Detection and Monitoring of Dumpsite-Induced Groundwater Contamination using Electrical Resistivity Method.

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ABSTRACT

This geophysical survey was conducted to determine the effects of the “Hercules” dumpsite on the aquifer units around Giwa-Okearo area of Ogun State, South Western Nigeria. A total of forty (40) Vertical Electric Soundings (VES) acquired using the Schlumberger array of the geophysical electrical method were occupied each in 1995 and 2005. The results were presented in the form of sounding curves, tables, cross sections and isoresistivity maps.

The results revealed that the study area is underlain by four geoelectric layers up to a depth of fifteen (15) meters and most of the hand-dug wells in the area terminated in the topmost aquifer within the third layer. The layer has an average thickness of about 6.6 meters thick, an average resistivity of about 350 Ohm-m and is overlain by sandy clay with and an average thickness of about 7.1 meters. The measured resistivity of the unpolluted saturated zone is about 230 Ohm-m, while the lowest resistivity value obtained for saturated zone is about 80Ω-m.

There is an increase in the resistivity of the water-bearing layer with increasing distance from the dumpsite. Low resistivity values persisted for a distance of about 72 meters north of the dumpsite. These anomalously low resistivities indicate areas with contaminated groundwater.

A comparison of the iso-resistivity map of the layer in 1995 with that of 2005 revealed an increase in the area extent of the contaminated low-resistivity zone. The results showed that the contaminant plume spread by about 652m^2 per year.

(Keywords: dumpsite, saturated zone, plume, geoelectric section, vertical electric sounding, VES, groundwater, contamination)

INTRODUCTION

The earth’s subsurface has become the safest and most abundant source of potable water as it is often shielded from direct human activities. However, any undetected contamination of this resource poses a threat to the well-being and continuous existence of man in these environments. The inhabitants of the study area, Giwa-Okearo in Ifo local Government area of Ogun State of Nigeria, (with a population of about eleven thousand) rely on groundwater for about 90% of their total water consumption.

Dumpsites are a common way of disposing waste. For safety reasons, they are often located far from human settlements. With growing population and urbanization, such locations are become habited; thereby constituting environmental health hazards. In most cases, especially in developing countries – as in the study area – disposal sites are not always properly planned; if planned at all. In this regard, shallow sources of groundwater, in the form of hand-dug wells, which constitute about 85% of sources for domestic and irrigation purposes, are at high risk of contamination from the Hercules dumpsite located south of the study area (Figure 1). Dumping of refuse at the site started at about 1985 but not in significant quantities until 1989, when the population there surged.

Geophysical techniques of investigating the composition, structure and nature of the subsurface have reached a high degree of sophistication with the convergence of the need to investigate the earth for scientific and societal problems. The geophysical electrical resistivity technique is particularly suited for the detection of ionic impurities in groundwater owing to the resistivity contrast (RC) between the polluted zone and the host rock. It is faster and more economical than going through the process of drilling to the target formation.

