African Journal of Environmental Science and Technology Vol. 5(7), pp. 473-481, July 2011
Available online at http://www.academicjournals.org/AJEST
ISSN 1996-0786 ©2011 Academic Journals

Full Length Research Paper

Investigation into the physico-chemical properties and hydrochemical processes of groundwater from commercial boreholes In Yenagoa, Bayelsa State, Nigeria

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Accepted 30 May, 2011

The physico-chemical and hydrochemical study of commercial borehole waters in Yenagoa, Bayelsa State have been carried out. Eight commercial borehole water samples were analyze for various physico-chemical parameters using standard methods. The results obtained shows that the water samples quality examined compared favourably with WHO (1998) standard for drinking water. Although the values for pH (5.20±0.14, 6.10±0.10, 6.20±0.10, 6.20±0.20 in well 2, 5, 6, and 7 respectively), electrical conductivity (EC) of 520.00±5.50 µS/cm in well 7, biochemical oxygen demand (BOD) of 9.55±0.26 mg/L in well 3, Ca (9.25±0.10, 8.25±0.03 and 7.90±0.10 mg/L in well 2, 3, and 7 respectively) and all values obtained for Fe exceeded the WHO permissible limits for safe drinking water. The concentration of heavy metals; lead, copper, chromium, cadmium and arsenic (major sources of ground water pollution) were below detectable limit except at well 5, 6, and 7 where lead values of 0.03±0.001, 0.008±0.00, 0.04±0.00 mg/L respectively were obtained. The hydrochemical analysis shows that ion exchange and silicate weathering are the major prevailing hydrochemical processes in the groundwater. All the results obtained were however not significantly different from other reported values within the Niger Delta region. The higher concentrations of some of the parameters (pH, Ec, BOD, Fe, Ca^{2+}) and the present of lead in some samples is an indication of some levels of pollution in the boreholes/ground water. This therefore calls for appropriate treatment measures before the consumption of these waters by the populace to avoid long term accumulative health problems of these pollutants. Recommendations on the strategies to reduce/eliminate some of these pollutants were made.

Key words: Physico-chemical properties, hydrochemical processes, groundwater, boreholes, Yenagoa.

INTRODUCTION

Water is one of the most essential needs of human beings and is the most abundant natural resources on the surface of the earth (Oyinloye and Jegede, 2004), while groundwater is the largest reservoir of drinkable water and due to the natural filtration, it is less contaminated as compared to surface water (Aiyesanmi et al., 2004 Groundwater is an important source of water for agricultural and domestic use especially in developing countries like Nigeria, due to long retention time and natural filtration capacity of aquifers. However, leachate from municipal, solid waste, landfills is potential sources of contamination of both surface water and groundwater (Odukoya et al., 2002). When water in its original

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sources is contaminated by domestic, industrial or agricultural waste and is sufficient to render the water unacceptable for its best usage, it is said to be polluted. The substances causing these unfavourable alterations are called “pollutants” (Ekpete, 2002).

Although, water is an absolute necessity for life, there is an inherent health implication in the consumption of contaminated or polluted water. It can lead to many diseases and even death when contaminated with organic and/or chemical pollutants (Bartran and Balance, 1996). But, clean unpolluted water is necessary for the maintenance of human health as well as quality of the environment (UNEP, 1996). Water that is safe for drink, pleasant in taste, and suitable for domestic purposes is designated as potable water and must not contain any chemical or biological impurity (Horsfall and Spiff, 1998).

Pollution of groundwater has gradually been on the increase especially in our cities with lots of industrial activities, population growth, poor sanitation, land use for commercial agriculture and other factors responsible for environmental degradation (Egila and Terhemen, 2004). The concentration of contaminants in the groundwater also depends on the level and type of elements naturally or by human activities distribute through the geological stratification of the area. The present of such contaminants in the groundwater, above the recommended standard set by water quality regulating bodies like EPA, FEPA and WHO may result in serious health hazards. (USEPA, 2002). This perceived consequence of consumption of unregulated waters (used as potable water) has triggered various studies on water aquifer and aquatic ecosystem. (Akpa and Offen, 1993; Udom et al., 1999; Ekpete, 2002; Oguzie et al., 2002; Aiyesanmi et al., 2004 ; Egila and Terhemen, 2004; Abam et al., 2007; Nwala et al., 2007; Bolaji and Tse, 2009). The main sources of water supply for domestic and agricultural use in Yenagoa Local Government Area of Bayelsa State are the untreated private and commercial boreholes. This is because the expected treated public water scheme is not available and the cost of obtaining water from commercial water processing and packaging companies for consumption is quite high and cannot be afforded by many. With the pace of industrialization of the city, the influx of oil - multinationals and infrastructural development in the city, groundwater resources contamination has become a matter of urgent concern. There is portends danger to the availability of safe drinking water arising from increasing sources of untreated commercial water supply, solid waste generation, effluent discharge and poor sanitary disposal system from various anthropogenic activities in the area. Ironically, there is no policy regulating the development and operations of private and commercial boreholes in the state. This is against the backdrop of reported water quality problems in the region, including the ingress of saline water in boreholes due to over pumping (Bolaji and Tse, 2009). To avoid any health hazard inherent in the possible consumption of disease infected/contaminated water, physico-chemical examination and hydrochemical study of water in the area is unavoidably important. It is against this backdrop we are carrying out this study, to determine whether these parameters meet the EPA and (WHO) World Health Organization standard for drinkable water, as well as to ascertain the possible causes of any contaminations in order to make appropriate recommendations. The results of the study will also serve as baseline data for water quality study in the Local Government Area and Bayelsa State in the future.

