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Research Paper

Groundwater Quality Evaluation around an Active Waste Dumpsite in Slaughter, Trans-Amadi Industrial Layout, Port Harcourt, Nigeria.

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Abstarct : This study aims at evaluating and assessing the impact of domestic and industrial wastes on groundwater quality within the Slaughter area, Trans Amadi industrial layout, Port Harcourt, Nigeria. Standard sampling techniques where adopted. Ten (10) borehole water samples collected from the Slaughter area of Trans/Amadi industrial layout of Rivers state, Nigeria were analyzed for nineteen (19) water quality parameters. These parameters were tested and compared with the World Health Organization guideline for drinking water quality. The results from the analyses of the borehole samples yielded parameters that met the requirements provided by WHO, with exception of Iron (Fe) that ranged between (0 - 2.8 mg/l) above the maximum 0.3 mg/l stipulated by WHO. 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 was identified by plotting the normalized concentrations of the major cations and anions in milliequivalent per liter on the Piper trilinear diagram. All the analyzed water samples of both the borehole water samples plotted within the Na+ - K+ - Cl- - SO42+ hydrochemical facies indicating origin from halite dissolution (Saline). The borehole samples meet the requirements stipulated by the World Health Organization guideline for drinking water quality. The hydrochemical facies analyses of the borehole water samples plotted within the (Na+ - K+ - Cl- - SO42+) which indicates originate from halite dissolution (Saline). It is therefore recommended from the foregoing that a proper landfill system should be provided and maintained for proper environmental sanitation in the study area. This will minimize and completely discourage indiscriminate dumping of waste which will reduce the tendency to which the pollutant will percolate into the groundwater. It is subsequently prescribed that standard water quality observed in the territory be done for legitimate ecological assurance and manageability.

Keywords: Groundwater, borehole, wastes, hydrochemistry, environmental sanitation, Trans-Amadi, Port Harcourt.

1. 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. The effective management of waste has been a major problem in the city of Port Harcourt, capital of Rivers State in the Niger Delta region of Nigeria (Gobo, 2002). This may be due to several factors, including, a poorly managed and uncoordinated approach to waste management practices, unhealthy cultural attitudes and habits, urbanization patterns, population growth, non-mechanized waste disposal methods and poor financing of the sector. Gobo (2002) and Nwankwoala & Ogbonna, (2017) further observed that solid waste management system options that have been carried out without success to solve the problem of refuse disposal in Port Harcourt over the years include incineration, composting, transfer stations and landfilling.

Shortage of land for sufficient for landfills regularly offers to ascend to an unpredictable dumping of decline in surface water bodies and ill-advised landfill frameworks. 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 contaminated by substances that break down in it or by strong particles and insoluble fluid beads that end up suspended in it. There is practically zero mindfulness by the occupants in the Slaughter zone of the risk that this unpredictable dumping of decline would posture to the groundwater asset.

There are high concentrations of commercial/domestic and industrial activities within and around the study area which give rise to a 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 water quality parameters determination of the concentration levels of parameters in groundwater of the Slaughter Area of Port Harcourt for drinking and other purposes.

2. Description of the Study Area

The study area lies within Longitudes 7001'00" and 7005'10" E; and between Latitudes 4048'20" and 4050'34" N of the Equator (Fig. 1). The study area lies within the mangrove freshwater swamps The Niger Delta has spread across a number of ecological zones comprising sandy coastal barriers, brackish or saline mangrove, freshwater, and seasonal swamp forests. The Niger Delta has two most critical aquifers, Deltaic and Benin Formations. With a normally dendritic seepage organize, this exceptionally porous sands of the Benin Formation enables simple penetration of water to energize the shallow aquifers. Nwankwoala et al., 2013 described the aquifers in this area as a set of multiple aquifer systems stacked on each other with the unconfined upper aquifers occurring at the top (Ngerebara hydrogeological province underlain by the deltaic plains. Aquifers are encountered at varying depths within the study area with varying water qualities. The depth of the water table ranges from a few meters to tens of meters within the study area. The high permeability, over-lying lateritic earth materials containing dense vegetation, the weathered top formations as well as the underlying shale strata provide the hydrologic conditions that favored aquifers in the study area. Recharge is high in the study area resulting from heavy rainfall that is an almost an-all year-round event.

The Niger Delta comprises of three diachronous units, to be specific Akata (most seasoned), Agbada and Benin (mostly youthful) developments. The Benin Formation (Oligocene to Recent) is about 2100m thick at the basin center and consists of medium to coarse-grained sandstones, thin shales and gravels (Weber and Nwankwoala, 2008). Revive to aquifers is immediate from the invasion of precipitation, the yearly aggregate of which changes between 5000mm at the drift to about 2540mm landwards. Groundwater in the area occurs in shallow aquifers of predominantly continental deposits encountered at depths of between 45m and 60m. The lithology contains a blend of sand in a fining up arrangement, rock, and earth. Well yield is excellent, with production rates of 20,000 liters /hour common and borehole success rate is usually high (Etu-Efeotor and Odigi, 1983; Amadi et al., 2012).

