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Groundwater quality assessment in parts of Eastern Niger Delta, Nigeria

Abstract Hydrogeochemical analyses were carried out on groundwater samples collected from 20 producing wells in different parts of the Eastern Niger Delta. Results show that the concentrations of the major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, SO_4^{2-}, HCO_3^-) are below the World Health Organization (WHO) standards set for domestic purposes. The occurrence of slightly saline water in certain areas is attributed to local hydrogeological processes occurring in the area. On the basis of the analytical results, two hydrogeochemical facies are delineated. These are calcium-magnesium-chloride-sulfate-bicarbonate (Ca-Mg-Cl-SO_4-HCO_3) and calcium-sodium-chloride-sulfate-bicarbonate (Ca-Na-Cl-SO_4-HCO_3) to the west and east of the study area, respectively.

Introduction

Akwa Ibom State (Fig. 1) has experienced tremendous population, industrial, and agricultural growth since it was created in 1987. The population has increased steadily from about 1.7 million in 1980 to about 2.3 million in 1991. This growing population and the increased industrial activities have gone hand in hand with the deterioration of groundwater resources. As a prelude to understanding and predicting the impact of future water development plans on the quality of water in the area, it is necessary to evaluate the hydrogeochemistry of the main source of drinking water in the area.

In this paper, an attempt is made to evaluate the different groundwater types and their suitability for domestic purposes. The study area (Akwa Ibom State) is located between latitude 4°30′ and 5°30′N and longitude 7°30′ ad

8°15′E (Fig. 1). It is characterized by a humid tropical climate (high temperature, humidity, and precipitation).

Generally, the seasons are marked by fluctuations of precipitation, the highest fainfall occurring between April and October (230–390 mm/mo) and the lowest between November and March (35–169 mm/mo).

The surface drainage basin within the study area is made up of three main catchment areas (Tahal 1980). These include the Qua Iboe River, the basin of which drains the western parts of the area, and Enyong Creek, which drains the northern parts. The southeastern part is drained by the Ikpo and Cross rivers.

Geology and hydrogeology

The area extends across parts of two Nigerian sedimentary basins, the Niger Delta and the Calabar Flank. The detailed geology of these basins is given elsewhere (Short and Stauble 1967; Murat 1972; Assez 1976; Kogbe 1976; Petters and Ekweozor 1982; Ramanathan and Fayose 1988).

The Niger Delta, which occupies more than 80 percent of the area is made up of the Akata Formation (shales, intercalated sands and siltstone), the Agbada Formation (sands and sandstones, intercalated with shales) in the middle, and the Benin Formation (coarse-grained, gravelly sands with minor intercalations of clays) at the top. However, only the Benin Formation is exposed in the study area.

