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RESEARCH ARTICLE

POLLUTION RISK OF GROUNDWATER IN RIVERS STATE: A FUNCTION OF LITHOLOGY AND POLLUTANT LOAD OF THE AREA

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ABSTRACT

The hydrogeological-environmental study undertaken in this work was to establish the influence of lithology and pollutant loading to the vulnerability and pollution risk of groundwater. Five case study centers were chosen for a comprehensive work. Water samples were taken and measured for taste, colour, odour, hardness, turbidity, temperature and p^H . Geoelectric cross-sections from VES and core samples from borehole drilling at the study sites were used to establish the lithologic sequence of the area. Chemical analysis was done by sequential extraction process and FAAS analytical tool. The results from the chemical analysis showed exceptionally high pollutant concentrations at the ground surface indicative of high pollutant loading. However, the concentrations decreased exponentially with depth, which is attributed to the adsorption ability of the clayey, fine sand and organic formation materials of the top layers of the lithologic sequence that adsorbed and occluded the pollutants as they percolate towards the groundwater. This phenomenon, the tested properties of the water samples and the exceptional high pollutant loading; make the groundwater of the study area at the moment less vulnerable but of high pollution risk.

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INTRODUCTION

Groundwater is an important natural resource that supplies billions of gallons of water for drinking, agriculture, industrial purposes and other uses. The known surface water bodies in the area are severely polluted by direct discharge of domestic and industrial waste into them, as such about 90% - 95% of the population of the area now solely depends on groundwater as their source of water. Thus, harnessing and preservation of clean and safe groundwater becomes imperative. Groundwater is an important source of water essential to human lives and continuous existence of the ecosystem. Water has some physical characteristics that guaranteed its wholesomeness: it must be colourless, odourless, tasteless, and readily foam with soap or detergents, it must also be devoid of pathogens and pollutants. Safe water must be used for domestic (drinking, washing, bathing, and cooking), agricultural, industrial processes, and recreational activities. Groundwater becomes vulnerable when the water quality starts deteriorating and contaminated severely up to certain extent beyond the potable standard. The contamination of this all important source will have devastating effect on the ecosystem especially man. Therefore, groundwater which cannot be easily restored when contaminated or polluted; should be well protected and not made vulnerable to pollution from unwholesome human and industrial activities for the continuous benefit of man, environment and the ecosystem to strive.

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Geology and Hydrogeology of the Study Area

The study covers five distinct urban centers (Port Harcourt, Okrika, Bonny, Omokuand Eleme) of the study area (Rivers State) as shown by Figure 1. These urban centers consist of broad riverine area through which the River Niger enters the Atlantic Ocean dividing into numerous rivulets, which fan out into the sea. It also includes a number of tidal creeks separating Small Islands.

Rivers State is part of the Niger Delta complex which generally indicates beds of fine to coarse sand typical of fluvial channel deposits. The geology of the area is composed of mainly two distinct formations: the Quaternary Deltaic plain (upper and lower) and the Tertiary Benin and Ameki formations. The Deltaic plain is made up of units consisting of coarse to medium grained unconsolidated sands, forming lenticular beds with intercalations of peaty matter and lenses of soft, silt clay and shale. The sandy beds of the formation form prolific aquifers. The high permeability of the Benin formation, the overlying lateritic red earth and weathered top of the formation as well as the underlying clay-shale member of the Bende-Ameki and Ogwashi-Asaba series provide the hydrologic conditions favoring aquifer formation in the area (Short and Stauble, 1967; Kogbe, 1989). Groundwater is encountered in two distinct aquifer systems referred to as the Shallow Groundwater and Deep Superficial Aquifer. The Shallow Groundwater is encountered just beneath the superficial clays and humorous layer at a depth of 6m to 8m below ground surface depending upon the time of year.

It is expected that the groundwater discharge into the deeper aquifer is in hydraulic connection with the shallow system. According to the Rivers State Ministry of Water Resources, the depth of the water tables or potentiometric surface levels of the saturated zone in Rivers State especially in all the chosen centers for the case study ranges from 5m to 10m for shallow aquifer and 15m to 35m for deep aquifer with a high recharge capacity due to the weather pattern, the amount and the time window of precipitation in a year (2013ENV. 2003; Tamunobereton-ariet *al.*, 2013; Tamunobereton-ari *et al.*, 2014).

Stauble, 1967; Telford *et al.*, 1976; Todd, 1959). The area is within the mangrove freshwater swamps hydrogeological province underlain primarily by the deltaic plains formation. Aquifers are encountered at varying depths and points with variations of water qualities.

