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QUALITY OF GROUNDWATER IN DELTA STATE, NIGERIA

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The physical, chemical and microbial contents of groundwater across Delta State in the western Niger Delta were investigated for quality and usability by standard methods. Water samples from thirty-eight groundwater sources (boreholes) were analyzed. Hydrochemical analyses indicate groundwater of moderately low pH presumably reflecting the effect of gas flaring associated with petroleum exploration activities in the area, and low solute content. Cationic concentrations are in the order of Na>Ca>Mg>K while anions occur in the order of Cl>HCO3>SO4>NO3>PO4. Groundwater salinity generally increases steadily from the northern to the southern region apparently reflecting the increasing influence of seawater encroachment. Several water types were delineated. Most prominent among these are the chloride types, and others including mixed chloride-bicarbonate, mixed chloride-sulfate and bicarbonate types. Total coliform bacteria and enterococcus faecalis were encountered in the borehole water from the three regions while the faecal coliforms were absent from the northern boreholes. The faecal coliforms were greater in the borehole water from the south (0-2.8 log MPN/100ml) than from the central region (0-1.8log MPN/100ml) thereby suggesting a north to south increasing vulnerability of groundwater to contamination by pathogens. This is attributable to the shallow nature of the aquifers and the effect of high population density associated with the petroleum industry in the central and southern regions. Although the groundwater across the regions is suitable for irrigation, treatment, repair and proper maintenance of borehole materials are needed in order to ensure potable groundwater supplies.

INTRODUCTION

Groundwater resources are generally abundant in the Niger Delta basin partly because of the abundance of rainfall in this region, and the underlying sedimentary formations that serve as a good reservoir. Efforts at developing this resource have been limited predominantly to exploitation to cope with increasing urbanization and the attendant population explosion that resulted from oil exploration and exploitation activities. Nevertheless, a primary consequence of rapid population explosion and steady rise in agricultural and industrial activities in the region is the degradation of the environment, especially groundwater.

Delta State lies in the western portion of the Niger Delta region. It covers a land area of about 15,000 km2 and is currently the leading state in oil production in Nigeria. Over 90% of the potable water needs of the state are obtained from shallow aquifers by the use of shallow tube and hand dug wells. The shallow nature of the aquifers makes them readily susceptible to chemical and microbial contamination. Similarly, the proximity to the sea makes saltwater contamination of the aquifer a permanent threat. This study was initiated to continuously monitor the physicochemical and bacteriological composition of groundwater resource in Delta State so as to identify and address changes that may be harmful to consumers. This paper reports on the first of such campaigns across the state.

STUDY AREA

Geographical Setting

Delta State covers the land area between longitudes 5^o to $6^o50^'$E and latitudes $4^o30^'$ to $5^o50^'$N. It is bounded on the west by the Atlantic Ocean and on the east by the Niger River (Figure 1). Physiographically, the land rises from less than 6 m above sea level in the lowlands that adjoin the sea, to heights greater than 150 m above sea level in the plateau that defines the northern fringe of the state. Drainage is defined by a series of southerly flowing perennial streams and a network of tidal creeks that adjoin the sea.

Delta State falls within the subequatorial climatic zone characterized by a double maximum annual rainfall that ranges from about 3000 mm in the south to about 2000 mm in the northern segments of the state. Temperature across the state is moderately hot and mean annual values range between 24 to 27^oC. Vegetation types within the state vary from saltwater swamp within the coastal strip adjoining the sea to rain forest towards the northern portions of the state.

Geology and Hydrogeology

The study area is located predominantly within the Niger Delta sedimentary basin, which occupies the coastal portion and southern edge of a northeast to southwesterly trending intra-cratonic tectonic basin, the Benue trough. Although the Benue trough is of Cretaceous age, this southward extension developed during the Tertiary to Recent as a result of progradation in response to a continuous interplay of transgression and regression of seawater that accompanied tectonic instability in the basin.

