

FACTA UNIVERSITATIS

Series: **Working and Living Environmental Protection** Vol. 7, N° 1, 2010, pp. 13 - 23

ANTHROPOGENIC ACTIVITIES – IMPLICATIONS FOR GROUNDWATER RESOURCE IN OKRIKA, RIVERS STATE, NIGERIA

UDC 631.432:628.515:691.43

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Abstract. This work is an attempt to establish aquifer distribution in the indicated area as an aid to locating possible and suitable sites to drill boreholes for safe, portable and sustainable water supply for the ever-growing population and industries in the area, and the vulnerability of this body of water to pollutants as a result of human and industrial activities in the area. Data collected from vertical electrical sounding were used to interpret, both laterally and vertically, varying successions of high and low resistive geoelectric layers throughout the area of study to establish the depth, thickness and lateral extent of an aquifer, and also to determine the layering of the study area down to the depth of interest; thus, to delineate the aquifer distribution of the area. To ensure the safety status of groundwater of the area, a chemical analysis of three pollutants (heavy metals) of interest {Lead (Pb), Copper (Cu), and Nickel (Ni)} was carried out on sixty soil samples collected randomly from ten locations at various depths from the ground surface to a depth of 25m to determine their total concentration in the soil at ground level and their degree of leaching towards the groundwater of the area. The energy Dispersive X-Ray Fluorescence (EDXRF) technique was used to analyze and determine the total concentration of the pollutants in the soil samples. The results show that there is good aquifer distribution laterally across the study area with aquifer thickness of between 50m to 60m. The groundwater resource of the area is less vulnerable to pollutants because of the presence of a thin layer of organic matter and clay deposits that adsorb the pollutants of interest and minimize the leaching of the pollutants towards the saturated zone.

Key words: resistivity, aquifer, leaching, groundwater vulnerability, pollutants, porosity, permeability

Received April 15, 2010

1. 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 bodies of water in the area are severely polluted by the direct discharge of domestic and industrial waste, so that about 95% of the population of the area now solely depends on groundwater as their source of water. Thus, harnessing and preserving clean and safe groundwater becomes imperative.

The study area (Okrika) is a host to the Port Harcourt Refining Company (PHRC), a subsidiary of the Nigerian National Petroleum Corporation (NNPC), a jetty and terminal for loading and unloading of oil and gas, and other oil and gas servicing activities; these have led to the continuous influx of associate companies and people into the area, whose activities have contaminated and polluted the available surface water resources by the discharge of effluents or pollutants in the runoff into the surface water. Consequently, there was an increased demand for a portable and sustainable water supply in the area, which necessitated the conduct of these hydrogeological and geophysical studies of the area to provide useful information regarding the location of productive aquifers and the possible drilling of such formations to meet the water needs of the ever-growing population and the industries of the area.

The vertical electric sounding (i.e. Schlumberger sounding) method was used to obtain the data due to the simplicity of the technique, easy interpretation and the rugged nature of the associated instrumentation. It is also economical, quick and effectively used in both soft and hard rock areas, which has been proven in solving most groundwater survey problems in different parts of the world (Breusse, 1993; Zohdy and Jackson, 1967; Frohlich, 1974, Urich and Frohlich, 1990). This method has also successfully been used to determine saltwater-freshwater interface and the lateral extent of saltwater intrusion in the Niger Delta (Zohdy, 1969; Etu-Efeotor et al, 1989; Amadi and Amadi, 1990; Oteri, 1990).

Water has some physical characteristics that guarantee its wholesomeness: it must be colourless, odourless, tasteless, and must readily foam with soap or detergents. The human body and blood is composed of 60%-75% of water, and as such needs enough water; at least 2-3 litres for an adult to enhance the effective functioning of the circulatory and metabolic systems of the body. Safe water must be used for domestic and agriculture purposes; anything contrary is hazardous to man and his environment. Safe water is dependent on the chemical components of the water.