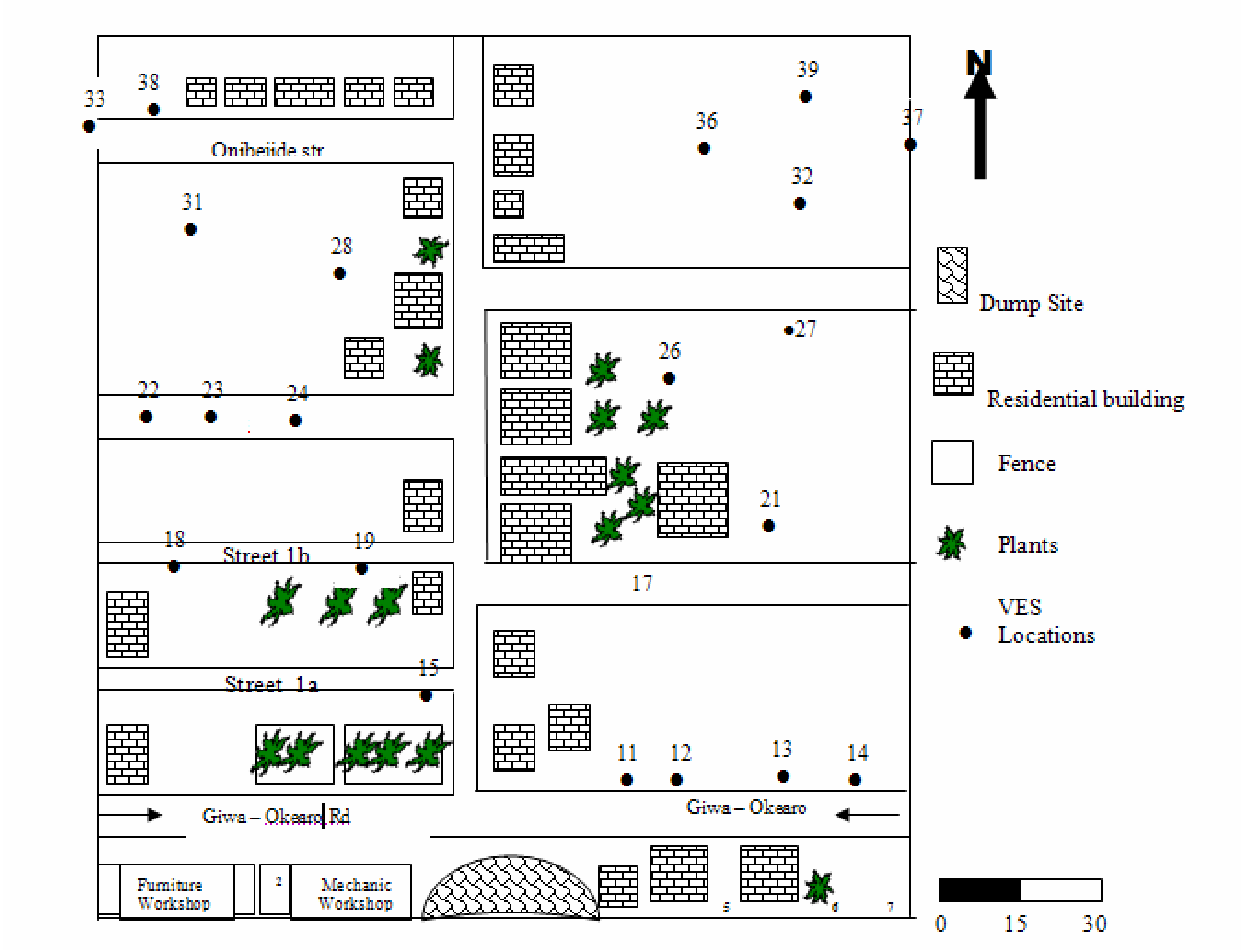


Figure 1: Base Map of the Study Area showing the Layout and VES Locations.

Geophysics provides spatially integrated information, which may be superior for some purposes to the point data provided by drilling.

The electrical resistivity method provides a veritable tool for mapping the degree and extent of contamination owing to the resistivity contrast between the zone of pollution and the immediate subsurface vicinity. It is a fast, economic, and non-invasive method of studying ground water contamination, as well as other environmental issues and it has proved to be promising and useful as predicted. The method is not used to directly detect contaminants. Rather, it is used in the investigation of the geological environment through which the contaminants move, and in the determination of the distribution of pollutant in space and time through monitoring.

Many chemical pollutants are associated with dumpsites depending on the sources of contamination. These are usually categorized as domestic, industrial, hydrocarbon, agricultural, etc. These pollutants may or may not alter the electrical properties of the waste, can often mix and interact, be absorbed or released from the soils, migrate and disperse rapidly or be retarded, and pool at various levels depending on the physiochemical properties and the degree of saturation. Many contaminants and operative biological processes will increase free ion concentration in the presence of soil or groundwater.

These produce vertical and laterally migrating leachates, commonly reducing resistivity. This decrease in resistivity can be distinguished from natural, non-saline groundwater using electrical resistivity, Ross, et al. (1990); electromagnetic methods Greenhouse and Slane (1983); seismic methoda, King, et al. (1989); Slaine et al, (1990); Ground Penetrating Radar, Davis and Annan (1989); or other integrated geophysical approach, Slaine and Greenhouse (1982). As a consequence, these methods are commonly used to define the extent of contamination and pollution plumes surrounding landfill sites. In this study however, the electrical resistivity method was adopted.