MATERIALS AND METHODS

Study area

Yenagoa City, the study area is the capital of Bayelsa State. It lies within latitudes 04°4N and 05°, 02N and longitudes 006°, 15E and 006°,24E and situated in the southern part of the Niger Delta (Figure 1). Its geomorphologic features consist mainly of fresh water swamp, mangrove swamps, beaches, bars and estuaries. The study area geology is consistent with the general geology of the Niger Delta complex (Bolaji and Tse, 2009).

Using lithological and geophysical logs, Etu-Efeotor and Akpokodje (1990) delineate five regional levels of aquifers in the Niger Delta including Yenagoa. The first aquifer occurs under pheatic conditions between depths of 0 and 45 m. It supplies water to small private and commercial boreholes and is the most extensively exploited causing water table decline, pollution and saline water intrusion. Most boreholes investigated in this study are within this aquifer. The second and third aquifers (45 to 130 m and 130 to 212 m deep, respectively) are semi-confined and are usually penetrated by medium sized industrial, community and municipal boreholes. The forth aquifer is 219 to 300 m deep and is tapped by few large scale deep boreholes for municipal and industrial water schemes. The fifth level of aquifer is more than 300 m deep. Majority of boreholes usually penetrate only the first and second aquifers. The regional groundwater problems include salt water intrusion and pollution in upper aquifers of coastal areas and mangrove swamp due to over pumping, high iron content in some horizons/areas; causing encrustation, contamination and eventual pollution.

Methods

This investigation of water quality in Yenagoa Local Government Area was conducted in 2008 on eight commercial borehole waters spread over the city. Samples were collected and analyzed for the month of January, May and July and the mean obtained. This was done to cover the dry season, wet season and the seasons' transition period. Water samples from the selected boreholes were collected at laminar flow according to prescribed sample collection procedure in pre-washed and clean 300 ml screw cap plastic containers (APHA, 2000; Bolaji and Tse, 2009). Before collection of the samples from the boreholes, the taps were allowed to flow for about three minutes to avoid any water retained in the pipe being taken as a sample.

A global positioning system (GPS), Germin 76 model was used for recording the geographical co-ordinates of the sampling points. Because the chemistry of groundwater is sensitive to environmental changes, the following parameters were measured and recorded *in situ;* temperature, colour, pH, and electrical conductivity. In the laboratory, the other parameters listed in Tables 1 and 2 were

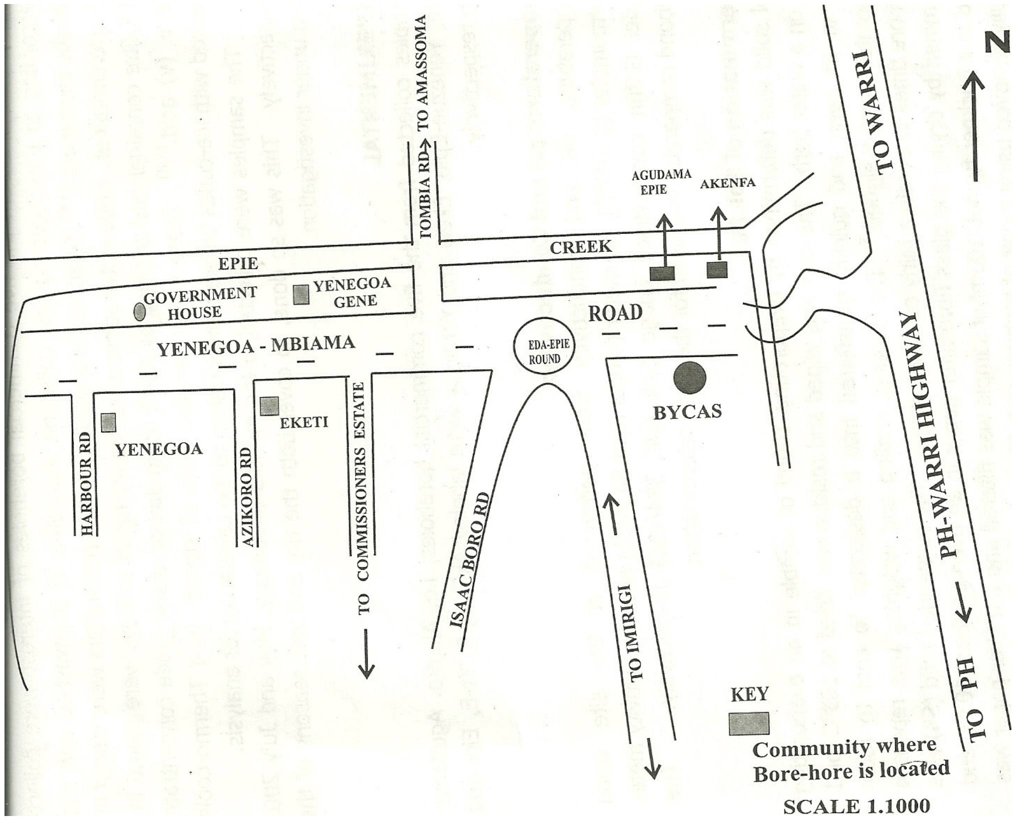

Figure 1. Map of the study area.