The Calabar Flank consists mainly of the Albian Awi Formation (conglomeritic sandstone), the Albian Mfamosing Limestone Formation, and the Cenomanian–Santonian Nkalagu Formation (shales intercalated with sandstones). The Lower Campanian to Maastrichtian sediments consist mostly of dark shale with lenses of gypsum, limestone, and siltstone beds, while the lower Tertiary Sediments are mostly shales with minor limestone and sandstone. Only the Lower Campanian to Lower Tertiary sediments outcrop in the study area. The stratigraphic setting in the area is shown in Table 1.
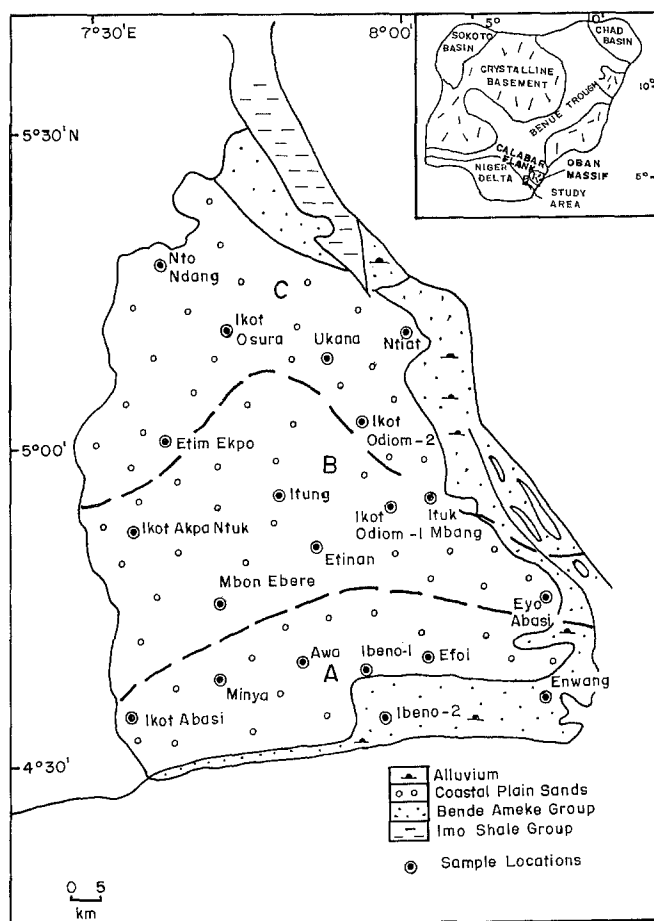
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Fig. 1. Study area showing sample locations, geology, and hydrogeological units

Aquifer(s)	Approximate thickness (m)
Alluvial Deposit	20
Coastal Plain Sands	80–200
Imo Shale Aquiclude	40
Lower Sand	20

Presently, only the Coastal Plain Sand aquifer is being tapped. Some hydrogeological data for this unit are as follows: total depth of boreholes, 42–172 m; saturated thickness of aquifer, 39–100 m; static water level, 1–55 m; Yield, 216–5304 m^3/d; transmissivity, 200–8300 m^2/d; hydraulic conductivity, 2–28 m/d; drawdown, 1.2–42.5 m; and storage coefficient, 0.10–0.30.

Tahal (1980) divided the area into three major hydrogeological units on the basis of static water levels (SWL) (Fig. 1): area A, < 20 m; B, 20–50 m; C, > 50 m. The main flow directions of the Coastal Plain aquifer are to the south and southwest.

Hydrochemistry

Groundwater samples were collected from 20 locations (Fig. 1) for analyses. The water samples were collected in clean 200-ml polyethylene plastic bottles and stored in a cooler for 24 h. Two samples were collected from each location; one was acidified with nitric acid for anion determination. Electrical conductivity, pH, and temperature of the samples were determined in the field. The electrical conductivity was estimated with the aid of a Mark V Electronic Switchgear conductivity meter and the pH by a visual comparison with Hach and permanent glass color standards using an appropriate comparator with standard indicators.

Analyses for the cations Na^+, K^+, Ca^{2+}, Mg^{2+}, total Mn, and total Fe was carried out by using a Perkin-Elmer atomic absorption spectrophotometer (model 1100). The anions SO_4^{2-}, Cl^-, and HCO_3^- were analyzed using a Dionex ion chromatograph 2000i.

The Benin Formation (Coastal Plain Sands), which covers about 80 percent of the area, forms the major aquiferous layer. Lithologically, it is made up of coarse- to medium-grained loose sands and gravels. Thin clay horizons and lenses occur in places disturbing the vertical and horizontal disposition of the aquifer, giving rise to a multiaquifer system. The aquifer may reach about 300 m in thickness. This aquifer is underlain by a thick shale (aquiclude) in the northern sector. A lower sand aquifer underlies the aquiclude (Table 1). The Alluvial Deposit aquifer overlies the Benin Formation in the southern parts of the area. The thickness of these aquiferous layers varies from place to place. However, a typical borehole section reveals the following:

Results and discussion

The results of the chemical analyses are presented in Table 2. Table 3 shows the range in values of each ion and the World Health Organization standards.

