Impact of Domestic and Industrial Waste on Surface and Ground Water Quality Within Slaughter Area, Trans-Amadi Industrial Layout, Port Harcourt, Nigeria

Akhigbe S, Udom GJ and Nwankwoala HO*

Department of Geology, University of Port Harcourt, Port Harcourt, Nigeria

Abstract

This study aims at evaluating and assessing the impact of domestic and industrial wastes on surface and groundwater quality within the Slaughter area, Trans Amadi industrial layout, Port Harcourt, Nigeria. Standard sampling techniques where adopted. Twenty (20) water samples comprising of ten (10) boreholes and ten (10) surface water samples collected from the study area. Results reveaed slightly acidic water for both the surface and bore water in the area. These parameters were compared with the World Health Organization (WHO) guidelines for drinking water quality. The results from the analyses of the borehole samples yielded parameters that met the requirements by WHO, with exception of Iron (Fe) that had values at some locations above the maximum 0.3 mg/l. This was considered to probably be as a result of corrosion from pipes used in water distribution or dissolution arising from high fabrication activities with in and around the study area. None of the surface water samples met the WHO requirments for drinking water quality. The hydrochemical facies of the water samples were identified by plotting the results of the major cations and anions in milliequivalent per litre in the Piper Trilinear diagram. All the analysed water samples of both the borehole and surface water samples plotted within the Na+ - K+ - Cl- - SO$_4^{2+}$ hydrochemical facies, indicating origin from halite dissolution (Saline). The surface water samples were tested against their suitability for irrigation purposes by plotting electrical conductivity which is a measure of the salinity hazard in the use of water for irrigation against Sodium adsorption ratio (SAR) expressed in milliequivalent per litre, in water classification diagram for irrigation. The result yielded high salinity water (C3) - Medium sodium water (S2) and Very high salinity water (C4) - High sodium water (S3) suggesting that adequate care is required in the use of the surface water for the purposes of irrigation. It is therefore recommended that regular water quality monitoring in the area be carried out for proper environmental protection and sustainability.

Introduction

In most of the developing countries, municipal solid waste (MSW) disposal has been a chronic problem, particularly in areas with high population density and high production of refuse. Scarcity of land for adequate for landfills often gives rise to indiscriminate dumping of refuse in surface water bodies and improper landfill systems. Landfills or open dumps have been demonstrated by several workers to pose serious threat to groundwater and surface water resources [1,2], especially those constructed and operated without impermeable layers meant to reduce the potential of contamination. The degree of threat is strongly influenced by the composition of the wastes in the landfill, the volume of leachates generated, as well as the Location of the landfill from water bodies such as groundwater and surface water [2]. This in turn has led to pollution of surface and groundwater causing over 20% of the world population (around 1.3 billion people) not to access safe drinking water. Water can be polluted by substances that dissolve in it or by solid particles and insoluble liquid droplets that become suspended in it. The Slaughter area in Port Harcourt, Rivers State, Nigeria (Figure 1), is surrounded by water bodies and is the hub for major commercial and industrial activities. These water bodies have become regions for indiscriminate waste disposals for the commercial activities (Figure 2) as well as effluents from the industries within and around the Slaughter area (Figure 3). There is little or no awareness by the inhabitants in the Slaughter area of the danger that this indiscriminate dumping of refuse would pose to the groundwater resource. This study therefore, examines selected borehole water and some surface water locations for water quality parameters to determine their suitability for drinking and other purposes.

There are high concentrations of commercial/domestic and industrial activities within and around the study area. These gave rise to high generation of both industrial and commercial/domestic waste within the study area. In the light of the above, there is no documented impact assessment of these commercial/domestic and industrial waste in the study area thereby not allowing for proper environmental monitoring. This study is aimed at assessing the borehole and surface water quality parameters of the Slaughter Area of Port Harcourt for drinking and other purposes.

Location of Study Area

The study area lies within Longitudes 70°02′00″ and 70°04′10″ E; and between Latitudes 40°49′00″ and 40°50′00″ N of the Equator (Figure 3). Rain falls in the study area almost all the year round and generally very heavy. The average annual rainfall is about 3200 mm. The mean maximum monthly temperatures range from 28°C to 33°C, while the mean minimum monthly temperatures are within the range of 17°C to 24°C. The hottest months are February to May. The relative

Figure 1: Waste dumps in the study area.

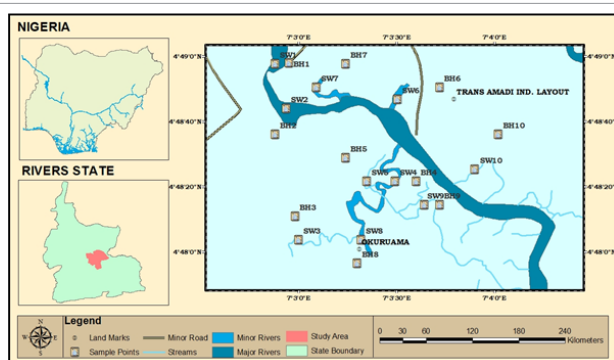**Figure 2**: Industrial effluents in the study area.

Figure 3: Location map showing the sampled points for borehole water samples (BH) and surface water samples (SW).

humidity is high throughout the year and decreases slightly during the dry season [3].

The vegetation of the study area comprises of an upland area dominated by rainforest with such economic trees as oil palm and the riverine area which is divided into three main hydro-vegetation zones; the beach ridge zone, the saltwater zone and the freshwater zone. The beach ridge zone consists of fresh water swamp trees, palms and shrubs on the sandy ridges and mangroves in the tidal flats. The saltwater zone consists of the tidal flat vegetated by red stilts rooted mangrove (Flhizophora racemose) and two other species of mangrove. The outliers of raised coastal plain terrace within the tidal flats are vegetated by tall forest tree species and oil palm. The freshwater zone consists of the Upper and Lower Delta flood plains.