Pollutant Loading in the Study Area

Pollutant loading in an area is the continuous deposition of pollutant in the environment, which is associated with the magnitude of uncontrolled human and industrial activities that

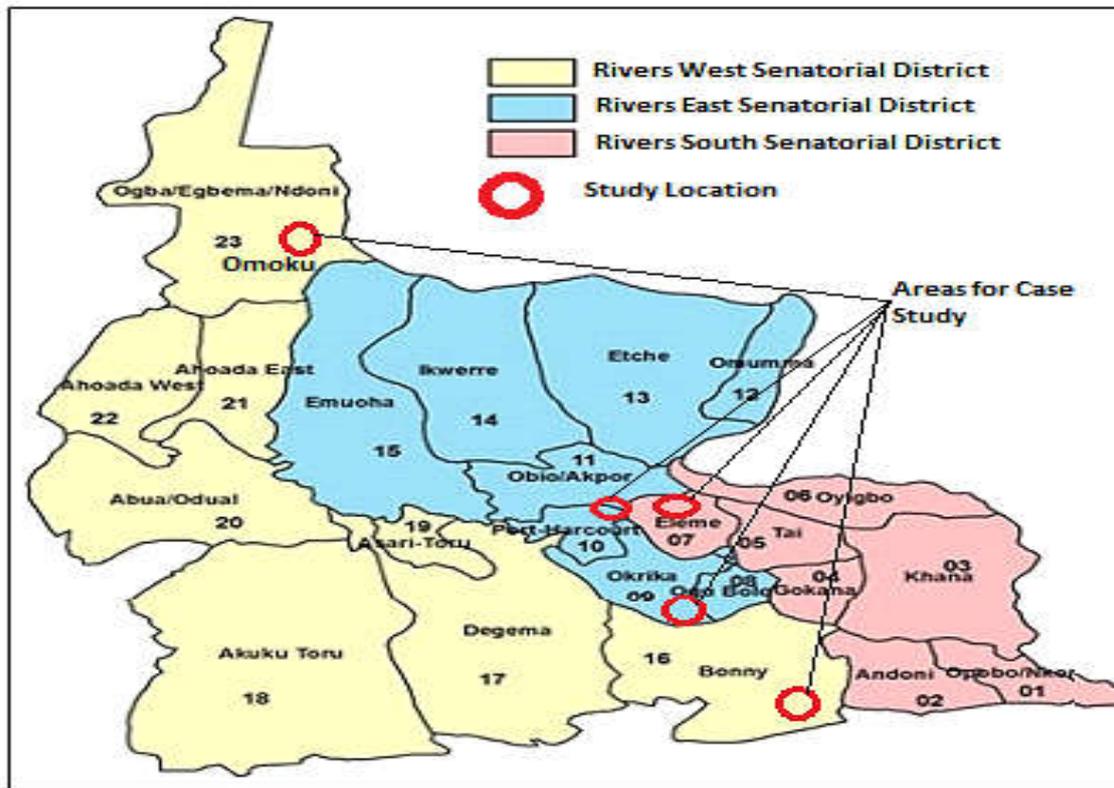


Fig. 1. The Map of Rivers state showing the Case Study Centers (Google, 2014)

Lithology of the Study Area

The auriferous zone of interest of the study area falls within the Benin formation, which is predominantly sandy (>90%) with a few intercalation of shale beds. The sands and the sandstones are coarse grained and are mostly coloured because of limonite coating, presence of hematite grains and feldspar minerals. The shales are grayish-brown, sandy or silty and contain plant remains and dispersed lignite (Short and Stauble, 1967).

These formations are commonly masked by thick partly weathered layers of the recent Niger Delta sediments and dense vegetation, which ranges from secondary to freshwater swamp flora in the inland, and mangrove swamps at the coast. The top clayey dense vegetative humorous layer adsorb most of the pollutants or contaminants deposited on the ground surface and those drained within this layer and are occluded to the fine particles of the clay material and the organic matters of the vegetative cover and the humorous layer (Alloway and Ayres, 1997; Tamunobereton-ari *et al.*, 2010b). The high porous and unconsolidated sands of the Benin formation have been identified as the freshwater bearing sands (Short and

discharges contaminants or pollutants into the environment. The urban centers chosen for the case study in this work are areas of high industrial and human activities with the presence of multi-national oil and gas companies and other associated companies. Port Harcourt is the capital city of Rivers State, which is the heart of all administrative activities of the State and industries operation in and around the State, and had resulted in the generation of enormous amount of waste from anthropogenic activities that had put stress on social and economic facilities in managing such waste (Alloway and Ayres, 1997; Tamunobereton-ari *et al.*, 2012a).

Bonny Island is the home of the Nigerian Liquefied Natural Gas (NLNG) and the loading jetties for oil and gas for exportation. Okrika is a host to the Port Harcourt Refining Company (PHRC) a subsidiary of the Nigerian National Petroleum Corporation (NNPC), jetty and terminal for loading and unloading of oil and gas, and other oil and gas servicing activities. Eleme is also a host to the Port Harcourt Refining Company (PHRC) a subsidiary of the Nigerian National Petroleum Corporation (NNPC), Eleme Petrochemical, The Federal Lighter Terminal (FLT) and the Federal Ocean Terminal (FOT) Port Harcourt.