To ascertain the safe status of the groundwater, soil samples were obtained across the study area at various depths of analysis to evaluate the degree of leaching of surface pollutants towards the groundwater resource (Alloway and Ayres, 1997).

Therefore, the provision of baseline hydrogeological, geophysical and safety information of aquifer characteristics of the area have become inevitable; based on the high demand for a quality, safe and sustainable water supply to meet the water needs of humans and industries in the area and to ensure public health.

2. LOCAL GEOLOGY OF THE STUDY AREA

Okrika in Rivers State, Nigeria is located in the coastal area of the transitional environment of the Niger Delta as shown by Fig.1, and is characterized by beaches, man-

groves, swamps and barrier bars. The area lies between longitude $7^{\circ}00'$ East and $7^{\circ}50'$ West and latitude $4^{\circ}45'$ South of Rivers State, (Nigeria, Federal surveys, 2,500/364/6-68). The area is underlain by the coastal plain sands (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, the presence of hematite grains and feldspar minerals.

The shales are grayish-brown, sandy or silty and contain some plant remains and dispersed lignite (Short and Stauble, 1967).

These formations are commonly masked by thick partly weathered layers of 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 high porous and unconsolidated sands of the Benin formation have been identified as the freshwater bearing sands (Short and Stauble, 1967; Mbonu et al, 1991). 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.

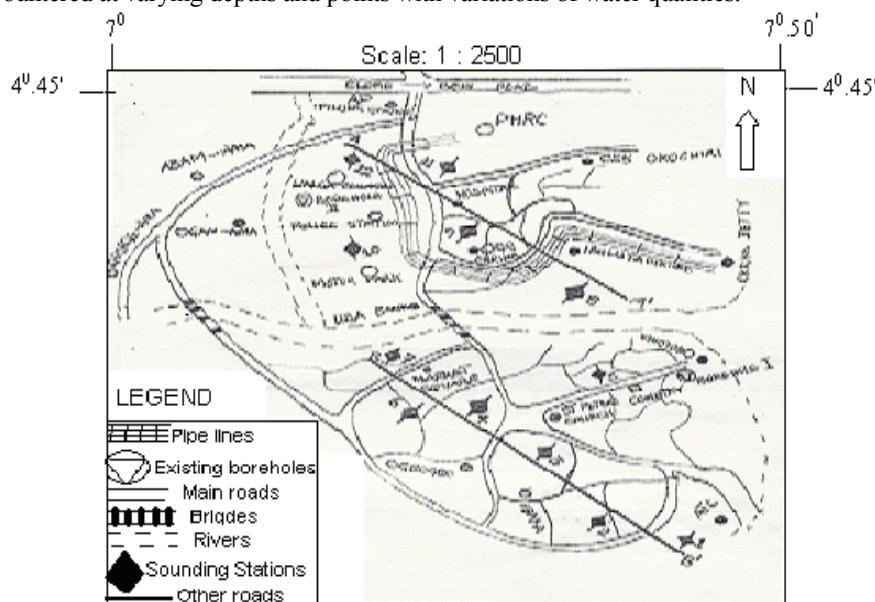


Fig. 1. Map of the study area showing the sounding locations

The depth of the water table ranges from few metres to tens of metres as you move from the Okrika Island inland to Okrika mainland, based on the topography of the area. The high permeability, the overlying lateritic earth materials containing dense vegetation, the weathered top of the formations as well as the underlying shale strata provide the hydrologic conditions that favoured aquifers in the area (Todd, 1959; Plummer and McGarry, 1993).

The considerable thickness of the aquifers, the high transmissivity of 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 m^3 volume of water to satisfy the water needs of the people and industries of the area through both public and private abstractions. Also, the aquifers in this area are less vulnerable to pollution despite the continuous human and industrial activities in the area, which perhaps is due to the presence of organic and clayey deposits at the top layer of this area that may have provided mechanical filtration of colloidal pollutants such as pathogens and chemicals owing to their fine-grain sizes, and sorption of charge pollutant species due to their charged surfaces and large surface areas; this favours the washing away of pollutants deposited on the surface by runoff, thereby minimizing or preventing the leaching of pollutants down to the groundwater during percolation of rain water or snow that precipitates on the surface. In this area, the development of a borehole is easy because of the considerable unconsolidation of the formation materials and the shallowness of the saturated zone (Todd, 1959; Plummer and McGarry, 1993; Alloway and Ayres, 1997; Kilner et al, 2005).