Relief in the study area may be grouped into three; the fresh water, the mangrove swamp and the Coastal sand ridges zone. The fresh water zone consists of the flood plain under 20 m above the sea level. It consists of silt and clay and it is more susceptible to perennial inundation by river floods. The southern part is affected by great tidal influence. Most water channels in the fresh water zone are bordered by natural levees, which are of great topographical interest and of great economic importance to the local people for settlements and crop cultivation. The upland is undulating to the hinterland; narrow strip of sandy ridges and beach ridges lies very close to the open sea. The soils of the sandy ridges are mostly sandy loams.

Drainage in the study area is poor because of the low-lying flood plain with much of the surface covered with water. The study area is drained by two main sources; the fresh water system whose waters originate either outside or wholly from the coastal lowlands including the Bonny and Calabar river systems and a host of effluent creeks and streams, and a tidal system.

The study area lies on the Coastal Plain of the Niger Delta. The geology of the study area consists of Recent fluvial deposits transported and redistributed by the Niger River distributaries. The depositional sequences signify a massive continental sand deposit overlying an alternation of sandstones and clays of marginal marine origin grading into marine clays. The study area consists mainly in the surface, sandy deposits belonging to the Benin Formation of the Niger Delta litho-stratigraphic unit. The subsurface geology comprises of the following rock-stratigraphic subdivision; Benin Formation, Agbada Formation, and Akata Formation [4]. These Formations range in age from Eocene to Recent.

Methods of Study

Samples were collected from ten (10) boreholes and ten (10) surface water sampling points in plastic sampling bottles. Sterilized water bottles were used to collect representative water samples to prevent contamination. At each borehole location, the sample bottles were washed and rinsed thoroughly with the sample water before being sampled. The samples were collected close to the well head to maintain the water integrity. The boreholes were allowed to flow for about 3 minutes to ensure stable conditions before samples were collected. The bottle was filled to the brim with the sample water, and the lid immediately replaced to minimize oxygen contamination and escape of dissolved gases. Sampling was done using two sets of prelabelled bottles of one litre capacity for ionic and heavy metals analysis respectively. Water samples for the determination of cations were stabilized by adding few drops of diluted HCl to them after collection. To maintain the integrity of the water samples, physico-chemical parameters sensitive to environmental changes such as pH, conductivity and temperature were measured and recorded *in-situ* using portable digital meters. The co-ordinates of all the sampling locations were recorded using a Garmin 78 model Geographic Positioning System (GPS). The samples were later transported to the laboratory in an ice chest for chemical analysis. Table 1 shows the analytical methods.

Heavy metals were determined using an Atomic Absorption Spectrophotometer (AAS) as described in APHA 3111B and ASTM D3651. This involved direct aspiration of the sample into an air/acetylene or nitrous oxide/acetylene flame generated by a hollow cathode lamp at a specific wavelength peculiar only to the metal programmed for analysis. For every metal investigated, standards and blanks were prepared and used for calibration before samples were aspirated. Concentrations at specific absorbance displayed on the data system monitor for printing. The equipment limit of detection is <0.001 mg/L. Table 1 shows the analytical methods used for analysis.

Parameter	Type of test	Equipment/Analytical Method	Standard
pH	*In-situ*	Digital pH meter	APHA 4500H*B
Temperature	*In-situ*	Mercury-in-glass thermometer	
Conductivity	*In-situ*	Digital conductivity meter	APHA 2510B
Turbidity	Laboratory	HACH2100AN tubidimeter	APHA2130B
Calcium, Magnesium, Potassium, Alkalinity	Laboratory	Direct atomic absorption	ASTMD511-93
Sodium, Hardness	Laboratory	Titration method	ASTM512B
Total Dissolved Solids	Laboratory	Filtration and evaporation	APHA 2510A
Sulphate and Phosphate	Laboratory	Turbidimetric method	ASTMS-516
Chloride	Laboratory	Silver nitrate titration	ASTM512B
Nitrate	Laboratory	Brucine method	APHA 4500*E
Bicarbonate	Laboratory	Colorimetric method	
Heavy metals	Laboratory	Atomic absorption spectrophotometer	APHA 3111B

Table 1: Equipment and analytical methods used for groundwater samples analysis.

Sodium hazard assessment

The mineralogical parameters on which the water was assessed for its use for irrigation purposes include the following:

1. Total salt concentration which is a measure of electrical conductivity (EC).

2. Percentage ratio of Sodium (Sodium hazard) compared with other major cations. The percent Sodium consideration in the surface water can be calculated using the following formulae:

% Na^+ = (Na^+) X 100/ (Ca^{2+} + Mg^{2+} + Na^{+1} + K^{+1})..................(1) after Wilcox [5].

The concentrations of Ca^{2+}, Mg^{2+}, Na^{+1} and K^{+1} expressed in milliequivalents per litre (meq/l).

Another method of determining the Sodium hazard in water is by Sodium Adsorptio Ratio (SAR) using the following equation.

$$SAR = \frac{Na}{\sqrt{Ca + Mg / 2}} \qquad (2)$$

RSC (Residual sodium carbonate) is given as follows:

RSC = (HCO_3^- + CO_3^{2-}) – (Ca^{2+} + Mg^{2+}) \qquad (3)

Where all the mineral concentrations are expressed in milliequivalents (meq/l).