The sedimentary sequence within the basin is in excess of 8000 m in thickness. It consists of a series of distinct formations that include from bottom to top: the Akata Formation, the Agbada Formation and the Benin Formation (Reyment, 1965; Short and Stauble, 1967) (Table 1). The Akata and Agbada Formations consist predominantly of high-pressure marine shale, and alternating

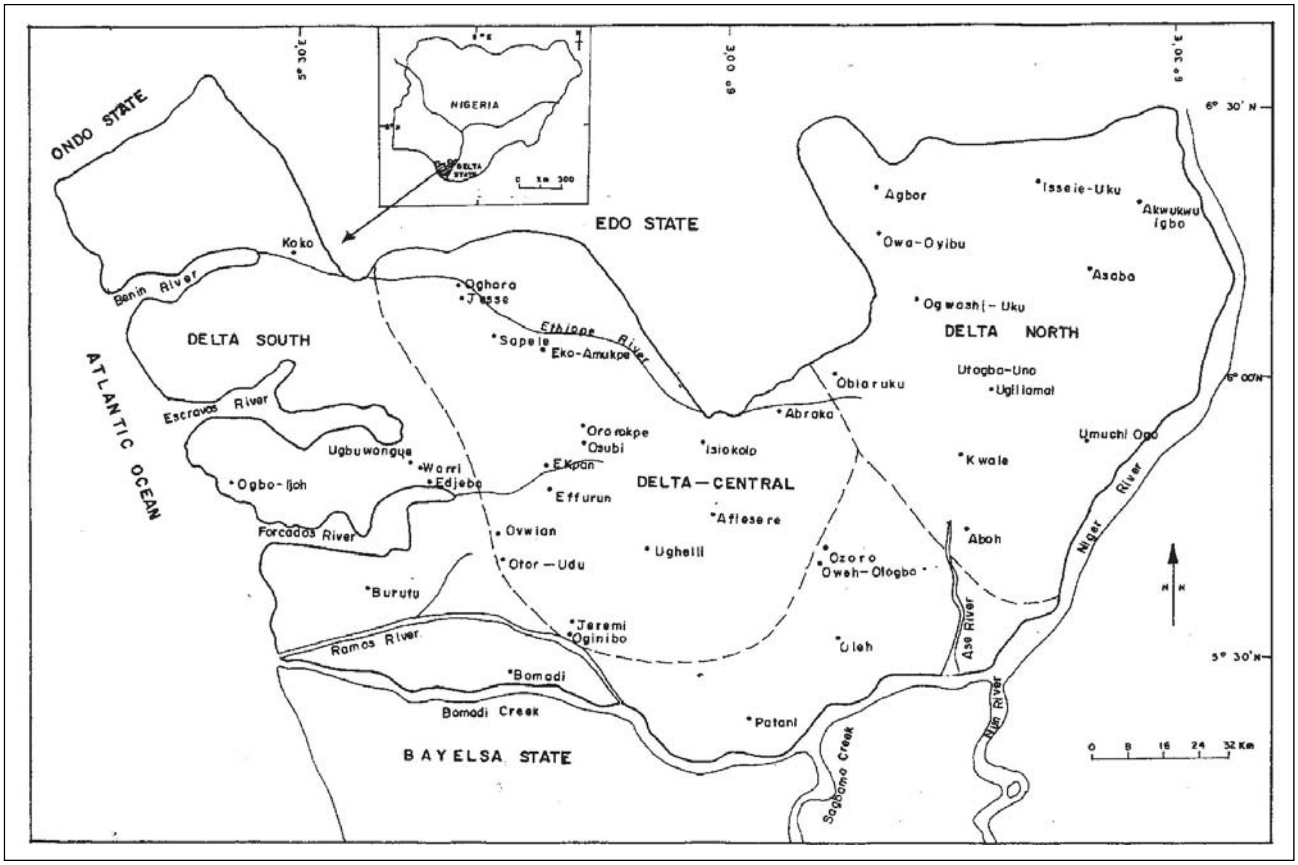

Figure 1. Geographical map of Delta State showing regional divisions and groundwater sampling points (Inset: Map of Nigeria showing Delta State).

