African Journal of Basic & Applied Sciences 3 (6): 271-277, 2011
ISSN 2079-2034

Hydrochemical and Suitability Evaluation of Groundwater in Bonny Island, Eastern Niger Delta

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Abstract: A hydrochemical and suitability appraisal of groundwater in Bonny Island, Eastern Niger Delta, Nigeria, has been carried out. Twenty three groundwater samples were analysed for their physical and chemical properties using standard laboratory methods. The constituents have the following ranges in the water: pH 6.40 - 7.23 (mean 6.56), conductivity 67.81 - 170.23uS/cm (mean 108.33uS/cm), hardness 3.00 - 22.47mg/l (mean 11.82mg/l), TDS 28.77 - 130.33mg/l (mean73.01mg/l). For the cations, Ca^{2+} 6.21 - 27.04mg/l (mean 14.63mg/l), Na^{+} 3.25 - 24.24mg/l (mean 8.06mg/l), Mg^{2+} 2.78 - 54.19mg/l (mean 14.02mg/l), K^{+} 1.08 - 23.23mg/l (mean 3.44) and Fe 0.05 - 0.48mg/l (mean 0.27mg/l). For the anions, HCO_{3-} 42.50 - 98.10mg/l (mean 76.72mg/l), Cl^{-} 6.51 - 41.01mg/l (mean 29.78mg/l) and SO_4^{2-} 3.00 - 14.91mg/l (mean 6.92mg/l). Na^{+} and K^{+} ions are lower than Ca^{+} and Mg^{2+} in the water. They show mean concentrations of 8.06mg/l for Na^{+} and 3.44mg/l for K^{+}. The concentration level of Na^{+} is lower than the permissible level of 200mg/l by WHO (2006) in all the locations. Thus, the groundwater in the area is safe in view of this parameter. Result also reveals that there is iron contamination at BH1, BH3, BH7, BH11, BH12, BH13, BH14, BH17, BH18 and BH23. The water at these locations should be treated otherwise it could cause objectionable tastes and could stain plumbing fixtures and laundered clothes. Aeration and filtration method could be a suitable treatment method. Results also show that Bicarbonate ions (HCO^{3-}) dominate the other anions (Cl^{-} and SO_4^{2-}). Bicarbonate ion has a maximum value of 98.10mg/l and a minimum value of 42.50mg/l, with a mean value of 76.72mg/l. The level of Chloride in the water averages 29.78mg/l with a minimum value of 6.51mg/l and a maximum of 41.01mg/l. At BH10 and BH18, the concentration of Chloride is above 40mg/l. This shows salt water encroachment in those locations and this is probably due to the closeness of these locations to the sea. From the trilinear plots, the hydrogeochemical facies of the area show that the area is characterized by two major types of groundwater: facie-1 (Calcium-Bicarbonate) and facie-2 (Magnesium). However, the Ca-HCO_3 facies dominate the Mg facies. The latter is only noticed in boreholes where there is saltwater encroachment. It is recommended that there should be regular groundwater quality monitoring in the area.

Key words: Water quality · Groundwater · Hydrochemistry · Aquifer · Bonny · Niger Delta

INTRODUCTION

The deterioration of water quality in the coastal areas due to saltwater intrusion into the freshwater aquifer has become a major concern [1-4]. The Niger Delta Island, which depend on groundwater for domestic purposes are particularly affected by saltwater intrusion [5].

Many communities in the eastern Niger Delta are facing an acute shortage of potable water because of the surrounding expanse of seawater and tidal creeks. Increasing population in the areas and the resulting increase in groundwater consumption has added to the problem, as seawater intrudes further inland in response to pumping. Other external influences such as tides and recharge events cause changes in the interface, thereby reducing the available freshwater resource [5, 6].

