

Facies classification and Ionic Ratio evaluation of Groundwater around Igbokoda Coastal Area, southwestern Nigeria

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**Abstract** – Facies classification of groundwater around Igbokoda Coastal Area, Southwestern Nigeria was carried out employing ionic ratio, Piper diagram, Chadha plot and Hydrochemical Facies Evolution Diagram (HFE-D). Ionic ratios of  $\text{HCO}_3^-/\text{Cl}^-$ ,  $\text{Na}^+/\text{Cl}^-$ ,  $\text{Ca}^{2+}/\text{Cl}^-$ ,  $\text{Ca}^{2+}/\text{Na}^+$ ,  $\text{Mg}^{2+}/\text{Cl}^-$ ,  $\text{K}^+/\text{Cl}^-$  and  $\text{SO}_4^{2-}/\text{Cl}^-$  were calculated and plotted against TDS to study the ingress of seawater into coastal aquifers of the area. Chemical analysis of groundwater from the area revealed average concentrations (mg/L) of  $\text{Ca}^{2+}$  (25.14),  $\text{Mg}^{2+}$  (3.46),  $\text{Na}^+$  (26.12mg/L),  $\text{K}^+$  (13.86),  $\text{HCO}_3^-$  (1.34),  $\text{Cl}^-$  (7.95 mg/L),  $\text{SO}_4^{2-}$  (2.46) and  $\text{PO}_4^{2-}$  (3.64). Plots of ionic ratios vs. TDS tend towards that of seawater with increasing TDS signifying seawater intrusion. The Piper diagram revealed dominant  $\text{Na}^+ - \text{Cl}^-$  water (85%) (indication of saltwater intrusion), Mixed  $\text{Ca}^{2+} - \text{Mg}^{2+} - \text{Cl}^-$  type (10%) and  $\text{Ca}^{2+} - \text{Cl}^-$  type (5%) respectively. The Chadha diagram revealed dominant  $\text{Na}^+ - \text{Cl}^-$  type (90%) and  $\text{Ca}^{2+} - \text{Mg}^{2+} - \text{Cl}^-$  (10%) signifying reverse ion exchange in the zone. The HFE-D indicated that 20% of the groundwater samples fell in the generalized seawater intrusion zone of the aquifer with facies representations of  $\text{Na} - \text{Cl}$  type (5%),  $\text{Mix Ca} - \text{Mix Cl}$  type (10%),  $\text{MixCa} - \text{Cl}$  type (5%) and  $\text{Ca} - \text{Cl}$  type (5%) while 15% of the groundwater samples were in the freshening phase (facies;  $\text{Ca} - \text{HCO}_3/\text{SO}_4$  (5%),  $\text{MixCa} - \text{HCO}_3/\text{SO}_4$  (5%) and  $\text{Na} - \text{MixCl}$  (5%) respectively. Majority of the groundwater samples (60%) fell into the simple binary mixing zone with little or no intervention of Base Exchange reactions. The HFE-D recognized the sequence of the facies in detail and therefore the succession and interpretation of processes in contrast to Piper and Chadha diagram.

**Keywords:** Hydrochemistry; ionic ratios; seawater; water facies; reverse ion exchange.

### 1. Introduction

Surface water is available in most part of Igbokoda Coastal Area. However, the surface water is colored by natural sea weeds apart from the incessant contaminant dumps arising from human activities. Hence, many of the inhabitants of Igbokoda Township have to depend on groundwater for daily water consumption and agricultural activities. The area is on sedimentary terrain where dissolution of ions in soils, sediments and rocks as water travels along mineral surfaces in the pores and fractures of unsaturated zone and the aquifer result into variation in groundwater chemistry (Shahbazi and Esmacili-Sari, 2009). The geological formations, water-rock interaction and relative mobility of ions are prime factors influencing the geochemistry of groundwater (Yousef et al., 2009). Under this situation, variability in groundwater chemistry warrants the investigation of hydrochemical facies which is critical for effective management and water use planning. Hydrogeochemical facies, an important diagnostic chemical aspect of groundwater solutions occurring in hydrologic systems, provides information on the distinct zones of cations and anions along different layers of aquifers (Christopher and Robert, 2005).

Research works (Oteri and Atolagbe, 2003, Talabi et al., 2012, Adeyemo et al., 2017, Talabi et al., 2018) revealed occurrence of salt water intrusion into the coastal area of Igbokoda. Salt water intrusion occurs in coastal freshwater aquifers when the different densities of both the saltwater and freshwater allow the ocean water to intrude into the freshwater aquifer. Saltwater intrusion into the coastal aquifer has long been recognized as a major threat to groundwater quality around the world. Successful management of coastal groundwater resources depends not only upon planning and regulation, but also on the accurate assessment and prediction of the behavior of the saltwater interface to both natural conditions and man's activities (Yuhr and Benzon, 1995). Igbokoda Coastal Area has suffered so many episodes of regressive /transgressive activities and with increased variations in world climate, coastal activities have increased leading to different hydrochemical facies.

Many researchers have worked on hydrochemical characterization to evaluate groundwater quality employing Piper Trilinear and Chalda graphical plots (Christopher and Robert, 2005, Nur et al., 2012, Ravikumar and Somashekar, 2017, Sridharan and Nathan, 2017, Gajul et al., 2017) while some employed ionic ratio (Sanchez-

Martos et al., 2002, Kim et al., 2003, Moujabber et al., 2006). However, in coastal environment, hydrochemical facies is a dynamic process which depends on the periodic changes in the recharge-discharge balance of the aquifer. Any influence, direct or indirect on the aquifer's water balance affects the position and movement of the seawater interface and the chemistry of the groundwater. The relationship between the dynamic and the hydrochemistry suggests that a study of the chemical variations will allow the phase of seawater intrusion of the aquifer to be identified as well as the evolution and dynamics of the saline front (phases of seawater intrusion or freshening) within the aquifer (Giménez-Forcada, 2010).