The Piper trilinear diagram is used in the classification of the hydrochemical facies present within the ground water. In plotting the Piper trilinear diagram, ionic concentrations of the major cations and anions in milligrams per liter (mg/l) were converted to milliequivallent per liter using the following formulae:

$$concentration\ in\ meq\,/\,l = \frac{concentration\ in\ mg\,/\,l \times valence}{molecular\ weight\ of\ ion} \qquad (4)$$

The milliequivalent per litre of the ions is the milliequivalent of the ion in one litre of a solution.

Results and Discussion

Temperature

The temperature in the water samples analysed ranges between 27°C to 31°C with a mean value of 30.2°C in the borehole water samples and 26.5°C to 31.1°C with a mean value of 30.2°C in the surface water samples (Tables 2a and 2b). Temperature is an important water quality parameter because it affects the physical, chemical and biological activates in water. When the water temperature is high, there is an increase in the rate of chemical processes and solubility of gases such as oxygen, carbon dioxide, nitrogen while others decrease.

pH

The pH of the samples analysed ranges between 5 and 6 with a mean value of 5.6 in the borehole water samples and 6.3 to 7.1 with a mean value of 6.8 in the surface water samples (Tables 2a and 2b). pH is an expression of the neutrality of acid or alkali in the water. The scale between 0 and 7 signifies acidity, 7 neutral, and 7 - 14 alkalinity. Considerable changes in water pH usually occur partly as a result of industrial discharges among other sources [6]. This could make the water unsuitable for drinking and other uses for industry and agriculture. For groundwater samples, the pH is acidic, and for surface water, results indicate that the pH is within the recommended guideline by NSDWQ [7]; WHO [8].

Electrical conductivity

The values of electrical conductivity generated from the samples analyzed ranged from 10µS/cm to 70 µS/cm with a mean value of 30 µS/cm in the borehole water samples and 1400 µS/cm to 3500 µS/cm with a mean value of 27000 µS/cm in the surface water samples (Tables 2a and 2b).

Total dissolved solids (TDS)

TDS generated for the borehole water samples analyzed is 20 mg/l for all the sampled boreholes and ranged from 13460 mg/l to 14780 mg/l with a mean value of 14079 mg/l for the surface water samples.

Total suspended solids (TSS)

The values of TSS generated from the samples analyzed ranged from 1.3 mg/l to 10 mg/l with a mean value of 3.6 mg/l in the borehole water samples and 920 mg/l to 1870 mg/l with a mean value of 1302 mg/l in the surface water samples (Tables 2a and 2b).

Dissolved oxygen (DO)

The DO values generated from the samples analyzed ranged from 4.6 mg/l to 6.6 mg/g with a mean value of 5.4 mg/l in the borehole samples and 1.44 mg/l to 5.64 mg/l with a mean value of 3.8 mg/l in the surface water samples (Tables 2a and 2b).

Total hardness

The water hardness ranged from 1.6 mg/l to 28 mg/l in borehole samples and 830.6 mg/l to 3100 mg/l in the surface water samples. Water hardness is a result of concentrations of calcium and magnesium (cations) and carbonate, bicarbonate, chloride and sulphate (anions) in water. The water hardness was classified based on Sawyer and McCarty's, 1967 classification for water hardness. The result from the classification scheme (Table 3) showed that the borehole water samples are soft and good for domestic use. The surface water samples are very hard resulting from high concentrations of calcium and magnesium ions, the mean value of calcium concentration for the surface water is 49.5 mg/l against the 500 mg/l limit stipulated by WHO [8] while the

Borehole water samples																			
									Anions				Cations						
Sample Identity	pH	Temperature (°C)	Alkalinity (mg/l)	Conductivity (μs/cm)	TDS (mg/l)	DO (mg/l)	TSS (mg/l)	Total Hardness (mg/l)	Sulphate (mg/l)	Chloride (mg/l)	CO_3 (mg/l)	HCO_3 (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cr (mg/l)	Zn (mg/l)	Fe (mg/l)	Cd (mg/l)
BH 1	5.3	31.1	5.6	20	10	5	1.3	28	0.7	12	5.6	5.6	0.1	0.5	0.2	2.7	Nil	0.04	2.4	Nil
BH 2	5.5	31.1	5.6	20	10	5.3	1.3	16	0.7	10.8	5.6	5.6	0.1	0.7	0.1	3.1	0.1	0.01	2.8	Nil
BH 3	5.3	31.1	3.6	70	35	5.3	2.3	14	0.7	25.6	3.6	3.6	0	0.6	5.5	3	0.01	0.02	2.1	Nil
BH 4	5.5	31.1	10	30	15	4.6	3.1	12	0.7	10.8	10	10	0	0.8	0.2	2.8	Nil	0	0.8	Nil
BH 5	6.2	26.7	4	10	5	6.6	10	1.6	0.7	7.2	7.4	7.8	0.3	0.4	0.3	2.8	Nil	0.1	0	Nil
BH 6	5.3	31.1	5.6	20	10	5	1.3	28	0.7	12.3	5.7	5.7	0.1	0.6	0.2	2.8	Nil	0.04	2.4	Nil
BH 7	5.5	31.1	5.6	20	10	5.3	1.3	16	0.7	10.5	5.4	5.4	0.1	0.7	0.1	3.2	0.1	0.01	2.8	Nil
BH 8	5.3	31.1	3.6	70	35	5.3	2.3	14	0.7	14.6	3.6	3.6	0	0.7	0.4	3.1	0.02	0.02	2.1	Nil
BH 9	5.5	31.1	10	30	15	4.6	3.1	12	0.7	10.6	11	11	0	0.9	0.2	2.9	Nil	0	0.8	Nil
BH 10	6.2	26.7	4	10	5	6.6	10	1.6	0.7	7.5	7.7	7.6	0.1	0.4	0.3	2.9	Nil	0.1	0	Nil
Max	6	31	10	70	35	6.6	10	28	0.7	25.6	11	11	0.3	0.9	5.5	3.1	0.1	0.1	2.8	Nil
Min	5	27	4	10	5	4.6	1.3	1.6	0.7	7.2	3.6	3.6	0	0.4	0.1	2.7	Nil	0	0	Nil
Mean	5.6	30.2	5.8	30	15	5.4	3.6	14	0.7	12.2	6.6	6.6	0.1	0.6	0.8	2.9	0.03	0.03	1.6	Nil
STD	0.4	1.9	2.4	22.1	0	0.7	3.5	8.9	0	5.2	2.5	2.5	0.1	0.2	1.7	0.2	0.1	0.04	1.1	Nil
WHO	6.5 - 8.5	NA	NA	500	500	NA	NA	500	250	250	NA	NA	7.5	50	200	200	0.05	NA	0.3	NA