analyzed. The analytical methods used in the determination of these parameters have been reported in Nwala et al. (2007) and Bolaji and Tse (2009) and were in accordance with ASTM and APHA standard procedures. The results were compared with reported values within the Niger Delta region and WHO (1998) standards for drinking water.

RESULTS AND DISCUSSION

The results of the physico-chemical analysis of the water samples are presented in Tables 1 and 2.

The temperature of the sampled borehole waters range between 26.5 to 29.8°C with a mean value of 28.04°C. These values obtained are similar to those reported by Braide et al. (2004) and Nwala et al. (2007). The pH values obtained ranged from 5.20±0.14 to 7.6±0.30. With exception of samples from Wells 2, 5, 6 and 7, all other samples fell within the WHO range for portable water. This pH result shows that the groundwater of the area is slightly acidic. Jones (1998) reported that acidic water results in corrosion of iron and steel materials (Pipe and Plumbing Fixture), clogging of distribution pipes cause objectionable taste of drinks and food and may stain clothes and rust cooking utensils; thus the corrosion level of pipes and water storage materials will be high. But these values obtained are similar to previously reported values in the Niger Delta region of Nigeria (Nwala et al., 2007; Manilla and Tamuno - Adoki, 2007; Bolaji and Tse, 2009). The colour value ranged from 10.50±0.50 to 56.50 ± 4.10 pt/co unit. This values show the presence of impurities in the ground water analyzed.

The electrical conductivity (EC) for all samples except for Well 7 fell within the permissible limit of 500 µS/cm set by WHO. EC is an indicator of water quality and soil salinity, hence the relatively high values observed in some water samples show high salinity; thus the water may not be very suitable for domestic and agricultural use. Total dissolve solid (TDS) values are generally below 180 mg/L which is within the WHO permissible limit for potable water (Sawyer et al., 2003) though in Wells 1 and 7, TDS values are relatively high with concentration of 190.00±2.20 and 220.00±5.20 mg/l, respectively. The total suspended solids (TSS) values are generally below WHO permissible limit but fairly high compare to other reported values in the region. This may be attributed to saltwater intrusion into the exploited first water aquifer from the Atlantic Ocean.

The alkalinity values of all the sampled water are below the stipulated limit range of 30 to 500 mg/L by WHO. They range from 14.00±1.00 to 77.50±3.10 mg/L. This again confirms the slightly acidic nature of water of the study area. Hence, water from these commercial boreholes requires some level of treatment to attain the required WHO standard.

Table 1. Physical and chemical parameters of samples.

