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Full Length Research Paper

Electrical resistivity imaging of contaminant zone at Sotubo dumpsite along Sagamu-Ikorodu Road, Southwestern Nigeria

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Electrical resistivity method was used to investigate the effect of leechate contamination of groundwater at Sotubo solid waste dumpsite. Both Vertical Electrical Sounding (VES) and Constant Separation Traverse (CST) technique were carried out using Schlumberger and Wenner electrode configuration, the estimated apparent resistivities (ρ) were interpreted using partial curve matching technique and computer iteration. The inferred lithology includes topsoil, sandy layer, limestone and sandy-clay with resistivity of 90, 421.5, 907.8, 143.0 Ωm and thickness of 1, ~3.8, ~29.0 m and infinity, respectively. The pseudosection revealed the leechate had a thickness of 19.8 to 25.0 m with ρ of 0.17 to 32.5 Ωm in the NW part of profile 1. In contrast, apparent resistivity of the leechate is less than 5.95 Ωm in profile 2. The leechate has infiltrated potential aquifers such as the sandstone layer. Aquiferous layer exceeding the depth of the contaminated zone can be drilled with screened borehole in order to avert groundwater pollution.

Key words: Leechate, contamination, ERI, Sotubo, groundwater.

INTRODUCTION

Land filling of municipal solid waste is a common waste management practice and one of the cheapest methods for organized waste management in many parts of the world (Jhamnani et al., 2009; Dsakalopoulous et al., 1998; El-Fadel et al., 1997). This practice is not restricted to low and medium income developing nations but developed countries as well. Landfills pose a serious threat to the quality of the ecosystem, especially surface and ground waters. The scale of this menace depends upon the composition and quantity of leechate and the distance of a landfill from water sources (Slomczynska and Slomczynski, 2004). Thus, environmental pollution and epidemic outbreaks of diseases are common hazard associated with such practices (Ronald, 1988). Municipal landfill leechate are highly concentrated complex effluents, which contain dissolved organic matters; inorganic compounds and heavy metals (Ogundiran and Afolabi, 2008; Tengrui et al., 2007; Christensen et al., 2001; Lee and Jones-Lee, 1993).

Leechate are produced by the percolation of water/ rainwater through unsealed landfills and open dumps (Figure 1). Leechate outflow and infiltration are the most critical source of groundwater contamination from existing solid waste management practices in Ogun State and environments (Longe and Enekwechi 2007; Longe et al., 1987). These problems are consequences of technical, financial and institutional constraints. The abundance of land and thick vegetation cover encourages the abuse of existing solid waste disposal facilities, indiscriminate

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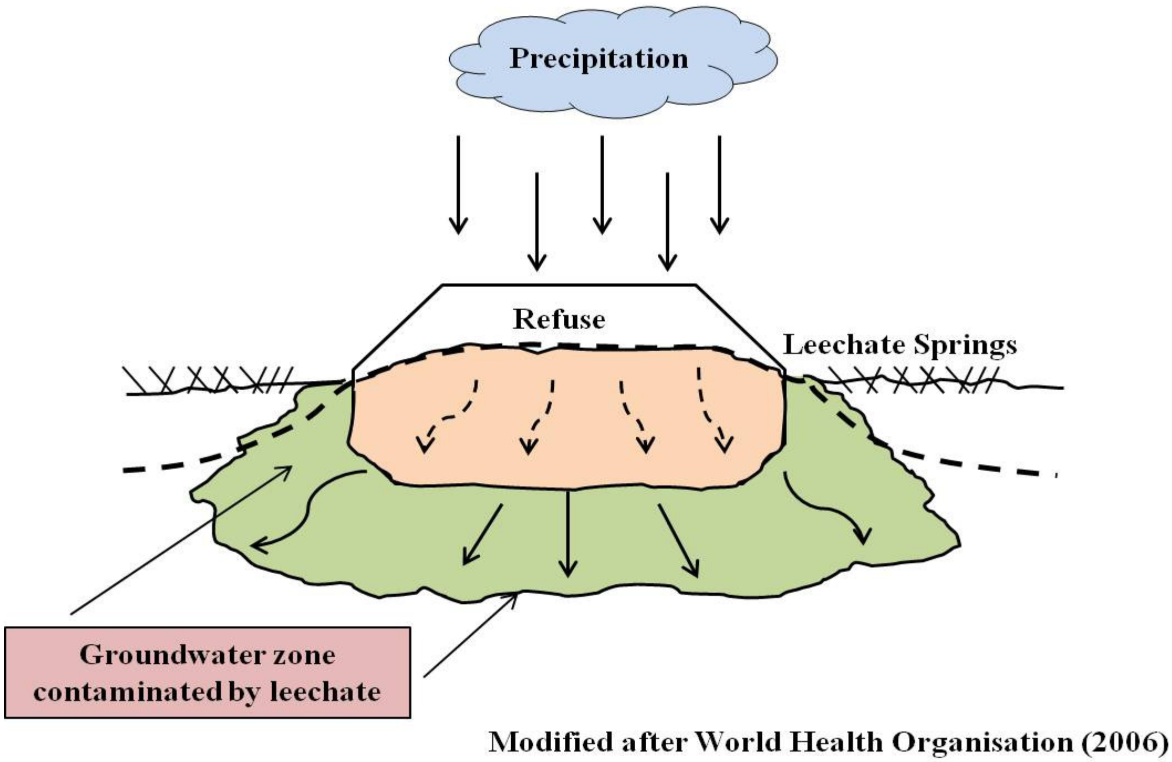