The aims of this reviewed paper are to identify the hydrochemical facies that characterize each stage of intrusion and freshening employing ionic ratio evaluation, Piper Trilinear and Chalda graphical plots in addition to Hydrochemical Facies Evolution Diagram (HFE-D).

### 1.1 Location and Geology

Igbokoda town (headquarter of Ese Odo local government) lies within latitude 6° 20' N to 6°24' N and longitude 4°45'E to 4°48'E (Fig.1). It serves as the gateway to other towns in the riverine area of Ondo State, Nigeria. The average annual rainfall in the area exceeded 2000 mm while the mean monthly temperature was 27°C. Igbokoda coastal area is an integral part of the Dahomey Basin. The Dahomey Basin is a combination of inland / coastal / offshore basin that stretches from south-eastern Ghana through Togo and the Republic of Benin to south-western Nigeria. It is separated from the Niger Delta by a subsurface basement high referred to as the Okitipupa Ridge (Obaje, 2009). Dahomey basin contains extensive wedge of Cretaceous to recent sediments, which thicken towards the offshore (Klemme, 1975). Dahomey basin has six lithostratigraphic units. The lithostratigraphic units from the oldest to the youngest include: Abeokuta Group (Cretaceous), Ewekoro Formation (Paleocene), Akinbo Formation (Paleocene-Eocene), Oshosun Formation (Eocene), Ilaro Formation (Eocene) and Benin Formation (Oligocene-recent). The known aquifers in the study area are mostly within the Benin Formation (Whiteman, 1982). The study area is covered by Quaternary alluvium deposits underlain by the Quaternary coastal plain sands with lenses of clayey shale (Okosun, 1998).

### 2. Materials and Method

Data for this study was extracted from the research of (Talabi, 2018) on "Hydrogeochemistry and Quality Assessment of shallow Groundwater in the Coastal Area of Igbokoda, Southwestern Nigeria". The present research employs Ternary plots of  $Mg^{2+}$ - $Ca^{2+}$ -( $Na^{+}+K^{+}$ ) and  $Cl$ - $HCO_3$ - $SO_4^{2-}$ , calculated ionic ratio, Piper Trilinear diagram and Chadha's plot as well as Hydrochemical Facies Evolution Diagram (HFE-D) to discriminate the various hydrochemical facies in the study area and use the facies to assess the dynamic character of sea water intrusion. Ionic ratios of  $HCO_3/Cl$ ,  $Na^{+}/Cl$ ,  $Ca^{2+}/Cl$ ,  $Ca^{2+}/Na^{+}$ ,  $Mg^{2+}/Cl$ ,  $K^{+}/Cl$  and  $SO_4^{2-}/Cl$  were calculated and plotted against TDS to study the ingress of seawater into coastal aquifers of the area (Nwankwoala and Udom, 2011, Batayneh et al., 2014, Sridharan and Nathan, 2017).

The Piper Tri-linear diagram is one of the most useful graphical representations in groundwater quality studies to understand the hydrogeochemical facies in terms of analogies, dissimilarities and water types (Piper, 1953). For example, chemically similar water can be classified and the evolution in water chemistry along the flow path be defined employing Piper diagram. To construct the Piper diagram, the relative abundance of cations with the % meq/L of  $Na^{+}+K^{+}$ ,  $Ca^{2+}$  and  $Mg^{2+}$  is first plotted on the cations triangle. The relative abundance of  $Cl$ ,  $SO_4^{2-}$ , and  $HCO_3^{-}+CO_3^{2-}$  is then plotted on the anions triangle. The two data points on the cations and anions triangles are then combined into the quadrilateral field that shows the overall chemical property of the water sample. Chadha's diagram can be used for various hydrochemical processes including base cation exchange, cement pollution, mixing of natural water, sulphate reduction, saline water and other related hydrochemical problems. Plotting Chadha's diagram involves obtaining the difference in milliequivalent percentage between alkaline earth ( $Ca^{2+} + Mg^{2+}$ ) and alkali metals ( $Na^{+} + K^{+}$ ), expressed as percentage reacting values is plotted on X axis while the difference in milliequivalent percentage between weak acid anions ( $CO_3^{2-} + HCO_3^{-}$ ) and strong acid anions ( $Cl + SO_4^{2-}$ ) is plotted on the Y axis. The plotting results into a square or rectangular field that describes the overall character of the water (Chadha, 1999). Since this study was carried out in a coastal area not far from the Atlantic Ocean the need to ascertain whether the aquifer was in the phase of seawater intrusion or freshening, indicating the status of the aquifer in terms of the advance or regression of the saline front becomes necessary. Therefore, a new multi-rectangular diagram proposed by (Giménez-Forcada, 2010), that aids interpretation of these important

coastal processes through the representation and evolution of hydrochemical facies (Hydrochemical Facies Evolution Diagram, HFE-D) was employed in this research.