S/N	Sample location	Geographical coordinate	Temp. °C	pH	Colour (pt/count)	Electrical conductivity (µS/cm)	TDS (mg/L)	TSS (mg/L)	Total alkalinity (mg/L)	Total hardness (mg/L)	BOD (mg/L)	Po_4^{3-} (mg/L)	So_4^{2-} (mg/L)	Cl- (mg/L)	No_3^- (mg/L)
1	Akenfa- Well 1	No4°59.895” E006^{0}22.648’	2.98	6.90 ± 0.20	10.50 ± 0.20	350.00 ± 5.20	190.00 ± 2.20	280.00 ± 2.40	35.30 ± 1.60	65.80 ± 2.10	4.98 ± 0.04	0.05 ± 0.002	8.20 ± 0.40	4.10 ± 0.25	6.50± 1.00
2	Agudama - Epie- Well 2	No4°59.077” E006°22.507”	28.0	5.20 ± 0.14	24.00 ± 2.10	19.00 ± 1.20	80.00 ± 2.00	50.00 ± 2.11	14.00 ± 1.00	173.00 ± 2.41	1.34 ± 0.03	ND	3.40 ± 0.08	16.00 ±1.00	1.20± 0.03
3	Opolo- Well 3	No. 4°56.977” E006^{0}20.163”	28.5	6.80 ± 0.20	32.00 ± 3.20	224.80 ± 4.32	125.00 ± 3.40	105.50 ± 3.20	57.00 ± 2.40	164.40 ± 4.10	9.55 ± 0.26	0.10 ± 0.001	16.40 ± 0.70	8.00 ± 0.30	8.70 ± 0.50
4	Yenazuegene- Well 4	No4° 56.472” E006°19.017”	27.5	7.60 ± 0.30	47.00 ± 1.22	300.00 ± 6.20	160.50 ± 5.90	190.00 ± 5.01	77.50 ± 3.10	13.00 ± 1.41	8.40 ± 0.20	0.14 ± 0.002	14.80 ± 1.30	7.10 ± 0.50	7.50 ± 0.35
5	Kpansa- Well 5	No4°55.853” E006°18.373”	27.0	6.10 ± 0.10	56.50 ± 4.10	240.50 ± 4.10	120.00 ± 3.10	114.00 ± 2.40	33.40 ± 1.70	180.04 ± 3.30	3.61 ± 0.08	0.16 ± 0.002	8.20 ± 0.50	10.50 ± 1.00	4.20 ± 0.20
6	Ekeki- Well 6	No4°55.761” E006°17.717”	28.0	6.20 ± 0.10	10.80 ± 0.12	250.00 ±7.27	100.00 ± 2.00	140.00 ± 4.00	45.40 ± 3.90	73.40 ±2.50	4.90 ± 0.30	0.05 ± 0.001	4.90 ± 0.25	10.00 ± 0.80	5.70 ± 0.80
7	Onopa- Well 7	No4°56.350” E006^{0}16.683”	26.5	6.20 ± 0.20	20.50 ± 0.60	520.00 ± 5.50	220.00 ± 5.20	250.10 ± 5.00	50.20 ± 2.10	96.10 ± 3.00	4.22 ± 0.10	0.01 ± 0.001	24.00 ± 1.50	6.80 ± 0.40	6.80 ± 0.40
8	Swali- Well 8	No4°55.123” E006°15.977”	29.0	7.20 ± 0.30	52.50 ± 2.30	370.50 ± 8.20	120.00 ± 3.00	220.00 ± 3.00	28.00 ± 1.60	68.30 ± 1.60	6.30 ± 0.30	0.02 ± 0.001	12.00 ± 0.90	7.20 ± 0.80	8.00 ± 0.50
	WHO limit			6.5-8.5	5.00	500	500	500	30-500	500	6-9	0-5	250	250	10.00

The World Health Organization (WHO) International Standard for Drinking Water (1998) classified water with a total hardness of $CaCO_3$ < 50 mg/L as soft water, 50 to 150 mg/L as moderately hard water and water hardness above 150 mg/L as hard $CaCO_3$. Based on this classifications, all the water samples analysis except Well 4 (soft water) are moderately hard water, thus the waters are suitable for domestic use in terms of hardness. This is because moderately hard water is preferred to soft water for drinking purposes as hard water is associated with low death rate from heart diseases (ISO, 1990).

The biochemical oxygen demand (BOD) values ranged from 1.34±0.03 to 9.55±0.26 mg/L. This is slightly above the WHO permissible range values of BOD for drinking water. This is an indicative of a slight pollution of the groundwater which may be attributed to perculation of hydrocarbon (crude oil) and other solid organic wastes. The phosphate

Table 2. Metal concentration in borehole water samples.

S/N	Sample location	Pumping depth (m)	Geographical coordinate	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Pb (mg/L)	Cu (mg/L)	Chrom (mg/L)	Cd (mg/L)	As (mg/L)
1	Akenfa- Well 1	7.5	No4°59.895” E006°22.648’	1.40 ± 0.03	0.91 ± 0.01	0.35 ± 0.05	0.20 ± 0.01	1.00 ± 0.02	ND	ND	ND	ND	ND
2	Agudama-Epie-Well 2	7.5	No4°59.077” E006^{0}22.507”	2.05 ± 0.01	0.11 ± 0.06	9.25 ± 0.10	6.50 ± 0.12	0.40 ± 0.02	ND	ND	ND	ND	ND
3	Opolo- Well 3	8.0	No.4°56.977” E006^{0}20.163”	1.03 ± 0.02	1.30 ± 0.08	8.25 ± 0.03	2.78 ± 0.23	1.40 ± 0.002	ND	ND	ND	ND	ND
4	Yenazuegene-Well 4	20.5	No4°56.472” E006°19.017”	1.38 ± 0.02	3.37 ± 0.10	0.55 ± 0.01	7.40 ± 0.10	1.40 ± 0.001	ND	ND	ND	ND	ND
5	Kpansa- Well 5	21.5	No4°55.853” E006°18.373”	1.77 ± 0.03	2.45 ± 0.11	4.22 ± 0.20	2.57 ± 0.10	0.60 ± 0.002	0.03 ± 0.001	ND	ND	ND	ND
6	Ekeki- Well 6	7.5	No4°55.761” E006°17.717”	2.01 ± 0.02	1.38 ± 0.04	6.75 ± 0.20	2.00 ± 0.002	0.90 ± 0.002	0.008 ± 0.000	ND	ND	ND	ND
7	Onopa- Well 7	6.8	No4°56.350” E006°16.683”	1.86 ± 0.05	2.25 ± 0.07	7.90 ± 0.10	4.40 ± 0.20	1.00 ± 0.005	0.04 ± 0.001	ND	ND	ND	ND
8	Swali- Well 8	7.5	No4°55.123” E006°15.977”	1.91 ± 0.02	1.80 ± 0.08	3.05 ± 0.12	0.84 ± 0.06	0.50 ± 0.001	ND	ND	ND	ND	ND
	WHO limits			200	200	7.5		50	0.30	0.05	0.05	0.01	0.05

values are generally very low ranging between ND to 0.16±0.002 mg/L, suggesting portability of the water samples. All the samples of sulphate analyzed gave values that are well below the WHO maximum permissible limit of 200 mg/L. These values are below reported values by Nwala et al. (2007) and Bolaji and Tse (2009) within the region.