In Bonny Island, freshwater is not easily accessible because of high iron content as well as saline water intrusion in the area. A lot of boreholes have been abandoned in the area as a result. The huge Nigeria Liquified Natural Gas Project hosted in the Island as well as other industrial activities whose waste disposal practices in the area could be responsible for the degradation of the groundwater quality and thus, affecting suitability of the groundwater as a source for human consumption. Consequently, reported cases of

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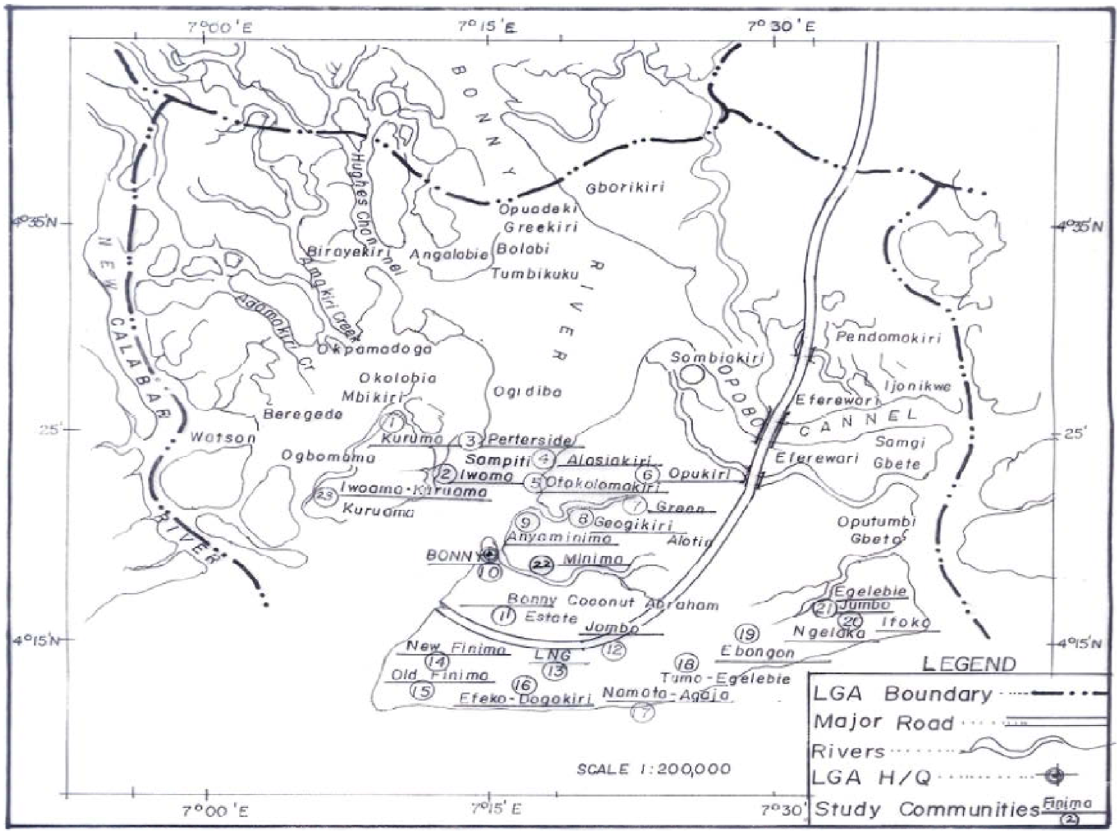

Fig. 1: Map of Bonny Island showing sampled Borehole locations

saline water intrusion, resulting to abandonment of some boreholes in the area have been on the increase. In view of this, it is important to ascertain the groundwater quality of the area for domestic and other uses. In this paper, a serious attempt is made to assess the suitability of groundwater in the area for domestic purposes as well as evaluate the different water types.

Geology/hydrogeology of the Area: Bonny Island (Fig. 1) falls within the Beach ridges on-shore geomorphic sub-environment of the Niger Delta. Geologically, these comprise Pleistocene and Recent sediments deposited by fluvial and shallow continental shelf hydrodynamic processes. The area is characterized by strong wave and tidal action, which further compacts the sediments. Plant growth on beach ridges over the years has resulted in the formation of extensive primary tropical freshwater forest. Energy conditions decrease from shore face to outer edge. The litho facies include the delta tip, mainly evenly laminated fine to medium sand.

The hydrogeology of the area is highly influenced by the presence of ferruginous sandy formation due to high oxidation condition of the near surface aquifers and predominant saline water intrusion. The sand forms the major aquifer in the area while the clay forms the aquitards. The water table in the area varies with season. The area has a declining water table during the dry season. Generally, water table ranges between 0.1 (surface) - 3m depending on the season. Water table in the area is dynamic with reversal tidal influence. Generally, the Delta is characterized by three formations, namely Akata (oldest), Agbada and Benin (youngest). These formations consist primarily of regressive Tertiary age sediments. The detailed geology of the Niger Delta formation is given by Reyment [7] and Short and Stauble, [8].