Omoku of course is one the main operational bases of Nigerian Agip Oil Company (NAOC) and a central business hub of Orashi region of the Rivers State of Nigeria. The presence of these companies in the study area and being business centers had led to the continuous influx of associate companies and people for economic and job opportunities; resulting to the massive generation and indiscriminate disposal of waste resulting to the increase in the pollutant loading of the area. Moreover, pollutant loading is on the increase, which is worrisome as waste generated by residents and companies are not properly treated and disposed of; to avoid cost and maximize profit, and rather prefer to dispose of both hazardous and non-hazardous waste indiscriminate and mostly in improperly designed and poorly managed landfills, and discharging the liquid waste components into underground pits and reservoirs thereby exposing the groundwater bodies to higher pollution risk. The likelihood for the transfer of pollutants from one case study center to the other due to the proximity of the locations is very high and possible. However, because of the amount of rain fall in the study area, the pollutant magnitude on the ground surface sometimes appear depleted due to erosion by runoffs (Fuentes *et al.*, 2004; Tamunobereton-ari *et al.*, 2012a; Tamunobereton-ari *et al.*, 2012b).

Groundwater

Groundwater as the name implies is water gotten from the subsurface beneath the ground, which is contained in the pore spaces in the bulk formation materials of an area. The saturated zone that yields the contained water therein to wells or boreholes is described as aquifer. Aquifer is always underlain by impermeable bedrock and overlain by either impermeable or permeable layer to give it its characteristics as confined or unconfined aquifer respectively. The considerable thickness of the aquifers, the high transmissivity of water through these aquifers due to the high degree of porosity and permeability and the adequate groundwater recharge capacity enhanced by the high annual rainfall in the area, makes the aquifers of the area reliable water resources that can yield and supply reasonable millions of volume of water to satisfy the water needs of the people and industries of the area through both public and private abstractions (Todd, 1959; Krivochieva and Chouteau, 2003, Tamunobereton-ari *et al.*, 2010a; Tamunobereton-ari *et al.*, 2010b).

The characterization and delineation of aquifer in the area becomes imperative as water samples from some existing wells and boreholes in the study area fall short of the acceptable characteristics of groundwater and during the dry season most wells and boreholes drop to a minimum yield and sometimes get dried up; perhaps shallow aquifers were drilled due to lack of hydrogeological information of the area and improper delineation of the aquifers to facilitate the precise identification of desired aquifer before drilling and well completion for sustainable supply of potable water to the people of the area (Edlefsen, and Anderson. 1941; Tamunobereton-ari *et al.*, 2013).

MATERIALS AND METHODS

To determine the pollution risk of groundwater in the study area, the DRASTIC features were the guide to ascertain the

degree of groundwater vulnerability by examining the water quality bases on the properties such as: colour, odour, taste, hardness, turbidity, temperature and pH. Resistivity survey was also carried out at some sites, core samples were obtained at different depth during borehole drilling to correlate with the lithological accounts of the area. Finally, chemical analysis was carried out on soil samples obtained from these sites to ascertain the level of leaching of the surface pollutants towards the groundwater bodies.

Physical Examination

The water samples gotten from the study centers were physically examined for colour, odour, and taste. The temperature reading of the samples was made using thermometer in °C. The pH of the samples was also measured using pH meter.

Measurement of Turbidity and Hardness of the water samples

Turbidity meter (Nephelometry), was used to measure the turbidity of the water samples in NTU. Hardness of water is a measure of the total concentration of the calcium and magnesium ions expressed as calcium carbonate. This is determined by EDTA titration and measured in mg/l.

Resistivity Survey

VES was conducted at two stations along a profile at each of the two chosen case study centers (Okrika and Omoku) to obtain the resistivity distribution and lithostratigraphic distribution with depth. This approach was employed due to the simplicity of the technique, easy interpretation and rugged nature of the associated instrumentation; it is also economical, quick and effective, which has been proven in solving most groundwater survey problems in different parts of the world (Zohdy *et al.*, 1973; Koefoed and Dirk, 1979). With the Schlumberger array, the potential (MN) electrodes separation is kept constant while the current electrodes AB as used in this work is increased in steps. A maximum current electrode separation (AB) of 100m was used in this work. In each measurement, the digital averaging instrument ABEM tetramer SAS 300 model displayed the resistance directly. The readings are made possible as the four electrodes driven into the ground are connected to AB and MN terminals of the meter through the reels of cables.

