



Litho-Hydraulic Effects on Groundwater Safety in Parts of Rivers State, Niger Delta, Nigeria

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Abstract This work focused on groundwater safety with respect to fluid flow intensity (infiltration and percolation rates) through different soil types and their adsorption capacity of pollutants; to be able to establish the vulnerability of the groundwater resource. ABEM Terrameter SAS 300 model was used for data collection from four vertical electrical sounding (VES) stations, and the interpretation of vertically varying succession of high and low resistive geoelectric layers throughout the area of study was done in WinResist software environment to establish the relationship between presence of pollutants and conductive levels of geoelectric layers. To ensure the safety status of groundwater of the area, chemical analysis of three pollutants (heavy metals) of interest {Copper (Cu), Lead (Pb), and Zinc (Zn)} was carried out on twenty four soil samples collected from four locations; six samples at each location at various depths from the ground surface to 10m depth at 2m interval to determine their total concentration in the soil at ground surface and their degree of leaching towards the groundwater of the area. Energy Dispersive X-Ray Fluorescence (EDXRF) technique was used to analyze and determine the total concentration of the pollutants in the soil samples. The high concentrations of the pollutants in the top soils was indicative of the lithologic role of the clayey and humurous content to have filtered, retained and adsorbed the pollutants of interest and minimize the leaching of the pollutants towards the saturated zone. The soil profile sequence affirmed the presence of clayey and humurous layers from the surface to a depth of about 8m, thereby validating the assertion that the lithology type influences the fluid flow and adsorption of pollutants from leaching toward the groundwater body thereby guaranteeing the safety of groundwater.

Keywords Infiltration, Lithology, Aquifer, Pollutants, Porosity, adsorption, Volatilization

Introduction

The ultimate interest of looking at Litho-hydraulic effects on groundwater safety is to investigate the role of lithology in ensuring that infiltration, percolation and drainage of precipitated surface water to recharge aquifers does not impair the quality of the underlying water resource. Infiltration can be considered as the process by which water from the surface moves into the ground. Percolation is the movement of infiltrated water in the sub-surface formation materials. Both infiltration and percolation are associated with primary porosity. Meanwhile, the drainage of water from the surface towards groundwater is a combination of infiltration and percolation; but seriously associated with secondary porosities and permeability due to fractures, faults, unconformities, burrows, sinkholes etc.

Several factors affect infiltration rate of a given soil type, these include the nature of the soil layer, the moisture content of the soil, rainfall intensity, temperature, vegetation cover, hydraulic characteristics, permeability and moisture content [1]. Water in excess of infiltration capacity of the soil will flow overland as surface run-off once the minor undulations in the surface have been filled. Thus, the role of the micro litho-strata (unsaturated or vadose zone) along the recharge column, which help filter out or transform harmful constituents in the soil solution as recharge water moves through the soil matrix en route to the aquifer.



Meanwhile, there other fluids such as gas and oil that shows little downward hydraulic effects on groundwater because of their densities that do not allow them to easily infiltrate and percolate towards groundwater under gravity; rather they spread laterally on the ground surface or along near-surface layer especially when they encounter impermeable or obstructive layer(s). Also, oil is especially more adsorbed to soil and organic particles than water; thereby well retained in near-surface formation materials when they spill on ground surface.

Vadose zone is a much more complex transport medium than an aquifer, for several reasons; because only part of the void space is filled with water, chemicals with a significant vapor pressure can move in the gas phase as well as in solution. The water flow rate can vary significantly. The resistance offered by the vadose zone to the flow of water through a given local soil volume is a nonlinear function of the water content, whereas in the saturated zone, it is a constant. The temperature varies in the surface regime in response to the cyclic inputs of radiant energy, and the composition of the air, solid, and solution phases of the soil is also dynamic, causing spatial and temporal variations in the chemical and biological reactions that transform chemicals in the vadose zone.

Also, the amount of water retained against gravity varies significantly with soil texture. Coarse-textured, sandy soils may hold as little as 10 to 20 percent of water-saturation after drainage becomes insignificant, while fine-textured silts or clays may hold as much as 90 percent. Restricting layers comprised of clay lenses or cementing agents can retard drainage greatly, even in otherwise permeable media. Soils that retain extensive water are prone to aeration problems [2-4].

There are many different processes that can remove chemicals or pathogens from the recharge water as it flows through the vadose zone. Some chemicals volatilize and escape to the atmosphere. They can be chemically or biologically transformed to a new form that may or may not be toxic. They can be attached (adsorbed) to stationary soil mineral or organic surfaces or precipitate out of solution. They can form complexes with dissolved constituents or particulate matter in solution, thereby reducing their attraction to the soil solid phase and enhancing their mobility in solution. Large pathogens such as parasites, some bacteria, and colloidal material containing contaminants/pollutants can be filtered out of solution by narrow soil pores, a process that slowly clogs the medium and eventually reduces its permeability if the contaminants/pollutants are not biodegraded. Viruses can be retained by soil solid phases and inactivated by reactions occurring in the soil [5-6]. The utmost interest in this study by focusing on the impact of lithology to minimizing the infiltration and percolation of pollutants so loaded at the surface toward the groundwater body; was underpinned by the fact that, the anthropogenic activities (especially oil and gas operations) and the associated pollutions in the area of study are enormous [7].