This paper is the output of a ten-year intensive research project, using the electrical resistivity technique, to detect and monitor the polluting effect of the Hercules dumpsite on the aquifer units underlying the study area. The data, acquired in two installments, has been employed in the time-aerial rate of spread of the pollution as well as the rate and directions of spread.

LOCATION OF STUDY AREA

The site is situated at Hercules bus stop, along Giwa-Okearo road (see Figure 1). The site is bounded by a gigantic gorge on the southern part. The gorge resulted from the activities of erosion over several years. Hercules is a residential area and the type of waste at the dumpsite can be categorized as domestic. The investigated area covers about $99,441m^2$.

The area has a seasonal climate characterized by two seasons: the wet season starts around mid-March and ends October with an average annual rainfall of about 1800 mm to 3700 mm while the dry season starts around November and ends in March with an average maximum temperature of about 31 C. The relative humidity is usually above 56% as a result of the moisture laden, south-west winds blowing towards the Guinea coast. However, this could also be attributed to proximity to the Atlantic ocean. The area is covered by tropical rain forest characterized by layers of evergreen trees.

It is drained along sloppy terrain, which eventually terminates in small streams with dendritic pattern. With the relatively slow flow of these streams and rivers, marshy to swampy areas have developed. A considerable amount of these waters percolate the subsurface leading to degeneration of zones where the soils are incompetent.

GEOLOGIC SETTING

The study area falls within the Benin (Dahomey) basin which forms one of a series of West African Atlantic Margin basins that were initiated during the period of rifting in the late Jurassic to early Cretaceous, (Omatsola and Adegoke, 1981; Weber and Daukorou, 1975; Whiteman, 1982). The stratigraphy of the Cretaceous and Tertiary Formations in the Nigeria sector of the basin is controversial. This is due primarily to different stratigraphic names that have been proposed for the same Formation in different localities in the basin (Billman, 1992; Coker, 2002).

The basin is mainly made up of sand, sandstone, clay, and limestone. The area is underlain by the Ilaro formation. The base of the basin consists of unfosilliferous sandstones and gravels weathered by underlying Precambrian basement. On top of these are marine shale, sandstone and limestone of Albian to Santonian age deposited prior to the Santonian tectonic episode. The next depositional cycle began with transgression that lasted into the Maastrichtian.

Jones and Hockey (1974), grouped all Cretaceous sediments under the Abeokuta formation. Omatsola and Adegoke (1981) further subdivided the Cretaceous sequence into three, namely: Ise, Afowo and Araromi formations, all under the Abeokuta group. Ogbe (1972) further subdivided the Ewekoro formation into Ewekoro and Akinbo formations. In Lagos and some parts of Ogun State, coastal plain sands and recent sediments overlie the Ilaro formation. It is, however, observed that rocks of the basement complex are found within the sedimentary basins but deeply buried by the overlying cretaceous and younger sediments about 2.5 km thick.

MATERIALS AND METHODS

The main measuring instrument is the ABEM SAS 300C Terrameter, a composite unit made up of a transmitter and a receiver unit, usually powered by either direct current (DC) or low frequency alternating current (AC) source. Current is sent into the ground through the two outer current electrodes A and B, Figure 2. The current induces a voltage across the two inner potential electrodes. The terrameter converts the voltage and current into electrical resistance, which is displayed on the screen.

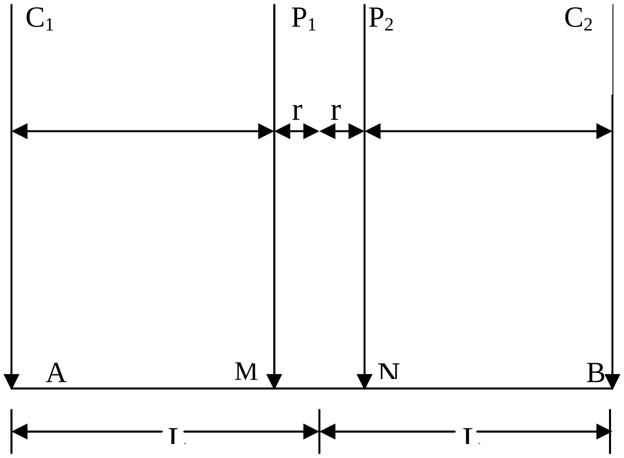


Figure 2: Typical Schlumberger Field Array

The associated ancillary tools include:

(i) Steel metal electrodes which are driven into the ground: They are usually four in number but could sometimes be less than four depending on the type of array used. Two of the electrodes, A and B, conduct electric current into the ground (current electrodes) while the other two (potential electrodes) are for the resultant potential difference produced by the current.