Chemical Analysis

Chemical speciation is the process of identifying and quantifying different species, forms of phases of elements that are present in a material (environmental sample). The speciation and fate of these pollutants in the natural environment, the biochemical action of the pollutants as nutrients or toxicants, and the effectiveness of the control processes (separation, recovery, and recycle) are all ultimately to be understood and eventually predicted on the basis of the electronic structures of the metals in coordination reaction with ligands, electronic transfer reactions and free radical reactions.

Table 1. Wavelengths, Detection limits, and Permissive level of the metals in the soil (Adapted from Fuentes *et al.*, 2004)

Metal	Wavelength (nm)	Detection limit (mg/l)	Permissive level in the soil ($\mu\text{g/g}$)
Copper (Cu)	324.8	0.077	30 – 40
Lead (Pb)	217.0	0.190	85 – 450
Zinc (Zn)	213.9	0.018	135 – 150

Table 2. The three-step of the sequential extraction procedures for the fractionation of the metals (Cu; Pb; and Ni)

Step 1	Step 2	Step 3
<p>*Weigh 1g of soil sample into 50ml extraction tube.</p> <p>*Add 25ml of solution A into the tube to make a mixture with the soil sample.</p> <p>*Shake the mixture in the extraction tube for 6 hours at room temperature using a mechanical shaker.</p> <p>*Centrifuge the mixture at 3000rpm for 10minutes, and decant the supernatant (i.e. the clear sample solution) for immediate analysis or store at 4°C prior to analysis.</p> <p>*Wash the residue by adding 20ml of distilled water into the residue, shake for 15 minutes and centrifuge at 3000rpm for 10minutes. Discard the supernatant and preserve the residue for the next step.</p>	<p>*Add 25ml of solution B into the residue from step 1 in the extraction tube.</p> <p>*Shake the mixture in the extraction tube for 6 hours at room temperature using mechanical shaker.</p> <p>*Centrifuge the mixture at 3000rpm for 10 minutes, and decant the supernatant for immediate analysis or store at 4°C prior to analysis.</p> <p>*Wash the residue by adding 20ml of distilled water into the residue, shake for 15 minutes and centrifuge at 3000rpm for 10minutes. Discard the supernatant and preserve the residue for the next step.</p>	<p>*Add 10ml of solution C into the residue from step 2 in the extraction tube.</p> <p>*Digest the mixture at room temperature for 1hour at 85°C in water bath; remove the cover to reduce the volume to about 5ml.</p> <p>*Add further aliquot of 10ml, digestion for another 1 hour at 85°C in water bath; remove the cover to reduce the volume to about 5ml.</p> <p>*Then add 25ml of solution D to the cool residue.</p> <p>*Shake the mixture in the extraction tube for 6 hours at room temperature using a mechanical shaker.</p> <p>*Centrifuge the mixture at 3000rpm for 10 minutes, decant the supernatant for immediate analysis or store at 4°C prior to analysis.</p> <p>* residue by adding 20ml of distilled water into the residue, shake for 15 minutes and centrifuge at 3000rpm for 10minutes. Discard the supernatant and preserve the residue for the next step.</p>

Table 3. Properties of Groundwater in the case study centers

Case Study Centers	Eastings	Northings	Colour	Odour	Taste	Temp. (°C)	pH	Hardness (mg/l)	Turbidity (NTU)
Bonny	527037.738	53355.46	NIL	NIL	NIL	26	5.9	7.0	<0.04
Eleme	520247.427	86235.668	NIL	NIL	NIL	27	6.0	3.5	<0.03
Okrika	520992.63	79955.54	NIL	NIL	NIL	27	6.1	5.0	<0.02
Omoku	470923.116	147373.28	NIL	NIL	NIL	28	6.4	2.3	<0.04
Port Harcourt	511447.458	85639.07	NIL	NIL	NIL	29	5.8	5.1	<0.03

Table 4a. Concentrations of Copper (Cu) in ($\mu\text{g/g}$) Extracted at Different Steps for the Different Sample Depth

Case Study Centers	Surface (0m)			Depth of 5m			Depth of 10m		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Bonny	33.2 \pm 1.7	13.2 \pm 0.4	12.9 \pm 0.6	7.1 \pm 1.2	1.7 \pm 0.0	8.7 \pm 0.6	2.7 \pm 0.3	1.8 \pm 0.0	5.0 \pm 0.4
Eleme	42.0 \pm 1.4	18.7 \pm 0.5	33.7 \pm 1.3	9.2 \pm 0.6	4.3 \pm 0.3	12.3 \pm 1.1	4.6 \pm 0.5	3.3 \pm 0.3	9.3 \pm 0.7
Okrika	35.4 \pm 0.9	9.4 \pm 0.4	19.7 \pm 1.2	7.6 \pm 0.7	2.9 \pm 0.3	6.8 \pm 0.5	3.3 \pm 0.2	ND	6.7 \pm 0.4
Omoku	29.7 \pm 1.2	7.1 \pm 1.0	15.2 \pm 0.8	5.9 \pm 0.0	2.3 \pm 0.2	3.4 \pm 0.2	2.9 \pm 0.3	1.7 \pm 0.3	4.3 \pm 0.4
Port Harcourt	24.9 \pm 0.8	5.9 \pm 0.0	11.9 \pm 0.3	3.8 \pm 0.4	ND	4.2 \pm 0.8	ND	ND	4.7 \pm 0.5