Figure 1. Conceptual model for groundwater contamination by leechate (WHO, 2006).

dumping of refuses and discharge of sewages. Previous research work has been done on the problem of underground contaminants in the study area and environs (Ehirim et al., 2009; Ariyo and Enikanoselu, 2007; Tesfaye, 2007; Samsudeen et al., 2006; Tałałaj et al., 2006; Tijani et al., 2004; Olayinka and Olayiwola, 2001).

The aim of this work was to investigate the impact of the dumpsite on the groundwater quality of the study area by delineating the limit of the leechate zone through (a) determination of the number of geoelectric layers, (b) estimation of the resistivity of each geoelectric layers, and (c) evaluation of the depth to the water table. In this work, we applied electrical resistivity techniques using both sounding and profiling to investigate the limit of leechate contamination at the dumpsite. Electrical resistivity method is found suitable for this research, as the limits of the leechate are shallow (Figure 2) and characterized by low resistivity, which makes it detectable from background resistivity values (Li et al., 2001; Mathias et al., 1994; Kayabali et al., 1998; Benson et al., 1983; Hughes 1976; Tchobanglous, 1977; Abdullahi and Rooyle, 1972).

MATERIALS AND METHODS

Brief description of the study area

The study area is characterized by gently undulating topography with average elevation of 260 m above sea level (Figure 1). The climatic condition is typical sub-equatorial belt of Southwestern Nigeria, which is sub-divided into wet and dry seasons. The rainy season starts from April to October with heavy downpours in June/July, while the remaining months are always dry with little or no rain (Ojo, 1997). The vegetation within the study area is greatly influenced by climate and relief. Present day vegetation cover is sparse owing to ongoing commercial and residential activities. The population of Sagamu, which is the closest town to the study area is ~253, 412 (Wikipedia, 2013). The proximity of Sagamu and the study area to Lagos has made it an industrial hub of Ogun state. Thus, environmental problem of indiscriminate refuse disposal is notorious with urchins and road side traders plying the Sagamu-Benin expressway.

Geology of the study area

Regionally, the study area falls within the Eastern Dahomey Basin. The basin is a peri-cratonic basin developed during the initiation of rifting associated with the opening of the Gulf of Guinea in early Cretaceous to Late Jurassic (Kingston et al., 1983; Whiteman, 1982; Klemme, 1975; Burke et al., 1971). The crustal separation and thinning of the basin was accompanied by an extended period of thermal-induced basin subsidence through the mid Cretaceous to Tertiary times as the South American and the African plates entered a drift phase to accommodate the emerging Atlantic Ocean (Mpanda, 1997; Storey, 1995). The Dahomey basin is bounded on the west by the Ghana ridge, an offset extension of the Romanche Fracture Zone (RFZ), and by the Benin hinge line on its eastern boundary. The Benin hinge line supposedly defines the continental extension of the Chain Fracture Zone (CFZ), and it is a basement escarpment which separates the Okitipupa structure from the Niger delta basin.