Chlorine which is in form of chlorine is one of the major anions in water, it is known in maintenance of acid - base balance, and hence excess of it may cause edema (Ekpete, 2002). The values obtained for chloride ranged from 4.10±0.40 to 16.00±1.00 mg/L. These values obtained are well below the recommended standard value of 250 mg/L by WHO; they are also within the range of values reported by Ekpete (2002) and Nwala et al. (2007); but are below the values reported by Manilla and Tamuno-Adoki (2007), Bolaji and Tse (2009) in the Niger Delta region. Nitrate values in the samples ranged from 1.20 ± 0.03 to 8.70±0.50 mg/L. The values are slightly below the WHO recommended limit of 10.0 mg/L; but these values are higher than those reported by Nwala et al. (2007) and Manilla and Tamuno-Adoki (2007). Earlier works have contended that nitrate above 44 mg/L in drinking

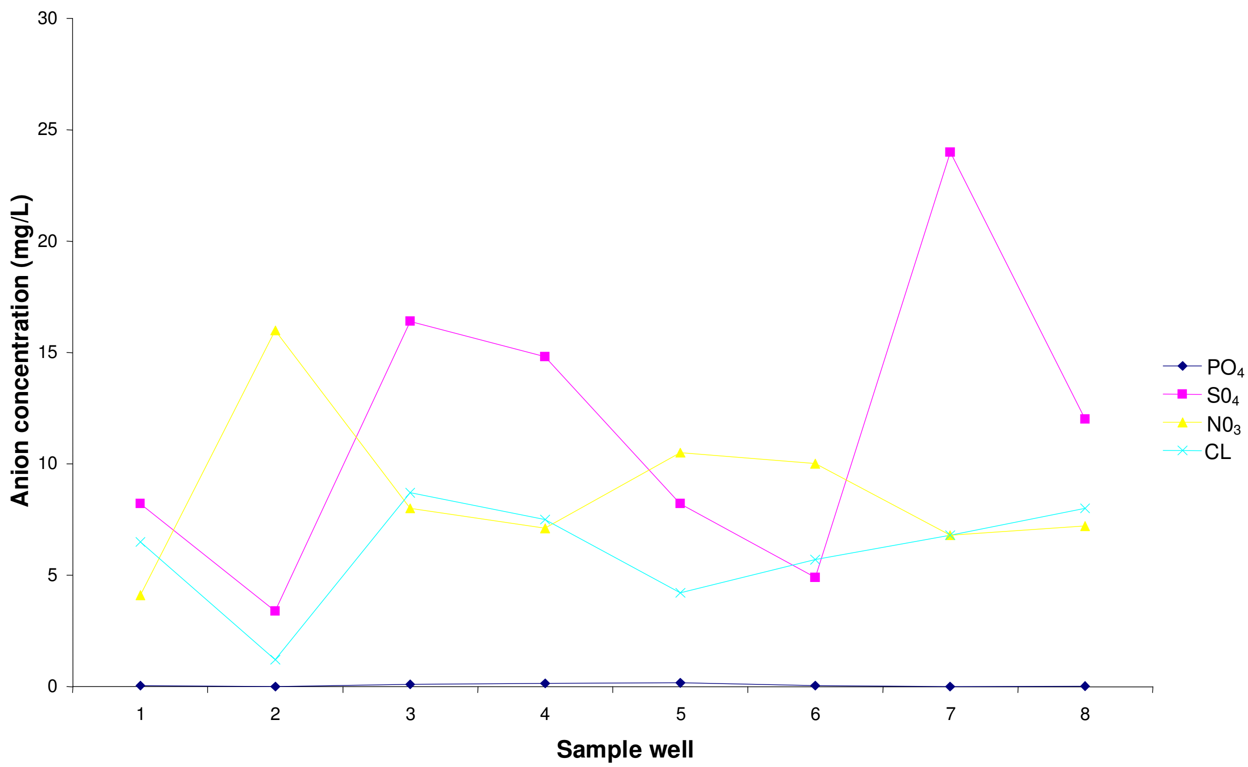

Figure 2. Distribution of anions in the groundwater samples.

water could cause methaemoglobinemia (blue water body) in children and death in farm animals (Nwala et al., 2007). Na^+ concentration in the analyzed water samples ranged from 1.03±0.02 to 2.05±0.01 mg/L while k^+ ranged from 0.11±0.06 to 3.37±0.10 mg/L. These concentrations of Na^+ and k^+ in these samples were well below the recommended limit of 200 mg/L for both. These values obtained are similar to those reported by Bolaji and Tse (2009) and has no health implication to the public consumer of the water in terms of Na^+ and k^+.