Table 4b. Concentrations of Lead (Pb) in($\mu\text{g/g}$)Extracted at Different Steps for the Different Sample Depth

Case Study Centers	Surface (0m)			Depth of 5m			Depth of 10m		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Bonny	211.7 \pm 5.8	118.7 \pm 7.2	235.2 \pm 2.3	45.3 \pm 1.6	17.2 \pm 0.8	40.4 \pm 1.0	31.1 \pm 0.8	14.9 \pm 0.7	28.5 \pm 0.9
Eleme	158.4 \pm 7.3	97.3 \pm 3.2	197.4 \pm 3.3	42.1 \pm 0.5	9.6 \pm 0.0	35.7 \pm 0.5	24.7 \pm 0.7	12.5 \pm 0.4	24.1 \pm 1.2
Okrika	192.9 \pm 3.9	153.2 \pm 3.2	177.5 \pm 2.7	41.6 \pm 1.0	12.9 \pm 0.0	29.8 \pm 1.2	26.1 \pm 0.7	11.4 \pm 0.5	18.6 \pm 1.0
Omoku	107.6 \pm 3.4	94.5 \pm 0.9	142.7 \pm 2.9	33.7 \pm 2.1	8.2 \pm 0.3	22.1 \pm 0.5	ND	ND	19.7 \pm 2.1
Port Harcourt	134.8 \pm 5.2	140.5 \pm 1.4	174.6 \pm 3.0	44.3 \pm 2.3	17.4 \pm 0.7	27.5 \pm 0.6	20.4 \pm 1.3	ND	42.2 \pm 2.6

Table 4c. Concentrations of Zinc (Zn) in ($\mu\text{g/g}$) Extracted at Different Steps for the Different Sample Depth

Case Study Centers	Surface (0m)			Depth of 5m			Depth of 10m		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Bonny	53.3 \pm 1.8	38.7 \pm 0.4	104 \pm 6.2	17.8 \pm 1.0	9.7 \pm 0.7	14.6 \pm 0.5	7.3 \pm 0.4	4.1 \pm 0.0	11.6 \pm 0.5
Eleme	111.2 \pm 1.3	44.5 \pm 2.3	78.1 \pm 1.0	33.8 \pm 1.1	25.6 \pm 1.7	17.4 \pm 0.8	5.7 \pm 0.3	3.2 \pm 0.2	12.8 \pm 3
Okrika	66.7 \pm 2.1	27.7 \pm 1.0	74.2 \pm 1.6	25.4 \pm 1.0	6.5 \pm 0.3	20.1 \pm 0.4	4.3 \pm 0.3	1.2 \pm 0.0	7.6 \pm 0.3
Omoku	79.4 \pm 2.1	33.5 \pm 1.8	62.7 \pm 1.1	13.7 \pm 0.5	8.7 \pm 0.9	4.4 \pm 0.3	1.3 \pm 0.0	ND	1.7 \pm 0.1
Port Harcourt	126.2 \pm 2.8	50.4 \pm 3.3	194.2 \pm 4.2	25.8 \pm 0.7	12.4 \pm 0.3	20.4 \pm 0.2	7.7 \pm 0.4	3.6 \pm 0.2	4.1 \pm 0.3

Table 5. Total Concentrations of theExtracted pollutants from the Three Steps for the Different Sample Depthin ($\mu\text{g/g}$)

Case Study Centers	Surface (0m)			Depth of 10m			Depth of 20m		
	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn
Bonny	59.3	565.6	196.0	17.5	102.9	42.1	9.5	74.5	23.0
Eleme	94.4	453.1	233.8	25.8	87.4	76.8	17.2	61.3	21.7
Okrika	64.5	523.6	168.6	17.3	84.3	52.0	10.0	56.1	13.1
Omoku	53.0	344.8	175.6	11.6	54.0	26.8	8.9	19.7	3.0
Port Harcourt	42.7	449.9	370.8	8.0	89.2	58.6	4.7	62.6	15.4

Chemical analysis was aimed at evaluating the degree of leaching and migration of the mobile forms of the surface pollutants towards the groundwater bodies (Ureet *et al.*, 1993; Hu, 2003; Tamunobereton-ari *et al.*, 2011a). Three pollutants of interest [Copper (Cu); Lead (Pb); Zinc (Zn)] are considered to realize the purpose of this work. Total of fifteen soil samples were collected from the five chosen case study centers; three from each location, at the surface, 10m and 20m depth. The soil samples were collected in a prescribed approach to avoid contamination. The fifteen soil samples collected from the field were pre-treated by oven drying them at a regulated temperature of 50°C for 48 hours.