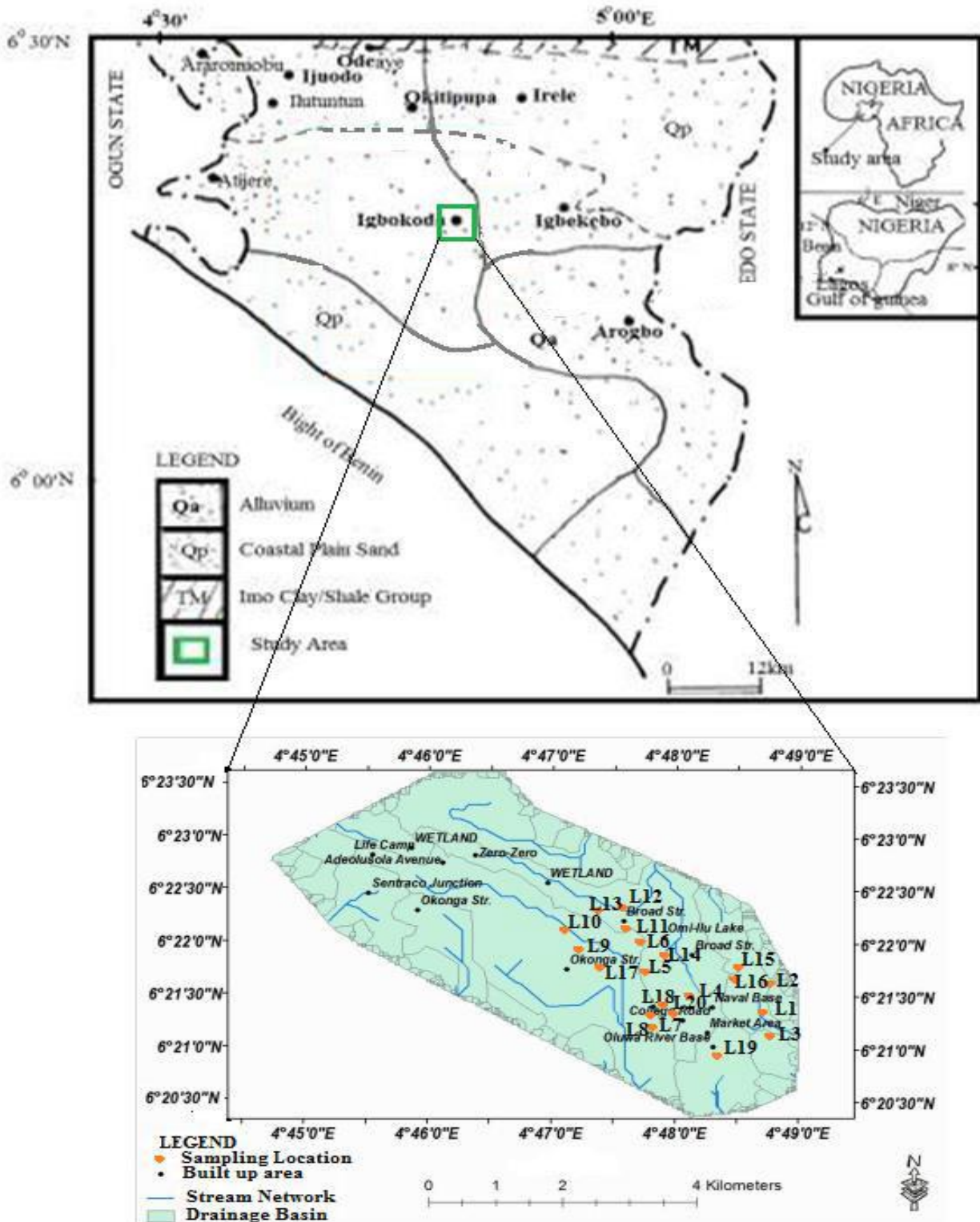


Fig. 1. Location and Geology Map of Study area (after Talabi, 2018)

In the diagram the percentages of either  $\text{Na}^+$  or  $\text{Ca}^{2+}$  with higher concentration in meq/L in the water reproducing the Base Exchange reactions is represented on the abscissa. The ordinate represents the percentages

of anions in which the %Cl<sup>-</sup> represents seawater and the %HCO<sub>3</sub><sup>-</sup> or %SO<sub>4</sub><sup>2-</sup> (depending on the dominant anion is freshwater) characterizes the recharge water. In other words, the %SO<sub>4</sub><sup>2-</sup> and %HCO<sub>3</sub><sup>-</sup> are not summed, but rather are represented by choosing the ion present in higher percentage (e.g. the Na-HCO<sub>3</sub>/SO<sub>4</sub><sup>2-</sup> facies can represent both the Na-HCO<sub>3</sub> facies and the Na-SO<sub>4</sub> facies. If there are waters of both facies then the sample will be represented using the percentage of bicarbonate (if %HCO<sub>3</sub><sup>-</sup> > %SO<sub>4</sub><sup>2-</sup>) or sulphate (if %SO<sub>4</sub><sup>2-</sup> > %HCO<sub>3</sub><sup>-</sup>), and this will be indicated in the centre of the diagram using different symbols. The result is a representation of four heterotopic facies out (Na-HCO<sub>3</sub>, Na-Cl, Ca-HCO<sub>3</sub> and Ca-Cl) of a total of sixteen facies (or 6 out of 24 facies if one takes into account that sulphate and bicarbonate waters can coexist (Chadha, 1999).

### 3. Results

Chemical analysis of groundwater samples from the study area revealed average concentrations (mg/L) of Ca<sup>2+</sup> (25.14), Mg<sup>2+</sup> (3.46), Na<sup>+</sup> (26.12mg/L), K<sup>+</sup> (13.86), HCO<sub>3</sub><sup>-</sup> (1.34), Cl<sup>-</sup> (7.95 mg/L), SO<sub>4</sub><sup>2-</sup> (2.46) and PO<sub>4</sub><sup>3-</sup> (3.64) (Table 1). The result indicated the dominance of alkali metals (Na<sup>+</sup>+K<sup>+</sup>) over the alkaline earths (Ca<sup>2+</sup>+Mg<sup>2+</sup>). The concentration values of all measured parameters fell within approved standard of WHO (2011) and the groundwater may not pose problems for irrigation and domestic uses. However, field observations revealed that the groundwater was coloured (greenish) arisen from continuous impacts of sea weeds. Ternary plots of Mg<sup>2+</sup>-Ca<sup>2+</sup>-(Na<sup>+</sup>+K<sup>+</sup>) and Cl<sup>-</sup>-HCO<sub>3</sub><sup>-</sup>-SO<sub>4</sub><sup>2-</sup> support dominance of alkali metals (Na<sup>+</sup> + K<sup>+</sup>) indicating that 85% of the samples were alkali-rich water (Fig. 2a). As regards the anions, chloride was dominant (80%) while sulphate and the non-dominance zone had 7% and 13% representations respectively (Fig. 2b). Deduction from Figs. 2a and 2b clearly revealed that the groundwater in the study area was dominated by Na- Cl -SO<sub>4</sub> water type.

