground water from various sampling stations in Ikot Abasi**

Sampling station	$NO_3^-$	$SO_4^{2-}$ (mg/L)	Cl <sup>-</sup> (mg/L)	$PO_4^{3-}$ (mg/L)
ST1	0.31	4.11	50.6	0.03
ST2	0.42	3.86	52.7	0.02
ST3	0.26	3.54	23.92	0.05
ST4	0.62	3.71	122.1	0.026
ST5	0.53	4.05	31.86	0.025
ST 6	0.37	5.22	37.19	0.041
ST1*	4.95	10.05	31.75	0.052
ST2*	3.97	9.85	130.1	0.052
ST3*	5.21	6.03	22.96	0.076
ST4*	3.96	11.42	107.8	0.056
ST5*	4.72	2.94	30.73	0.072
ST6*	3.97	5.17	38.22	0.091
<b>Dry season mean</b>	0.42	4.08	53.06	0.03
<b>Wet season mean</b>	4.46	7.58	60.26	0.07
<b>WHO limit</b>	50	<250	<250	< 3

Dry season concentrations of total hydrocarbon, alkalinity and total hardness in the water sample (Table 2) ranged from 1.62 to 3.92 mg/L, total alkalinity has values ranging from 40.03 to 160.7 and 17.54 to 137.1 mg/L respectively. The corresponding mean concentrations were 2.57, 101.4 and 76.91 respectively. However, wet season means concentrations of total hydrocarbons, total alkalinity and total hardness (Table 2) were 0.643, 35.69 and 43.35 mg/L respectively. Wet season data were spread

within the following ranges (Table 2).0.075 to 2.06, 15.07 to 118.5 and 10.83 to 90.14 mg/L respectively. In both seasons, mean value of total hydrocarbon is above the WHO limit of less than 0.003 mg/L (WHO, 2011), which is a major public health concern, while total alkalinity and total hardness are below the WHO limits for potable waters. The observed total hydrocarbon is due to contamination of the water by crude oil, which is native of the study area (Standards of Nigeria, 2007; Atakpo, 2009).



### 3.2 Concentrations of metals and exchangeable ions

Concentrations of heavy metal ions from all the sampling stations are recorded in Table 4, for both dry and wet seasons. Dry season concentrations of iron ranged from 1.07 to 2.97 mg/L (mean = 1.78 mg/L). The ranged for the concentrations of Mn, Zn, Pb, Cd, As and Hg 0.051 to 0.51 mg/L, 1.97 to 4.72 mg/L, 0.002 to 0.008 mg/L, 0.001 to 0.002 <0.001 mg/L and <0.001 mg/L respectively. The corresponding dry season mean concentrations were 0.145, 3.098, 0.005, 0.001, <0.001 and <0.001 mg/L. However, concentration ranges for the wet seasons were 0.072 to 2.04, 0.032 to 0.084, 2.73 to 4.21, 0.001 to 0.007, 0.001 to 0.002, <0.001 and <0.001 mg/L for Fe Mn, Zn, Pb, Cd, As and Hg respectively. Concentrations of all the measured heavy metal ions were below the permissible limits except for iron and zinc (Table 4) which implies that the water is contaminated with respect to iron and zinc. Concentrations of exchangeable cations (including Ca, Mg, K and Na are also

recorded in Table 4. From the recorded mean concentrations (Table 4) and the recommended limit for these ions, the water is not contaminated with respect to these ions. (Dahunsi *et al.*, 2014; Adekola *et al.*, 2015).