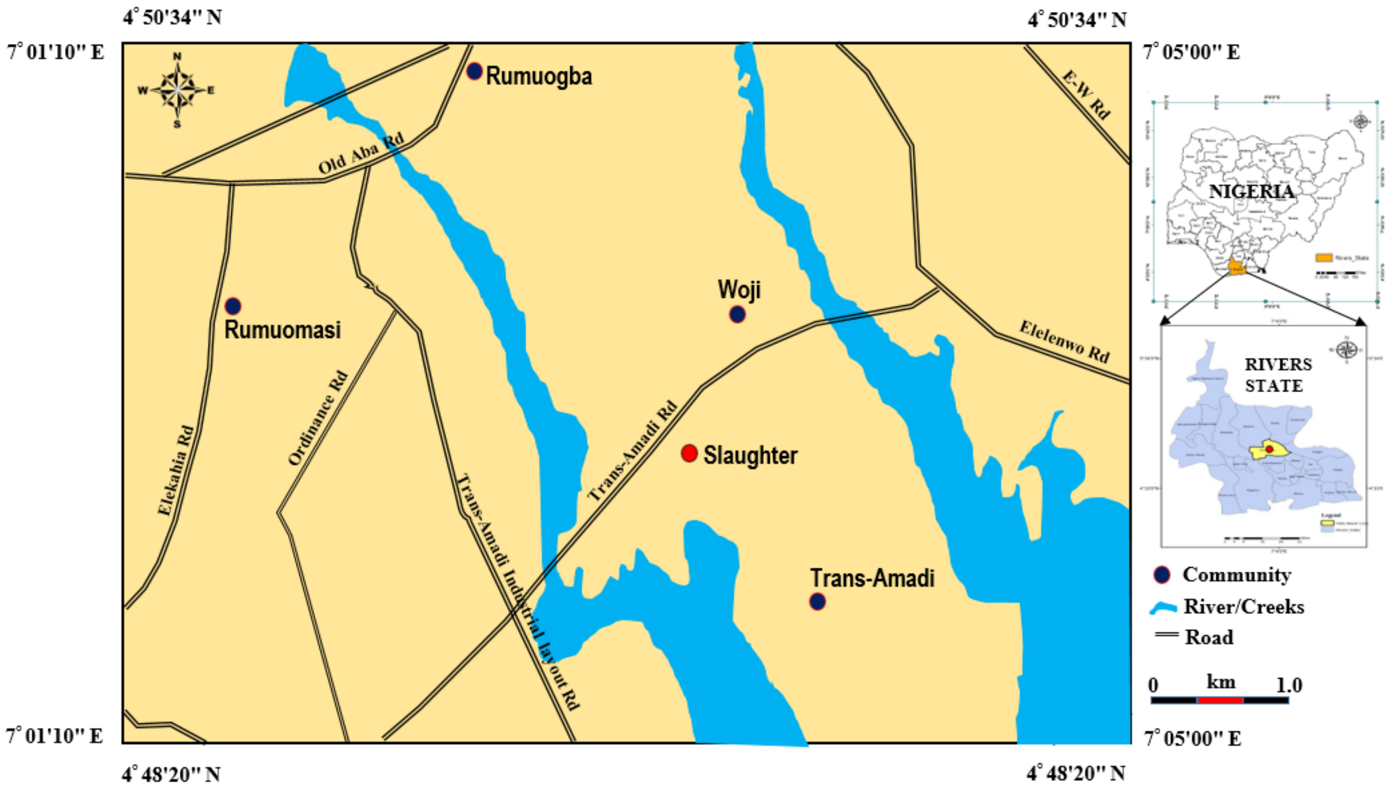


Figure -1: Location map showing the sampled points for borehole water samples (BH)

3. Methods of Study

Tests were gathered from ten (10) boreholes. All examples were conveyed to the research center and were investigated for different physical-substance parameters. Cleaned water bottles were utilized to gather delegate water tests to anticipate sullying. At each borehole area, the example bottles were washed and flushed completely with the example water before being examined. The examples were gathered near the well make a beeline for keep up the water respectability. The boreholes were permitted to stream for around 3 minutes to guarantee stable conditions previously tests were gathered. The jug was filled to the overflow with the example water, and the top quickly supplanted to limit oxygen defilement and break of broken down gases. Inspecting was finished utilizing two arrangements of prelabelled containers of one-liter limit with regards to ionic and overwhelming metals investigation individually. Water tests for the assurance of cations were balanced out by including few drops of weakened HCl to them after gathering. To keep up the trustworthiness of the water tests, physico-synthetic parameters delicate to ecological changes, for example, pH, conductivity and temperature were estimated and recorded in-situ utilizing compact computerized meters. The coordinates of all the inspecting areas were recorded utilizing a Garmin 78 demonstrate Geographic Positioning System (GPS). The examples were later transported to the research facility in a fridge for concoction investigation.

Substantial metals were resolved to utilize an Atomic Absorption Spectrophotometer (AAS) as depicted in APHA 3111B and ASTM D3651. This included a direct goal of the example into an air/acetylene or nitrous oxide/acetylene fire created by an empty cathode light at a particular wavelength exceptional just to the metal customized for examination. For each metal examined, principles and spaces were arranged and utilized for adjustment before tests were suctioned. Focuses at particular absorbance showed on the information framework screen for printing. The gear furthest reaches of identification is <0.001 mg/L. Table 1 demonstrates the scientific strategies utilized for investigation. Table 1: Equipment and Analytical Methods used for Groundwater Samples Analysis.