(ii) Connecting cable: four reels of insulated cables, usually in two colors “red and black” are connected to the electrodes and the terrameter with crocodile clips.

(iii) The measuring tape: used for making accurate measurements of length in the field (i.e., for measuring inter-traverse spacing, electrode spacing, field dimension, etc.)

(iv) The hammer: used for driving the electrodes into the ground.

(v) The cutlass: for clearing paths when working in a bushy or inaccessible areas, cutting tree branches, which, could be used as staking material, and for loosening hard soils to allow better electrode penetration and contact.

(vi) The compass for defining directions in the field.

(vii) Data recording materials comprising of a pencil, datasheet showing location of survey, date, VES location, observers, electrode array used, instrument used, sounding points, potential and current electrode spacing, the geometric factor, etc.

Baselines were established in the North-South direction and traverses were marked perpendicular to the baselines, thereby forming a network of grids. A total of 40 VES locations were established on the nodes of the grids. The electrode spacing (AB/2) was varied from 1 to 50m with a maximum spread length of 100m.

Vertical electrical sounding method (VES) was employed in which Schlumberger array was used. Artificially generated current was transmitted into the ground through two current electrodes (C_1 & C_2) and the resulting potential difference measured by another pair of inner electrodes (P_1 & P_2).

The current electrode spacing is directly proportional to the depth of penetration (the greater the electrode spacing the greater the depth of penetration).

The apparent resistivity value is calculated from the known parameters using the formula

$\rho_a = kR$

where $k = \pi \dfrac{(AB/2)^2 - (MN/2)^2}{MN}$

= geometric factor
ρ_a = Apparent resistivity
AB = Current electrode spacing
MN = Potential electrode spacing
R = Electrical resistance

The apparent resistivities “ρ_a” obtained were plotted against electrode spacing “*AB/2*” on a tracing paper superimposed on the ABEM log-log graph, to obtain the depth sounding curves. The tracing paper is placed on a master curve to match the sounding curve with model curves segment-by-segment on the master curve. The tracing paper is then moved until a perfect or near perfect model is found for each segment of the sounding curve.

The origin is marked with a cross and the number of the curve usually denoted by "k_n" is noted. The sounding curve is then moved to the auxiliary curve depending on the type curve. The curve on the auxiliary curve with the same number as the one on the master curve is then traced out with a broken line on the tracing paper and the thickness ratio "t_n/t_{n-1}" is also noted. The process is repeated until all the curves are matched. The sounding curve is returned to the log-log graph and the value of resistivity and electrode spacing corresponding to the positions marked with the cross is written out as resistivity and thickness replacements "ρ_r and t_r" respectively. The true resistivity, thickness and depth are calculated as follows:

$$\rho_n = K_{n-1} \times \rho_{(n-1)\,r}$$
$$t_n = (t_n/t_{n-1}) \times t_{(n-1)\,r}$$
$$d_n = \Sigma\, t_n \quad n = 1,2,3, \ldots\ldots\ldots$$

where n = number of layers and
d = depth

For the computer modeling and iteration, the *RESIST*® software package was used. The field data and the model parameters obtained from the curve matching process above, constitute the input.

PRESENTATION & DISCUSSION OF RESULTS

The results of data analysis are presented as sounding curves, tables of geoelectric parameters, and iso-resistivity maps.

The predominant field curve in the area is the KQ type, a four-layer subsurface setup, Figure 3. Table 2 is a summary of the typical latest results of the geoelectric sequence obtained in the study area.

The table shows that the study area is underlain by four geoelectric layers spanning an average depth of about 15 metres. They are: an upper topsoil, clayey sand, moisturized clayey sand underlain by sandy clay.

Most of the hand-dug wells in the area terminate in the shallow third- layer aquifer unit. The average thickness of the layer is about 6.6 m and is overlain by sandy clay with an average resistivity of about 350 Ωm and an average thickness of 7.1 m. The geoelectric behavior of this third layer have been analysed and compared based on the field surveys conducted in 1995 and again in 2005.