Table 2a: Analytical results for the borehole water samples.

Surface water samples																			
									Anions				Cations						
Sample Identity	pH	Temperature (°C)	Alkalinity (mg/l)	Conductivity (μs/cm)	TDS (mg/l)	DO (mg/l)	TSS (mg/l)	Total Hardness (mg/l)	Sulphate (mg/l)	Chloride (mg/l)	CO_3 (mg/l)	HCO_3 (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cr (mg/l)	Zn (mg/l)	Fe (mg/l)	Cd (mg/l)
SW 1	6.9	31.1	36	35000	14460	2.9	1360	3003	399.04	7400	36	36	55.5	114.8	487.8	119.2	Nil	0.1	11.4	Nil
SW 2	7	31.1	28	31000	14780	4	1800	2502.5	412.8	8640	28	28	54.1	111.9	480.1	120	Nil	0	2.6	Nil
SW 3	6.9	31.1	26	28000	13820	5.1	1060	2502.5	295.8	6840	26	26	51.5	119.9	514.4	96.6	Nil	0.01	3.3	Nil
SW 4	6.9	31.1	27.2	28000	13760	5.4	920	3003	289	6700	27.2	27.2	48.9	113	511.9	96.1	Nil	0.3	3.6	Nil
SW 5	6.3	26.7	20.8	26000	13575	1.4	1200	840.8	117.7	1880	24.5	25.6	28.5	29.1	504.1	97.1	Nil	0.1	0.8	Nil
SW 6	7.1	31.1	34	34000	13460	1.9	1460	3020	400	7402	34	28	54.5	113	489.6	120	Nil	0.04	10.4	Nil
SW 7	6.8	31.1	26	32000	14580	5	1870	2504	417	8460	30	29	54.3	121.9	483.1	125	Nil	0	2.7	Nil
SW 8	6.9	31.1	28	27000	13920	4.1	1160	2402.5	279.8	6750	27	27	53.5	115.9	520.4	94.6	Nil	0.01	3.4	Nil
SW 9	6.7	31.1	29	28000	14760	5.6	940	3100	297	6730	27.8	27.6	47.9	114	531.9	95.2	Nil	0.3	3.4	Nil
SW 10	6.5	26.5	20	27000	13675	2.4	1250	830.6	106.6	6890	25.5	26.6	46.5	113	513.1	95.2	Nil	0.08	1	Nil
Max	7	31.1	36	35000	14780	5.6	1870	3100	417	8640	36	36	55.5	121.9	531.9	125	Nil	0.3	11.4	Nil

Min	6.3	26.5	20	27000	13460	1.4	920	830.6	106.6	1880	24.5	25.6	28.5	29.1	480.1	94.6	Nil	0	1	Nil
Mean	6.8	30.2	27.5	27000	14079	3.8	1302	2370.9	301.5	6769	28.6	28.1	49.5	106.7	503.7	105.9	Nil	0.1	4.3	Nil
STD	0.2	1.9	5	7615.8	510.5	1.5	328	851.1	114.2	1858.5	3.7	3	8	27.4	17.6	13.1	Nil	0.1	3.6	Nil
WHO	6.5 - 8.5	NA	NA	500	500	NA	NA	500	250	250	NA	NA	7.5	50	200	200	NA	NA	0.3	NA

Table 2b: Analytical results for the surface water samples.

Sample Identity	(Na⁺) × 100	(Ca²⁺ + Mg²⁺ + Na⁺¹ + K⁺¹)	% Na⁺
SW1	2120	36.4	58
SW2	2090	35.9	58
SW3	2240	37.4	59
SW4	2230	36.5	61
SW5	2190	28.2	77
SW6	2130	36.4	58
SW7	2100	36.9	56
SW8	2260	37.2	60
SW 9	2310	37.3	61
SW10	2230	36.3	61

Table 3: Percent Sodium values for the surface water samples.

mean value of magnesium concentration for the surface water is 106.7 mg/l against the 500 mg/l limit stipulated by WHO [8]. Figure 4a shows the plot of conductivity, total hardness and dissolved oxygen against borehole sample locations while Figure 4b is the plot of conductivity, total hardness and dissolved oxygen against surface water sample locations.