Table - 1:

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

4. Results Presentation

The analytical results for the borehole water samples are shown in Tables 2 and 3 for both anions and cations in mille-equivalents per liter.

Table 2: Analytical results for the borehole water samples.

Borehole water samples																				
									Anions				Cations							
Sample Identity	pH	Temperature (ºc)	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)	CO3 (mg/l)	HCO3 (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 (2011)	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 3: Analytical results for the Borehole water samples in mill equivalents per liter.

	Borehole Cations									Borehole Anions							
	Ca		Mg		Na		K		Na+K	SO4		cl		CO3		HCO3	
Sample Identity	Conc. (mg/l)	Conc. (meq/l)	Conc. (mg/l)	Conc. (meq/l)	Conc. (mg/l)	Conc. (meq/l)	Conc. (mg/l)	Conc. (meq/l)	Conc. (meq/l)	Conc. (mg/l)	Conc. (meq/l)	Conc. (mg/l)	Conc. (meq/l)	Conc. (mg/l)	Conc. (meq/l)	Conc. (mg/l)	Conc. (meq/l)
BH. 1	0.1	0.01	0.5	0.05	0.21	0.01	2.7	0.07	0.09	0.69	0.01	12	0.34	5.6	0.19	5.6	0.09
BH. 2	0.12	0.01	0.7	0.06	0.13	0.01	3.14	0.08	0.09	0.69	0.01	10.8	0.31	5.6	0.19	5.6	0.09
BH. 3	0.04	0.002	0.6	0.05	5.53	0.24	3.02	0.08	0.32	0.69	0.01	25.6	0.72	3.6	0.12	3.6	0.06
BH. 4	0.01	0.001	0.8	0.07	0.19	0.01	2.8	0.07	0.08	0.69	0.01	10.8	0.31	10	0.33	10	0.16
BH. 5	0.27	0.012	0.4	0.03	0.25	0.01	2.78	0.07	0.08	0.69	0.01	7.2	0.2	7.4	0.25	7.8	0.13
BH. 6	0.1	0.01	0.6	0.05	0.22	0.01	2.8	0.07	0.08	0.69	0.01	12.3	0.35	5.7	0.19	5.7	0.09
BH. 7	0.12	0.01	0.7	0.05	0.14	0.01	3.2	0.08	0.09	0.69	0.01	10.5	0.3	5.4	0.18	5.4	0.09
BH. 8	0.04	0.002	0.7	0.05	0.43	0.02	3.12	0.08	0.1	0.69	0.01	14.6	0.41	3.6	0.12	3.6	0.06
BH. 9	0.01	0.001	0.9	0.07	0.2	0.01	2.91	0.07	0.08	0.69	0.01	10.6	0.3	11	0.37	11	0.18
BH. 10	0.13	0.01	0.4	0.03	0.3	0.01	2.88	0.07	0.09	0.69	0.01	7.5	0.21	7.7	0.26	7.6	0.13

5. Discussion of Results

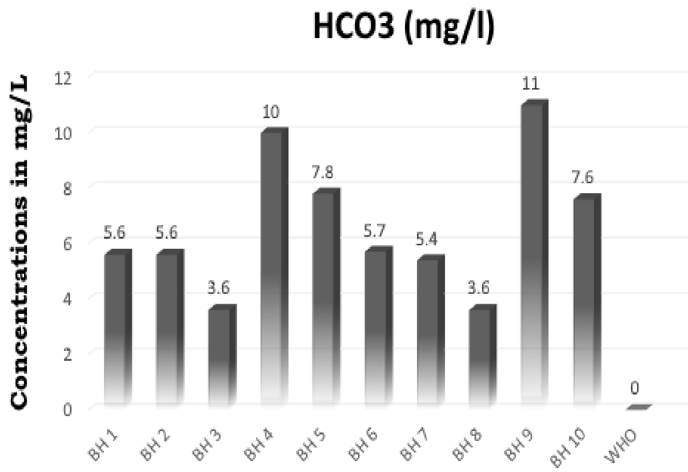
5.1. Physical/Chemical Properties

The temperature in the water samples analyzed ranges between 27°C to 31°C with a mean value of 30.2°C in the borehole water samples. The pH of the samples analyzed ranges between 5 and 6 with a mean value of 5.6 in the borehole water samples. The values of electrical conductivity generated from the samples analyzed ranges from10 micromhos/cm to 70 µS/cm with a mean value of 30 µS/cm in borehole water samples (Table 2). 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. 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. 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. The water hardness ranged from 1.6 mg/l to 28 mg/l in borehole samples.

5.2. Anion/Cation Analyses

Bicarbonate concentrations in the samples analyzed ranges from 3.6 mg/l to 11 mg/l with a mean value of 6.6 mg/l in the borehole water samples. Chloride concentrations in the samples analyzed ranges from 7.2 mg/l to 25.6 mg/l with a mean value of 12.2 mg/l in the borehole sample. Sulfate concentrations in the samples analyzed is 0.69 mg/l for the borehole. Carbonate concentrations in the water samples analyzed ranges from 3.6 mg/l to 11 mg/l with a mean value of 6.6 mg/l in the borehole water samples (Table 3).