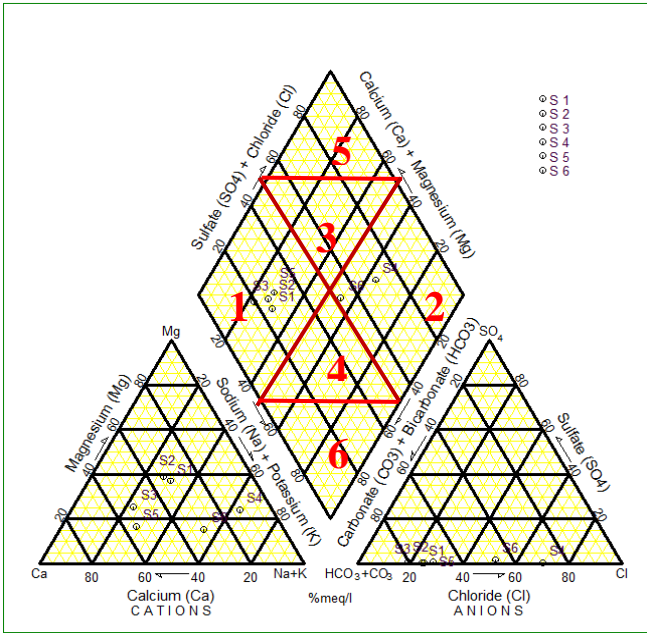
### 3.3 Water types

Water type can be established through the Piper, Durov, and Gandha plots (Lloyd and Heathcote, 1985). The Piper Plot classifies the sample points in the piper diagram into six different water facies which include. Ca - HCO<sub>3</sub> type; 2. Na-Cl type; 3. Ca-Mg-Cl type; 4. Ca-Na-HCO<sub>3</sub> type; 5. Ca-Cl type; 6. Na - HCO<sub>3</sub> type. However, in the present study water facies were confined to only two types, with the majority of the samples (67%) plotted in the Ca-Mg-Cl water type 3, while the remaining 23% of the samples fitted the Na-Cl water type 2. Evaluation of the samples using a piper plot suggests a freshness of the water with a minor indication of saline contribution.

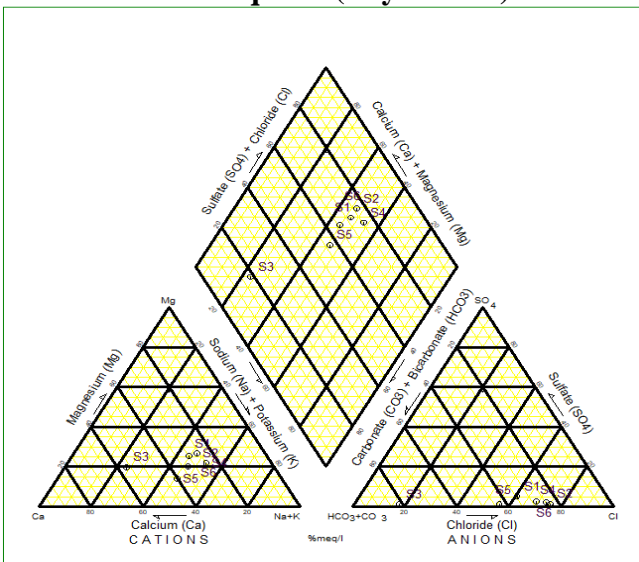
**Table 4: Concentration of heavy metals**

Sampling station	Fe(mg/l)	Mn (mg/l)	Zn (mg/l)	Pb (mg/l)	Cd (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)
ST1	1.36	0.07	2.41	0.003	< 0.001	27.6	11.8	1.87	34.5
ST2	2.07	0.51	1.97	0.002	< 0.001	30.71	13.07	1.72	31.98
ST3	1.09	0.051	2.19	0.005	0.001	27.82	5.07	0.73	15.86
ST4	2.11	0.074	3.91	0.005	0.002	10.56	7.64	3.72	70.27
ST5	2.97	0.092	3.39	0.006	0.002	30.07	3.39	1.09	19.86
ST 6	1.07	0.073	4.72	0.008	< 0.001	11.61	2.19	1.62	27.05
ST1*	0.072	0.034	4.05	0.007	0.001	10.04	3.17	2.07	19.06
ST2*	1.41	0.052	3.27	0.004	0.002	28.92	11.04	3.73	67.82
ST3*	2.04	0.084	4.21	0.003	< 0.001	32.05	4.11	1.32	17.15
ST4*	0.093	0.032	4.062	0.002	< 0.001	21.62	6.93	3.18	59.34
ST5*	1.82	0.072	3.96	0.001	< 0.001	15.97	2.07	2.96	23.07
ST6*	1.076	0.081	2.73	0.003	< 0.001	8.75	1.96	1.83	15.82
<b>Dry season mean</b>	1.60	0.15	3.10	0.00	0.00	23.06	7.19	1.79	33.25
<b>Wet season mean</b>	1.09	0.06	3.71	0.00	0.00	19.56	4.88	2.52	33.71
<b>WHO limit</b>	< 0.3	0.4	3	< 0.001	0.003	< 200	< 150		





**Fig 3: Piper plot for cations and anions of water from Ikot Abasi aquifer (Dry Season)**

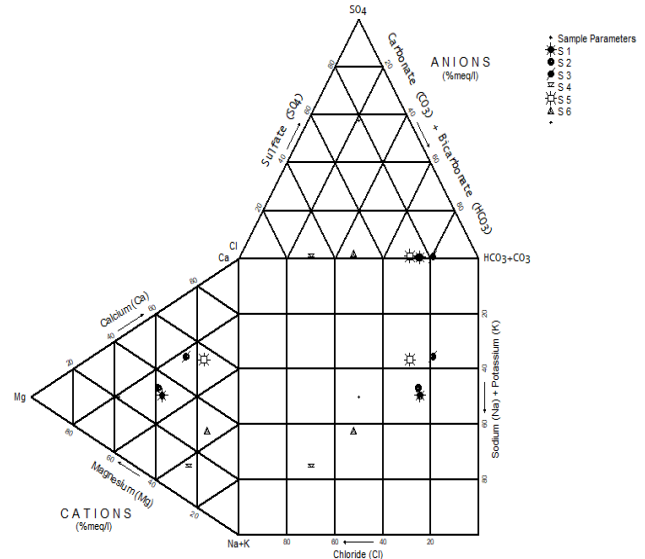


**Fig 4: Piper plot for cations and anions of water from Ikot Abasi aquifer (Wet Season)**

The result of Durov diagram revealed that 66.6% of the samples plot aligned with the reverse ion exchange zone – suggesting inverse / reverse ion exchange process occurring due to direct exchange of  $Ca^{2+}$  and  $Mg^{2+}$  from the aquifer matrix with  $Na^+$  and  $K^+$  from the groundwater. While However 33.4% plots along the dissolution or mixing line.