3. METHODOLOGY

To obtain the hydrogeologic data of the study area, the vertical electric sounding (VES) method was used and the soundings were carried out at twelve different stations as shown by (Fig.1) along two profiles using the Schlumberger electrode configuration with a maximum current electrode separation of 600m. A digital self-averaging Resistivity meter, the R-Plus, was used for data acquisition by displaying the apparent resistivity of the different layers. A quantitative interpretation of the field curves was done by the conventional curve matching technique using three layer master curves and drawing auxiliary point diagrams (Koeford, and Dirks, 1979). Computer assisted interpretation was used to obtain the desired results of the resistivities and thicknesses of the geoelectric layers as shown in Table 1, while Figures 2 and 3 show the graphical presentation of the results.

The implications of the anthropogenic activities on the groundwater resource of the study area was determined by the chemical analysis of sixty soil samples collected randomly from ten (10) locations at various depths; from ground surface to about 25m deep at 5m intervals identified by A-to-F: A=0m, B=5m, C=10m, D=15m, E=20m, and F=25m. This depth range was chosen because the water table in the area of study is shallow and falls between 20m-30m deep. This sampling design was used to evaluate the degree of leaching of pollutants from the surface down to the earth's interior during the percolation of rain or snow waters. The samples collected were oven dried and ground to the desired particle size of about nanometers $10^{-9} m$ for analyses. For the determination of the total concentrations of the pollutants, the soil samples were analyzed with a multi-elemental analytical tool; the Energy Dispersive X-Ray Fluorescence (EDXRF) SPECTRA X-LAB 2000 Model shown by Figure 2. (Kebbekus and Mitra, 1998; Stead-Dexter and Ward, 2004; Alloway and Ayres, 1997).

3. RESULTS AND DISCUSSION

The numerical data of the geoelectric sounding survey are given in Table 1. Showing the resistivity values at different sounding points and the thicknesses of the layers as worked out by the current electrode space geometry, and the graphical presentation of the

resistivities and thicknesses at the sounding stations of the study area are shown in Figures 3 and 4. These results from the interpretation revealed that the study area consists of three distinct geoelectric/hydrogeologic layers from the ground surface to the maximum depth (about 200m) that was probed vertically. These layers were distinguished based on their unique formation materials and the resistivity values laterally across. Based on Figures 3 and 4, the second layer was considered the aquiferous zone because of the high resistivity values between $1230\Omega\text{m}$ -to- $1500\Omega\text{m}$, meaning that the water therein was the desired fresh water, which is less conductive, since conductivity of the water is dependent on the presence of impurities, salts and pollutants.



Fig. 2. A photograph of the SPECTRA X-LAB 2000 and PC-data processor

Table 1. Resistivity values and layer thicknesses of sounding stations

Station no.	Resistivity of layers (Ωm)				Thickness of layers (m)			
	1	2	3	4	1	2	3	4
1	170.00	1280.00	80.00	200.00	15.00	45.00	104.50	35.20
2	154.00	1300.00	78.00	190.00	18.00	31.00	125.00	25.00
3	160.00	1400.00	78.00	–	18.50	51.00	128.50	–
4	220.00	1250.00	75.00	–	16.50	58.50	124.30	–
5	210.00	1180.00	77.00	–	18.20	50.20	131.50	–
6	200.00	1350.00	76.00	–	19.30	67.50	112.00	–
7	190.00	1345.00	75.00	–	12.50	86.40	100.30	–
8	250.00	1500.00	78.00	–	16.50	46.50	136.00	–
9	220.00	1400.00	60.00	–	17.50	43.50	138.20	–
10	200.00	1400.00	62.00	–	15.30	50.20	134.50	–
11	210.00	1420.00	67.00	–	21.00	57.50	120.80	–
12	190.00	1230.00	55.00	–	22.30	60.70	116.50	–