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. 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. 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. 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. 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. The expansion in centralizations of iron (Fe) found in these boreholes could result from consumption of steel and solid metal channels utilized in water circulation 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. 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. Figs. 2 - 11 shows the plots of various parameters while figure 12 shows the plot of conductivity, total hardness and dissolved oxygen against borehole sample locations. Figure 13 is the plot of some anions/cations concentrations against borehole sample locations while Fig.14 shows the Piper trilinear diagram for major cations and anions in the borehole water samples in the study area (after Piper, 1944).



Figur- 2: Plot of Bi-carbonate concentrations against borehole sample locations.

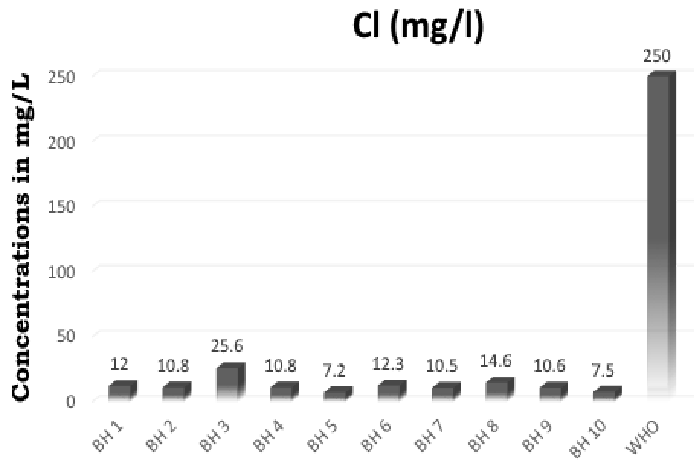


Figure - 4: Plot of Chloride concentrations against borehole sample locations.

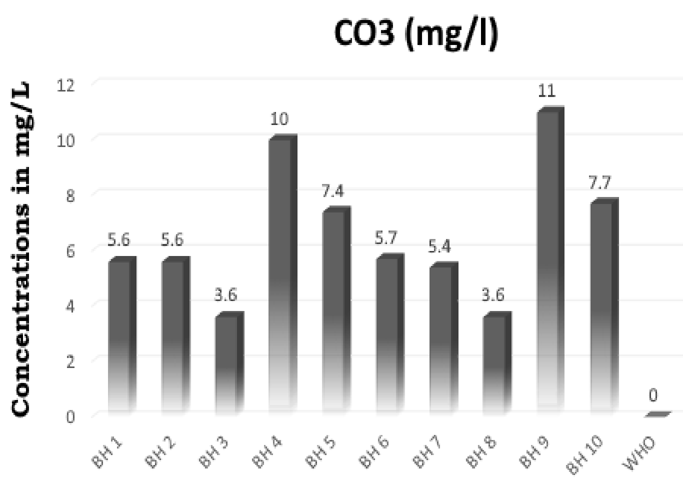


Figure 3: Plot of Carbonate concentrations against borehole sample locations.

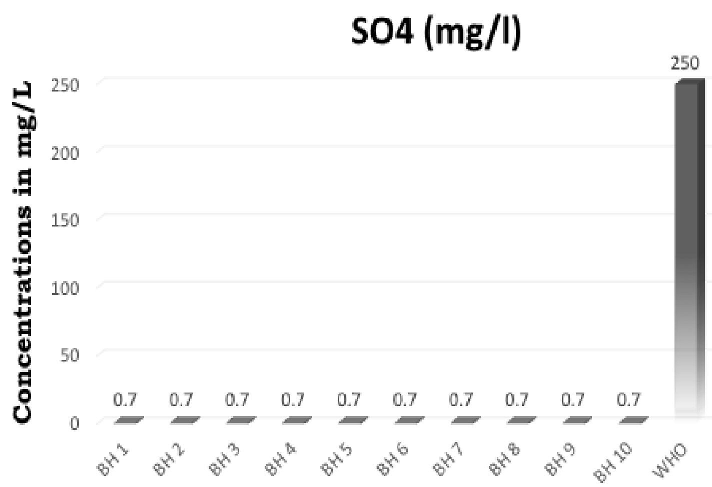


Figure - 5: Plot of Sulphate concentrations against borehole sample locations.