Stratigraphy of Dahomey basin

The lithostratigraphic unit of the eastern Dahomey basin is

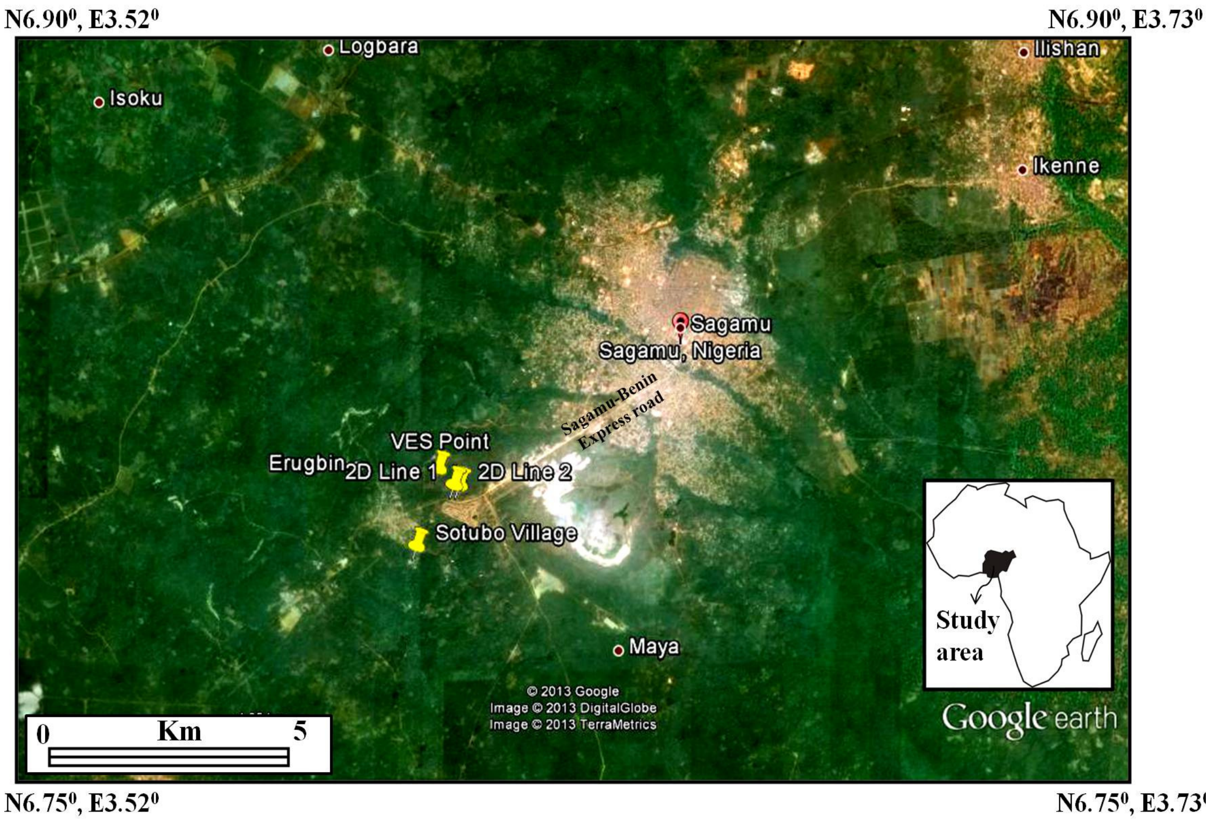

Figure 2. Topographical map of the study area showing relief, accessibility and position of survey points. Inset: the position of the study area on the Map of Nigeria and Africa. ©Google earth image downloaded 17.30 GMT 28.04.2013.

Table 1. Stratigraphical column of Dahomey Basin.

Era	Jones and Hockey (1964)		Adegoke and omatsola (1981)		Agagu (1985)	
	Age	**Formulation**	**Age**	**Formulation**	**Age**	**formulation**
Quaternary	Recent	Alluvium	Recent	Alluvium	Recent	Alluvium
Tertiary	Pleistocene-Oligocene	Costal-plain sands	Pleistocene-Oligocene	Costal-plain sands	Pleistocene-Oligocene	Costal-plain sands
	Eocene	Ilaro	Eocene	Ilaro Oshosun	Eocene	Ilaro Oshosun
	Paleocene	Ewekoro	Eocene		Paleocene	Akinbo Ewekoro
Late cretaceous	Late Senonian	Abeokuta	Maastrichian Neocomian	Araromi Afowo Ise	Maastrichian Neocomian	Araromi member Afowo member Ise member

summarized in Table 1 and Figure 3. The rocks of the study area belong to the Abeokuta group, the oldest group of sediment in the basin (Jones and Hockey, 1964). Omatsola and Adegoke (1981) recognized three (3) Formations in the Abeokuta group based on lithologic homogeneity and similarity of origin. They include Ise, Afowo and Araromi Formations; as a group, they represent the thickest unit within the basin.