The average measured resistivity of the unpolluted saturated zone is about 230Ω-m, while the lowest resistivity value obtained for the saturated zone is about 80Ω-m (see Table 2).

Table 1 is a summary of geoelectric parameters of the saturated layer as deduced from the field surveys conducted in 1995 and 2005. The values of the resistivity values have been posted on the base map of the study area (Figure 1) to produce the isoresistivity maps, Figure 4. The maps revealed the extent of contamination of the saturated layer over the ten-year period of study, 1995 - 2005.

Figures 4(a) and (b) are the isoresistivity maps of the third layer as deduced from the 1995 and 2005 surveys, respectively. Both maps revealed two distinct zones of low and high resistivity corresponding to the contaminated and unpolluted subsurface. The degree of contamination is expectedly severest closest to the dumpsite and reduces northwards. The east-west spread, Figure 4(b), appeared hampered by probable presence of impermeable rock units in these directions. Conversely, the rapid northward spread of the contamination appeared to have been aided by the porous and impermeable rock units along this axis.

This is a probable direction of flow of subsurface fluid. Resistivity Contrast (*RC*), ratio of average maximum to minimum layer resistivity is 2.9.

$$= \frac{\text{Resistivity of Layer before Pollution}}{\text{Resistivity of Layer after Pollution}}$$

$$= \frac{230\ \Omega\text{m}}{80\ \Omega\text{m}}$$

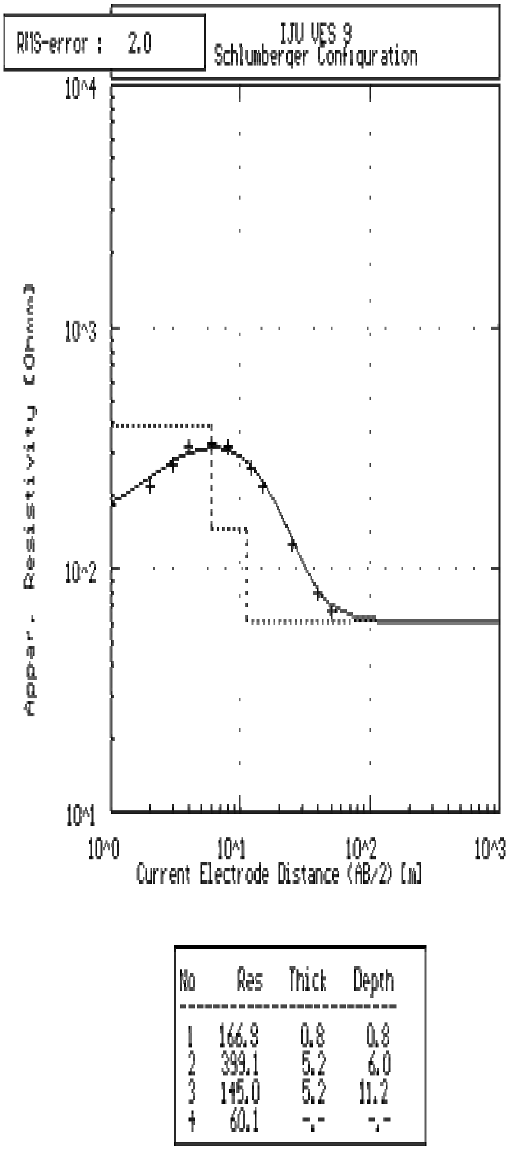
$$= \ 2.9$$

That is the resistivity contrast caused by contamination of the groundwater by leachates is a factor of about 2.9, this is approximately 1.5 times what was obtained in 1995, a span of ten (10) years.

The contour maps of the resistivity of the water-bearing layer show that there is an increase in the resistivity of the formation with increasing distance from the dumpsite.

Table 1: Summary of Geoelectric Parameters of the Saturated Layer as Deduced from 1995 and 2005 Field Surveys.