Distributions of cations

Calcium ranges in concentrations from 0 mg/l to 0.3 mg/l with a mean value of 0.1 mg/l in the borehole water samples and 28.446 mg/l to 55.54 mg/l with a mean value of 49.5 mg/l in the surface water; Magnesium ranges in concentrations from 0.35 mg/l to 0.86 mg/l with a mean value of 0.6 mg/l in the borehole samples and 29.10mg/l to 121.87mg/l with a mean value of 106.7 mg/l in the surface water samples. Sodium ranges in concentrations from 0.13 mg/l to 5.53 mg/l with a mean value of 0.8 mg/l in borehole water samples and 480.09 mg/l to 531.94 mg/l with a mean value of 503.7 mg/l in the surface water samples. Potassium ranges in concentrations from 2.7 mg/l to 3.14 mg/l with a mean value of 2.9 mg/l in borehole water samples and 94.62 mg/l to 125.01 mg/l with a mean value of 105.9 mg/l in surface water samples. Calcium, magnesium, sodium, and potassium are the dominant constituents present in water in significant concentrations. Calcium, magnesium and potassium are major plant nutrients. Sodium is not a plant major nutrient and can be toxic to some plant in higher concentrations.

The values of iron generated from the samples analyzed ranged from 0 mg/l to 2.8 mg/l with a mean value of 1.6 mg/l in the borehole samples and 0.795 mg/l to 11.375 mg/l with a mean value of 4.3 mg/l in the surface water samples (Tables 2a and 2b). 0.3 mg/l is set by WHO [8] for iron concentration in drinking water. The increase in concentrations of iron (Fe) seen in these boreholes could result from corrosion of steel and cast iron pipes used in water distribution from the boreholes. It could also result from dissolution and infiltration into the aquifers from the high activities of metal fabrications within and around the studied area. Iron (Fe) is one of the most abundant metals occuring within the Earth's crust. It occurs in the range of 0.5 – 50mg/L in natural fresh water. Within humans and all other animals, iron plays a crucial role of carrying oxygen within the blood in the form of hemoglobin. Excess iron in drinking water can produce an unpleasant taste and stain home
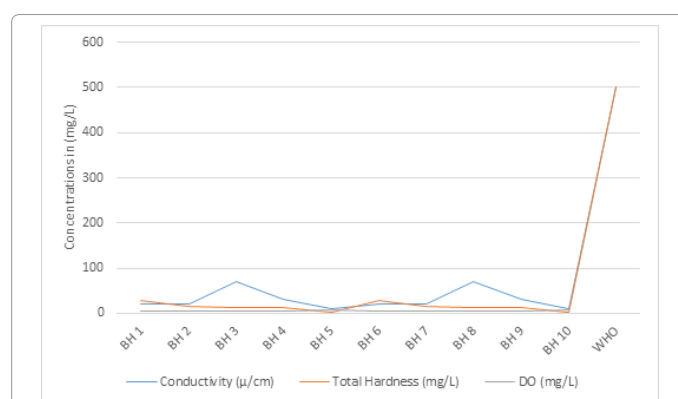

Figure 4a: Plot of conductivity, total hardness and dissolved oxygen against borehole sample locations.
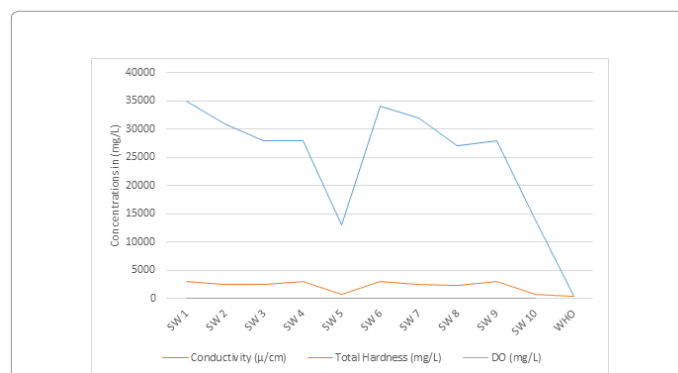

Figure 4b: Plot of conductivity, total hardness and dissolved oxygen against surface water sample locations.

fixtures. Iron is transported into the environment mostly through water and is naturally present in groundwater [9]. However, drainage from abandoned mines can deliver toxic levels of iron into rivers and streams.

The values of zinc generated from the samples analyzed ranged from 0 mg/l to 0.1 mg/l with a mean value of 0.03 mg/l in borehole water samples and 0 mg/l to 0.3 mg/l with a mean value of 0.1 mg/l in the surface water samples (Tables 2a and 2b). Zinc is a bluish – white shiny metal that is typically extracted from ore deep within the earth's crust. Zinc is the 24th most abundant element in the earth's crust. In soil, the average zinc concentration is 64 ppm. Zinc is often found in the water supply as a dissolved constituent since zinc compounds are highly soluble in water. One example is rainwater picking up zinc when it gets into contact with galvanized surfaces. Zinc occurs as particulate zinc and dissolved zinc as Zn^{2+}. Zinc is an important dietary element, but concentrations above 5 mg/L can impart an unpleasant taste to water. Exposure to large amounts of zinc can cause stomach cramps and anaemia, and also can decrease good cholesterol. In marine waters, aquatic species suffer acute effects from zinc at 90 μg/l. Adverse effects of dissolved zinc, include altered behaviour, blood and serum chemistry,
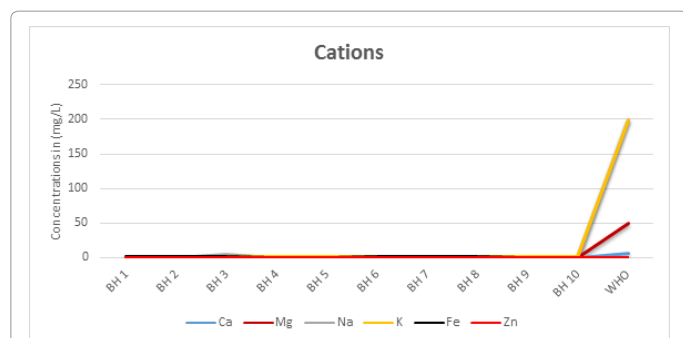
Figure 5a: Plot of cations concentrations against borehole sample locations.
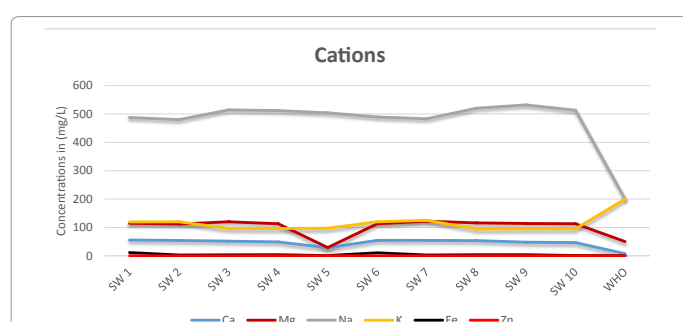