deltaic sand and shale respectively. As a result of their deep location, those two formations are of no hydrological significance. The Benin Formation caps this sequence of formations and consists predominantly of fresh water continental sands and gravel with intercalations of shale. This formation has excellent aquifer properties and constitutes the most productive and hence most tapped aquifer in the central portion of the state where it is exposed. The annual water storage and recharge of this aquifer have been estimated to be 6.163×10^8 m^3 (Oteze, 1981). Within the coastal zone of the state, this sequence is covered by a thin sheet of deltaic plain sediment that is usually lesser than 120 m in thickness. These sediments consist of fine to medium and coarse-grained unconsolidated sands, and gravely beds with intercalation of peat and lenses of plastic clay. Hydraulic conductivities within the sands vary from 3.82×10^{-3} to 9.0×10^{-2} cm/sec. This formation constitutes the aquifer tapped in coastal areas of the state.

Table 1. Geological sequence within Delta State (modified after Short and Stauble, 1967).

Formations		Age
Deltaic Plain Sediments		Late Pleistocene-Holocene
Benin Formation		Oligocene-Pleistocene
Agbada Formation	Ogwashi-Asaba Formation	Oligocene-miocene
Akata Formation	Ameki Formation	Eocene

The Ogwashi-Asaba Formation, the surface equivalent of the Agbada Formation, constitutes the dominant aquifer in the northern sections of the state. This formation consists of friable, loose and high permeability sands with intercalations of lignite. This formation consists of multiple aquifers that are tapped at different levels in the area.

The variation in the rainfall regime and spatial distribution of the hydrogeologic units is reflected in the variation in the depth of the water table across the state. Mean static water levels vary from 0.5 m in the south to 4.5 m in the central area to greater than 150 m in the northern sections of the state.

Sampling and Analytical Procedures

A total of 38 boreholes were sampled at designated points across the state (Figure 1) during the months of March and April 2003. These samples were analyzed for their physical, chemical and bacteriological characteristics.

Before samples were collected the taps were allowed to run for 5 minutes in order to obtain a representative sample of the aquifer system. Replicate samples were collected from each well with 1 liter plastic cans. For microbiological analysis sterilized glass containers were used. Analytical procedures were generally in accordance with the specifications of APHA (1992) and ASTM (1995). Unstable parameters such as temperature, conductivity, and pH and were measured in-situ in the field. While temperature was measured with a mercury filled Celsius thermometer, total dissolved solids (TDS) content and electrical conductivity were estimated with the Oakton TDS/conductivity-meter. pH was estimated using the ATI-Orion pH meter. The concentrations of Na^+ and K^+ were determined with a flame Emission Analyser. Ca^{2+} and Mg^{2+} were measured by EDTA titrimetry. Cl^-, HCO_3^-, CO_3^{2-} were also measured with appropriate titrimetric methods. NO_3^- was measured by colorimetry while SO_4^{2-} was determined by precipitation using $BaCl_2$ and measurement of absorbency with a spectrophotometer. The concentrations of heavy metals (Fe, Zn, and Mn) were estimated with a model SP 2900 Pye-Unicam Atomic Absorption Spectrophotometer.

For the microbiological analysis, total coliform bacterial counts were determined by the standard Most Probable Number (MPN) procedure (APHA, 1992). Inoculated MacConkey broth was incubated at 37^0C for 24-48h. For faecal coliforms, the broth was incubated at 45^0C for 24-48h. Positive tubes were subcultured on MacConkey agar and incubated at 37^0C and 45^0C for 48h for total and faecal coliforms, respectively. Gram stain and biochemical tests (IMViC) were performed on typical colonies to complete the tests. Similarly the MPN technique was used for the enumeration of *Enterococcus faecalis* using Glucose azide broth (Oxoid) and *Clostridium perfringens* using Differential Reinforced Clostridial Medium (DRCM). The appearance of red or maroon colored colonies on Glucose azide agar confirmed the presence of *E. faecalis* while "stormy clot" in freshly steamed and cooled litmus milk to which water sample pre-heated at 80^0C for 10 minutes was added, confirmed the presence of *Cl. perfingens.* The purpose of pre-heating was to eliminate non-spore formers.

RESULTS AND DISCUSSION

For the purpose of discussion of the results, the study area has been divided into three regions; the southern, central and northern regions. The southern region constitutes the coastal tract of the state. The central region covers the middle portions while the northern region represents the northern fringes of the state (Figure 1).