S/N	VES Location	Saturated layer Resistivity (Ω-m)		Depth to top of layer (m)	
		1995	2005	1995	2005
1.	1	210	205	10.1	10.1
2.	2	142	190	10.2.	9.8
3.	3	85	135	9.0	8.6
4.	4	80	130	9.2	9.8
5.	5	145	210	10.3	10.1
6.	6	200	210	10.7	10.2
7.	7	230	230	14.1	10.0
8.	8	201	210	10.7	10.1
9.	9	145	200	11.2	10.4
10.	10	90	140	8.8	10.1
11.	11	95	145	10.3	10.4
12.	12	151	200	11.4	10.2
13.	13	211	200	11.4	10.3
14.	14	231	240	18.4	10.3
15.	15	86	130	11.6	11.4
16.	16	90	130	10.7	10.8
17.	17	220	210	14.2	11.2
18.	18	242	235	13.9	11.6
19.	19	219	210	13.9	11.5
20.	20	221	220	12.6	11.7
21.	21	230	220	12.3	11.6
22.	22	241	235	12.6	11.8
23.	23	230	240	11.9	12.0
24.	24	225	230	14.9	12.1
25.	25	232	220	18.4	12.1
26.	26	231	230	16.6	12.0
27.	27	232	240	11.2	12.4
28.	28	221	230	12.3	12.8
29.	29	218	210	11.6	12.6
30.	30	231	220	7.9	12.9
31.	31	236	240	14.4	13.2
32.	32	240	230	13.8	13.2
33.	33	229	235	16.1	13.4
34.	34	241	240	7.4	13.6
35.	35	238	240	14.2	13.5
36.	36	240	240	13.6	13.5
37.	37	222	220	12.3	13.6
38.	38	235	230	14.5	14.3
39,	39	219	220	14.6	14.0
40.	40	230	220	15.3	14.4



No	Res	Thick	Depth
1	166.9	0.8	0.8
2	399.1	5.2	6.0
3	145.0	5.2	11.2
4	60.1	-.-	-.-

Figure 3: Typical Field Curve Predominant in the Study Area.

Table 2: Geoelectric Parameters and Layer Interpretation of the 2005 Survey.

Layer	Average Resistivity (Ω-m)	Thickness (m)	Depth To top (m)	Geological Interpretation
1	420	0.5 – 0.9	0.00	Sandy clay
2	310	6.0 – 8.2	6.4 – 9.1	Clayey Sand /sand
3	220	5.5 – 7.6	11.9 – 16.7	Clayey Sand (Wet)
4	104	–	–	Clay