MATERIALS AND EMTHODS

Sampling and Chemical Analysis: Groundwater samples were collected in clean 1000 ml plastic bottles. Borehole samples were got from the closest taps to the wellheads. The boreholes are all used for drinking water supply, except for few which yield saline groundwater and few others which yields odorous groundwater. The taps were run for sometime until the temperature of the water

Table 1: Summary of the Analytical Methods

Parameters	Analytical Methods
Colour	Lovibond Comparator
Electrical Conductivity	Conductivity meter (MarkV Electronic Switchgear)
pH	pH Meter (Bromthymol Blue pH Kit)
Hardness Cl^-, HCO_3^-, Ca^{2+}, Mg^{2+}	Titration
Na^+, K^+	Flame Photometric
Fe^{2+}	Colorimetric
TDS, SO_4^{2+}, Mn^{2+}	Gravimetric

remained constant before samples were taken. This was to ensure collection of representative samples from the aquifer. After each sampling, the bottle was capped immediately to minimize oxygen contamination and the escape of dissolved gases. The samples were then carried in ice-packed coolers to the laboratory for analysis within 24 hours. However, on-site analyses comprised temperature, electrical conductivity (EC) and pH because of their unstable nature. The methods of analyses are summarized in Table 1 below:

RESULTS AND DISCUSSION

The quality of any water resources is its suitability for the intended use. This thus, is a function of the physical, chemical and biological (bacteriological) characteristics of the water which in turn depends on the geology of the area and impacts of human activities [9]. The results of the laboratory measurements of pH, conductivity, hardness and total dissolved solids (TDS), as well as major ions (Ca, Na, Mg, K, Fe, HCO_3, Cl and SO_4) are presented in Table 2. These constituents have the following ranges in the water: pH 6.40 - 7.23 (mean 6.56), conductivity 67.81 - 170.23uS/cm (mean 108.33uS/cm), hardness 3.00 - 22.47mg/l (mean 11.82mg/l), TDS 28.77 - 130.33mg/l (mean73.01mg/l).

The pH range of 6.40 - 7.23 shows slightly acidic to slightly alkaline groundwater in the area. WHO [10] puts the acceptable range of pH in drinking water at 6.5 -8.5. With respect to this standard, groundwater samples in BH5, BH7 and BH9 need treatment to raise the pH to at least 6.5. This can effectively be achieved with the base-exchange method using dolomite. The slight acidity in groundwater in the area may be due to the oxidation of dissolved ferrous iron or the presence of organic matter in the soil, or it could even be associated with gas flaring in the area [11]. This phenomenon releases CO_2 into the atmosphere and during precipitation, this gas can enter the groundwater system as the rainwater percolates underground to reduce pH. Acidic waters promote the growth of iron bacteria which cause incrustation of pipes.

Results of the study reveals that the Electrical Conductivity (EC) values range between 67.81 - 170uS/cm with a mean value of 108.33uS/cm. These values are lower than the stipulated value of 1400uS/cmby WHO [10] in drinking water. Electrical conductivity up to 2000uS/cm is permissible for irrigation [12] hence the water would not be injurious to crops in the area. According to Langenegger [13], the importance of EC is its measure of salinity, which greatly affect the taste and thus has a significant impact on the users' acceptance of the water as potable. The Total Hardness values (Table 2) show soft groundwater in the area when compared with the classification scheme by Dufor and Becker [14]. The water is not likely to have any adverse reaction with soap. The subject of health in relation to hardness has been discussed by Muss, [15] Neri *et al*. [16] and Hopps [17]. These authors tend to support the hypothesis that there is greater incidence of heart disease in areas with soft water than those with hard water due to reduced magnesium content. However, this apparent correlation is affected by other factors such as low alkalinity and high sulfate content of the water, thereby making the postulation doubtful. Total Dissolved Solids (TDS) show values in the range of 28.77 -130.33mg/l, with an average of 73.01mg/l. These values are within acceptable limits. Values up to 500mg/l are satisfactory for domestic purposes [18].