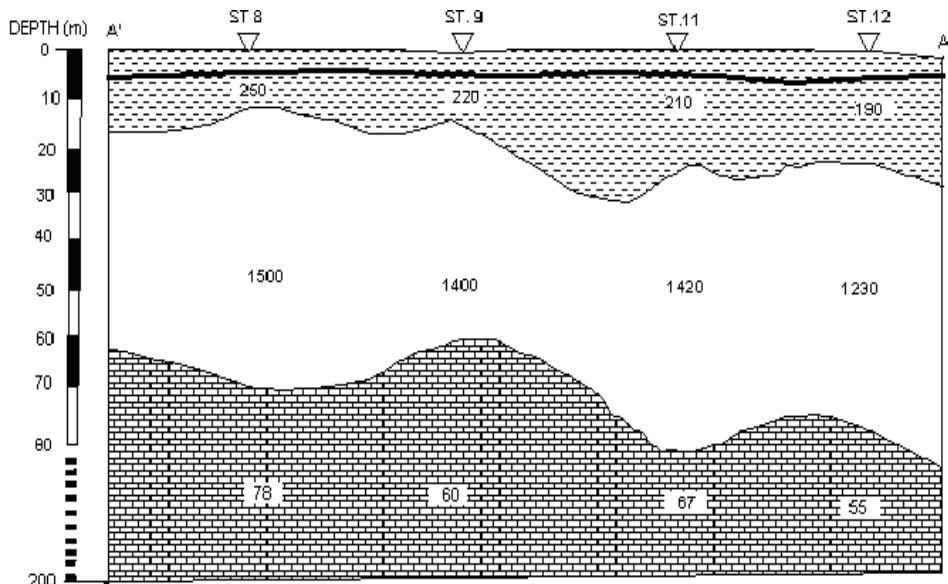


Fig. 3. Resistivity cross-section for profile A'

■ Silty-sand □ Gravely-sand ■ Limy-sandstone — Organic/clayey deposits

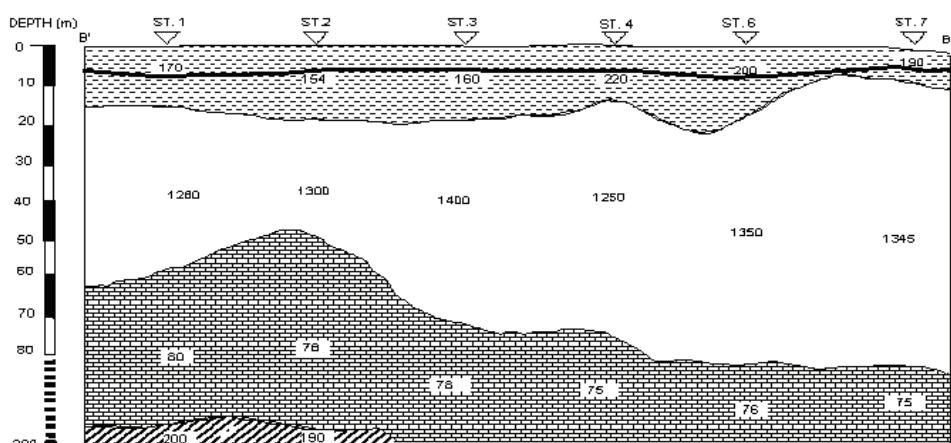


Fig. 4. Resistivity Cross-section for Profile B'B

■ Silty-sand □ Gravely-sand ■ Limy-sandstone ■ Limestone — Organic/clayey deposits