1.1. Soil Properties

The ideal vadose zone that guarantees high degree of aquifer integrity is one that allows rapid infiltration and complete removal of all constituents of concern. Unfortunately, no such medium exists because the attributes required to achieve one goal hamper the achievement of the other. In surface soil, coarse-textured materials (sand and gravel) are desirable for infiltration because they transmit water readily; however, the large pores in these soils are inefficient at filtering out contaminants, and the solid surfaces adjacent to the main flow paths are relatively nonreactive. In contrast, fine-textured soils (Clay and loam) are efficient at contaminant adsorption and filtration, but they have low permeability and their small pores clog easily.

Though, worm holes or root holes or cracks can create secondary porosity and permeability; these also create large flow paths, which completely dominate the movement of material and much of the matrix is bypassed [4, 5, 8, 9].

1.1.1. Sand and Gravel

When coarse sand or gravel is put into a bucket of which the bottom is perforated and a cup of water is added on top of it, the water moves easily through the sand to the bottom of the bucket (fig. 1). The water flows easily through the pores (open space) between the grains; water easily flows through sand and gravel. Sand and gravel are thus very permeable.



1.1.2. Clay and loam

Clay and loamy soils and soils composed of fine grain particles and organic matters; making these soils humorous. The opposite of sand and gravel is seen with clay and loam. When wet clay is put in a bucket (compressed as in a layer of soil) and a cup of water is added, the water will remain on top (fig. 1). Clay particles are very small (and 'sticky') as are the pore spaces between the particles; water does not easily flow through clay. Clay is therefore described as impermeable. The presence of these layers of organic and clayey deposits within the top hydrogeologic layer can provided mechanical filtration of colloidal pollutants such as pathogens and chemicals (pollutants) owing to their fine-grain sizes, and sorption of charge pollutant species due to their charged surfaces and large surface areas [9].

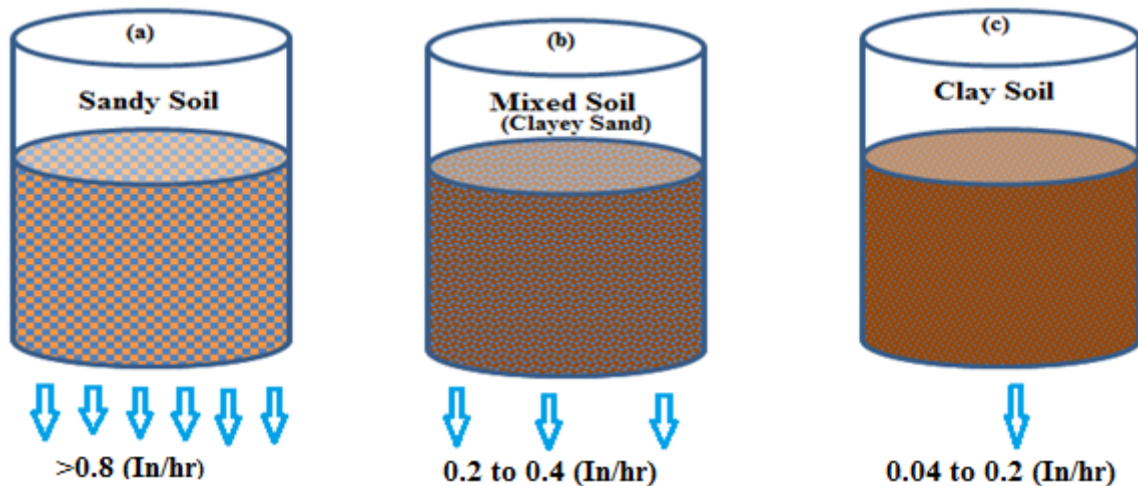


Figure 1: Three Types of Soil and the Infiltration Rate

Particle name Particle size

Clay < 0.004 mm, Silt 0.004 – 0.06 mm, Sand (fine, medium, coarse) 0.06 – 2 mm

Gravel and pebbles 2 – 64 mm, Stones and boulders > 64 mm

1.1.3. Mixed formations

In most cases the formation consists of a mixture of clay, silt, and sand or gravel particles. For example, clay and sand (clayey sand) can exist as a homogeneous layer (clay and sand are mixed) or in alternating thin layers (layered; small sand and clay layers on top of each other). When those soils are put in a bucket and a cup of water is added, the water slowly flows through the soil (fig. 1).