Cations Distribution: The cations determined in this study include Fe^{2+}, Ca^{2+}, Mg^{2+}, Na^+ and K^+ with Mg^{2+} and Ca^{2+} dominating with respective average concentrations of 14.02mg/l and14.63mg/l, respectively. However, their concentration levels are below the stipulated 150mg/l for Magnesium and 500mg/l (as $CaCO_3$) for Calcium [10], showing that the water is potable in view of these parameters. These low values are correlatable to low hardness values in the area because Ca and Mg are the constituents which cause hardness in water. Calcium in the water probably owes its origin from the silicates and feldspars which characterize the Coastal Plain Sands where the boreholes tap water from, while Magnesium

Table 2: Concentration of Constituents in Groundwater in the Study Area

Borehole	pH	EC (μS/cm)	Hardness (mg/L)	TDS (mg/L)	Ca^{2+} (mg/L)	Na^{+} (mg/L)	Mg^{2+} (mg/L)	K^{+} (mg/L)	Fe^{2+} (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)
BH1	7.00	102.11	11.30	60.81	12.31	3.00	4.34	4.72	0.32	68.30	17.17	11.04
BH2	6.92	93.20	6.45	40.01	9.50	5.60	4.67	2.67	0.11	51.31	6.91	4.33
BH3	6.81	98.31	7.81	78.30	12.00	5.40	3.78	1.55	0.35	72.50	12.03	5.72
BH4	6.55	101.22	9.77	56.79	10.20	7.83	6.81	3.71	0.10	81.33	7.91	3.00
BH5	6.40	73.40	13.42	52.84	6.21	3.55	2.78	1.09	0.22	63.20	20.10	4.91
BH6	6.72	90.81	10.71	97.32	6.78	4.24	4.77	2.04	0.08	54.54	11.80	9.02
BH7	6.44	134.50	9.91	83.00	15.17	6.11	5.33	1.98	0.45	42.50	14.20	4.77
BH8	6.93	120.17	2.35	70.51	9.34	4.38	4.21	23.23	0.23	98.10	15.31	3.72
BH9	6.33	97.78	10.53	82.17	6.80	7.27	6.73	4.05	0.05	71.05	37.07	3.40
BH10	6.72	117.21	3.00	88.41	11.31	6.54	7.22	2.37	0.21	80.21	41.01	14.01
BH11	6.88	124.00	7.10	90.01	6.88	5.44	5.66	1.06	0.52	64.16	32.01	3.78
BH12	6.81	107.55	10.80	110.22	20.04	4.50	4.52	1.57	0.32	66.15	24.25	14.91
BH13	6.93	150.18	22.30	98.30	18.12	15.70	52.31	3.73	0.48	69.16	18.80	10.33
BH14	7.21	130.11	21.03	90.00	11.23	14.00	33.11	3.61	0.31	82.17	23.01	14.08
BH15	7.13	71.71	12.40	31.81	9.34	5.72	8.11	1.97	0.24	89.13	15.40	3.40
BH16	7.22	67.81	17.93	28.77	10.33	4.33	7.20	2.05	0.28	55.30	29.30	5.00
BH17	7.23	80.57	16.37	36.74	6.66	3.25	6.47	2.24	0.39	62.61	37.90	4.80
BH18	7.10	104.79	6.21	81.78	8.91	5.70	3.09	1.79	0.46	70.12	40.11	4.01
BH19	7.09	95.60	8.48	79.14	11.10	3.92	5.50	3.71	0.06	88.30	22.50	11.00
BH20	6.83	98.41	6.70	82.91	21.52	4.22	6.63	2.03	0.28	99.01	35.60	4.05
BH21	6.60	108.57	8.41	108.00	24.31	22.81	37.81	4.22	0.24	48.91	11.92	3.10
BH22	6.73	170.23	22.47	130.33	27.04	24.24	54.19	2.01	0.20	64.31	6.51	10.34
BH23	6.57	153.40	17.94	120.04	23.17	23.10	52.70	1.78	0.37	98.07	20.50	6.50
MAX	7.23	170.23	22.47	130.33	27.04	24.24	54.19	23.23	0.48	98.10	41.01	14.91
MIN	6.40	67.81	3.00	28.77	6.21	3.25	2.78	1.08	0.05	42.50	6.51	3.00
MEAN	6.54	108.33	11.82	73.01	14.63	8.06	14.02	3.44	0.27	76.72	29.78	6.92
WHO 2006	6.5-8.5	1400.00	500.00	1000.00	500as $CaCO_3$	200.00	150.00	-	0.30	-	250.00	400.00