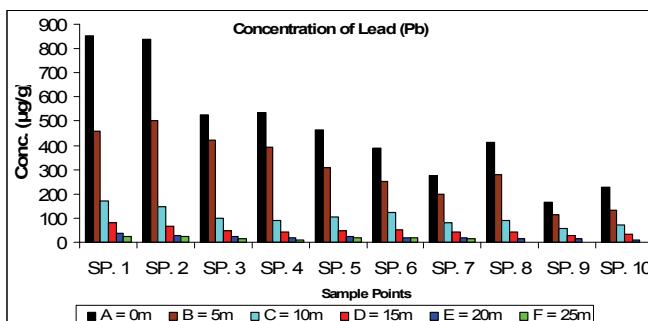
Table 2. Soil Guideline/Target Values (adapted from Fuentes et al, 2004)

Pollutants	Soil guideline/Target values ($\mu\text{g/g}$)
Lead (Pb)	85 – 450
Copper (Cu)	30 – 40
Nickel (Ni)	30 – 75

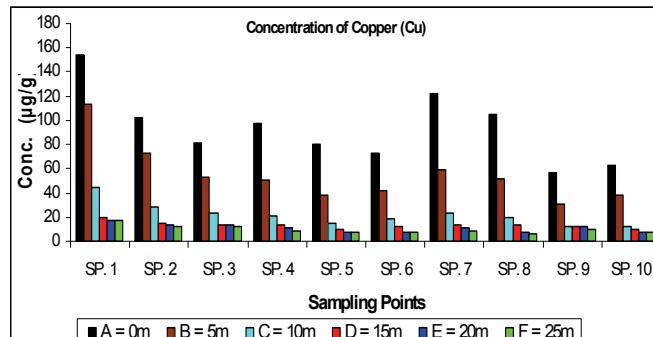
Table 2 gives the soil guideline or target values showing the acceptable concentration range of the pollutants of interest. The concentration level of the pollutants beyond these target values is unacceptable. These soil guideline/target values vary depending on the land-use purpose. The area of study is an urban development area, which was not used for farming. Thus, the problem of the bioaccumulation of pollutants by plants or animals was not seriously put into consideration.

Table 3. Total concentration of lead (Pb)

Sample locations/ sampling depths	Concentration values ($\mu\text{g/g}$)					
	A = 0m	B = 5m	C = 10m	D = 15m	E = 20m	F = 25m
SP. 1	854.3 \pm 3.6	458.7 \pm 2.1	171.5 \pm 1.7	80.3 \pm 0.7	38.5 \pm 0.5	22.8 \pm 1.1
SP. 2	840.0 \pm 3.6	502.4 \pm 2.2	145.3 \pm 1.7	66.5 \pm 0.9	28.2 \pm 0.5	21.7 \pm 0.8
SP. 3	525.2 \pm 2.9	419.7 \pm 1.8	98.6 \pm 1.1	45.2 \pm 1.1	22.5 \pm 0.6	14.3 \pm 0.4
SP. 4	533.4 \pm 3.2	394.8 \pm 2.0	88.2 \pm 0.7	42.1 \pm 0.5	19.6 \pm 0.4	11.5 \pm 0.3
SP. 5	465.0 \pm 2.8	306.5 \pm 1.7	102.5 \pm 1.0	48.3 \pm 0.8	21.7 \pm 0.6	18.4 \pm 0.5
SP. 6	388.6 \pm 4.1	249.2 \pm 1.8	121.3 \pm 0.8	51.4 \pm 1.2	20.9 \pm 0.4	20.7 \pm 0.4
SP. 7	275.0 \pm 2.7	201.3 \pm 1.4	82.6 \pm 0.7	40.4 \pm 0.7	18.3 \pm 0.9	12.5 \pm 0.4
SP. 8	411.5 \pm 3.0	277.6 \pm 16	91.5 \pm 0.8	43.1 \pm 1.0	16.4 \pm 0.5	ND
SP. 9	165.7 \pm 1.6	111.4 \pm 0.7	56.9 \pm 0.4	30.2 \pm 0.5	13.8 \pm 0.7	ND
SP. 10	228.5 \pm 2.3	134.5 \pm 0.9	71.4 \pm 0.6	34.6 \pm 0.7	11.3 \pm 0.3	ND