1.2. Volatilization

Volatilization refers to the evaporation of chemical vapor from soil or water bodies and its subsequent loss to the atmosphere; which is very important with the context of this work as volatilization can help reduce the final pollutant load in a given location. Many organic compounds are volatile in water, as are some nitrogen compounds (e.g., ammonia, nitrous oxide) generated from biological transformations. In addition, some inorganic chemicals (e.g., selenium compounds) may be rendered volatile through biological reactions.

The chemical characteristic that is most indicative of a compound's volatility is its Henry's constant, which is the ratio between the vapor pressure and the solubility of the pure chemical in water. It may also be expressed in dimensionless form as the ratio between the chemical concentration in the gaseous and aqueous phases [10].

For a given chemical, the extent of volatilization loss is very dependent on the soil and atmospheric conditions. The primary factor determining loss is the air phase concentration maintained at the interface with the atmosphere. In general, volatilization is greatly reduced in soil compared to water because the soil solid phase retains the chemical mass, thereby reducing its vapor pressure. In addition, the soil can offer substantial resistance to the transport of chemical from the soil profile to the surface, particularly if the soil is wet and little upward flow of water is occurring. Therefore, in a typical Niger Delta infiltration and percolation processes where recharge water is ponded over the surface for prolonged periods of time, the primary route for



volatilization loss will be from the surface of the standing water. During the drainage cycle when the soil becomes unsaturated, volatile constituents in solution near the surface can also evaporate and escape to the atmosphere.

1.2.1. Volatilization from Surface Water

Volatilization from standing water can be represented conceptually as a two-film resistance model, in which the dissolved compound moves from the bulk fluid through a liquid film to the evaporating surface, and then diffuses through a stagnant air film to the well mixed atmosphere above [11]. The two-film model assumes that the chemical is well mixed in the bulk solution below the liquid film and that mass transfer across each film is proportional to the concentration difference. With these assumptions, a chemical in the water body volatilizes at a rate proportional to the bulk concentration, so that the entire loss process can be characterized by an effective "half-life," defining the amount of time required to reduce the mass in solution by 50 percent.

Thomas [12] reviewed volatilization loss models for chemicals present in water bodies and performed model calculations for a number of compounds. The film thicknesses depend on specific conditions within the water and air, but may be crudely estimated from default values given in Thomas (1982) when no actual data are available. Table 1 summarizes effective volatilization half-lives calculated for a range of Henry's constant values.

As seen from Table 1, the effective half-life varies widely, depending on Source: Default values for film transfer coefficients are taken from Thomas [12], and K_H values are taken from Jury et al. [13]. Value of the Henry's constant. Clearly, compounds with half-lives that are considerably less than the detention time of the water on the surface will not enter the soil. For instance, volatilization losses of 22 to 73 percent were found for a wide spectrum of hydrocarbons in wet-land swampy areas [10,14].

Table 1: Effective Volatilization Half-Life Ranges as a Function of Dimensionless Henry's Constant Values for a Stagnant Water Body of 1-m Depth (After Thomas, 1982 [12])

Henry's Constant K_H	Example	Half life (days)
10^{-8} - 10^{-7}	Bromacil	10^4 - 10^5
10^{-7} - 10^{-6}	Amine	10^3 - 10^4
10^{-6} - 10^{-5}	Phenol	10^2 - 10^3
10^{-5} - 10^{-4}	Diazinon	10-100
10^{-4} - 10^{-3}	EPTC	1-10
10^{-3} - 10^{-2}	Bromobenzene	~ 1
10^{-2} - 10^{-1}	Benzene	~ 1
10^{-1} - 1	Methyl bromide	~ 1
1- ∞	Vinyl chloride	~ 1

1.2.2. Volatilization from Soil

The volatilization loss rates of chemicals from soil are generally smaller than those from standing water for several reasons. First, the diffusion resistance of soil is greater than that of free air because of the solid and liquid barriers to gas movement. Second, adsorption of chemical to soil solids reduces the vapor pressure of the compound by removing mass from solution. Because the transport pathways from the soil to the surface are much more complex than in free water, the two-film resistance model of volatilization is not applicable to soil, and more sophisticated estimation methods must be used.

Jury et al. [13, 15, 16] developed a comprehensive screening model for evaluating volatilization losses of chemicals after their incorporation into a soil layer of arbitrary thickness. They performed calculations covering a range of initial conditions on a large group of organic compounds, allowing the volatilization losses of different chemicals to be compared and grouped. In general, they found that compounds with dimensionless Henry's constant values less than 10^{-4} were not prone to significant volatilization after deposition in the soil, but that extremely volatile compounds could move upward to the surface from substantial distances if they were not rapidly degraded. Under certain conditions, water evaporation can greatly enhance volatilization from soil by concentrating the chemical mass at the surface and raising its vapor pressure.