After drying, a sieve of mesh size 600µm was used to remove large undesired particle sizes. The sieved samples were then grinded to powdered form using an agate mortar and pestle leaving particle sizes in the nanometers range, which ensure the homogenization of the test samples and also to enhance the samples to be in suspension in the mixture during the extraction processes for optimum extractability. Each sample was divided into three parts; each part for each pollutant. In this work, High quality chemicals and reagents of analytical grades were used for the extraction schemes and the adjustments of the pH of the solutions with purity range between 98%-99% to ensure the acquisition of reliable experimental results. The Community Bureau of References (BCR) three-stage sequential extraction procedure was employed, which operationally classified metals into four fractions based on their metal-soil interaction, they are: (a) exchangeable and specifically adsorbed fraction extractable with 0.11 mol/L of solution A; (b) Reducible fractions bound to Fe/Mn oxide extractable with 0.1 mol/l of solution B; (c) Oxidizable fractions bound to soil organic matter extractable with solutions C and D; and (d) the residual fractions occluded in mineral structures of the sample particles (Keith, 1991; Ureet *et al.*, 1993; Tamunobereton-ari *et al.*, 2011b).

Table 2 shows the sequential extraction stages. The sample solutions from the extraction processes were analyzed with Flame Atomic Absorption Spectrometer (FAAS) after calibration to ascertain the sensitivity of the instrument so that the results are reliable. Table 1 shows the pollutants, their respective wavelength values, their detection limits and their permissive level in the soil.

RESULTS AND DISCUSSION

Physical Properties of Groundwater

The results of the assessed properties of the groundwater samples from the study area are presented by Table 3 with GPS positions for clarity. The assessment made on the properties of the groundwater samples shows evidence that the water samples are colourless, odourless and tasteless. The temperature values range from 26°C to 29°C, which is normal for groundwater. The turbidity values of the samples ranges from <0.02NTU to <0.04NTU showing that the samples are clear water devoid of suspended solids caused by clay, silt and other substances that enter boreholes from the aquifer or from the soil surface. The hardness values measured from the samples 2.3mg/l to 7.0mg/l is also very much within the mean tolerable limit for fresh water.

However, the pH readings of the samples ranging from 5.5 to 6.4 is well within the acidic domain, which is not too good for health; though it's within the tolerable boundary for groundwater.