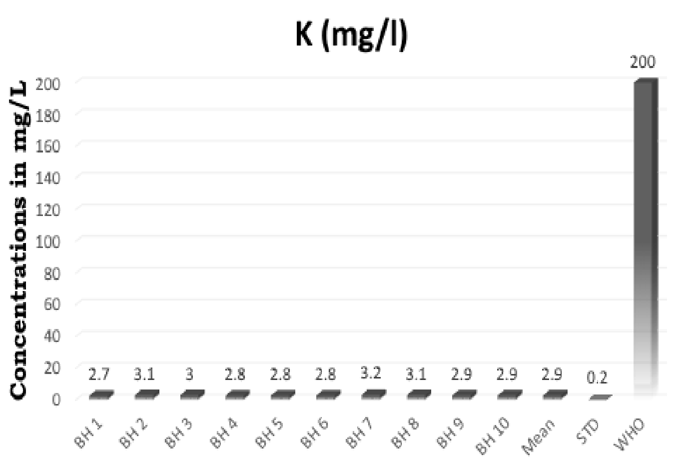


Figure - 6: Plot of Potssium concentrations against borehole sample locations

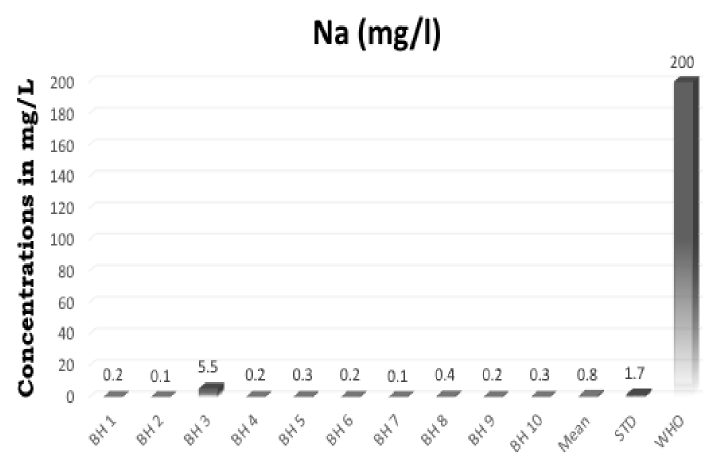


Figure - 7: Plot of Sodium concentrations against borehole sample locations.

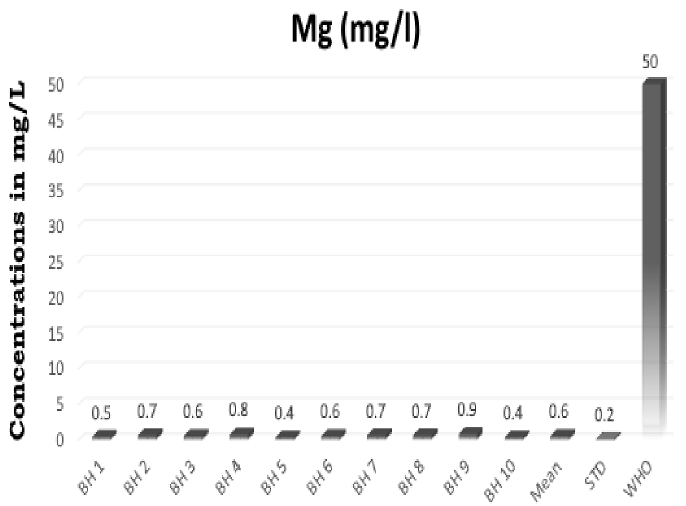


Figure -8: Plot of Magnesium concentrations against borehole sample locations.