The factors will be controlled by the framework of geological conditions within which the groundwater flow system occurs and is determined by such features as sediment texture, pore space, geologic structure, fractures, etc. This provides a most important input to the hydrogeological interpretation. Groundwater flow at any specific location is part of the hydrologic cycle and is mainly determined by hydraulic gradients between higher 'head' recharge areas and lower head discharge areas.

As water infiltrates into the ground, the pore space can be filled either partially or totally. This defines two separate zones-the vadose and saturated zone.

1.3. Solute Sorption during Transport

Chemicals that are hydrophobic or positively charged do not travel at the speed of the flowing water, but rather are slowed by their attraction to stationary solid sorption sites. Although the sorption process is very dynamic at the molecular scale, it is useful to conceptualize an adsorbed molecule as existing in a distinct phase that is temporarily immobilized by virtue of its attachment to stationary solid matter. There are several different types of sorption reactions, distinguished primarily by the nature of the sorbing surface and the charge characteristics of the sorbing molecule. Positively charged ions in solution are attracted to negatively charged clay mineral surfaces and are temporarily immobilized by the process known as cat-ion exchange. This is a partitioning reaction that divides the chemical mass between solution and adsorbed phases; it does not completely strip a compound from solution, nor is it permanent. The reaction depends on the nature of the molecule and also on the composition of the soil solution [5, 17].

In addition, some positively charged species, notably the trace metals, appear to be specifically sorbed strongly to certain oxide surfaces [18]. Anions are repelled from clay mineral surfaces that are negatively charged, but are attracted to positively charge broken end faces of minerals and also to free oxides in the soil. These surfaces have charges that are strongly pH dependent, and attract anions most strongly under acidic conditions.

Neutral organic molecules such as nonionic pesticides sorb primarily to organic matter surfaces in a reaction that can be approximated by a partition coefficient.

2. Methodology

2.1. Data Acquisition

To achieve the aim of the study, three research approaches were used; Vertical Electrical sounding (VES), Core Samples, and Chemical Analyses.

2.1.1. VES

The materials used in the VES are: ABEM Terrameter SAS 300 model, two reels of three core 2.5mm flexible copper wire cables, four stainless metal stakes and 12 volt battery power source as shown by Figure. 2. In this work, four (4) stations were sounded along two profiles MN and OP along Adibawa, north-west of Omoku in Rivers State, two (2) stations separated by 250m along each profile to obtain the relevant data, and the stations are geo-referenced with their coordinates as presented in Table 1.

Schlumberger array layout was employed for the survey because of its advantages over other arrays. In this method the fraction of total current which flows at depth varies with the current-electrode separation. The field procedure used a fixed center with an expanding spread. 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 with respect to the depth of interest (0m to 30m). In each measurement, the digital averaging instrument ABEM terrameter SAS 300 model displayed the resistance directly. This procedure was repeated for each sounding station along the marked profiles. Vertical Electrical Sounding (VES) data interpretation was started by first plotting the apparent resistivity computed from field measurements versus electrode spacing in a WinResist software environment. The sounding curve is then compared with internally built standard curve generated by the software program, to obtain the parameters of the geoelectric layers in terms of layer resistivity, depth and thickness.





Figure 2: Showing the Field work operational instruments for VES survey

2.1.2. Core Samples

To establish the lithostratigraphic sequence of the geology of the study area, two well were drilled, one along each profile to obtain core samples for analyses for relevant lithologic information for precise interpretation.

2.1.3. Chemical Analyses

To evaluate the safety or vulnerability status of the underground water bodies (aquifer) in the study area, total of twenty four Soil samples were collected; six (6) from each sounding station from the surface of the ground that is 0m to a depth of 10m at 2m interval. These samples were collected and prepared for total concentration analyses of three (3) pollutants of interest (Cu, Pb, and Zn) with the use of the Energy Dispersive X-Ray Fluorescence (EDXRF) Spectrometer the SPECTRA X-LAB 2000 MODEL as shown by Figure 3 below.



Figure 3: A photograph of SPECTRA X-LAB 2000 and PC- Data processor

Table 1: VES Stations and their Geo-referenced Coordinates

Stations	Coordinates	
	Easting	Northing
VES 1	E445118	N130005
VES 2	E444935	N129836
VES 3	E444745	N129660
VES 4	E444396	N129320

Table 2: Soil Guideline/Target Values (adapted from Fuentes et al [19])

Pollutants	Soil guideline/Target values (µg/g)
Lead (Pb)	85 – 450
Copper (Cu)	30 – 40
Zinc (Zn)	135 - 150

3. Results and Discussions

3.1. Results

The results from the field work; the numerical data from VES measurement and chemical analyses are presented by Tables 3 to 9, while the respective charts and curves are also shown by Figures 4 to 10. The sample collected at sample locations labeled LH 1 to LH 4 are at the VES sounding stations 1 to 4 respectively. Figure 11 was a show of the soils profiles for Wells A and B from the ground surface to a depth of 35m.