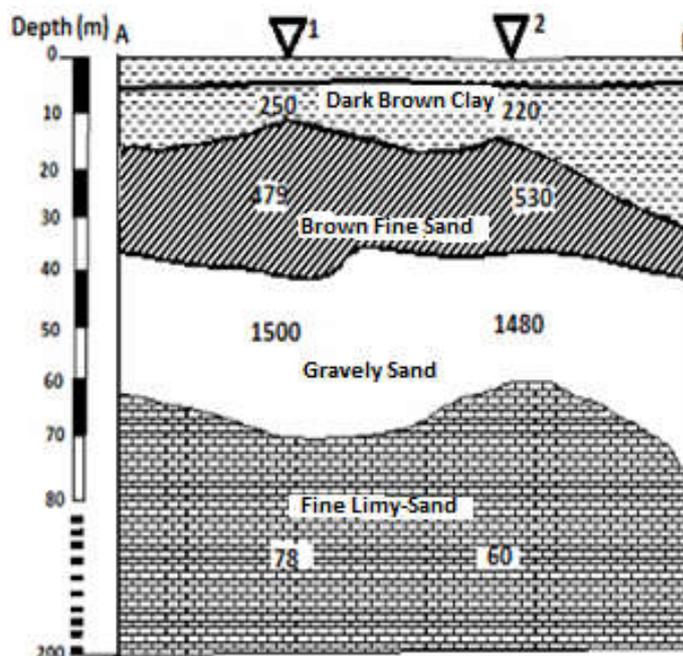


Fig. 2a. Geoelectrical cross-section for Okrika

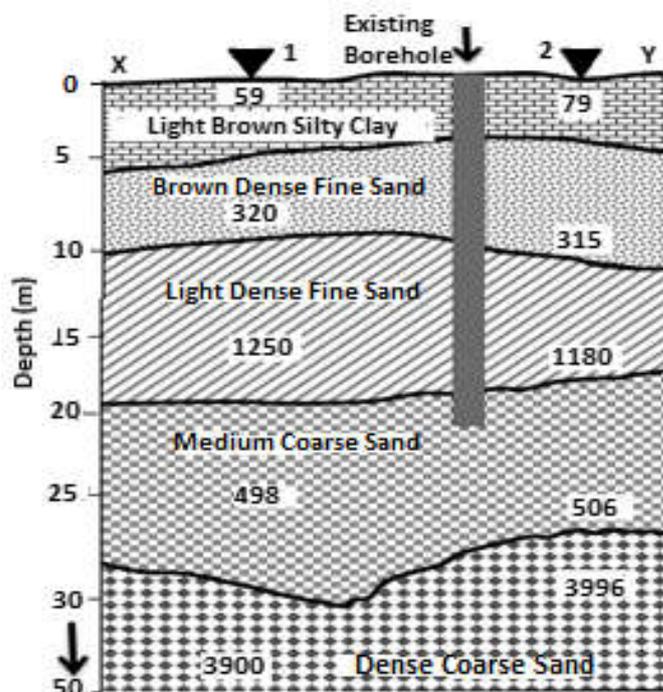


Fig. 2b. Geoelectrical cross-section for Omoku

Resistivity Survey

The data extracted from the VES was to show the geoelectrical cross-sections to be able to establish the lithological distribution and to make comparison with the core samples obtained from the drilling operations.

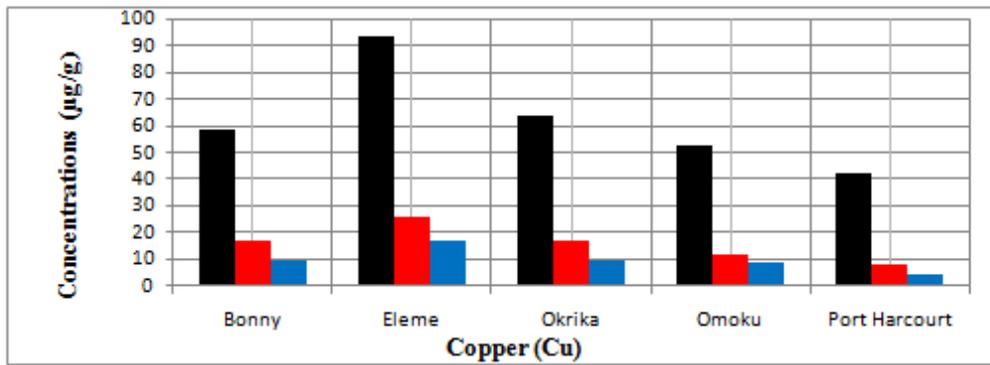


Fig. 3. Chart showing concentrations of Cu at the three sample depths for the study centers

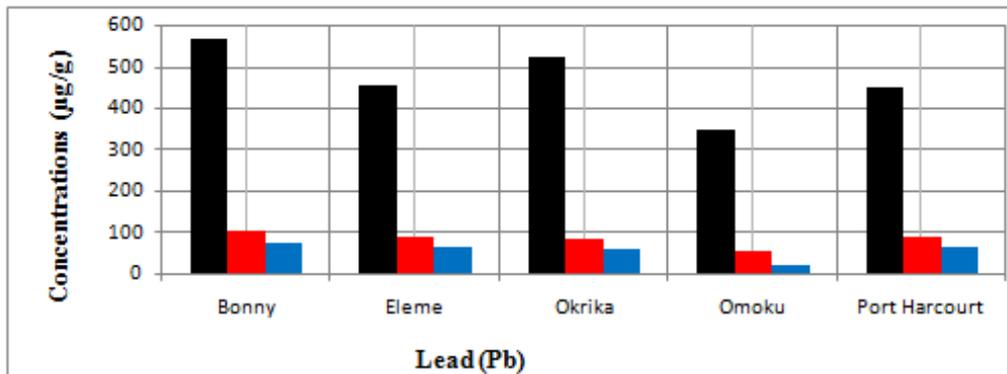


Fig. 4. Chart showing concentrations of Pb at the three sample depths for the study centers

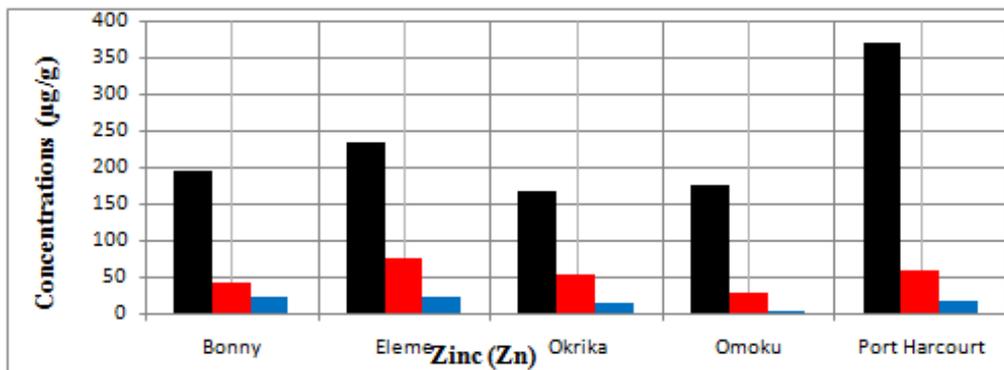


Fig. 5. Chart showing concentrations of Zn at the three sample depths for the study centers