Physico-Chemical Quality

The results obtained indicate that groundwater within the study area is generally of low pH and of low solute content. A statistical summary of the physical and chemical constitutions of groundwater in each of the three regions are presented in Tables 2 and 3 and discussed below.

Physical Parameters

The water samples are generally colorless with in-situ temperatures ranging from 25 to 33°C. pH values indicate a generally mildly acidic groundwater across the state. Of the total number of samples measured, 64% have values below the lowest limit of 6.5 units recommended for drinking water (WHO, 1993). The acidic nature of the groundwater may cause corrosion of borehole casing, storage tanks and plumbing fixtures constituting the water distribution system, and may be a significant factor in the high rate of borehole failures experienced in the study area. Generally, tropical regions of high rainfall and abundant flora and organic matter usually have acidic groundwater (Rose et al., 1979). The low pH status of groundwater in the state is further aggravated by the enormous volumes of gas flared by the petroleum upstream industries operational in the area. The water-soluble portions of these gases eventually dissolve in rainwater and recharge the aquifer as acid rain. Recent studies have reported substantial acidity in rainwater within the state (Ogunkoya and Efi, 2003). TDS values (5-158 mg/l) indicate that the groundwater in the study area is generally characterized by low solute content. Mean TDS values increase significantly from the northern to the southern region, (Table 2), despite an increase in the water depth in the opposite direction, apparently reflecting the intensity of salinization of the aquifers by recharging saline water in coastal areas. Electrical conductivity (12–313 µS/cm) and TDS values indicate freshwater of low to medium salinity hazard (Richards 1954; Davis and DeWiest, 1966). As expected, the

Table 2. Statistical summary of physical qualities of groundwater in Delta State.

Variables	**Range within regions**			**Mean ± Standard deviation**		
	South (N=12)	Central (N=14)	North (N=12)	South	Central	North
pH	5.13-7.33	5.18-7.86	5.14-7.17	6.34±0.69	6.06±0.76	6.08 ± 0.67
Temp. ^{0}C	28.00-33.00	28.00-32.00	25.00-32.00	30.46±1.50	30.11± 1.09	28.77± 2.27
TDS mg/l	8.00-128.00	12.00-158.00	5.00-17.00	71.09±44.50^a	43.35± 5.86^{ab}	11.44±4.09^{ab}
EC µs/cm	17.90-267.00	24.00-312.00	12.20-34.00	147.59±89.50^a	88.11±94.39^{ab}	24.16±7.74^{ab}
DO mg/l	1.50-4.20	1.50-4.50	2.20-4.20	3.22±0.79	3.17±0.85	3.40±0.71
TH mg/l	0.84-74.78	2.25-120.30	1.12-12.15	40.55± 24.39a	28.69 ± 35.22	3.62 ± 3.31a

* a, b indicate significant difference (t-test; P< 0.05)

Table 3. Statistical summary of chemical concentration of groundwater in Delta State.