Table 3: Resistivity Data for VES 1

AB/2 (m)	MN/2 (m)	Resistance (Ω)	ρ (Ω m)
1	0.3	24.174425	115.2
1.5	0.3	7.5588797	85.5
2	0.3	3.1647785	64.8
3	0.3	1.6159902	75.4
4	0.3	2.2564865	188
5	0.3	1.6788638	219
7	1	3.5539996	268
7	1	5.4783312	413.11
10	1	2.5590083	398
15	3	2.9121579	329.4
15	3	3.7396563	423
20	3	3.477105	711.95
30	3	1.9379023	904.2
40	3	1.1066026	921.97
50	3	2.1602914	2818

Interpreted Geoelectric Layers		
ρ (Ω m)	depth (m)	Thickness(m)
79.5	2.94	2.94
315	7.04	4.1
1400	12.64	5.6
1000	27.64	15
3996	**	**

Table 4: Resistivity Data for VES 2

AB/2 (m)	MN/2 (m)	Resistance (Ω)	ρ (Ω m)
1	0.3	26.650625	127
1.5	0.3	9.5480586	108
2	0.3	3.1647785	64.8
3	0.3	1.1637701	54.3
4	0.3	0.7081527	59
5	0.3	0.5182246	67.6
7	1	0.856673	64.6
7	1	1.7386749	131.11
10	1	0.9078693	141.2
15	3	2.413537	273
15	3	2.4420928	276.23
20	3	1.3088899	268
30	3	0.855146	399
40	3	0.5485183	457
50	3	0.5680539	741

Interpreted Geoelectric Layers		
ρ (Ω m)	depth (m)	Thickness (m)
150	1.5	1.5
25	4.2	2.7
189	11	6.8
330	19.1	8.1
980	**	**

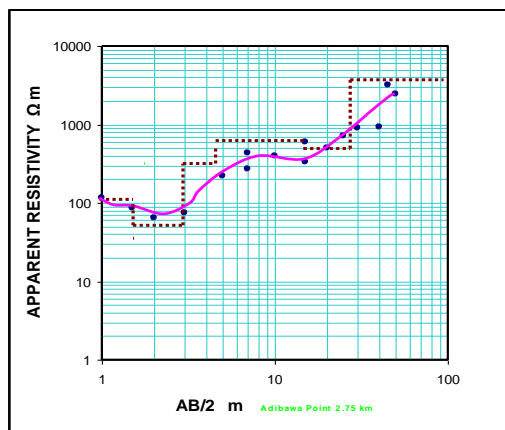


Figure 4: Resistivity Curve for VES 1

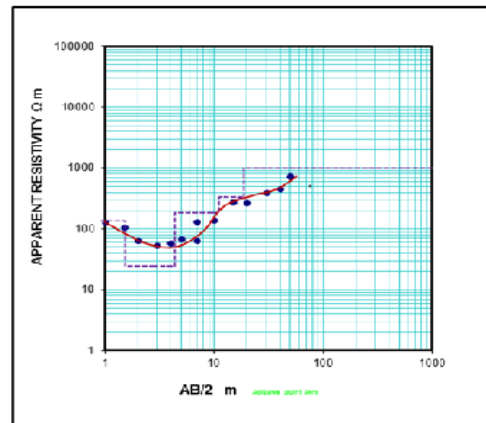


Figure 5: Resistivity Curve for VES 2



Table 5: Resistivity Data for VES 3

AB/2 (m)	MN/2 (m)	Resistance (Ω)	ρ (Ω m)
1	0.3	23.083219	110
1.5	0.3	7.3820638	83.5
2	0.3	3.1647785	64.8
3	0.3	1.6288495	76
4	0.3	2.4005176	200
5	0.3	2.2998134	300
7	1	6.617335	499
7	1	3.3564078	253.1
10	1	3.2276939	502
15	3	3.4302284	388
15	3	4.5353278	513
20	3	1.5628536	320
30	3	1.0866141	507
40	3	1.1978583	998
50	3	0.9199254	1200
Interpreted Geoelectric Layers			
ρ (Ω m)	depth (m)	Thickness (m)	
111	1.6	1.6	
55	3.3	1.7	
320	4.7	1.4	
610	16	11.3	
240	32	16	
1500	**	**	

Table 6: Resistivity Data for VES 4

AB/2 (m)	MN/2 (m)	Resistance (Ω)	ρ (Ω m)
1	0.3	23.608	112.5
1.5	0.3	7.5589	85.5
2	0.3	3.1745	65
3	0.3	1.9546	91.2
4	0.3	2.3645	197
5	0.3	2.3151	301.99
7	1	4.7051	354.8
7	1	5.4504	411
10	1	3.292	512
15	3	3.209	363.08
15	3	4.4036	498.11
20	3	2.2323	457.09
30	3	1.2914	602.56
40	3	1.1066	921.97
50	3	0.7491	977.24
Interpreted Geoelectric Layers			
ρ (Ω m)	depth (m)	Thickness (m)	
59	3	3	
320	4.6	1.6	
1250	11.6	7	
678	27.6	16	
3900	**	**	