Ise Formation

This is the oldest Formation in the Abeokuta group, and it unconformably overlies the basement complex. The Ise Formation consists of conglomerate at the base, gritty to medium grained loose sand, capped by kaolinite clay (Agagu, 1985; Omatsola and Adegoke, 1981). The maximum thickness of the members is about 1965 and 600 m as penetrated by the Ise-2 well, while similar sections of the Ise Formation were exposed near Ode-Remo on the Lagos-Ibadan expressway. The unit has not been found to be bituminous both at surface and subsurface section.

Afowo Formation

The Afowo Formation is composed of coarse to medium grained sandstone with variable but thick interbedded shale, siltstone and claystone. The sandy facies is tar-bearing while the shale are organic-rich (Enu, 1985). Using palynological assemblage, a Turonian age is assigned to the lower part of this Formation, while the upper part ranges into Maastrichian.

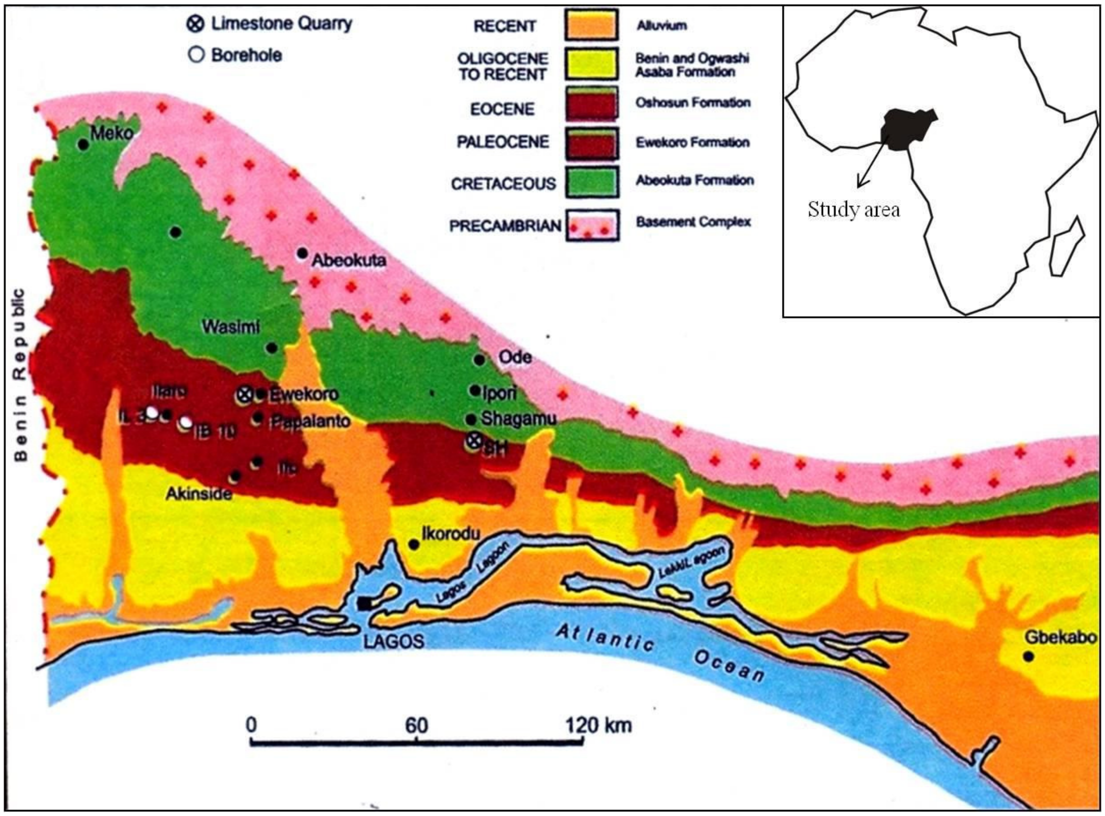

Figure 3. Generalized geological map of Eastern Dahomey Basin (Modified after Billman, 1976).

Araromi Formation

Sediments of the Araromi Formation represent the youngest top most sedimentary sequence in the Abeokuta group. The Formation is composed of shales, fine-grained sand, thin interbeds of limestone clay and lignite bands (Omatsola and Adegoke, 1981; Agagu, 1985). It is an equivalent of a unit known as Araromi shale. The age ranges from Maastrichian to Palaeocene.

The Abeokuta group is overlain by the Imo (Ewekoro and Akinbo Formations- Nton and Elueze, 2005; Nton, 2001; Adegoke, 1969; Ogbe, 1972; Jones and Hockey, 1964), the Oshosun (Nton, 2001; Jones and Hockey, 1964), Coastal plain sands and the Recent Alluvium (Jones and Hockey, 1964).