Variables	**Range within regions**			**Mean ± Standard deviation**		
	South (N=12)	Central (N=14)	North (N=12)	South	Central	North
Na^+ mg/l	4.12-42.73	1.88-24.32	2.12-6.34	18.04 ±16.22^{ab}	8.07±5.72^a	4.75±1.57^b
K^+ mg/l	3.06-14.38	0.28-6.84	0.24-6.10	7.78±4.09^{ab}	3.02 ±1.95^a	2.32±1.81^b
Ca^{2+} mg/l	0.55-200.26	2.45-39.25	0.82-5.27	29.79±57.02	8.68±10.97	2.73±1.61
Mg^{2+} mg/l	2.18-50.36	0.17-9.54	0.42-2.28	10.40±13.68^{ab}	2.61±2.77^a	1.15±0.63^b
Fe mg/l	0.09-25.73	0.12-14.33	0.10-1.25	3.49±7.53	2.38±4.50	0.50±0.43
Zn mg/l	0.12-3.73	0.12-4.38	0.15-0.30	1.22±1.13^a	1.28±1.22^b	0.20± 0.05^{ab}
Mn mg/l	0.00-0.01	0.01-0.02	0.00-0.01	0.006-±0.004	0.009±0.003	0.005±0.004
SO_4 mg/l	0.14-18.80	0.14-20.78	0.14-3.70	9.46± 6.44^{ab}	2.96± 5.32^a	1.36 ±1.25^b
HCO_3 mg/l	2.00-25.00	3.00-28.00	2.00-10.00	13.05± 8.46^a	7.41± 5.94^{ab}	4.78± 2.73^b
CO_3mg/l	0.12-12.50	0.20-9.00	0.52-2.15	4.48± 4.15^a	2.28± 2.45	1.27± 0.57^a
NO_3mg/l	0.15-2.19	0.27-2.56	0.37-2.56	1.28± 0.53	1.09± 0.73	1.25± 0.81
PO_4mg/l	0.30-1.84	0.10-1.84	0.03-1.36	0.94± 0.49	0.79± 0.47	0.49± 0.52
Cl mg/l	5.00-72.15	5.00-65.00	2.50-400	28.93± 23.33^a	13.86± 16.13^a	49.67± 131.39

a, b indicate significant difference (t-test; P< 0.05) electrical conductivity values followed a similar distribution trend with TDS and consequently show significant variation between the regions.

Chemical Parameters

The concentration levels of cations and anions are summarized in Table 3. The sequence of abundance of both cations and anions in the investigated water samples has the following order: Na>Ca>Mg>K and Cl>HCO3>SO4>NO3>PO4. Sodium and potassium have concentration values ranging between 1.88 mg/l to 42.73 mg/l and 0.24 mg/l to 14.38 mg/l respectively. Na concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability (Todd, 1980). The level of sodium hazard of irrigation water to the soil is expressed as its sodium absorption ratio (SAR). The calculated values of this parameter within the study area are generally low and vary from 0.03 to 0.65. The SAR values along with the low values of electrical conductivity, permits the rating of the water as excellent for irrigation purposes within the central and northern regions and good to excellent in the southern region (Table 4) (Johnson, 1975; Wilcox, 1955).

The calcium and magnesium concentrations are much lower than the permissible limits of 200 mg/l and 150 mg/l recommended for drinking water (WHO, 1993). This trend of low concentrations of calcium and magnesium is reflected in the low total hardness (TH) values (0.84 to 120.30 mg/l) recorded in the water samples (TH = 2.5 Ca(mg/l) + 4.1 Mg(mg/l)). On the water hardness classification scheme of Sawyer and McCarty (1967), groundwater from central and northern regions classify as soft to moderately hard (Table 5). This implies suitability for use in household laundry and industrial purposes such as boilers and other heat exchange equipment.

Table 4. *Classification of groundwater for irrigation water.

Water class	Electrical cond. µs/cm	Sodium absorption ratio(SAR)	Salinity hazard	Borehole in regions (%) South (N=12)	Central (N=14)	North (N=12)
Excellent	< 250	0-10	Low	80	100	100
Good	250-750	10-18	Medium	20	0	0
Permissible	750-2000	18-26	High	0	0	0
Doubtful	2000-3000	26-30	V. High	0	0	0

*Based on the quality classification of Wilcox (1955)

Table 5. Hardness of groundwater samples.

*Classification	Location of boreholes (region) % South (N=12)	Central (N=14)	North (N=12)
Soft	82	100	100
Moderately hard	18	0	0
Hard	0	0	0
Very hard	0	0	0

*Hardness $CaCO_3$ (mg/l): soft, 0-75; moderately hard, 75-150; hard, 150-300; very hard, > 300.