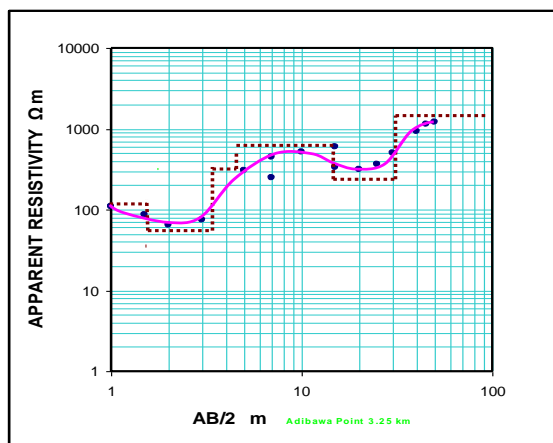


Figure 6: Resistivity Curve for VES 3

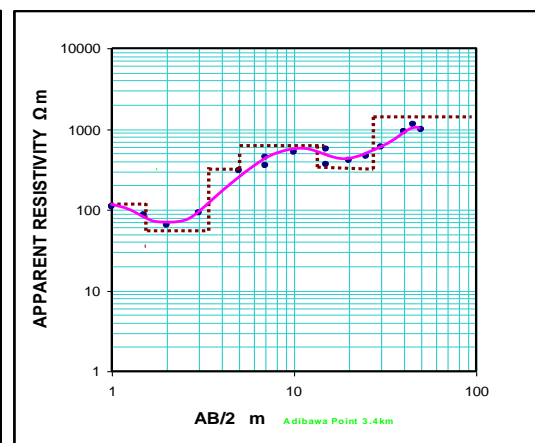


Figure 7: Resistivity Curve for VES 4

Table 7: Total Concentration of Copper (Cu)

Sample Locations/ Sampling Depths	CONCENTRATION VALUES ($\mu\text{g/g}$) for Cu					
	A = 0m	B = 2m	C = 4m	D = 6m	E = 8m	F = 10m
LH. 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
LH. 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
LH. 3	122.6 \pm 1.9	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
LH. 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

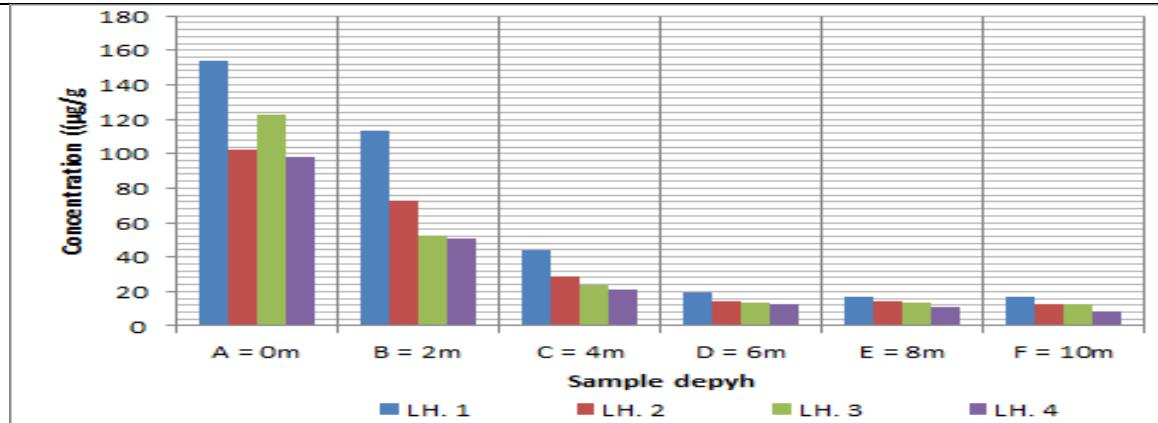


Figure 8: Concentration of Copper (Cu) from the Sampling Points at various Depths

Table 8: Total Concentration of Lead (Pb)

Sample Locations/ Sampling Depths	Concentration Values ($\mu\text{g/g}$) for Pb					
	A = 0m	B = 2m	C = 4m	D = 6m	E = 8m	F = 10m
LH. 1	764.3 \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
LH. 2	650.0 \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
LH. 3	505.2 \pm 2.9	275.0 \pm 2.7	98.6 \pm 1.1	45.2 \pm 1.1	22.5 \pm 0.6	14.3 \pm 0.4
LH. 4	493.4 \pm 3.2	277.6 \pm 16	88.2 \pm 0.7	42.1 \pm 0.5	19.6 \pm 0.4	11.5 \pm 0.3