Figure 5b: Plot of cations concentrations against surface water sample locations.

impaired reproduction, and reduced growth occurs in salmon at very low levels (5.6 µg/l in freshwater). In mammals, ingesting large amounts of zinc can cause infertility and underweight of off-springs. Figure 5a is the plot of cations concentrations against borehole sample locations while Figure 5b is the plot of cations concentrations against surface water sample locations.

Distributions of anions

The important anions present in water in significant concentrations include Bicarbonates, Chloride, Sulphate, Carbonates and Nitrate. Bicarbonate concentrations in the samples analysed ranges from 3.6 mg/l to 11 mg/l with a mean value of 6.6 mg/l in the borehole water samples and 25.6 mg/l to 36 mg/l with a mean value of 28.1 mg/l in the surface water samples Chloride concentrations in the samples analysed ranges from 7.2 mg/l to 25.6 mg/l with a mean value of 12.2 mg/l in the borehole sample and 1880 mg/l to 8640 mg/l with a mean value of 6769 mg/l in the surface water samples. Sulphate concentrations in the samples analysed is 0.69 mg/l for the borehole and ranges from 106.6 mg/l to 417 mg/l with a mean value of 301.5 mg/l in the surface water samples; while carbonate concentrations in the water samples analysed ranges from 3.6 mg/l to 11 mg/l with a mean value of 6.6 mg/l in the borehole water samples and from 24.5 mg/l to 36 mg/l with a mean value of 28.6 mg/l in the surface water samples. Sulphate and nitrates are major plant nutrients. High concentration of chloride is toxic to some plants, concentrations of carbonates and bicarbonates in the water give the total alkalinity and pH rating of the water. The concentrations of the anions are plotted in scatter diagrams (Figures 6a and 6b).

Quality Evaluation for Agricultural Purposes

The results generated from analysing the borehole and surface water samples are discussed on the bases of the suitability of the water quality for drinking and domestic uses, variations in the hydrochemical facies

of the ground water samples and suitability of the surface water for irrigation purposes. The different water quality parameters measured were compared with WHO [8] guidelines for drinking water quality. The result shows that all the parameneters analysed for in the borehole water samples met the required concentrations for the WHO [8] guidelines for drinking water quality with exemption to concentrations of Iron (Fe) in all the boreholes apart from boreholes BH_5 and BH_{10}. On the other hand, all the parameters analysed for in the surface water, all exceeded the required concentrations for the WHO [8] guidelines for drinking water quality with exemption to pH and concentrations of potassium (K) which were within the required concentration. Concentration of Bicarbonate (HCO3); high concentration of bicarbonate in water can cause precipitation of calcium and magnesium thereby increasing the Sodium concentration in the form of Residual Sodium Carbonate (RSC).

The United States of America, Agriculture Department classification of ground water for irrigation with respect to percent sodium (Table 3). The United States of America, Agriculture department classification of water for irrigation with respect to sodium hazard (Table 4). The United States of America, Agriculture Department (RSC) water classification for irrigation (Tables 5-8). Table 6 is the classification of water for irrigation with respect to sodium hazard. Figure 7 is the Sodium Hazard Classification of the surface water samples in the study area [5].

The water classification diagram for irrigation purposes consists of two major components vis: conductivity (C1 – C4) and Sodium (S1 – S4) components. C1 represents conductivity in low – salinity
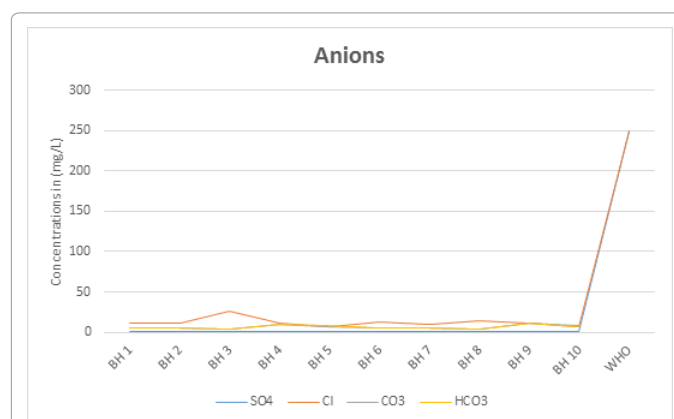

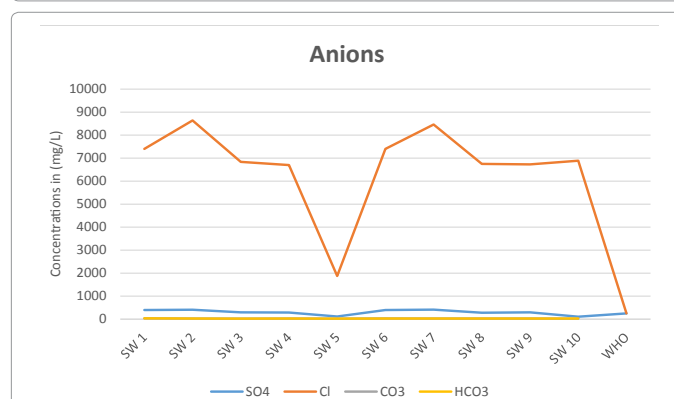Figure 6a: Plot of some anions concentrations against borehole sample locations.