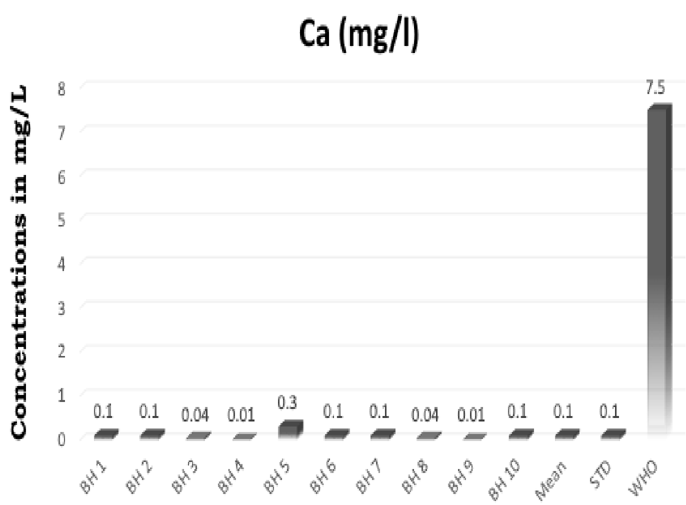


Figure - 9: Plot of Calcium concentrations against borehole sample locations

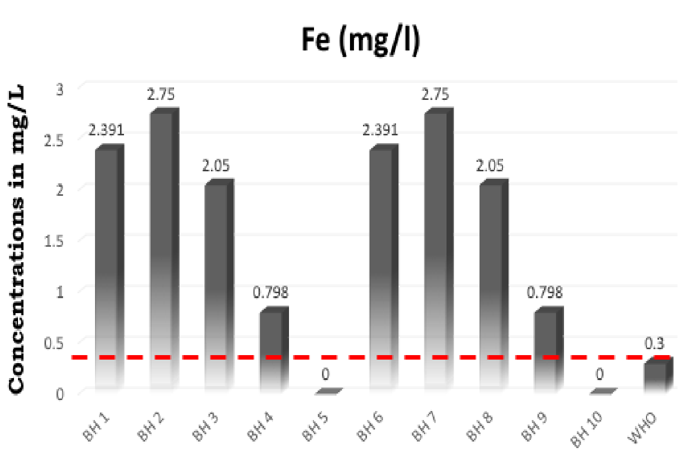


Figure - 10: Plot of Iron concentrations against borehole sample locations

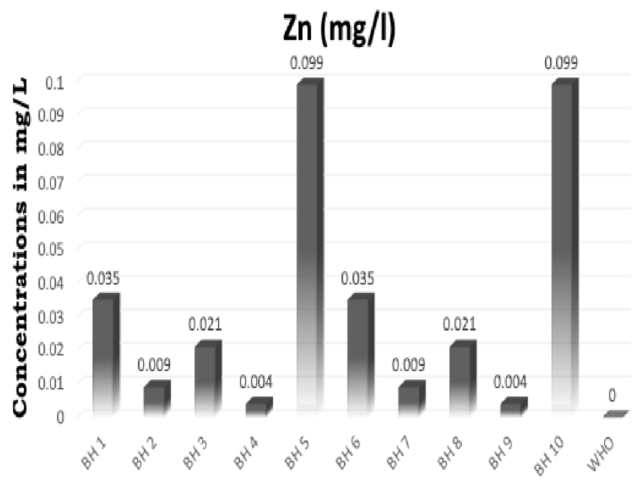


Figure - 11: Plot of Zinc concentrations against borehole sample locations

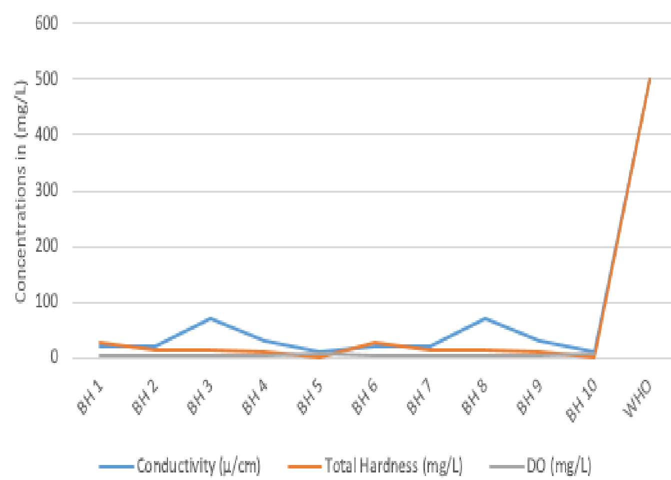


Figure - 12: Plot of conductivity, total hardness and dissolved oxygen against borehole sample locations

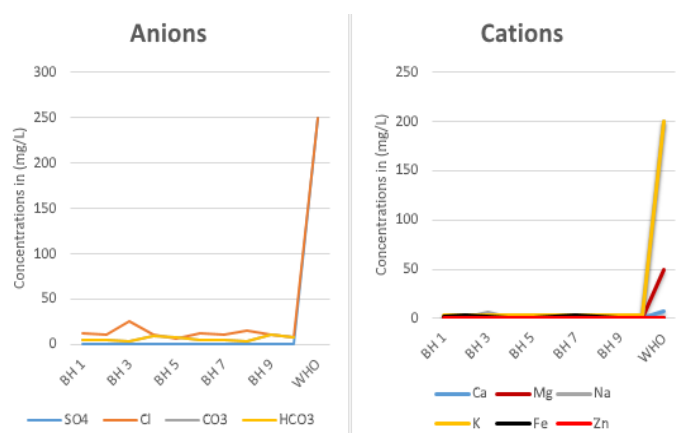


Figure - 13: Plot of some anions/cations concentrations against borehole sample locations

6. Interpretation of Hydro-chemical Analysis

The results generated from analyzing the borehole 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 groundwater samples and suitability of the water for irrigation purposes. The different water quality parameters measured were compared with WHO (2006) guidelines for drinking water quality (Tables 2 & 3). The result shows that all the parameters analyzed for in the borehole water samples met the required concentrations for the WHO (2006) guidelines for drinking water quality with an exemption to concentrations of Iron (Fe) in all the boreholes apart from boreholes BH5 and BH10.

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 (Piper, 1944). Generally, groundwater 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 groundwater.

These hydrochemical facies classifications of Piper, (1944) include the following:

- Ca^{2+} - Mg^{2+} - Cl^{-} - SO_4^{2-} facies: This hydrochemical facies corresponds to the region of permament hardness water type.
- Na^{+} - K^{+} - Cl^{-} - SO_4^{2+} facies: This hydrochemical facies corresponds to the region of saline water type.
- Na^{+} - K^{+} - HCO_3^{-} facies: This hydrochemical facies corresponds to the region of alkali carbonates water type.
- Ca^{2+} - Mg^{2+} - HCO_3^{-} facie: This hydrochemical facies corresponds to the region of temporal hardness water type.

The hydrochemical facies for the borehole water samples analyzed in the study are plotted in the (Na+ - K+ - Cl- - SO42+ facies); hydrochemical facies (ii) which corresponds to the region of saline water type (Figs 4.15a & 3). This suggests that the source of the groundwater samples are from halite dissolution (Saline) which supported the work of Nwankwoala and Udom, (2011).