Ca^{2+} and Mg^{2+} values obtained for the water samples ranged from 0.35±0.05 to 9.25±0.10 mg/L for Ca^{2+} and 0.20±0.01 to 7.40±0.10 mg/L for Mg^{2+}. The values obtained for Mg^{2+} are well in agreement with values reported by Bolaji and Tse (2009) in Port Harcourt. However, Ca^{2+} values obtained are slightly above the WHO recommended limit for drinkable water. The high values of the metal especially in Wells 2, 3, 6 and 7 waters may be responsible for samples moderate hardness. These values are departure from the values reported by Nwala et al. (2007), but agree with the values reported by Bolaji and Tse (2009) and NDES (2000) in the region.

Fe value in the sampled water ranged from 0.40±0.001 to 1.40±0.002 mg/L. This shows that Fe concentration in all the eight sampled borehole waters are far above the WHO limit of 0.3 mg/L. This high concentration of metallic iron may be responsible for the observed turbid and brownish colouration of the water when allow to settle. This is due to the oxidation of Fe^{2+} to Fe^{3+} which causes nuisance to laundry and sanitary wares (Aiyesanmi et al., 2004). It is generally observed that high Fe concentration is mostly associated with relatively shallower wells and boreholes (< 40 m deep) as concentration in relatively deeper boreholes (>40 m deep) are observed to be low (Bolaji and Tse, 2009). Lead ion (Pb) was detected at boreholes Well 5, 6 and 7. This portends some health hazard as accumulative effect of these levels may possibly lead to Pb poison (Ademoriti, 1996). The concentration of other heavy metals (Copper, Chromium, Cadmium and arsenic) analyzed in these water samples were below detection limits. Their absence in these water samples is an indication of the wholesomeness of the water as well as their fitness for domestic and other uses, if not for the detection of Pb in some samples analyzed.

Figure 2 shows the distribution of anions in groundwater samples over the sampled location wells, while Figure 3 shows the distribution of the cations in the groundwater samples. The spatial variation of these ions over the sampled groundwater shows the presence of different contaminants at different boreholes groundwater. This is so because all the boreholes sampled share the same geological features (Etu-Efeotor and Akpokodje, 1990). The variation in contaminant may therefore be attributed to the following; drilling equipment/ chemicals, depth of these boreholes, water intruision from the sea due to their proximity to the sea and aquifer level of these boreholes which may allow different