For the cations, Ca^{2+} 6.21 - 27.04mg/l (mean 14.63mg/l), Na^{+} 3.25 - 24.24mg/l (mean 8.06mg/l), Mg^{2+} 2.78 - 54.19mg/l (mean 14.02mg/l), K^{+} 1.08 - 23.23mg/l (mean 3.44) and Fe 0.05 - 0.48mg/l (mean 0.27mg/l). For the anions, HCO_{3-} 42.50 - 98.10mg/l (mean 76.72mg/l), Cl^- 6.51 - 41.01mg/l (mean 29.78mg/l) and SO_4^{2-} 3.00 - 14.91mg/l (mean 6.92mg/l)

could come from ferromagnesian minerals in the adjoining Oban Massif, or partly fro the sea. Na^+ and K^+ ions are lower than Ca^+ and Mg^{2+} in the water. They show mean concentrations of 8.06mg/l for Na^+ and 3.44mg/l for K^+. The concentration level of Na^+ is lower than the permissible level of 200mg/l by WHO [10] in all the locations (Table 2). Thus, the groundwater in the area is safe in view of this parameter. The limit for K^+ is not stated by WHO [10] for domestic water. Sodium and potassium could be derived from the feldspars also. Total Fe ranges in concentration from 0.05 to 0.48mg/l. WHO [10] standard for iron in water meant for drinking is 0.3mg/l. A comparison of the results (Table 2) with this standard shows that there is iron contamination at BH1, BH3, BH7, BH11, BH12, BH13, BH14, BH17, BH18 and BH23. The water at these locations should be treated otherwise it could cause objectionable tastes and could stain plumbing fixtures and laundered clothes. Aeration and filtration method could be a suitable treatment method. Here the water is exposed to the atmosphere so that Fe^{2+} could oxidize to Fe^{3+} and precipitate ferric-hydroxide which is then filtered out. The primary source of the iron in the water is geologic. Iron is abundant in iron-bearing minerals of igneous, metamorphic and sedimentary rocks. Thus, it could be derived from the minerals like goethite, haematite and limonite in the Benin Formation or from the plant debris in the alluvial soils.

Anions Distributions: Results of this study show that Bicarbonate ions (HCO_3^-) dominate the other anions (Cl^- and SO_4^{2-}). Bicarbonate ion has a maximum value of 98.10mg/l and a minimum value of 42.50mg/l, with a mean value of 76.72mg/l. the limit of this parameter is not stated by WHO [10]. Bicarbonate owes its source to CO_2 from the atmosphere and activity of biota in the soil. The level of Chloride in the water averages 29.78mg/l with a minimum value of 6.51mg/l and a maximum of 41.01mg/l. At BH10 and BH18 (Table 2), the concentration of Chloride is above 40mg/l. This shows salt water encroachment in those boreholes (locations). This is probably due to the closeness of these boreholes (locations) to the sea. Chloride contents of 40mg/l and above are indicative of salt water contamination [19]. At these two boreholes, Ca/Mg and Na/Cl ratios are low. These ratios are below fresh water of 1.00. Salt water contamination is a common groundwater pollution problem in most coastal areas of the world, particularly where there is over abstraction of groundwater from the hinterland, causing the saltwater-freshwater interface to move inland. This problem had earlier been identified in other parts of Rivers State by Udom *et al*. [20], Ngerebara & Nwankwoala [21], Nwankwoala *et al*. [22], Nwankwoala and Udom [23]. The concentration level of Sulphate in the water is low 3.00 - 14.91mg/l compared to WHO [10] standard. These very low concentrations of sulphate suggest absence of any abuse of the water by septic tanks in the area. The Sulphate probably owes its source in the area to industrial waste from adjoining areas.

Evolution of Groundwater: The evolution of the groundwater in the study area can be explained by the order of encounter as stated by Freeze & Cherry [24]. The theory states that the order in which groundwaters encounter strata of different mineraological compositions can exert an important control on the final water chemistry. As groundwater flows through strata of different mineralogical composition, the water composition undergoes adjustments caused by imposition of new mineralogically controlled thermodynamic constraints.