Bicarbonate, sulfate and nitrate all occur in low concentrations while chloride has elevated values (Table 3). The mean chloride concentrations in the southern region (28.93 mg/l), central region (13.86 mg/l) and northern region (49.66 mg/l) reflect the geology and hydrochemical activities prevalent in the various regions. Within the southern region groundwater from certain locations has a salty taste and is occasionally objectionable. The high chloride content of groundwater in the southern region, which corresponds to the coastal strip of the state, has been explained as resulting from seawater intrusion into the aquifers (Offodile, 1991; Oteri, 2004; Olobaniyi and Owoyemi, 2004). During high tide, seawater gains access into the southern region either directly or via streams and numerous creeks that characterize the Niger delta, and recharges the aquifer. Nevertheless, substantial dilution of ionic concentrations in groundwater occurs in this region resulting from high annual rainfall (> 3000 mm). The central region has diminished values of chloride (Table 3) presumably because of its location farther away from the coast and hence reduced tidal influence on its streams. The high values of chloride concentration within groundwater from the northern region can be related in part to ionic contributions from the saline formation water of the Benin and Ogwashi-Asaba Formation that underlie the area, and to the distance of water travel to the water table. As stated above, mean static water level exceeds 150 m in this region. This implies a considerable distance of travel of groundwater to the water table, which permits significant water-geological matrix interaction. Chebotarev (1955) has noted that the composition of groundwater tends to progress towards that of seawater with increasing distance of travel and time within the soil.

The trace element contents Zn, Mn and Pb (Table 3) are generally within limits accepted for drinking water (WHO, 1993). On the other hand iron has concentration levels often higher than the mandatory limit of 1.00 mg/l for drinking water (WHO, 1993). Locations with such enhanced iron values are notably restricted to the southern and central regions of the study area. In some of the worst affected locations, groundwater rapidly turns a turbid brown on exposure to air. The source of iron in the water can be related to the leaching of Fe^{2+} into groundwater from iron-bearing minerals such as hematite, limonite and goethite that are abundant within sediments of the deltaic plain sands and the Benin Formation that underlie the affected areas. Fe^{2+} gets oxidized to Fe^{3+} on exposure to air and eventually precipitates the rust-coloured ferric hydroxide, which stains laundry, plumbing fixtures and household cooking utensils and imparts objectionable taste to food and drinks.

Hydrochemical Facies

The result of chemical analysis was used to classify the water types present in the groundwater of the study area. Based on the predominance of both cations and anions, a plot on the Piper's trilinear diagram was made. From the interpretation of this plot, several water types were delineated. Prominent among these are the chloride types of alkali and alkaline earth elements, which constitute about 71% of the total water samples analyzed. Mixed chloride-bicarbonate types constitute about 18%. Other facies of minor occurrence include bicarbonates of sodium and calcium, and mixed chloride-sulfate types. The general abundance of the facies types in each of the three regions is indicated in Table 6. The spatial distribution of the water types is shown in Figure 2. On this diagram, chlorides of Na, Ca and Mg show spatial dominance in the southern and northern regions with local enclaves of the $Cl\text{-}HCO_3$ facies. The central region is occupied by both significant amounts of chloride and bicarbonate water types.