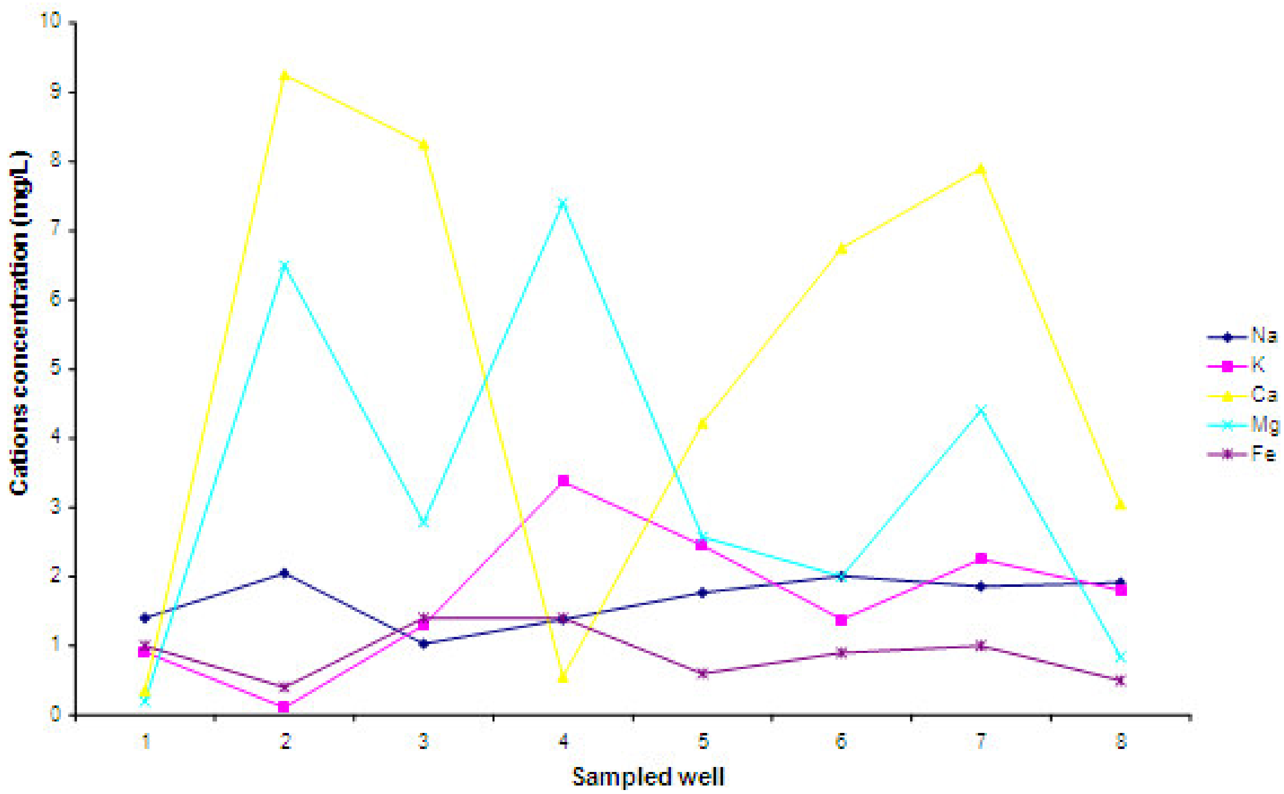

Figure 3. Distribution of cations in the groundwater samples.

level of contamination from waste dump sites, surface run-off and hydrocarbon pollution from nearby oil fields etc.

The results of the chemical analysis were used to identify the geochemical processes taking place in the groundwater system. In the study area, the molar ratio of Na/cl for groundwater generally ranged from 0.128 to 0.341 (Figure 4). All samples have Na/Cl molar ratio less than 1, which indicate that ion exchange is the major process that is prevalent in the study area (Lakshmanan et al., 2003). A regression analysis of the scattered diagram shows a strong correlation between Na/Cl and electrical conductivity with a regression coefficient of 0.862. This again confirmed the ion exchange in the groundwater process.

The Ca/Mg ratio of groundwater from the study area ranges from 0.074 to 3.631 (Figure 5). The overall mean is greater than 2 indicating the dissolution of silicate minerals which contributes calcium and magnesium to the groundwater (Maya and Loucks, 1995). The chemical composition of he groundwater is thus of Ca and Mg in the study area and has resulted from silicate weathering (Bolaji and Tse, 2009). This study led to the following recommendations which may help to reduce some of the effects and shortfalls in the groundwater quality of the study area.

1. Borehole drillers and operators should adopt the percussion drilling technique, since they are least exposed to contamination by the drilling mechanism. This also enables a detailed soil stratigraphy of the borehole to be recorded.
2. The second and third water aquifers should be exploited in this area to improve water quality, since the first aquifer is characterized with contamination and saline intrusion.
3. All boreholes waters in this area should be treated according to the groundwater quality analysis of that particular borehole water to meet the various WHO parameter standards for portable water before releasing to livestock and the public for consumption.

Conclusion

The results of the physico-chemical and hydrochemical analysis of commercial borehole water in Yenagoa Local Government Area of Bayelsa State shows that physico-chemical characteristics and parameters varied with distance and the different activities in the area. In most of the analysis, the results fell within the limits set by WHO and other water quality regulating bodies like FEPA. However, some of the parameters like pH, Ec, BOD, Ca^{2+} and Fe deviated from the recommended standard of WHO. The pH values of the samples were slightly lower indicating acidity of the waters. The EC, Ca and BOD,