The average values for the calculated ionic ratios for HCO<sub>3</sub><sup>-</sup>/Cl<sup>-</sup>, Na<sup>+</sup>/Cl<sup>-</sup>, Ca<sup>2+</sup>/Cl<sup>-</sup>, Ca<sup>2+</sup>/Na<sup>+</sup>, Mg<sup>2+</sup>/Cl<sup>-</sup>, K<sup>+</sup>/Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>/Cl<sup>-</sup> and Ca<sup>2+</sup>/Mg<sup>2+</sup> as presented in Table 2 were 0.14, 5.8, 5.08, 1.24, 1.74, 1.87, 1.05 and 0.45 respectively. The ionic ratios plotted against TDS and Cl<sup>-</sup> vs. TDS were presented in Figs. (3a -3h). The plot of Cl<sup>-</sup> vs. TDS gave a correlation coefficient of  $r = 0.79$  (Fig.3h) indicating that Cl<sup>-</sup> contributed substantially to TDS.

Piper Tri-linear diagram (Fig. 4) for groundwater samples from the study area revealed three water types; Na<sup>+</sup>-Cl<sup>-</sup> type, Mixed Ca<sup>2+</sup>-Mg<sup>2+</sup>-Cl<sup>-</sup> type and Ca<sup>2+</sup>- Cl<sup>-</sup> type. It is evident from the piper plot that the Na<sup>+</sup>-Cl<sup>-</sup> type was dominant representing 85% of the water types while Mixed Ca<sup>2+</sup>-Mg<sup>2+</sup>-Cl<sup>-</sup> and Ca<sup>2+</sup>- Cl<sup>-</sup> types have 10% and 5% representations respectively.

The Chadha diagram (Fig. 5) revealed that 90% of the groundwater samples fell into the domain of alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions (Na<sup>+</sup>-Cl<sup>-</sup> type) while the remaining 10% fell into the zone of alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions (Ca<sup>2+</sup>-Mg<sup>2+</sup> -Cl<sup>-</sup> type) respectively.

The HFE-D usually presents four heterotopic facies (Na-HCO<sub>3</sub>, Na-Cl, Ca-HCO<sub>3</sub> and Ca-Cl). The diagram in the present study (Fig. 6) revealed that five samples representing 25% of the groundwater samples fell in the generalized seawater intrusion zone of the aquifer. The facies representations in the zone include Na-Cl type (5%), Mix Ca-MixCl type (10%), MixCa-Cl type (5%) and Ca-Cl type (5%). Three of the groundwater samples were in the freshening phase facies (5% each); Ca-HCO<sub>3</sub>/SO<sub>4</sub>, MixCa-HCO<sub>3</sub>/SO<sub>4</sub> and Na-MixCl while 60% of the groundwater samples fell along the line of mixing (A) (4-7-10-13) indicating simple binary mixing with little or no intervention of Base Exchange reactions (Fig. 6).

### 4. Discussion

The concentration of dissolved ions in groundwater samples are generally governed by lithology, nature of geochemical reactions and solubility of the aquifers rocks (Nosrat et al, 2010). However, in any coastal area, transgression and regression of seawater to and from the coastal aquifers often result into fluctuation in the groundwater chemistry due to mixing of saline water with fresh groundwater. Ionic ratio has been employed for comprehensive study of saltwater intrusion along the coastal aquifers (Barbecot et al., 2000, Kim et al., 2003, Moujabber et al., 2006, Batayneh et al., 2014). Apart from using chemistry of groundwater to study saltwater intrusion, mineralogy of rocks can also be utilized to some extent (Nwankwoala and Udom, 2011). The graphical plots of the ionic ratios vs. TDS were employed to study the ingress of seawater into coastal aquifers in this research (Nwankwoala and Udom 2011, Batayneh et al., 2014, Sridharan and Nathan, 2017). The ratios of HCO<sub>3</sub><sup>-</sup>/Cl<sup>-</sup> in all the samples were greater than that of the seawater ratio of 0.0069 but as indicated in Fig 3a, the ratios tends towards seawater with increasing TDS signifying seawater intrusion. Na<sup>+</sup>/Cl<sup>-</sup> vs. TDS was tending to no

correlation ( $r = 0.04$ ), an indication that both ions were co-existing during intrusive phase of seawater (Batayneh et al., 2014). However, the poor correlation of  $\text{Na}^+/\text{Ca}^{2+}$  vs. TDS (Fig. 3b) is an indication of occurrence of Base ion exchange reactions in the coastal aquifer of the study area.

**Table 1.** Chemical parameters of shallow groundwater of Igbokoda coastal area (after Talabi et al., 2018).

Code	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO <sub>3</sub> (mg/L)	Cl (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)	PO <sub>4</sub> (mg/L)
IGB-1	44.52	4.76	39.75	26.04	1.98	6.88	0.42	0	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	4.5	1.86	0.36	0.86	0.15	4.11	4.18
IGB-4	18.42	1.9	31.5	12.09	1.95	5.63	0.77	0	3.23
IGB-5	9.51	0.98	3.01	1.86	1.63	1.97	0.99	0	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	5.6	46.5	22.32	1.45	10.76	1.34	0	0.84
IGB-8	21.32	2.31	25.5	9.3	1.74	6.89	0.92	0	1.67
IGB-9	54.23	6.49	54.5	16.74	1.79	19.14	1.61	0	4.06
IGB-10	2.14	0.93	7.5	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	5.85
IGB-12	44.47	4.52	29.25	16.74	1.44	15.11	1.68	0	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	1.8	17.25	11.16	1.86	8.02	0.65	0	4.66
IGB-15	0.85	1.27	3.01	1.86	0.29	0.49	0.5	0.94	3.11
IGB-16	2.11	4.99	24.14	16.74	nil	10.14	3.33	3.72	4.9
IGB-17	0.47	0.78	4.5	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	4.78
IGB-19	44.78	5.23	32.85	35.34	1.41	10.92	1.11	0	3.94
IGB-20	35.86	3.05	32.31	21.39	1.82	12.18	1.53	0	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	3.46	26.12	13.86	1.34	7.95	2.46	0.90	3.64

Median	21.94	2.79	24.82	11.63	1.45	7.73	1.05	0.00	3.76
Stdev	20.04	2.61	20.09	10.22	0.57	5.44	5.72	1.33	1.56

In addition, other ionic ratios ( $Mg^{2+}/Cl^-$ ,  $K^+/Cl^-$ ,  $Na^+/Cl^-$  and  $SO_4^{2-}/Cl^-$ ) have negative correlations with TDS indicating enhancement of  $Cl^-$  i.e. decrease in ratio with increase in TDS. Ionic ratios evaluation revealed chloride enhanced groundwater in the study area. The Piper Diagram has been widely used to study the similarities and differences in the composition of waters and to classify them into certain chemical types. In this study, the  $Na^+-Cl^-$  type (85% of the groundwater samples) was in the saline enrichment zone an indication of saltwater intrusion into the coastal groundwater of the study area.