Basically, the Niger Delta water resources are drawn from the Eastern littoral, hydrological and the Niger South hydrological zones. Infiltration and percolation processes from these broad recharge network flow southwards into the underlying aquifers of the Benin Formation beneath the Continental Shelf [21]. Both the structural and stratigraphic setting of the Niger Delta favours hydraulic gradient flow towards the coast and hence into the Continental Shelf. This forms the basis of most freshwater aquifers located within the Continental Shelf. The general rainfall pattern in the Niger Delta ensures a permanent supply of water to the region.

The Niger Delta Sedimentary Basin extends across Bonny Island. Stratigraphically, the Basin is made up of the following Formations: Benin, Agbada and Akata in order of increasing age. The geology of the regressive Tertiary age sediments in these formations has been extensively discussed by Reyment [7], Allen [25] and Short & Stauble [8]. The Benin Formation (Coastal Plain Sands) consists of freshwater continental (fluiviatile) sands and gravel with occasional shally intercalations towards the base and an overall thickness ranging from 0 to about 2130m in the Niger Delta [26]. It is Miocene to Recent in age. In Bonny, this formation is characterized by alluvial deposits near the creeks and the sea.

Hydrogeochemical Facies: The concept of hydrogeochemical facies has been used [27, 28] to denote the diagnostic chemical character of water solutions in hydrologic systems. The facies reflect the effect of chemical processes occurring between the minerals of the lithologic framework and groundwater [29]. The subsequent flow patterns modify the facies and control their distribution. Piper [30] Trilinear diagram was used to classify groundwater types in the area. It permits the cation and anion compositions of many samples to be presented on a single graph in which major groupings or trends in the data can be discerned visually [24].

From the trilinear plots (Fig. 2) of the major cations and anions, the hydrogeochemical facies of the area show that the area is characterized by two major types of groundwater: facie-1 (Calcium-Bicarbonate) and facie-2 (Magnesium). However, the Ca-HCO_3 facies dominate the Mg facies. The latter is only noticed in boreholes where there is saltwater encroachment.

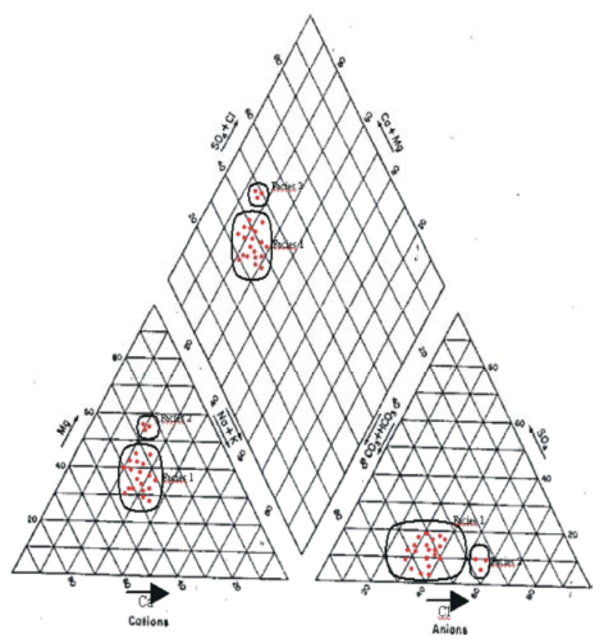

Fig. 2: Piper Trilinear plots of the major cations and anions in the samples in the study area

CONCLUSION

- The results of this study have revealed that the groundwater in the area is soft and low in dissolved constituents and suitable for drinking and other domestic purposes if treated for iron and acidity.
- Since pH values in the area show slightly acidic to slightly alkaline groundwater, polyvinyl chloride (PVC) pipes and other non-corrosive materials should be used for borehole construction in the area because acidic waters can be very aggressive [31].
- The effects of salt water intrusion in the coastal parts of the Niger Delta Sedimentary Basin are felt in this study. The high Chloride (up to 40mg/l) noticed at two locations as well as low Ca/Mg and Na/Cl are indicative of salt water encroachment in the area, hence saltwater-freshwater interface should be delineated in the area.
- Trilinear plots of the results show two hydrochemical facies in the area: a dominant Ca-HCO_3 facies and a less prominent Mg-facies where the boreholes are contaminated with salt.

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