Table 1. Stratigraphic relations of geologic units in the area, including type of aquifers

Age	Formation	Aquifer
Recent	Alluvium Beach ridges	Alluvial Deposit Aquifer
Pliocene–Pleistocene	Benin Formation or Coastal Plain Sands	
Oligocene–Moicene		Coastal Plain Sand Aquifer
Late Eocene	Ogwashi-Asaba or Lignite Formation	
Middle Eocene	Bende-Ameke Group	
Early Eocene–Paleocene	Imo Shale Group	Aquiclude
Maastrichtian	Nsukka Formation Ajali Sandstone	Lower Sand Aquifer

Table 2. Chemical composition of groundwater samples of study area

Locations	pH	Temp. (°C)	Conductivity (µS/cm)	TDS (mg/l)	Fe (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{2+} (mg/l)	K^+ (mg/l)	Mn (mg/l)	SO_4^{2-} (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)
1. Eyo Abasi	6.4	26.0	104.4	72.8	0.9	3.5	11.5	2.0	16.7	0.01	4.6	31.3	19.0
2. Efoi	6.0	25.5	241.6	100.8	8.7	3.0	10.2	3.7	7.8	0.2	5.5	72.5	39.0
3. Ibeno-1	6.0	26.5	93.2	62.3	11.4	4.7	7.5	2.7	3.6	0.2	1.5	28.0	27.0
4. Ibeno-2	6.0	26.0	89.7	77.5	9.2	5.9	10.4	5.1	6.9	0.2	4.2	26.9	32.0
5. Awa	5.7	26.0	184.1	99.7	0.1	14.9	9.2	1.4	0.5	0.01	3.1	55.	14.0
6. Ntiat	8.3	25.0	15.0	79.9	0.04	33.4	0.7	1.5	4.8	0.01	4.9	4.50	9.3
7. Ikot Abasi	5.0	25.5	11.2	85.6	0.04	37.3	0.5	1.1	2.6	0.03	1.9	3.4	15.3
8. Ikot Osurua	5.0	25.0	80.6	26.2	0.3	25.6	11.0	1.8	0.6	0.02	20.9	24.2	18.3
9. Nto Ndang	6.0	26.0	56.5	116.2	8.5	26.8	10.8	2.6	0.6	0.04	5.0	17.0	20.4
10. Itung	5.3	26.0	33.5	93.9	0.9	27.5	5.1	1.8	0.6	0.1	6.6	10.1	40.9
11. Ituk Mbang	6.3	25.5	203.5	80.7	4.2	5.8	7.8	1.2	2.7	0.3	1.8	61.1	50.3
12. Ikot Odion-1	5.7	24.0	102.6	118.5	1.6	21.3	12.2	1.6	1.0	0.6	9.6	30.8	27.0
13. Ikot Odion-2	5.0	25.5	168.8	300.5	2.8	69.4	34.5	1.4	1.0	0.1	8.5	50.7	32.0
14. Minya	6.0	25.5	80.6	84.4	0.1	35.4	10.6	1.8	5.5	0.1	1.9	24.2	15.3
15. Mbon Ebere	5.0	25.5	33.4	98.7	1.5	40.0	10.5	1.4	7.8	0.01	2.0	10.0	27.1
16. Ikot Akpa Ntuk	6.4	26.0	107.6	80.7	4.2	33.4	8.6	2.5	0.5	0.04	3.2	32.3	20.4
17. Etim Ekpo	6.0	26.0	14.9	93.5	1.1	41.5	10.5	1.4	2.6	0.04	4.8	14.5	9.3
18. Ukana	6.0	25.0	93.1	100.5	0.5	23.7	11.5	1.7	0.7	0.1	1.7	28.0	32.1
19. Enwang	6.2	26.0	117.9	65.4	0.9	5.5	1.4	1.1	0.3	0.1	2.9	35.4	39.0
20. Etinan	5.8	24.0	18.4	94.5	1.7	26.6	6.4	3.4	1.0	0.1	4.1	5.5	19.5