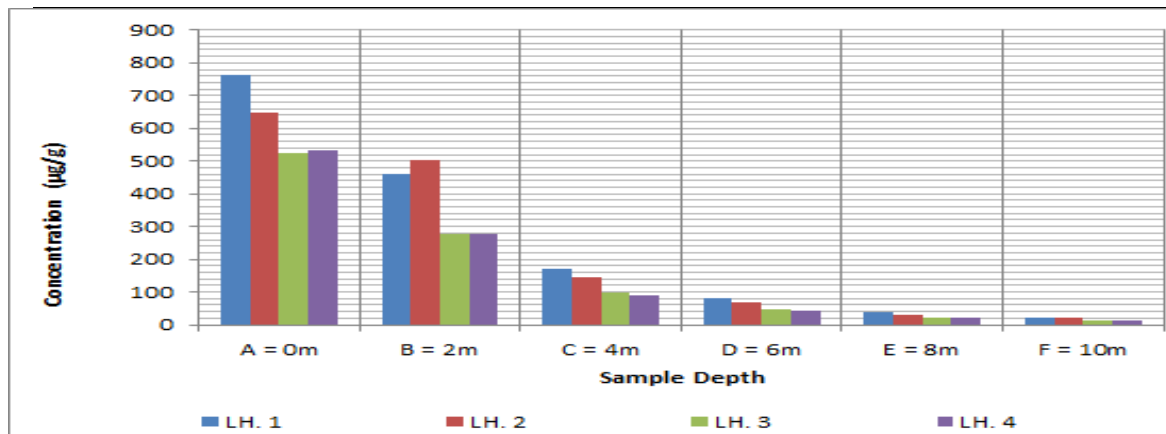


Figure 9: Concentration of Lead (Pb) from the Sampling Points at various Depths

Table 9: Total Concentration of Zinc (Zn)

Sample Locations/ Sampling Depths	Concentration Values ($\mu\text{g/g}$)					
	A = 0m	B = 2m	C = 4m	D = 6m	E = 8m	F = 10m
LH. 1	175.0 \pm 2.7	101.3 \pm 1.4	82.6 \pm 0.7	30.4 \pm 0.2	13.3 \pm 0.1	7.5 \pm 0.08
LH. 2	141.5 \pm 3.0	97.6 \pm 16	91.5 \pm 0.8	33.1 \pm 0.3	11.4 \pm 0.2	4.2 \pm 0.1
LH. 3	165.7 \pm 1.6	91.4 \pm 0.7	56.9 \pm 0.4	20.2 \pm 0.5	8.8 \pm 0.2	5.5 \pm 0.07
LH. 4	128.5 \pm 2.3	114.5 \pm 0.9	71.4 \pm 0.6	24.6 \pm 0.4	7.3 \pm 0.2	3.1 \pm 0.05