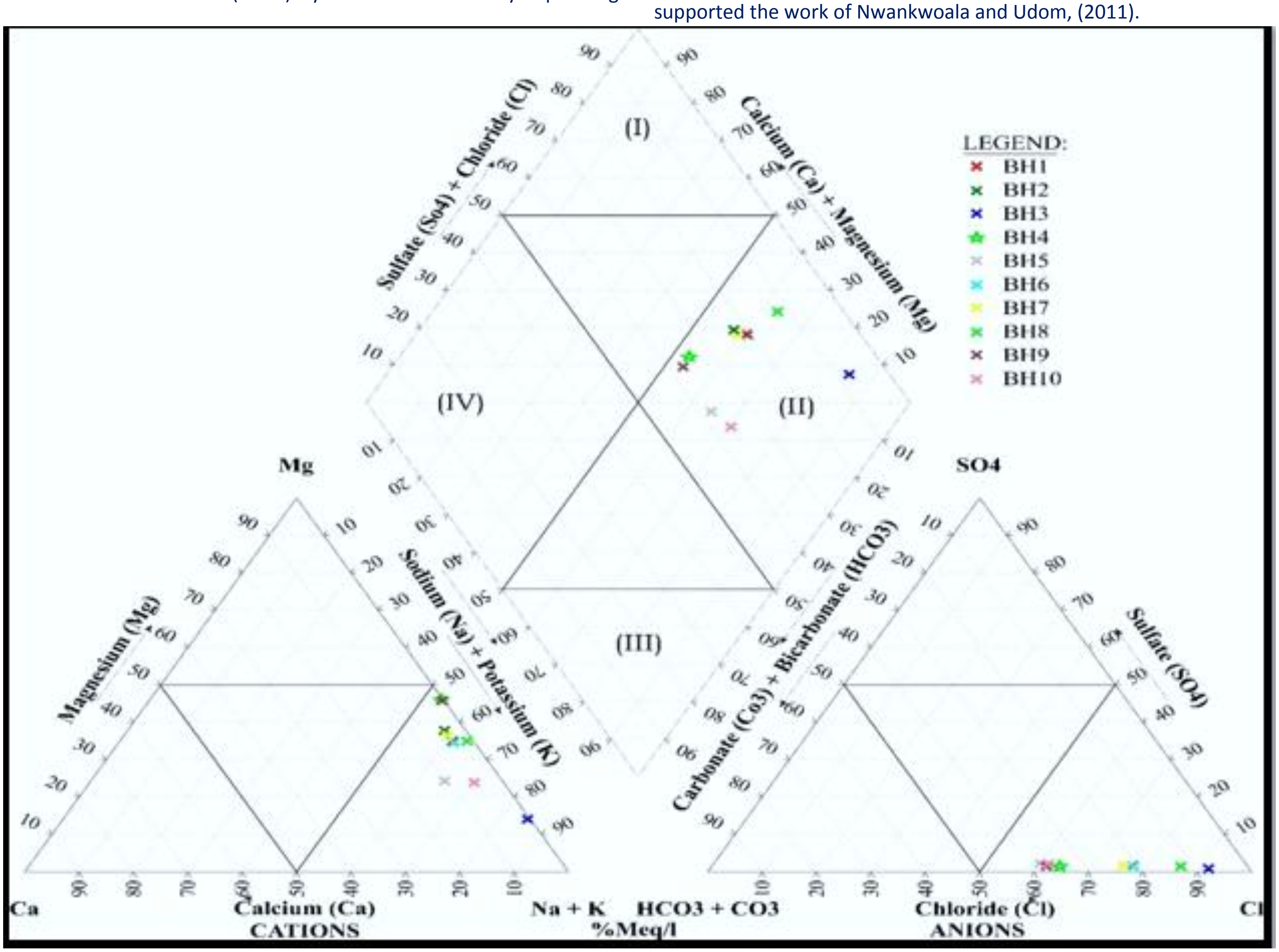


Figure - 14: Piper trilinear diagram for major cations and anions in the borehole water samples in the study area (after Piper, 1944).

7. Conclusion

The results from the analyses of the borehole samples yielded parameters that met the requirements provided by (WHO) 2006, with exception of Iron (Fe) that ranged between (0 - 2.8) mg/l above the maximum 0.3 mg/l stipulated by (WHO) 2006. 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 was identified by plotting the normalized concentrations of the major cations and anions in milliequivalent per liter on the Piper trilinear diagram. All the analyzed water samples of both the borehole water samples plotted within the Na+ - K+ - Cl- - SO42+ hydrochemical facies indicating origin from halite dissolution (Saline). The borehole samples meet the requirements stipulated by the World Health Organization (WHO) 2006 guideline for drinking water quality. The surface water samples did not meet the requirements stipulated by the World Health Organization (WHO) 2006 guideline for drinking water quality. The hydrochemical facile analyses of the borehole indicate that they originated from halite dissolution (Saline). It is therefore recommended from the foregoing that the proper landfill system should be provided and maintained for proper environmental sanitation in the study area. This will minimize and completely discourage indiscriminate dumping of waste which will reduce the tendency to which the pollutant will percolate into the groundwate