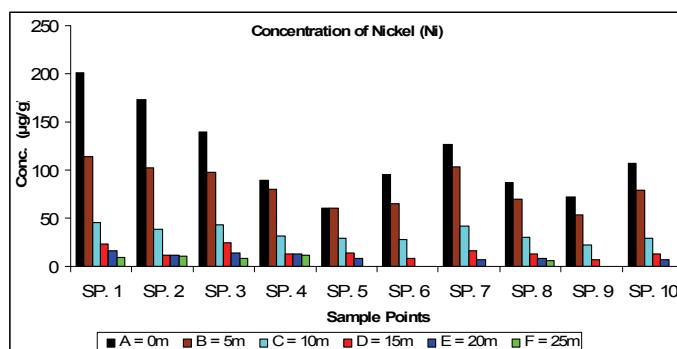
**Fig. 5.** Concentration of lead (Pb) from the sampling points at various depths**Table 4.** Total concentration of copper (Cu)

Sample locations/ sampling depths	Concentration values ($\mu\text{g/g}$)					
	A = 0m	B = 5m	C = 10m	D = 15m	E = 20m	F = 25m
SP. 1	153.5 \pm 2.2	113.6 \pm 0.9	43.8 \pm 0.6	19.7 \pm 0.5	17.2 \pm 0.6	17.0 \pm 0.6
SP. 2	101.9 \pm 1.7	73.1 \pm 0.7	28.5 \pm 0.7	14.6 \pm 0.6	14.0 \pm 0.6	12.4 \pm 0.5
SP. 3	81.5 \pm 1.5	52.4 \pm 0.7	23.5 \pm 0.7	13.2 \pm 0.5	13.2 \pm 0.5	12.5 \pm 0.5
SP. 4	97.8 \pm 1.6	50.8 \pm 0.8	21.2 \pm 0.3	13.0 \pm 0.5	10.8 \pm 0.5	8.6 \pm 0.4
SP. 5	80.5 \pm 1.3	38.5 \pm 0.5	14.8 \pm 0.4	10.4 \pm 0.7	7.9 \pm 0.5	7.9 \pm 0.5
SP. 6	73.2 \pm 1.4	41.7 \pm 1.0	18.6 \pm 0.5	12.8 \pm 0.6	7.6 \pm 0.4	7.6 \pm 0.4
SP. 7	122.6 \pm 1.9	59.2 \pm 1.2	22.9 \pm 1.0	13.0 \pm 0.5	10.7 \pm 0.5	8.2 \pm 0.5
SP. 8	104.7 \pm 0.8	51.3 \pm 0.6	20.1 \pm 0.8	13.4 \pm 0.5	8.0 \pm 0.4	5.8 \pm 0.3
SP. 9	56.3 \pm 0.6	30.3 \pm 0.5	12.4 \pm 0.3	12.2 \pm 0.3	12.0 \pm 0.3	9.4 \pm 0.3
SP. 10	62.7 \pm 0.5	37.9 \pm 0.4	12.0 \pm 0.3	10.2 \pm 0.3	7.5 \pm 0.3	7.5 \pm 0.3

**Fig. 6.** Concentration of Copper (Cu) from the Sampling Points at various Depths**Table 5.** Total concentration of nickel (Ni)