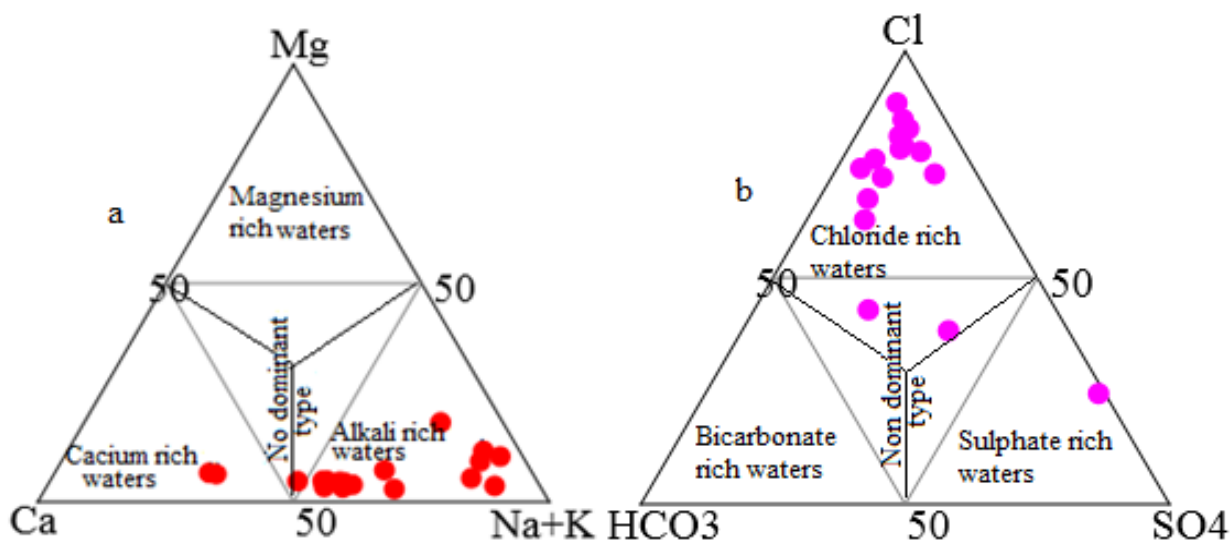


Fig. 2. (a) Na+K–Ca–Mg showing dominant cation and (b).  $HCO_3^-$ – $Cl^-$ – $SO_4$  systems displaying dominant anion

The Mixed  $Ca^{2+}$ - $Mg^{2+}$ - $Cl^-$  was in the mixed zone, where types of groundwater cannot be identified as either anion or cation dominant (Todd and Mays, 2005). However, the  $Ca^{2+}$ -  $Cl^-$  (5%) belongs to the permanent hardness category wherein non-carbonate hardness exceeds 50 %, giving an indication of groundwater from active recharge zone with short residence time (Hounslow, 1995). The Piper diagram deciphered seawater intrusion into the coastal aquifer of the study area in addition to groundwater from active recharge zone with the exception of the non-dominant zone.

Chadha diagram has all the advantages of the Piper diagram and can be used to study various hydrochemical processes including base cations exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water etc (Chadha, 1999). The plotting of Chadha diagram always results into a square or rectangle depending on the size of scale chosen for X and Y co-ordinates. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type as follows:

- i) Alkaline earths exceed alkali metals.
- ii) Alkali metals exceed alkaline earths.
- iii) Weak acid anions exceed strong acid anions
- iv) Strong acid anions exceed weak acid anions

**Table 2.** Calculated Ionic Ratios of Groundwater from Igbokoda Coastal Area.

Code	HCO <sub>3</sub> <sup>-</sup> /Cl <sup>-</sup>	Na <sup>+</sup> /Cl <sup>-</sup>	Ca <sup>2+</sup> /Cl <sup>-</sup>	Ca <sup>2+</sup> /Na <sup>+</sup>	Mg <sup>2+</sup> /Cl <sup>-</sup>	K <sup>+</sup> /Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup> /Cl <sup>-</sup>	Ca <sup>2+</sup> /Mg <sup>2+</sup>	TDS (mg/L)
IGB-1	0.17	8.79	11.32	1.29	2.02	3.40	0.59	0.11	321.60
IGB-2	0.03	9.02	11.50	1.27	2.23	3.54	0.63	0.12	432.82
IGB-3	0.24	7.96	1.40	0.18	2.44	1.94	1.26	1.04	21.44
IGB-4	0.20	8.51	5.73	0.67	0.98	1.93	0.51	0.10	200.33
IGB-5	0.47	2.33	8.45	3.63	1.45	0.85	1.71	0.10	69.01
IGB-6	0.06	4.15	5.12	1.23	0.99	0.90	1.10	0.12	176.21
IGB-7	0.08	6.58	7.64	1.16	1.52	1.86	0.82	0.12	341.47
IGB-8	0.14	5.63	5.42	0.96	0.98	1.21	0.81	0.11	176.21
IGB-9	0.05	4.33	4.96	1.14	0.99	0.78	1.26	0.12	301.50
IGB-10		9.06	2.97	0.33	2.15	4.64	0.46	0.43	58.96
IGB-11	0.06	0.91	4.91	5.39	0.86	0.67	1.29	0.11	158.79
IGB-12	0.05	2.95	5.15	1.75	0.87	0.99	0.88	0.10	348.40
IGB-13		4.64	0.91	0.20	0.63	1.89	0.33	0.42	96.48
IGB-14	0.13	3.27	4.83	1.48	0.65	1.25	0.52	0.08	157.45
IGB-15	0.34	9.35	3.04	0.32	7.56	3.41	2.22	1.49	24.79
IGB-16		3.62	0.36	0.10	1.44	1.48	0.97	2.36	140.03
IGB-17		9.25	1.11	0.12	3.07	1.13	2.73	1.66	21.44
IGB-18	0.05	6.96	4.40	0.63	1.87	0.96	1.94	0.25	481.73
IGB-19	0.07	4.58	7.18	1.57	1.40	2.90	0.48	0.12	319.59
IGB-20	0.09	4.04	5.15	1.28	0.73	1.58	0.46	0.09	272.02
Min	0.03	0.91	0.36	0.10	0.63	0.67	0.33	0.08	21.44
Max	0.47	9.35	11.50	5.39	7.56	4.64	2.73	2.36	481.73
Mean	0.14	5.80	5.08	1.24	1.74	1.87	1.05	0.45	206.33
Median	0.08	5.14	5.04	1.15	1.42	1.53	0.85	0.12	176.21
Stdev	0.12	2.66	3.09	1.27	1.53	1.12	0.66	0.65	140.07