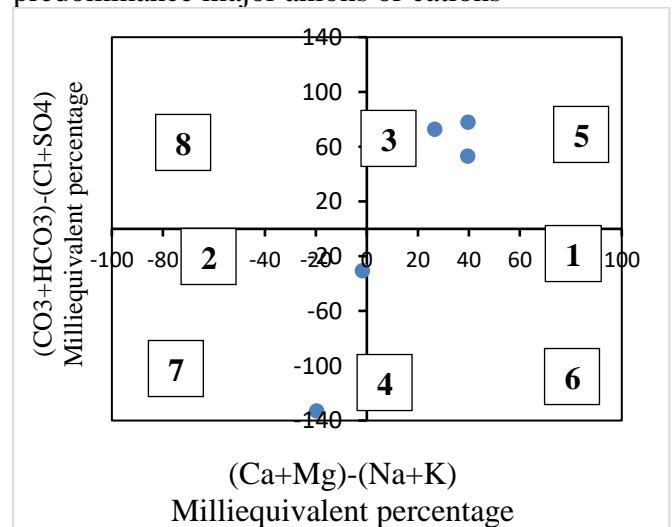
Chadha divided this plot into eight sub-fields which are alkaline earth exceeding alkali metals, 2. metals exceeding alkaline earth, 3. weak acidic anions exceeding strong acidic anions, 4. strong

acidic anions exceed weak acidic anions, 5. Alkaline-earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively, 6. alkaline earth exceed alkali metals and strong acidic anions exceed weak acidic anions, 7. alkaline metals



**Fig. 5: Durov Plot of Ikot Abasi Coastal Aquifer**

Based on the classification of Lloyd and Heathcoat, 1985, the observed trend can be attributed to fresh recent recharge water that exhibits simple dissolution or mixing without predominance major anions or cations



**Fig 6: Chadla Plot of Ikot Abasi Coastal Aquifer**

exceed alkaline earth and strong acidic anions exceed weak acidic anions. 8. Alkali metals exceed alkaline earth and weak acidic anions exceed strong





acidic anions (Igbemi *et al*, 2019 ) The Chadha plot for the groundwater within the study area (Fig. 6) revealed that 66.6% of the samples plot within sub-field 5 representing  $Ca^{2+} - Mg^{2+} - HCO_3^-$  type, while the remaining 33% plots lies within sub-field 4 – strong acidic anions exceed weak acidic anions.

#### 4.0 Conclusion

The hydrochemical studies of groundwater provide information about the source, water types and extent of groundwater pollution, which determines suitability for various purposes. Depending upon some specific standards, the groundwater quality in comparison can be determined for different purposes. Groundwaters from Ikot Abasi coastal aquifer were investigated to evaluate the water types prevalent, the extent of groundwater pollution, the extent of saline water intrusion and water quality for domestic and irrigation purposes. The results of the hydrochemical analysis show that groundwater in the study area are characterized as dominantly fresh and less of brackish, and slightly acidic in nature, in both dry and wet seasons. The dominant water type in the study area is Ca-Mg-Cl type and less of Na -Cl type. The study also reveals that the waters in the study area exhibit the reverse ion exchange zone – suggesting inverse /reverse ion exchange process occurring due to direct exchange of  $Ca^{2+}$  and  $Mg^{2+}$  from the aquifer matrix with  $Na^+$  and  $K^+$  from the groundwater. From the Chadha plot, water aquifer in the study area reveal that alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively, while strong acidic anions exceed weak acidic anions.

The distribution of major anion and cations, and the occurrence of different hydrochemical facies suggest that the composition of groundwater is influenced by water-rock interactions and less of seawater intrusion in coastal aquifers to reach a final stage of evolution characterized by ion-exchange interaction. The study further suggests that water-rock interactions in the coastal aquifer and evaporation are the main mechanisms controlling the water chemistry in the study area. Also, by the water hardness classification, based on US-EPA, the mean water hardness in the area is 76.91 mg/L, during the dry season, which falls in the class of moderately hard water (75 – 150 mg/L)

and 45.35 mg/L, during the wet season, which falls in the class of soft water (0 – 75 mg/L)

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### **Conflict of Interest**

The authors declared no conflict of interest