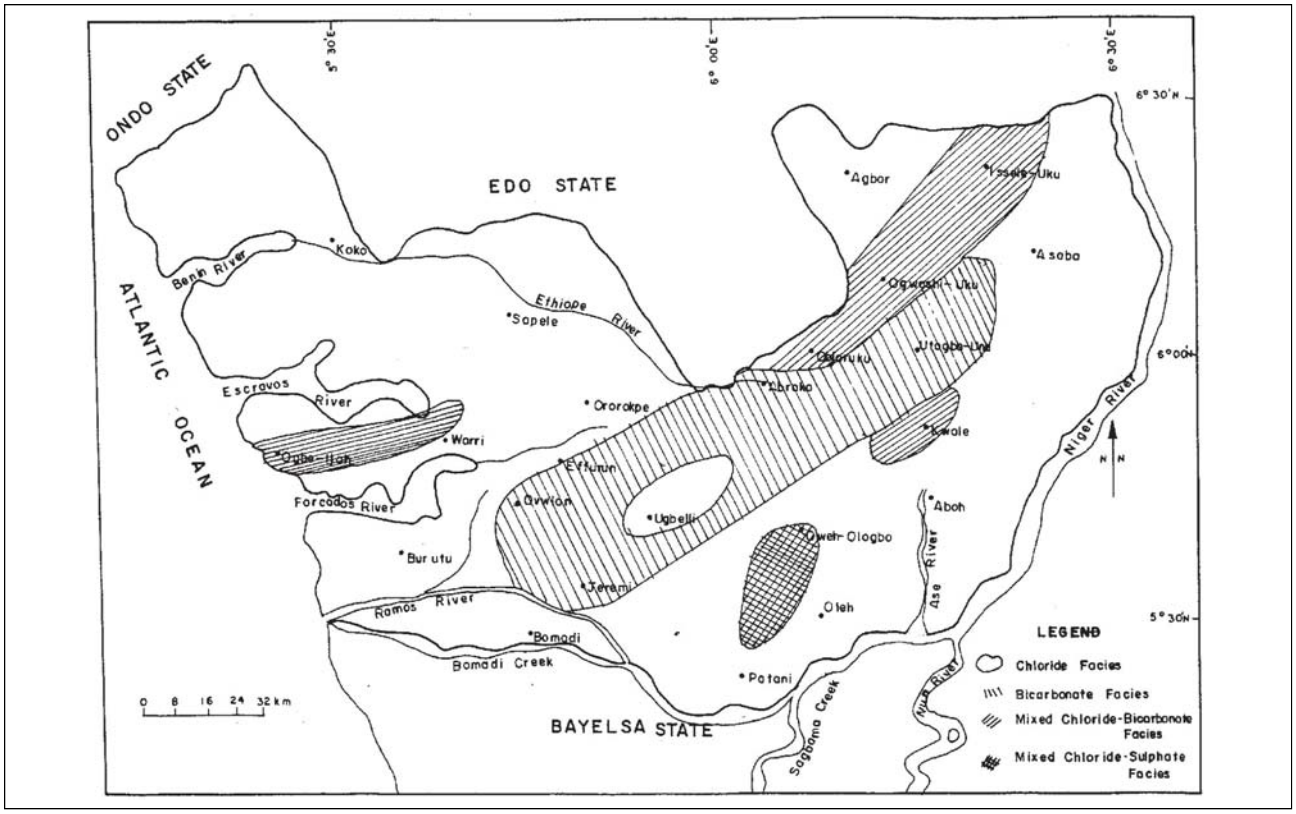

Figure 2. Spatial distribution of groundwater types in the study area.

The hydrochemical facies of groundwater is usually determined by an interplay of several factors. In the study area among several other factors, saline water incursion, natural water recharge, water/rock interaction and base exchange processes seem to have played more prominent roles in determining water types. The spatial dominance of the chloride facies in the state as shown in Figure 2 has been attributed to several factors. Probably the most significant of these is the geographical proximity of the study area to the shores of the Atlantic Ocean and the presence of numerous rivers, tidal inlets and creeks, which constitute ready channels for seawater migration

Table 6. Classification of chemical facies of groundwater.

Chemical Facies	**Location of boreholes (region) %**		
	South (N=12)	**Central (N=14)**	**North (N=12)**
Chlorides of Na, Ca and Mg.	72	67	51
Bicarbonate of Na and Ca.	0	22	13
Mixed chloride-bicarbonate of Na and Ca.	16	12	37
Mixed chloride-sulfate of Ca and Mg.	8	0	0

inland during high tide. These channels permeate the southern and part of the central region allowing the incursion of seawater that eventually causes substantial salinization of the aquifers. On the other hand, the dominance of the chloride water type in the northern region has been attributed above to contributions from saline formation water, and the influence of geology that causes significant distance of groundwater migration. The bicarbonate water type reflects areas of natural water recharge.

Microbiological Quality

Total coliform bacteria had the highest mean values across the region and were encountered in all the borehole water samples tested in the north and to a lesser extent in the other regions (Table 7). Although the counts differ from north to south, the range and mean values did not differ markedly (Table 7). In contrast no faecal coliform was encountered in the north and marked differences in range values occurred between central and south while the mean values of faecal coliform were not markedly different (Table 7). However faecal coliforms occurred in more boreholes in the south than in the central region. *Clostridium perfringens* was not detected in all the samples across the region unlike *E. faecalis* that was encountered in more boreholes in the north than the other regions (Table 7). On the average, the populations of the indicator bacteria were low (<2.5 log MPN/100 ml) although faecal coliforms exceeded WHO acceptable limits.