Figure 6b: Plot of some anions concentrations against surface water sample locations.

% Na$^+$	Water class	Surface water analysed
<20	Excellent	
20-40	Good	
40-60	Permissible	SW1, 2, 3, 6 and SW7
60-80	Doubtful	Others
>80	Unsuitable	

Table 4: Classification of groundwater for irrigation with respect to percent sodium.

Sample Identity	Ca + mg	$\dfrac{Ca + mg}{2}$	$\sqrt{\dfrac{Ca + mg}{2}}$	$\dfrac{Na}{\sqrt{Ca + Mg/2}}$
SW1	12.2	6.1	2.47	8.58
SW2	11.9	5.95	2.44	8.57
SW3	12.5	6.25	2.5	8.96
SW4	11.7	5.85	2.42	9.21
SW5	3.8	1.9	1.35	16.2
SW6	12	6	2.45	8.69
SW7	12.7	6.35	2.54	8.3
SW8	12.2	6.1	2.47	9.15
SW9	11.8	5.9	2.43	9.51
SW10	11.6	5.8	2.41	9.25

Table 5: Sodium adsorption ratio (SAR) in study area.

Sodium Hazard class	SAR in Equivalents per mole	Remark on quality
S1	10	Excellent
S2	10 – 18	Good
S3	18-26	Doubtful
S4 and S5	>26	Unsuitable

Table 6: Classification of water for irrigation with respect to sodium hazard.

Sample Identity	HCO$_3$ + CO$_3$	Ca + Mg	RSC
SW1	1.78997	12.2	-10.41
SW2	1.38887	11.9	-10.51
SW3	1.2961	12.5	-11.2
SW4	1.35576	11.7	-10.34
SW5	1.2395	3.8	-2.56
SW6	1.58887	12	-10.41
SW7	1.47825	12.7	-11.22
SW8	1.3425	12.2	-10.86
SW9	1.3823	11.8	-10.42
SW10	1.2859	11.6	-10.31

Table 7: RSC values for the surface water samples in study area.

RSC (Meq/l)	Remark on quality
<1.25	Good
1.25-2.5	Doubtful
>2.5	Unsuitable

Table 8: RSC water classification for irrigation in study area.

water; C2, conductivity in medium salinity water; C3, conductivity in high salinity water and C4, conductivity in very high salinity water while S1 represents low sodium water; S2, medium sodium water; S3, high sodium water and S4 very high sodium water. The surface water analysed plotted in C3 - S2 and C4 - S3 sections corresponding to high salinity and medium sodium water; and very high salinity and high sodium water. High salinity water (C3) can only be used for irrigation on selected plants with good salt tolerance, while Medium sodium water (S2) can only be used on coarse-textured or organic soils with good permeability [5].
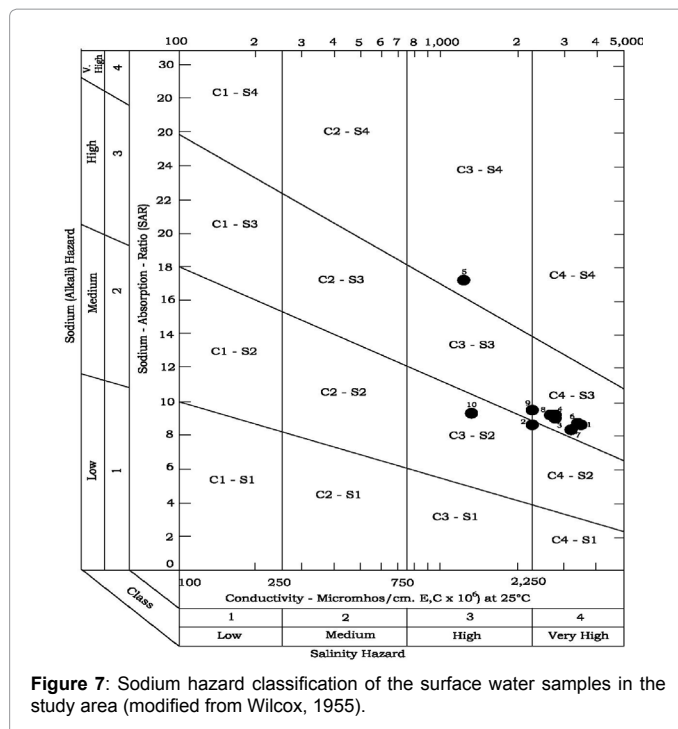

Figure 7: Sodium hazard classification of the surface water samples in the study area (modified from Wilcox, 1955).

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions but may be used in soils with very high permeability and adequate drainage system. Irrigation water must be applied in excess to provide considerable leaching and must be applied only on very high tolerant crops, while High sodium water (S3) may produce harmful degree of exchangeable sodium in most soils and will require special soil management. In all cases, adequate care is required in the use of the surface water for the purposes of irrigation.