Sample locations/ sampling depths	Concentration values ($\mu\text{g/g}$)					
	A = 0m	B = 5m	C = 10m	D = 15m	E = 20m	F = 25m
SP. 1	201.6 \pm 2.3	113.5 \pm 2.1	45.7 \pm 1.1	23.5 \pm 0.6	16.7 \pm 0.5	9.8 \pm 0.5
SP. 2	172.8 \pm 3.0	101.8 \pm 1.5	38.5 \pm 0.7	11.3 \pm 0.3	11.3 \pm 0.3	10.0 \pm 0.3
SP. 3	139.2 \pm 2.2	97.1 \pm 0.9	42.6 \pm 1.2	24.8 \pm 0.8	14.5 \pm 0.5	8.5 \pm 0.3
SP. 4	89.9 \pm 1.6	80.6 \pm 1.3	31.5 \pm 0.8	12.9 \pm 0.6	12.9 \pm 0.6	12.0 \pm 0.6
SP. 5	60.7 \pm 1.2	60.7 \pm 1.2	29.4 \pm 0.4	14.4 \pm 0.0	8.3 \pm 0.6	ND
SP. 6	95.0 \pm 2.2	65.6 \pm 1.6	27.9 \pm 0.5	8.3 \pm 0.2	ND	ND
SP. 7	126.7 \pm 1.6	103.5 \pm 1.5	41.4 \pm 0.9	15.9 \pm 0.7	6.8 \pm 0.3	ND
SP. 8	87.7 \pm 1.5	70.1 \pm 1.0	30.8 \pm 0.5	12.4 \pm 0.4	8.2 \pm 0.4	5.4 \pm 0.2
SP. 9	72.3 \pm 1.3	53.8 \pm 0.7	22.6 \pm 0.3	7.3 \pm 0.0	ND	ND
SP. 10	107.3 \pm 1.5	79.0 \pm 1.4	29.3 \pm 0.5	12.7 \pm 0.3	6.5 \pm 0.3	ND

ND = not detected

**Fig. 7.** Concentration of Nickel (Ni) from the sampling points at various depths

The chemical analysis results of the soil samples at various depths for the three pollutants are also given in Tables 3, 4 and 5, for Pb, Cu, and Ni respectively. The graphical presentations of the chemical analysis results of the elements are shown in Figures 5, 6

and 7 for Pb, Cu and Ni respectively. These results clearly revealed that the concentration of the pollutants (Pb, Cu, and Ni) at the ground surface of almost all the sampling locations is very high and far beyond the permissible level. Therefore, this calls for urgent intervention by private and government agencies for the proper monitoring and control of these anthropogenic activities.

At a depth of 5m, the analytical results also show a significant concentration of the pollutants averagely beyond the permissible level, perhaps due to reasonable amount of the pollutants leached from the surface during the percolation of rain water.

Nevertheless, from 10m down to 25m, the concentrations of pollutants were far below the target limits and well within the permissible limits of concentration as clearly shown in Figures 5, 6 and 7, which perhaps is due to the presence of organic and clayey deposits observed at a depth between 6m-to-8m across the area as shown in Figures 3 and 4. They may have provided mechanical filtration of colloidal pollutants such as pathogens and chemicals owing to their fine-grain sizes that adsorb these pollutants, and the sorption of charge pollutant species due to their charged surfaces and large surface areas; this favours the washing away of pollutants deposited on the surface by runoff, thereby minimizing or preventing the leaching of even the water soluble components of the pollutants down to the groundwater during percolation of rain water or snow that precipitate on the ground surface

4. CONCLUSION

This work puts together two distinct studies: aquifer delineation and leaching of surface pollutants to be able to correctly establish the vulnerability of groundwater resources. The results of this work have revealed the amount and concentration of pollutants deposited into our soil as a result of uncontrolled and unmonitored anthropogenic activities in the area. The concentration of these pollutants (Pb, Cu, and Ni) at the ground surface is alarming, as shown in Figures 5, 6, and 7; this calls for an intervention, though there was an observed decreasing trend of their concentration with depth, especially from a depth of 10m to 25m.

This work also clearly delineated the aquiferous zone, which laterally spread across the study area. This aquifer varies in thickness from station to station but is within the thickness range of 50m to 60m which indicates a very good aquifer. Figures 3 and 4 show the lithostratigraphic distribution within the study area as having three hydrogeologic layers with a thin band of organic and clayey deposits within the top layer embedded at a depth of around 6m to 8m. This thin band of organic and clayey deposits was not detected by a geoelectric sounding method, perhaps due to suppression. This layer was mapped during drilling to obtain the soil samples. To precisely define this thin band or layer, a crosshole-seismic method may be required.