Table 3. Range in values of chemical parameters in study area and WHO standards for drinking water

Parameter	Range	WHO guideline[a]
Conductivity (µS/cm)	11.19–241.63	1400
pH	5.0–8.3	6.5–8.5
Temperature (°C)	24–26.5	No guideline value set
TDS (mg/l)	62.3–300.5	1000 g/l
Ca^{2+} (mg/l)	3.0–69.4	500 as $CaCO_3$
Mg^{2+} (mg/l)	0.5–34.5	
Na^+ (mg/l)	1.1–3.7	200
K^+ (mg/l)	0.5–16.7	
Total Mn (mg/l)	0.01–0.3	0.1
Total Fe (mg/l)	0.04–11.40	0.3
HCO_3^- (mg/l)	9.3–50.3	
SO_4^{2-} (mg/l)	1.5–20.9	400
Cl^- (mg/l)	3.4–72.5	250

[a] After WHO (1984)

The mean groundwater temperatures in the study area are between 25 and 26.5°C, which correspond with mean annual air temperatures. The mean seasonal variations are in the range of 0.5 to 2.0°C.

The pH ranges from 5 to 8.3 with an average of 5.9. A look at the values (Table 2) reveals that more than 90 percent of the samples had pH values outside the permissible range of 6.5–8.5 (Nigerian Standards 1971; WHO 1984). The high acidity of the water in this area could be related to dissolved CO_2.

The range of electrical conductivity (EC) in the investigated area is between 11.21 and 241.6 µS/cm. According to Langenegger (1990), the importance of EC is its measure of salinity, which greatly affects the taste and thus has a significant impact on the users' acceptance of the water as potable.

In addition, according to Mallevialle and Suffet (1987), the single most important class of consumer complaints with regard to water supplies are related to taste and odor problems. A look at Table 2 indicates that all the EC values are far below the WHO (1984) guideline of 1400 µS/cm.

Turbidity may be detected by the naked eye at 5 nephelometric turbidity units (NTU). The WHO guideline value is 5 NTU, but preferably less than 1 NTU when disinfected. Groundwaters in the investigated area in most cases have a turbidity level below 1 NTU.

Iron and manganese occur in relatively small concentrations (Table 2). The level of total iron (ferrous and ferric) measured under natural conditions is usually 0.04–11.40 mg/l (Table 3), which is higher than the WHO (1984) maximum permissible level for drinking water. Those of manganese are below 0.30 mg/l (Tables 2 and 3). The WHO guideline values for iron and manganese are 0.30 mg/l and 0.10 mg/l, respectively.

According to Amadi and others (1989), important factors that could influence the solubility and subsequent concentration of iron in the groundwater include local geologic structure, hydrological conditions of the basin, and the complex physiochemical and biochemical factors such as pH and Eh, dissolved CO_2, sulfur, and organic substances. Hem (1985), noted that a pH between 6 and 8 can be sufficiently reducing to carry as much as 50 mg/l of ferrous ion at equilibrium where bicarbonate activity does not exceed 61 mg/l. Thus the relevance of pH cannot be overemphasized in this area.

The geology of the area could probably be another source of iron. According to Amadi and others (1989), iron-bearing minerals can be derived from igneous, metamorphic, and sedimentary rocks. In the study area, these minerals are probably derived from the adjoining Precambrian Oban massif and the sedimentary rocks within
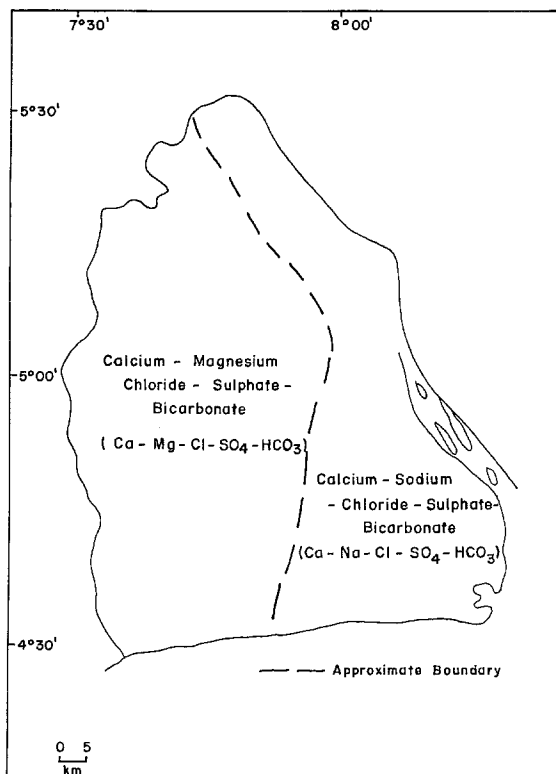
Fig. 2. Hydrogeochemical facies of the study area