Hydrochemical Facies

The graphical representations of the groundwater with major cations and anions in the Piper trilinear diagram helps in the understanding of the hydrochemical evolution, groupings and probably, areal distribution of the water types [10]. Generally, ground water is classified on the basis of the dominant cations and anions concentrations into four (i – iv) hydrochemical facies by expressing the concentrations of the cations and anions in milliequivalent per liter of the ground water.

These hydrochemical facies classifications of Piper [10] include the following:

i. Ca^{2+} - Mg^{2+} - Cl^- - SO_4^{2-} facies: This hydrochemical facies corresponds to the region of permanent hardness water type.

ii. Na^+ - K^+ - Cl^- - SO_4^{2+} facies: This hydrochemical facies corresponds to the region of saline water type.

iii. Na^+ - K^+ - HCO_3^- facies: This hydrochemical facies corresponds to the region of alkali carbonates water type.

iv. Ca^{2+} - Mg^{2+} - HCO_3^- facies: This hydrochemical facies corresponds to the region of temporal hardness water type.

v. The milliequivalent values of the cations and anions are presented in Piper trilinear diagram (Figures 8a and 8b) for the borehole and surface water samples to evaluate the hydrochemical facies of the
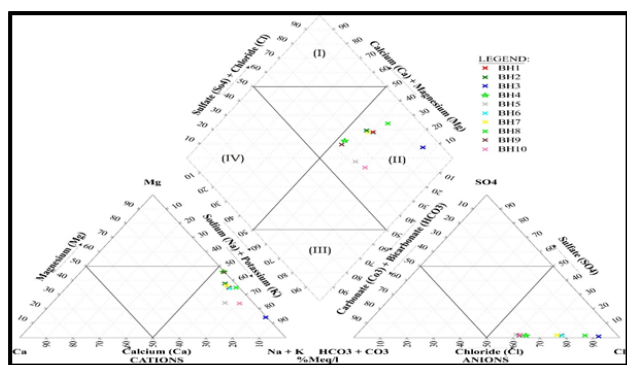
Figure 8a: Piper trilinear diagram for major cations and anions in the borehole water samples in the study area (after Piper, 1944).
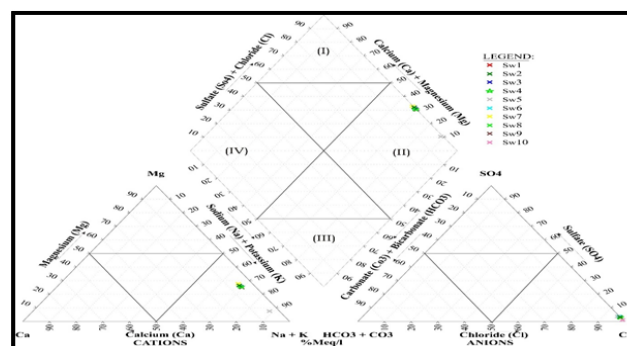

Figure 8b: Piper trilinear diagram for major cations and anions in the surface water samples in the study area (after Piper, 1944).

analysed water samples.

The hydrochemical facies for the borehole and surface water samples analysed in the study area plotted in the ($Na^+ - K^+ - Cl^- - SO_4^{2+}$ facies); hydrochemical facies (ii) which corresponds to the region of saline water type (Figures 8a and 8b). This suggest that the source of the the borehole and surface water samples are from halite dissolution (Saline) which supported the work of Nwankwoala and Udom [11,12].

Conclusion

The results from the analyses of the borehole samples yielded parameters that met the requirements provided by WHO [8] with exception of Iron (Fe) that ranged between (0 - 2.8) mg/l above the maximum 0.3 mg/l stipulated by WHO [8]. This was considered to probably be as a result of corrosion from pipes used in water distribution or dissolution and infiltration from high fabrication activities within and around the study area. The hydrochemical facies of the water samples were identified by plotting the normalized concentrations of the major cations and anions in milliequivalent per litre on the Piper trilinear diagram. All the analysed water samples of both the borehole and surface water samples plotted within the $Na^+ - K^+ - Cl^-$ - SO_4^{2+} hydrochemical facie indicating origin from halite dissolution (Saline). The surface water samples were tested against their suitability for irrigation purposes by plotting electrical conductivity which is a measure of the salinity hazard in the use of water for irrigation against Sodium adsorption ratio expressed in milliequivalent per litre in water classification diagram for irrigation. The result yielded High salinity water (C3) - Medium sodium water (S2) and Very high salinity water

(C4) - High sodium water (S3) suggesting that adequate care is required in the use of the surface water for the purposes of irrigation.

The borehole samples meet the requirements stipulated by the World Health Organization [8] guideline for drinking water quality. The surface water samples did not meet the requirements stipulated by the World Health Organization [8] guideline for drinking water quality. The hydrochemical facies analyses of the borehole and surface water samples plotted within the ($Na^+ - K^+ - Cl^- - SO_4^{2+}$) which indicates origine from halite dissolution (Saline). The water classification diagram of the surface water samples for irrigation purposes suggests that adequate care is required in the use of the surface water for the purposes of irrigation.

It is therefore recommended from the foregoing that proper landfill system should be provided and maintained for proper environmental sanitation in the study area. This will minimize and completely discourage indescrimate dumping of refuse into the surface water which contributed to the high values of the analysed parameters in the studied surface water samples, and also reduce the tendency to which the pollutant will percolate into the ground water aquifer. The study area may be developed, using the surface water as a medium for other recreational activities and as channels for water transportation but not for drinking and domestic use.

References

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