The sharp reduction of the concentration of the pollutants from 10m to 25m was perhaps due to the presence of this thin band or layer of organic and clayey deposits within the top hydrogeologic layer embedded at a depth of around 6m to 8m, which may have provided mechanical filtration of colloidal pollutants such as pathogens and chemicals owing to their fine-grain sizes, and sorption of charge pollutant species due to their charged surfaces and large surface areas (Kilner et al, 2005).

The aquifer characteristics makes the aquifers of the area reliable water resources that can supply reasonable millions of m³ volume of water to satisfy the water needs of the people and industries of the area through both public and private abstractions. The minimal leaching of surface pollutants renders the groundwater resource less vulnerable to surface pollutants despite the continuous human and industrial activities in the area.

Finally, to safeguard and preserve this all-important resource, there should be regular determination and evaluation of the mobility of these surface pollutants toward the groundwater and the establishment of the safety status of the groundwater resource.

Acknowledgement. *The authors are very grateful to the staff of the Rivers State water board of the Ministry of Water Resources for providing useful information for the realization of this work. We are also grateful to the Institute of Pollution Studies, Rivers State University of Science and Technology, Port Harcourt for their technical assistance. Success computers are also well appreciated for their assistance in data analysis.*

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ANTROPOGENE AKTIVNOSTI - POSLEDICE ZA PODZEMNA IZVORIŠTA VODE U OBLASTI OKRIKA, RIVERS STATE, NIGERIJA

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Ovaj rad predstavlja pokušaj da se utvrdi rasprostranjenost poroznog kama u navedenoj oblasti kako bi se omogućilo utvrđivanje mogućih i pogodnih lokacija za bušotine za bezbedno, prenosno i održivo snabdevanje vodom za stanovništvo koje je u porastu i za potrebe industrije u razvoju u toj oblasti. Takođe, potrebno je da se utvrdi podložnost ovog izvorišta vode na zagađenje koje je rezultat ljudskih i industrijskih aktivnosti u ovoj oblasti. Podaci prikupljeni uz pomoć uzdužnih električnih sondi korišćeni su da bi se dobila lateralna i vertikalna interpretacija različitih nizova visoko i nisko otpornih geoelektričnih slojeva kroz čitavu istraživanu oblast, kako bi se utvrdila dubina, debljina i bočno pružanje poroznog kama, i kako bi se odredili slojevi strukture istraživane oblasti na željenoj dubini; tako bi se razgraničila distribucija poroznog kama u navedenoj oblasti. Kako bi se obezbedila čistoća podzemnih voda u toj oblasti, hemijska analiza tri zagađivača (teških metala) {olovo (Pb), bakar (Cu), i nikl (Ni)} je sprovedena na 60 uzoraka koji su nasumice prikupljeni sa 10 lokacija pri različitim dubinama od površine pa sve do dubine od 25m, kako bi se utvrdila njihova ukupna koncentracija u zemljištu pri tlu i stepen izlivanja u pravcu podzemnih voda u toj oblasti. Disperzivna rentgenska fluorescencija (engl. Dispersive X-Ray Fluorescence (EDXRF)) tehnika je korišćena kako bi se analizirale i odredile sveukupne koncentracije zagađivača u uzorcima zemlje. Rezultati pokazuju da je distribucija poroznog kama dobra lateralno duž ispitivane oblasti i da je debljina poroznog kama između 50m i 60m. Izvor podzemne vode u toj oblasti je manje izložen dejству zagađivača jer je prisustvo tankog sloja organske materije i slojeva gline dovoljno da upiže zagađivače i minimizira njihovo isticanje u ispitivane zone.

Ključne reči: *otpornost, porozni kamen, curenje, podložnost podzemnih voda zagađenju, zagađivači, poroznost, propustljivost*