the Calabar Flank (Fig. 1). In addition, shales can also be a source of iron (Davis and DeWiest 1966). Therefore, the leaching of those shales found in the northern parts of the area (Imo Shale Group) could possibly contribute to high iron concentration at Nto Ndang. Furthermore, the fact that groundwaters occur at shallow depths (for example 1.0 m and 1.2 m at Efoi and Ibeno 2, Fig. 2), according to Amadi and others (1989), suggests an open system where there is frequent contact between such waters and the atmosphere. Recharge reaching the water table is generally oxygenated owing to this contact and any reduced iron minerals, especially pyrite, which the solution contacts, will be attacked to yield ferric iron and sulfate. Hem (1985) attributed high iron content in groundwater to oxidation of reduced iron in sedimentary rock. Another source of iron is corrosion of well construction materials (steel).

Manganese resembles iron in its chemical behavior and in its occurrence in natural water (Johnson 1975). Manganese also is less abundant in rock materials than iron. As a result, its occurrence in water is less common and the concentration is generally much less than that of iron (Tables 2 and 3). In groundwater, manganese can occur in soluble form under reducing conditions as Mn^{2+}, due to low pH. Secondly, manganese can be precipitated as Mn^{4+} in the presence of oxygen with the help of slime-forming bacteria, hence the high pH. These situatons are probably responsible for the range in pH from 5.0 to 8.3 in the study area.

Sodium, potassium, calcium and magnesium occur in small concentrations (Table 3) when compared with water

where these cations are the major constituents. These cations are probably derived from chemical weathering of feldspars and micas, which are some of the minerals characterizing the rocks of the area (Coastal Plain Sands). Three ions, Na^+, Ca^{2+}, and Mg^{2+}, are among the species that are constantly involved in cation exchange processes and interaction with aquifer material (Mercado 1985).

Sulfate concentration in the area is low and therefore poses no problem to the groundwater quality. These low values are most probably due to the removal of SO_4^{2-} by the action of bacteria (Amadi and others 1989).

Chloride ion ranges between 3.4 and 72.5 mg/l (Table 3). According to Lusczynski and Swarzenski (1966), a Cl^- concentration of 50 mg/l is indicative of salt-water intrusion, while Tremblay and others (1973) used 40 mg/l as indicative of salt-water contamination and groundwater with Cl^- content greater than 100 mg/l to be part of the zone of diffusion. A look at Table 2 indicates that the coastal towns of Efoi and Awa have Cl^- values of 72.5 mg/l and 55.3 mg/l, respectively. Furthermore, relatively high Cl^- concentrations around Ikot Odion-2 (50.70 mg/l) and Ituk Mbang (61.1 mg/l) suggest that no area bears any individual saline character. The low values of bicarbonate around these areas are an indicative of salinization (Mercado 1985).