v) Alkaline earths and weak acid anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness.

vi) Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit sodium carbonate in irrigation.

vii) Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses.

viii) Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions.

Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. In the present research, the waters of the study area have been categorized into  $\text{Na}^+\text{-Cl}^-$  type (90%) and  $(\text{Ca}^{2+} \text{-Mg}^{2+} \text{-Cl}^-)$  type (Fig. 5). The  $\text{Na}^+\text{-Cl}^-$  water type generally creates salinity problems both in irrigation and drinking uses. Excessive amounts of dissolved salts are detrimental to practically all water uses especially when it is as a result of seawater encroachment into the coastal area. Many strategic scientific approaches may be required to ameliorate salt effects on drinking and irrigation uses.

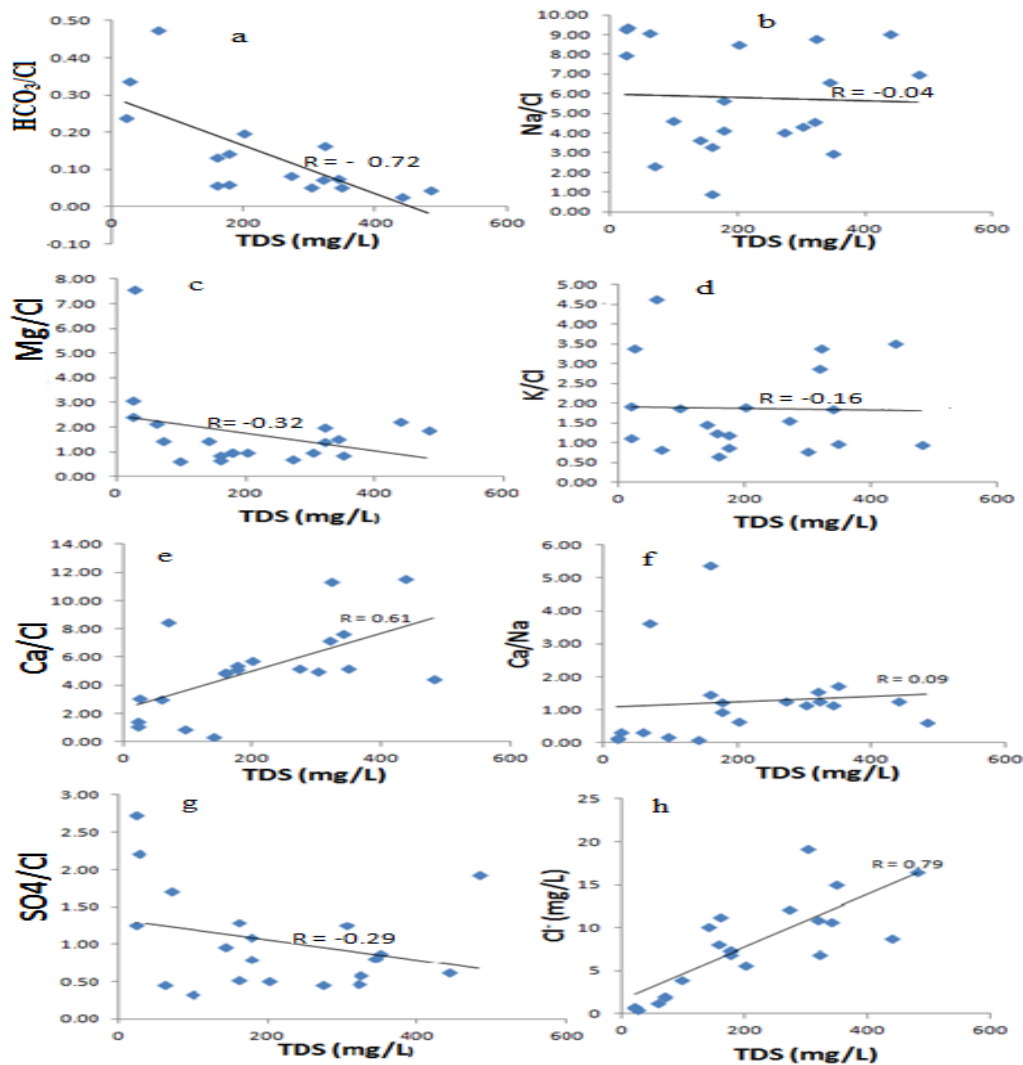


Fig.3. Plot of ionic ratios vs. TDS



As for drinking purpose, water softening and use of treatment plants can be adopted. However, for irrigation purpose, the following six methods have been suggested; keeping basin water level high, creating a fresh water ridge near sea, creating pumping trough or extraction barrier trough, developing artificial subsurface barriers, adopting rainwater harvesting technology and artificial recharging structures and implementing aquifer improvement plans (Maity et al., 2018). In addition to this listed suggestions, a comprehensive salinity management policy is necessary in Nigeria to address salinity issues that adversely impact water within its coastal environment. The remaining 10% fell into the zone of alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. The  $Ca^{2+}$ - $Mg^{2+}$ - $Cl^-$  type signifying reverse ion exchange in the samples of the zone. Such water will have a permanent hardness (non-carbonate hardness exceeds 50 %) and does not deposit residual sodium carbonate in irrigation use.