8. References

1. J.Albaiges, F.Casado and F.Ventura. Organic indicators of groundwater pollution by a sanitary landfill: Water. Res., 20 (9):1152 – 1159, 1986.
2. A.N.Amadi, P.L.Olasehinde, J.Yisa, E.A.Okosun, H.O.Nwankwoala and Y.B.Alkali. Geostatistical Assessment of Groundwater Quality from Coastal Aquifers of Eastern Niger Delta, Nigeria. Journal of Geosciences, 2(3):51-55, 2012.
3. A.E.Greenberg, L.S.Clesceri and A.D.Eaton. American Public Health Association (APHA); Standard Methods for the Examination of Water and Wastewater. 20th Edition , AWWA (American Water Works Association), WEF *The Water Environment Federation), 1998.
4. American Public Health Association (APHA). Standard Method for Examination of Water and Wastewater. 21st ed. APHA, AWWA, WPCF, Washington, 2005.
5. R.C.Borden and F.Yanoschak. Ground and surface water quality impacts of North Carolina sanitary landfills. Water Res. Bull., 26(2):269 – 277, 1990.
6. H.Doust, E.Omatsola, J.D.Edwards and P.A.Santogrossi. Divergent/passive Margin Basins, AAPG Memoir 48: Tulsa, American Association of Petroleum Geologists, 239-248, 1990.
7. J.O.Etu-Efeotor and M.T.Odigi. Water Supply Problems in the eastern Niger Delta. Bulletin Nigeria Mining and Geoscience Association, 20,1983-1992, 1983.
8. A.E.Gobo. Solid waste management options for the Niger Delta: Waste Management and Pollution in the 21st Century. Second national level workshop, Rivers State Ministry of Environment and Natural Resources, Port Harcourt, 2002.
9. O.E.Ige. Vegetation and Climatic History of the Late Tertiary Niger Delta, Nigeria, based on Pollen Record. Research Journal of Botany, 6, 21-30, 2011.
10. J.P.Murray. Groundwater contamination by sanitary landfill leachate and domestic wastewater in carbonate terrain; Principal source diagnosis, chemical transport characteristics and design implications.Water Research, 15, 745 – 757, 1981.
11. Nigeria Standard for Drinking Water Quality, Nigeria Industrial Standard(NSDWQ), Approved by Standard Organization of Nigeria Governing Council. ICS 13. 060., 20, 15 – 19, 2007.
12. O.D.Ngerebara and H.O.Nwankwoala. Groundwater potentials in the offshore Niger Delta environment, Nigeria. Electronic Journal of Environmental Hydrology,16,P28,2008.
13. H.O.Nwankwoala. An integrated approach to sustainable groundwater development and management in Nigeria. Journal of Geology and Mining research, 3(5):123-130 ,2011.
14. H.O.Nwankwoala and G.J.Udom. Influence of land reclamation on the status of groundwater in Borokiri area of Port Harcourt; Niger Delta, Nigeria. International J. Natural and Appl. Sci., 4 (4):431-434, 2009.
15. H.O.Nwankwoala and G.J.Udom. A Preliminary Review of Potential Groundwater Resources of the Niger Delta. International J. Appl. Environ. Sci., 6(1):57-70, 2011.
16. H.O.Nwankwoala, A.N.Amadi, E.Oborie and F.A.Ushie. Hydrochemical Factors and Correlation Analysis in Groundwater Quality in Yenagoa, Bayelsa State, Nigeria. Journal of Applied Ecology and Environmental Sciences,2(4):100-105,2015.
17. H.O.Nwankwoala, S.A.Ngah. Groundwater resources of the Niger Delta; Quality implications and management considerations. International Journal of Water Resources and Environmental Engineering, 6(5):155-163, 2014.
18. H.O.Nwankwoala, V.A.Ogbonna. Water quality surveillance of boreholes around landfill site in Eligbolo-Eliozu, Obio/Akpor local government area, Rivers State, Nigeria. Environ Risk Assess Remediation, 1(1):44-49, 2018.
19. O.V.Odukoya, T.Arowolo and O.Bamgbose. Effects of a solid waste landfill on underground and surface water quality at ring road, Ibadan, Nigeria. Global J. Environ. Sci., 1(1):43-52, 2002.
20. K.Ogedengbe and C.O.Akinbile. Impact of Industrial Pollutants on Quality of Ground and Surface water at Oluyole Industrial Estate, Ibadan, Nigeria. Nigerian Journal of Technological Development, 4 (2):139-144, 2004.
21. A.B.O.Oyediran. A keynote Address on Waste Generation and Disposal in Nigeria in "Perspectives in Environmental Management" in NEST Annual Workshops 1991 to 1995 (Okali, D., Ologe, K. O., and Igbozurike, U. M., eds). NEST – Desktop Publications, Ibadan, Nigeria, 95-100, 1997.
22. A.M.Piper. A graphic procedure in the geochemical interpretation of water analyses. Transactions of the America Geophysical Union, 25:914 – 923, 1944.
23. R.A.Reyment. Aspects of Geology of Nigeria. University of Ibadan Press, Nigeria, pp133, 1965.
24. P.M.Shannon and N.Naylor. Petroleum Basin Studies: London, Graham and Trotman Limited, 53-169, 1989.
25. K.C.Short and A.J.Stauble. Outline of the geology of the Niger Delta. Bull AAPG., 51:761-779, 1967.
26. I.Tamunobereton-ari, E.D.Uko and V.B.Omubo-Pepple. Anthropogenic activities- Implications for groundwater resource in Okrika, Rivers State, Nigeria. Research Journal of Applied Sciences, 5(3):204-211, 2010.
27. United States of America Department of Agriculture (USDA)/Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soil. US Department of Agricultural Hand Book 60, Washington.
28. K.J.Weber and E.M.Daukoru. Petroleum geology of the Niger Delta: 9th World Petroleum Congress Proceedings, 2:209-221,1975.
29. World Health Organization (WHO) Guidelines for drinking water quality criteria: 2nd Ed, 281-308. World Health Organization. Geneva, 2006.