Other criteria for the determination of salinization are the Ca/Mg, Ca/Cl, and Na/Cl ratios. A look at Table 4 shows that the ratios of Ca/Cl and Na/Cl are highest around Ntiat and Ikot Abasi. The ratio of Na/Cl falls below freshwater (1.00) and seawater (0.86) values. This is the general trend in the whole area. Hence, in addition to the low bicarbonates, these ratio values are an indication of salt-water encroachment (Mercado 1985). Low Ca/Mg values, according to Sarma and Krishnaiah (1976), are due to the influence of salt water as observed in Efoi, Awa, Ituk Mbang and Ikot Odion-2. The low Ca/Mg ratio

Table 4. Ratio values

Locations	Ca/Mg	Ca/Cl	Na/Cl
1. Eyo Abasi	0.32	0.11	0.06
2. Efoi	0.30	0.04	0.05
3. Ibeno-1	0.63	0.17	0.10
4. Ibeno-2	0.57	0.22	0.19
5. Awa	1.62	0.27	0.02
6. Ntiat	49.85	7.42	0.32
7. Ikot Abasi	77.71	11.10	0.32
8. Ikot Osurua	2.33	1.06	0.07
9. Nto Ndang	2.48	1.58	0.15
10. Itung	5.39	2.73	0.18
11. Ituk Mbang	0.74	0.09	0.02
12. Ikot Odion-1	1.75	0.69	0.05
13. Ikot Odion-2	2.01	1.37	0.03
14. Minya	3.35	1.46	0.07
15. Mbon Ebere	3.80	3.99	0.14
16. Ikot Akpa Ntuk	3.88	1.03	0.08
17. Etim Ekpo	3.95	2.86	0.09
18. Ukana	2.06	0.84	0.06
19. Enwang	0.44	0.16	0.03
20. Etinan	4.16	4.81	0.62

corresponds to the relatively high Cl⁻ concentration in these localities.

The source of saline water in this area may be diversified. Back (1966) noted that the source may be due to retention of ions from salt water trapped at the time of deposition, intrusion of salt water after deposition due to change in sea level or in discharge, solution of minerals and concentration of the constituents by filtration by clay, and recharge by atmospheric precipitation containing ions. All these factors might be responsible for the saline water in the area, especially as there is no clear pattern of distribution. Relatively low values of Cl⁻ near the coast are most probably due to the fact that most of the boreholes samples are shallow and pumping is not excessive.

Hydrogeochemical facies

The concept of hydrogeochemical facies has been used (Seaber 1962; Morgan and Winner 1962; Back 1960) to denote the diagnostic chemical character of water solutions in hydrologic systems (Back 1966). The facies reflect the effect of chemical processes occurring between the minerals of the lithologic framework and the groundwater. The subsequent flow patterns modify the facies and control their distribution.

The hydrogeochemical facies of the area show that the area is characterised by two major types of groundwater: type 1, calcium-magnesium-chloride-sulfate-bicarbonate occupying the western parts of the study area; and type 2, calcium-sodium-chloride-sulfate-bicarbonate to the east (Fig. 2).

Evolution of groundwater

The evolution of this groundwater can be explained by the order of encounter as stated by Freeze and Cherry (1979). The theory states that the order in which groundwaters encounter strata of different mineralogical composition 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.

Conclusions

1. Groundwater geochemistry indicates the water to be soft, potable, and good for domestic and other purposes.
2. The waters are of low alkalinity, slightly acidic, and aggressive (pH 5.0–8.3). Such water would be corrosive and therefore would attack carbonate minerals as well as borehole materials. This should be taken into consideration during borehole designs.
3. The relatively high salinity of the water can be explained as being due to localized hydrogeological processes going on in the study area rather than seawater intrusion.

4. High iron concentration will favor the growth of iron bacteria (e.g., *Crenothrix*) and these could produce a clogging effect and reduced rate of flow (Walton 1970).
5. There are two water types: type 1, calcium-magnesium-chloride-sulfate-bicarbonate (Ca-Mg-Cl-SO₄-HCO₃), and type 2, calcium-sodium-chloride-sulfate-bicarbonate (Ca-Na-Cl-SO₄-HCO₃).
6. Since this is a baseline study, it is recommended that groundwater analysis be carried out frequently to monitor the rate and kind of contaminations.

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