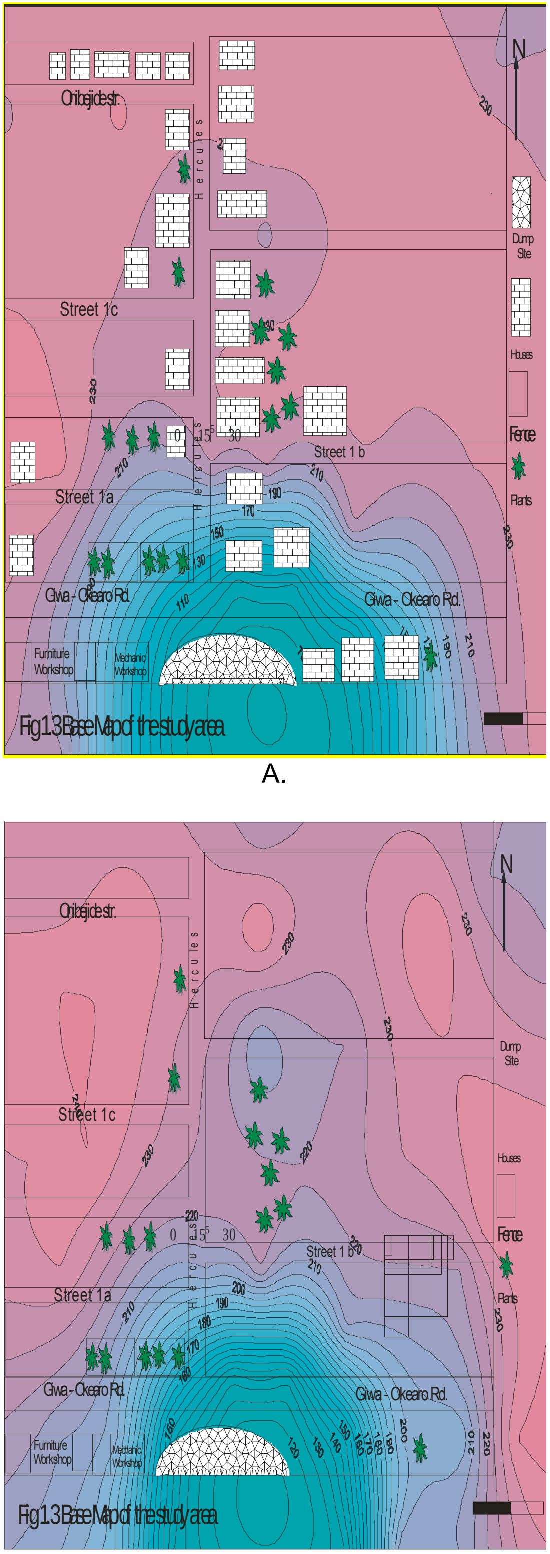


Figure 4: Iso-Resistivity Map of the Third Layer Depicting the Extent of Contamination as of (a) 1995 and (b) 2005.

This is possibly an indication that the source of pollution is conductive and the conductivity decreases as one moves northwards away from the dumpsite.

By comparing the isoresistivity maps of the area in 1995 with that of 2005 in Figures 4A and 4B, an increase in the low-resistivity zone was observed in the latter. This shows that the contaminant plume is spreading out hemispherically.

The estimate of the area affected in 1995 and in 2005, was obtained by dividing the affected area on the isoresistivity maps into square grids of known dimensions. The area is then calculated from the summation of the number of squares covered.

The result revealed that a subsurface area of about 4275 m^2 was affected by the pollution in 1995. This had increased to 10800 m^2 in 2005; a staggering spread of over 100% within ten years.

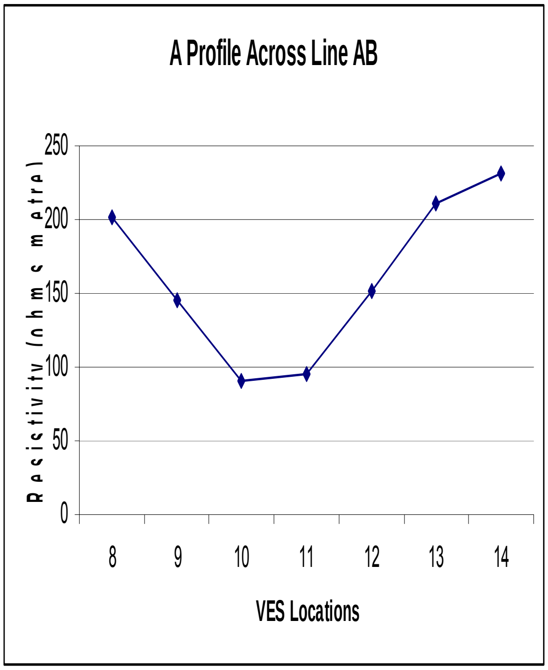


Figure 5: SW – SE Cross-Section Across the Study Area Depicting the Extent of Contamination.

CONCLUSION

The result of this survey shows that the sharp low-resistivity contrast within 36m east and west, and 56m north of the dumpsite has revealed that the wells have been contaminated. The contaminant is spreading radially and has affected an area of about 10800m^2.

The aerial spread of the pollution between 1995 and 2005, a period of 10 years, is about 6,525m^2; connoting a rate, assuming a homogeneous and isotropic medium of about 652.5 m^2/ per year.

The dumpsite constitutes a potential hazard to families living in houses with hand-dug shallow wells in the study area. The local authorities are hereby enjoined to urgently enforce the discontinuation of dumping refuse in this area. It is strongly recommended that a thorough geochemical study be carried out in this area to ascertain the nature of the pollutants. Meanwhile, the water abstracted from the area must be treated appropriately to mitigate hazards to the inhabitants.

ACKNOWLEDGEMENTS

The author hereby expresses his profound appreciation to the Integrated Development Solutions Enterprises Nigeria, for granting the logistic support for this study. Mr. Ojo ---, formerly of the Department of Applied Geophysics, University of Technology, Akure, Nigeria, assisted in the initial data processing for which the author is equally grateful.

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SUGGESTED CITATION

Enikanselu, P.A. 2008. "Detection and Monitoring of Dumpsite-Induced Groundwater Contamination using Electrical Resistivity Method". *Pacific Journal of Science and Technology*. 9(1):254-262.

Pacific Journal of Science and Technology