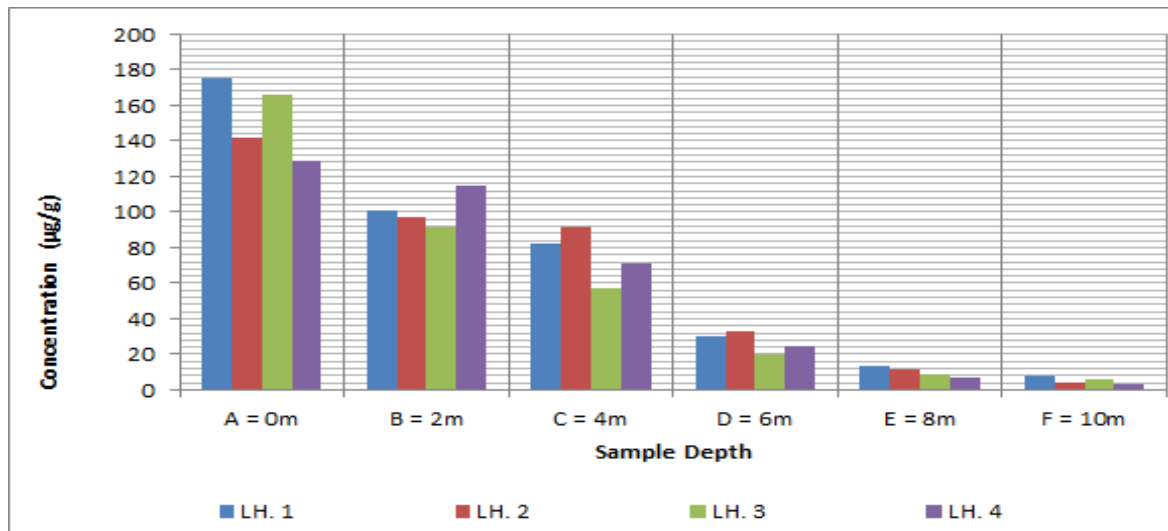


Figure 10: Concentration of Zinc (Zn) from the Sampling Points at various Depths

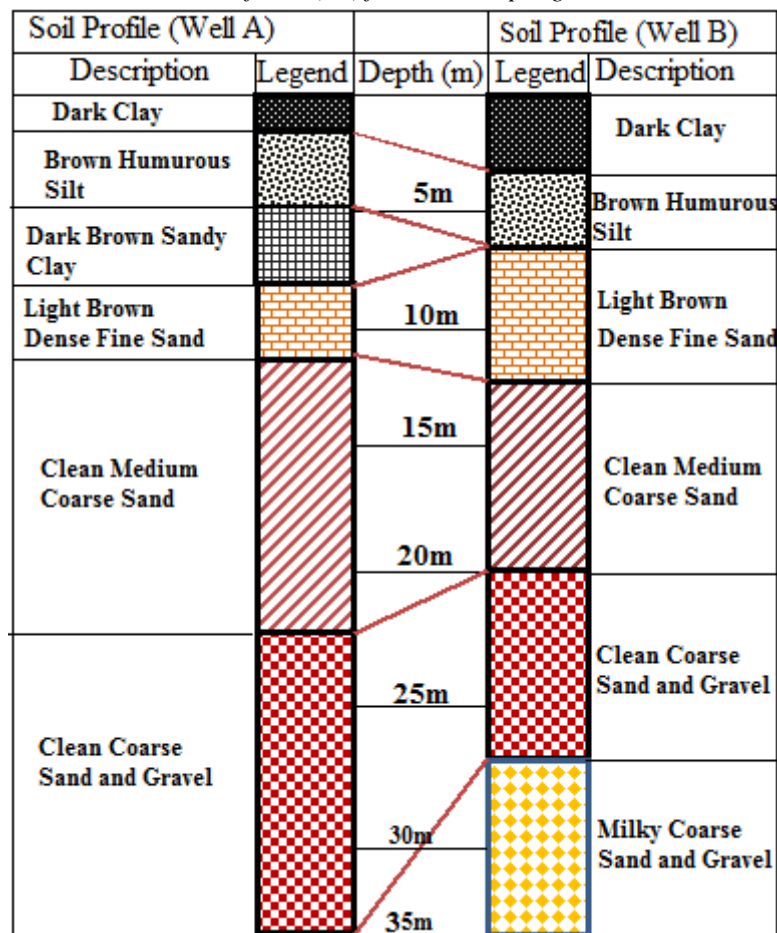


Figure 11: Soil profile for two wells showing the sequence of the core samples

3.2. Discussions

The results from the VES survey; the interpreted Geoelectric layers revealed that the first two top layers from surface to about 7m depth in all the stations have significantly low resistivity from (25Ωm to 320Ωm), an indication of highly conductive lithology. These high conductivities are seriously attributed to the surface

pollutants load and the lithologic content of the surface to near-surface formation materials. The sounding stations, all show five (5) layer scenarios.

Table 2 above gives the soil guideline or target values showing the acceptable concentration range of the pollutants of interest. 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 associated with oil and gas operations.

The chemical analysis results of the soil samples at various depths for the three pollutants are also given by Tables 7, 8 and 9, for Cu, Pb and Zn respectively. While the graphical presentations of the chemical analysis results of the elements were shown by Figures 8, 9 and 10 for Cu, Pb and Zn respectively. These results clearly revealed that the concentration of the pollutants decayed exponentially with depth from the ground surface; at the ground surface of almost all the sampling locations, the concentrations are so high and far beyond the permissible level. Nevertheless, from 6m down to 10m, the concentrations of the pollutants are sharply low far below the target limits and are well within the permissible limits of concentrations as clearly shown by Figures 8, 9 and 10. Figure 11 shows soil profiles from two study wells; these revealed top clayey and humurous soils occupying the ground surface to a depth of about 8m.

4. Conclusions

This work focused on groundwater safety with respect to fluid flow intensity (infiltration and percolation rates) through different soil types and their adsorption capacity of pollutants; to be able to establish the vulnerability of the groundwater resource. The results of this work have revealed the amount and concentration of pollutants deposited unto our soil as a result of uncontrolled and unmonitored anthropogenic activities in the area. The concentration of these pollutants (Pb, Cu, and Zn) at the ground surface is alarming as shown by Figures 8, 9, and 10; and affirmed by the high conductive top layers shown by the VES surveys, therefore calls for urgent intervention by private and government agencies for proper monitoring and control of these anthropogenic activities that had necessitated the deposition of these high level pollutants load across the study area.

The sharp reduction of the concentration of the pollutants from 6m to 10m was perhaps due to the presence of this thin band or layer of organic and clayey deposits within the top hydrogeologic layer embedded at around 0m to 4m depth, 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.

Also, the groundwater body is safe to a significant degree 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 the study 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.

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 establishment of the safety status of the groundwater resource.

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