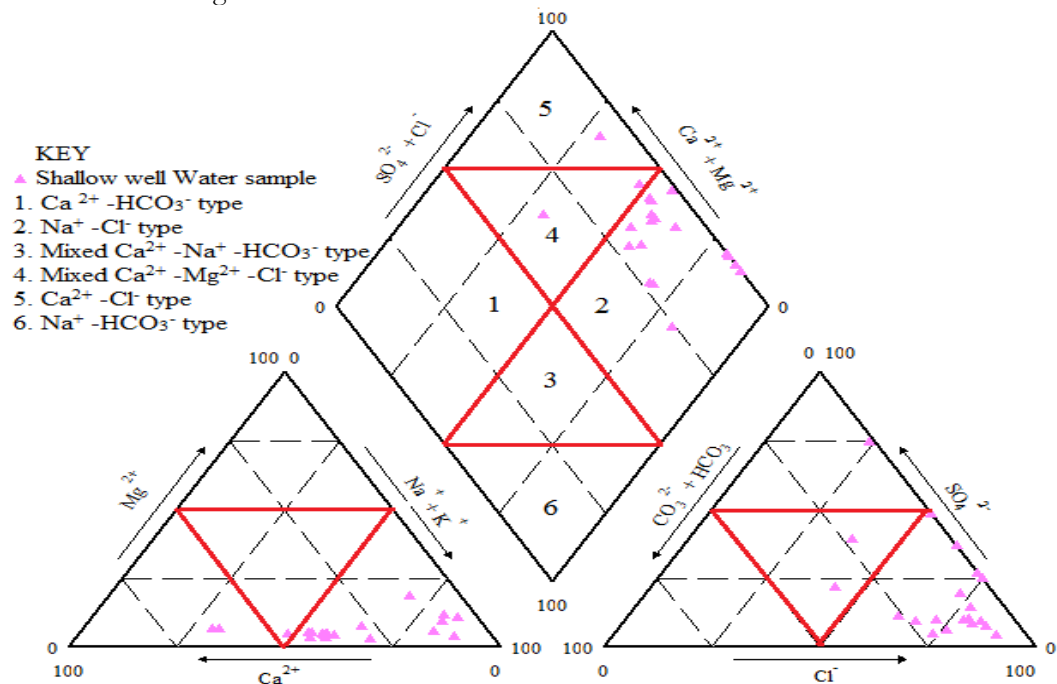


Fig. 4. Piper Trilinear Diagram

In addition, the occurrence of this facies ( $Ca^{2+}$ - $Cl^-$ ) facies confirmed seawater intrusion as the facies is recognized as the clearest feature of the advance inland of the saline wedge, while the  $Na^+$ - $HCO_3^-$  facies characterizes the freshening phase (Giménez-Forcada, 2010). The Chadha diagram without doubt confirmed the Piper diagram but was able to categorize the water into two major water types without the ambiguity of non dominant zone.

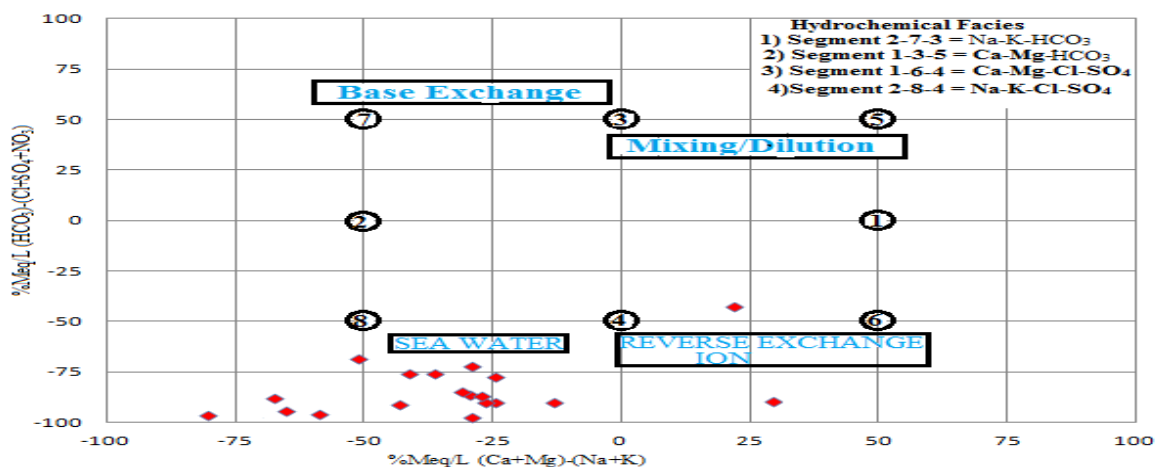


Fig. 5. Chadha (1999) Plot for groundwater of the study area

The Hydrochemical Facies Evolution Diagram (HFE-D) was plotted to ascertain whether the aquifer is in the phase of seawater intrusion or freshening, indicating the status of the aquifer in terms of the advance or regression of the saline front. Al-Agha and El-Nakhal, (2004), confirmed that integrating the interpretation of the phases of freshening and intrusion in the central diamond-shaped field of the Piper diagram gave an evolutionary trend for each stage of the process (intrusion and freshening), but it was difficult to recognize the sequence of the facies in detail and therefore the succession and interpretation of processes. In contrast, this is possible using the HFE-D. The HFE-D recognized the sequence of the facies in detail and therefore the succession and interpretation of processes in contrast to Piper and Chadha diagrams.