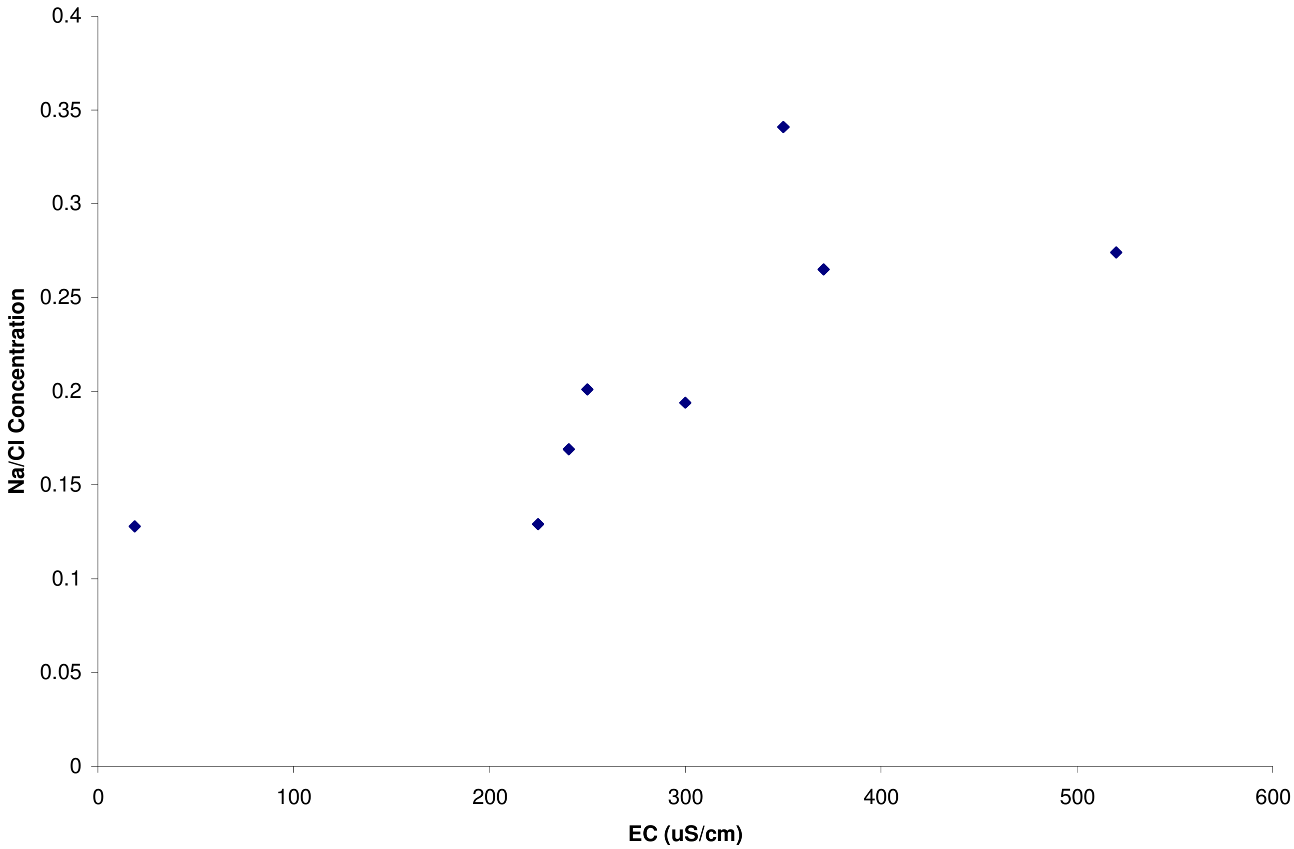

Figure 4. Plot of Na/Cl ratio vs EC.

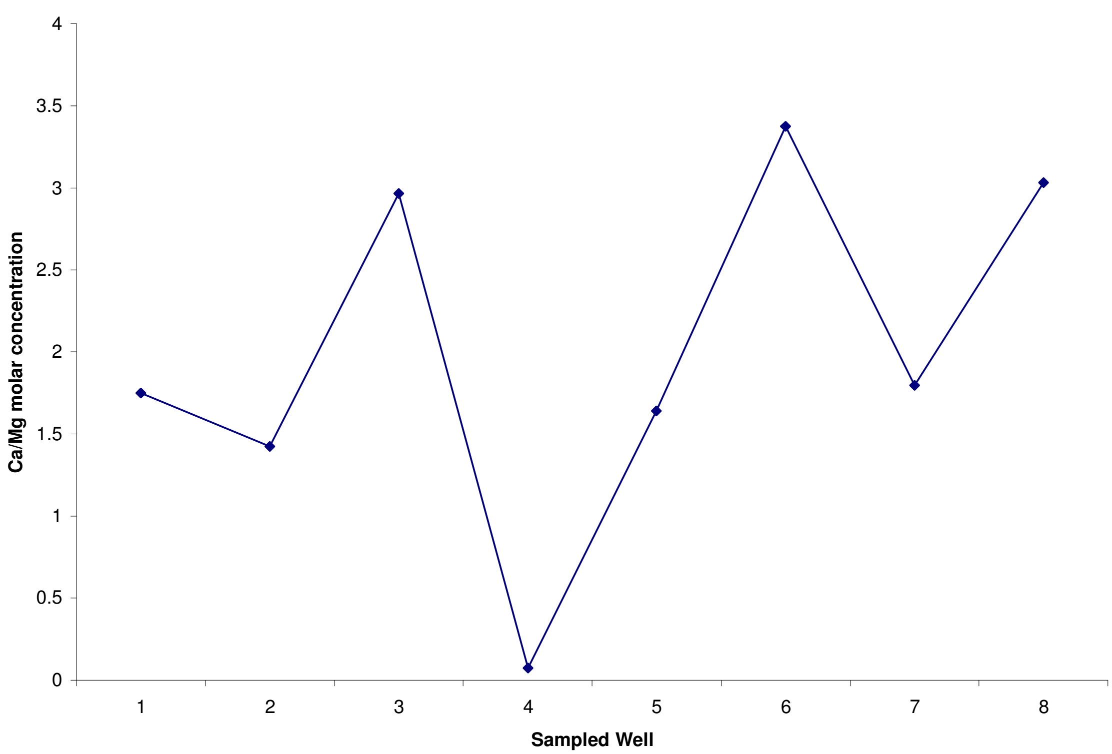

Figure 5. Plot of Ca/Mg molar ratio.

values were slightly above WHO standard while Fe values were all generally higher. The hydrochemical data suggests that ions exchange and silicate weathering are the prevailing hydrochemical processes responsible for the groundwater chemistry of the studied area. However, these variations were not too pronounced to cause serious health hazards. The fact that the concentration of heavy metals (copper, chromium, cadmium and arsenic) supposed to be major sources of pollution, in the water samples were below detection level is an evidence to attest to the wholesomeness of the water samples. But this does not rule out completely the need for the appropriate treatment of these water sources for portability and safe drinking. This is against the backdrop that some of the parameters analyzed exceeded the WHO limits for drinking water and the detection of Pb, a serious health hazardous heavy metal in some water samples which their long term accumulation could result to health hazards.

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