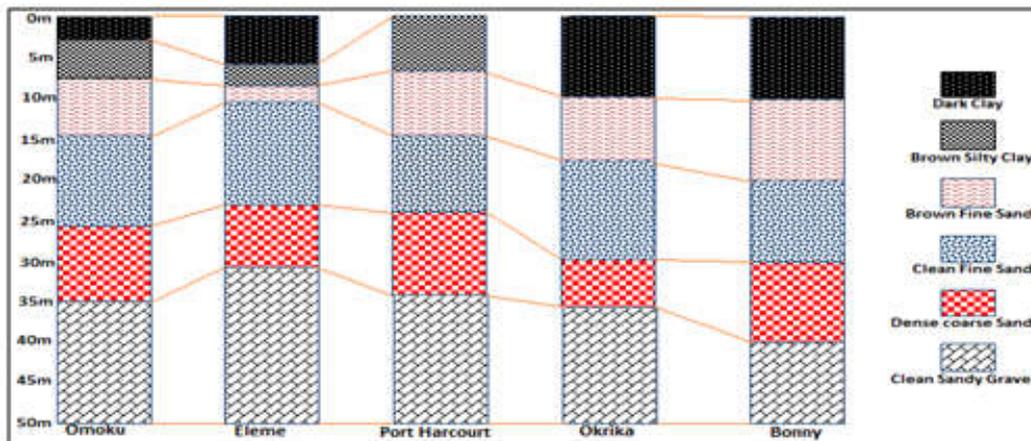


Fig. 6. Lithologic Sequences established from the borehole drilling core samples for the study centers

Figures 2a and 2b are geoelectrical cross-sections obtained from Okrika and Omoku respectively; which actually show that the upper layer of Figure 2a (i.e. Okrika) ranging from the surface to about 15m is made up of clay materials, while Figure 2b for Omoku show clay layer thickness extending from the surface to about 7m. beyond these depths, you have fine sand that also create very large surface area for pollutants to occlude onto.

Chemical Analysis

Tables 4a, 4b and 4c show the numerical results of the analytical steps at different depths for the different case study centers for the pollutants Cu, Pb and Zn respectively. While, Table 5 shows the total concentrations of the Extracted pollutants from the Three Step extraction approach for the Different Sample Depth in ($\mu\text{g/g}$) of the study centers. The black bars of the charts represent pollutants concentrations at the surface (0m), the orange bars represent the concentrations of the pollutants at 10m depth beneath the ground surface, while the blue bars represent the concentrations of the pollutants at 20m depth beneath the surface of the ground.

It was evident from the charts that the concentrations of the pollutants from the surface samples are much higher as shown by the black bars than the concentration levels from the samples at 10m and 20m depths. The concentration levels of the pollutants in the soil samples at 10m and 20m depth are well within the permissible limit, while the concentration levels of the pollutants in the soil samples from the surface are exceptionally high and are well above their permissible levels in soil sample.

Figures 2 and 5 show the Lithologic sequences of top clayey and fine sand formation materials. The subsurface formation materials play a filtration role on percolating water; but this trend of reduced pollutant concentration with depth in this context is strongly associated with the top clayey dense vegetative humorous layer that adsorb most of the pollutants or contaminants deposited on the ground surface as they drained within these layers and are occluded by the fine particles of the clay material and the organic matters.

Conclusions

The aim of this work is to evaluate the pollution risk faced by the groundwater bodies as a result of the leaching of surface pollutants towards the groundwater. It was discovered based on the tested properties of the groundwater that the groundwater bodies are at the moment less vulnerable. The high concentrations of the pollutants at the ground surface of the study area was an evidence of exceptional pollutant loading, which indeed exposes the groundwater bodies to potential pollution risk, which calls for intervention by government and relevant agencies to critically scrutinize the anthropogenic activities for environmental safety especially the groundwater, which cannot be easily remedied when polluted for the good of the entire ecosystem especially mankind. However, the top clayey and fine sand formation materials of the lithologic sequences and the organic matters protected the groundwater by reducing the pollutant concentration with depth as they strongly adsorb and occlude most of the pollutants or contaminants deposited on the ground

surface as they drained through these layers towards the groundwater. Finally, this hydrogeological-environmental study in this work is to create consciousness in the mind of people in the study area and people in others regions having similar lithologic sequence with a thick clayey and fine sand top layers of a relative safety of their groundwater by the interaction ability of these formation materials with pollutants to reduce leaching and percolation to polluting the groundwater bodies.

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