The occurrence of total coliforms in higher numbers than faecal coliform or *E. faecalis*, suggests that contamination of the borehole water is not mainly of faecal origin (Al-Jebouri and Trollope, 1984). The coliform group is heterogeneous and other possible sources include soil and decaying organic matter. The faecal coliforms are considered true indicators because they are always present in faeces and in higher numbers than enteric pathogens (Morinigo et al., 1990). Thus their presence in unacceptable levels in 25-50% of the boreholes in the south and central zones indicate a vulnerability of the boreholes to pathogenic organisms. Many authors consider *E. faecalis* to be a good indicator of faecal pollution because of their greater resistance than coliforms to environmental pressure (e.g. Morinigo et al., 1990; Philip, 1991; Sinton et al., 1993; Rees, 1993). However, several other studies indicate that they can be found in other habitats and

Table 7. Bacterial water quality indicators in borehole water

Indicator Bacteria[a]	**Statistics**	**Location of Boreholes (regions)**		
		North	Central	South
Total coliform	Range	0-2.5	0-2.7	0-2.2
	Mean±SD	1.89±0.78	2.40±0.46	1.80±0.62
	[b]Occurrence (%)	100	93.0	90.9
Faecal coliform	Range	0.0	0-1.8	0-2.8
	Mean±SD	0.0± 0.0	0.47± 0.94	0.65± 0.78
	[b]Occurrence (%)	0	25	45.5
Enterococcus Faecalis	Range	0-2.0	0-1.0	0-2.0
	Mean±SD	1.22± 0.90	0.23± 0.51	1.00± 0.83
	[b]Occurrence (%)	70	18.5	63.6
Clostridium Perfringens	Range	0-0	0-0	0-0
	Mean±SD	0.0± 0.0	0.0± 0.0	0.0± 0.0
	[b]Occurrence (%)	0	0	0

a, Log MPN/100ml; b, number of borehole water samples containing indicator bacteria.

that their population is not clearly related to faecal sources (Mundt and Johnson, 1982; APHA, 1992; Sinton et al., 1993). Thus its presence in the three regions, especially the north where no faecal coliform was detected, suggests non-faecal sources like the total coliforms. The distribution (range, mean) of *E. faecalis* did not show any identical pattern with faecal coliform in this investigation. Indeed like the total coliforms, the results showed that it occurred in more boreholes in the north (no faecal coliforms) than the other regions where faecal coliforms were encountered. The use of *Clostridium perfringens* is due to the presence of spores, which can resist stress better than any other indicator bacteria. However its low and inconsistent numbers in faeces makes it of limited value as its absence here shows.

The absence of faecal coliforms in the north and the observation that it was encountered more in the south than in the central region, suggests a "north to south" increasing vulnerability of groundwater to contamination by pathogens. The deeper aquifer in the north is a big hurdle for bacteria to cross in order to reach groundwater. The central and southern regions are areas of high population densities associated with intense economic activities due to petroleum exploration, exploitation and refining activities, which is absent in the north. Thus the shallow aquifers which underlie the central and southern regions may become vulnerable especially when septic tanks, pit toilets, indiscriminate refuse disposal and poor drainages characterize the urban centers in these two regions. The presence of the indicator bacteria generally may be attributed to ingress of surface runoff associated with broken pipes and sealants and poor maintenance, which was observed in the course of sample collection.

CONCLUSION

This investigation has revealed that groundwater from the study area is generally characterized by low pH and low salinity, which increases from north to the south. Its chemical composition can be classified as belonging dominantly to the chloride water type with subordinate mixed chloride–bicarbonate, and bicarbonate types. Except for the low pH values and local occurrences of relatively high iron content, groundwater within the study area possesses chemical qualities compatible with the WHO standard for drinking water. However the occurrence of faecal coliforms in boreholes located in the south and central regions suggests that the groundwater is vulnerable to pathogens. This implies that although groundwater may be suitable for use in irrigation, it would require various forms of treatment as may be applicable in the locality to eliminate faecal contaminants and adjustment of pH qualities to specifications needed for certain domestic and industrial purposes.

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