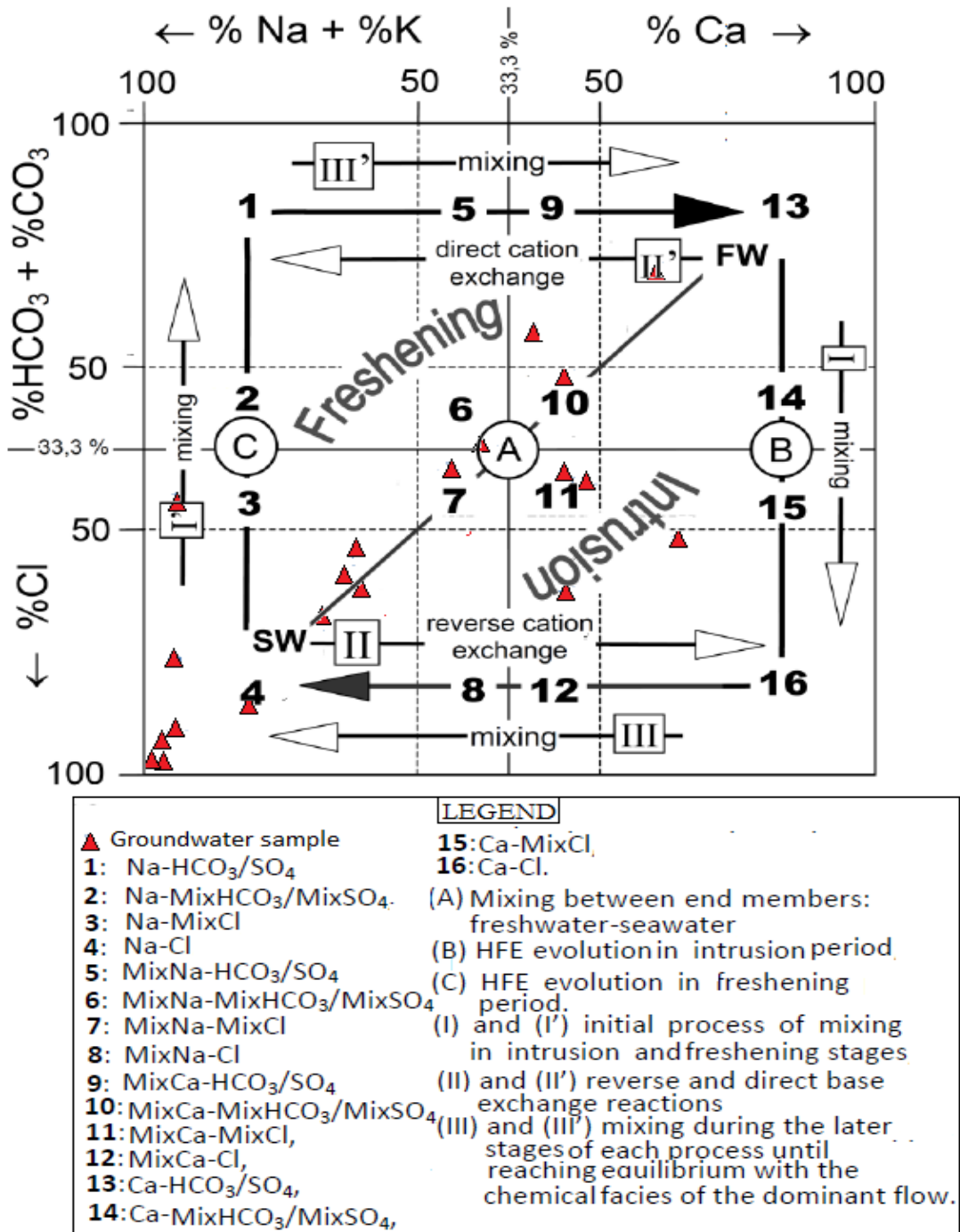


Fig. 6. Hydrochemical Facies Evolution Diagram (HFE-D) showing the main processes occurring in intrusion and freshening stages of groundwater in the study area.

## 5. Conclusion

In the present investigation, hydrochemical techniques (ionic ratios, Piper Trilinear diagram, Chadha plot and HFE-D) have been used to discriminate the various hydrochemical facies in the coastal area of Igbokoda and the dynamic character of sea water intrusion. Ionic ratios of  $\text{HCO}_3^-/\text{Cl}^-$ ,  $\text{Na}^+/\text{Cl}^-$ ,  $\text{Ca}^{2+}/\text{Cl}^-$ ,  $\text{Ca}^{2+}/\text{Na}^+$ ,  $\text{Mg}^{2+}/\text{Cl}^-$ ,  $\text{K}^+/\text{Cl}^-$  and  $\text{SO}_4^{2-}/\text{Cl}^-$  in meq/L were calculated and plotted against TDS showed the signature of seawater influx along the coastal aquifers of the study area. Ternary plot of Na+K–Ca–Mg and  $\text{HCO}_3^-$ –Cl– $\text{SO}_4$  revealed alkali metals as dominant cations while chloride dominated the anions. The Piper diagram revealed three groundwater facies; dominant  $\text{Na}^+$ -Cl type, Mixed  $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$ -Cl type and  $\text{Ca}^{2+}$ -Cl type. The Chadha diagram revealed two main water facies;  $\text{Na}^+$ -Cl type and  $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$ -Cl type. The Chadha diagram confirmed the Piper diagram without the ambiguity of non dominant zone. The HFE-D confirmed seawater intrusion into the coastal area of Igbokoda indicating that majority of the groundwater samples were in the simple binary mixing zone with little or no intervention of Base Exchange reactions. The Piper and Chadha diagrams as well as the HFE-D showed evidence of seawater ingression of the coastal aquifer of the study area. However, the HFE-D recognized the sequence of the facies in detail and therefore the succession and interpretation of processes in contrast to Piper and Chadha diagrams.

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