Ewekoro Formation

The Ewekoro Formation consists of shelly limestone of about 12.5 m thick which tends to be sandy and divided into three microfacies. Lithological composition of the unit is sandy biomicrite, shelly biomicrite, algal biosparite and red phosphatic biomicrite. The sandy biomicrosparite is light to brownish grey. The Ewekoro Formation is Palaeocene and associated with shallow marine environment due to abundance of coralline algae gastropods, polypods, echinoid fragment and other skeletal debris (Nton, 2001; Reyment, 1965).

Akinbo Formation

The Akinbo Formation overlies the Ewekoro Formation and consists of shales, clayey sequence (Ogbe, 1972). The base of the Formation is defined by the presence of a glauconitic band. The type locality is at Ewekoro quarry, east of Ijebu-Ode. The Formation replaces the Ewekoro Formation, which thins out westwards and extends into the Republic of Benin and Togo. The shales are grey, fissile, clayey and concretionary in outcrop with gentle dip of <5° SW (Nton, 2001). The age of the Formation is Palaeocene to Eocene age. The Akinbo Formation is overlain by the Oshosun Formation, Ilaro Formation and Coastal Plain sands and recent Alluvium (Okosun, 1998; Ako et al., 1983; Adegoke, 1969; Russ, 1924). The study area is a sedimentary environment and dominated by the Akinbo Formation, which is a sequence of shale and clayey lithology as mentioned earlier.

Methods

Two Wenner-profiling and a Vertical Electrical Sounding (VES) were carried out over the dumpsite (Figure 4). The ohmmeter terrameter measures the variation in the electrical resistivity of the subsurface by injecting electric current through current electrodes (AB) and picking the potential difference from the potential electrodes (MN). The instrument is designed to measure the resistance; initial parameters used for the survey include a current of 5 mA and four cycles for averaging the resistance value. Furthermore, the VES station was designed using Schlumberger array over a traverse ~150 m. For profiling, the Wenner electrode configuration was used with an assumption that the resistivity does not change in a direction perpendicular to the survey line. The Wenner configuration entails that constant electrode spacing is maintained between the adjacent electrodes while the whole spread is transverse. The electrode spacing between the adjacent electrodes is assigned “a” with initial spacing of 5 m and subsequent spacing being multiple of 5. The maximum electrode spacing used was 40 m over a survey line of 160 m.

Figure 4. a to c: Activities during the geophysical survey and (d) random dumping of refuses by some inhabitant of the area.

Table 2. Layer parameters of the geo-electric section (VES).

Number of layers	Resistivity (ohm)	Thickness (m)	Depth (m)	Inferred description
1	90.0	1.0	1.0	Top soil
2	421.5	3.8	4.8	Sandy layer
3	907.8	29.0	33.8	Limestone
4	143.0	∞	∞	Sandy clay

The apparent resistivity was obtained from the product of the resistance and the geometric factor for the adopted electrode configuration. The value obtained were plotted against the electrode spacing (AB/2) on a log-log paper, and later curved matched on a standard master curve in order to build a resistivity model for iteration on the WINRESIST software. From the final plot, the resistivity, depth and thickness of the different layers were estimated. Consequently, the apparent resistivity value was uploaded onto the DIPROfWin software in order to produce the profiling pseudosection. The contoured pseudosection was inverted to plot the apparent resistivity against true vertical depth.

The profiling data are presented as contoured pseudosection while the VES data was used to determine the lithology in the area. The interpretation of the sounding curves was done both qualitatively and quantitatively. The qualitative interpretation entails observation of the sounding curves as plotted on log-log graph paper. Electrical surveys are among the simple to interpret quantitatively because of the simple theoretical bases of the technique. Quantitative interpretation of the VES data was carried out in stages: (1) plotting and smoothing of the apparent resistivity field data curve and removing the noise appropriately; (2) curve matching the smooth curve on tracing paper using two layer model master and the corresponding auxiliary curves (Bhattacharya and Patra, 1968); (3) initial geoelectrical model (thicknesses and resistivities) emerging from the previous stage was prepared; and (4) entering the geoelectrical model into the Vander Velpen (1988) geoelectric modeling and inversion package. The iteration was achieved using WinResist software at a minimum root mean square error. The field curves and the interpreted models are presented in Figure 5. The interpreted geo-electric sections are shown in Table 2 and their

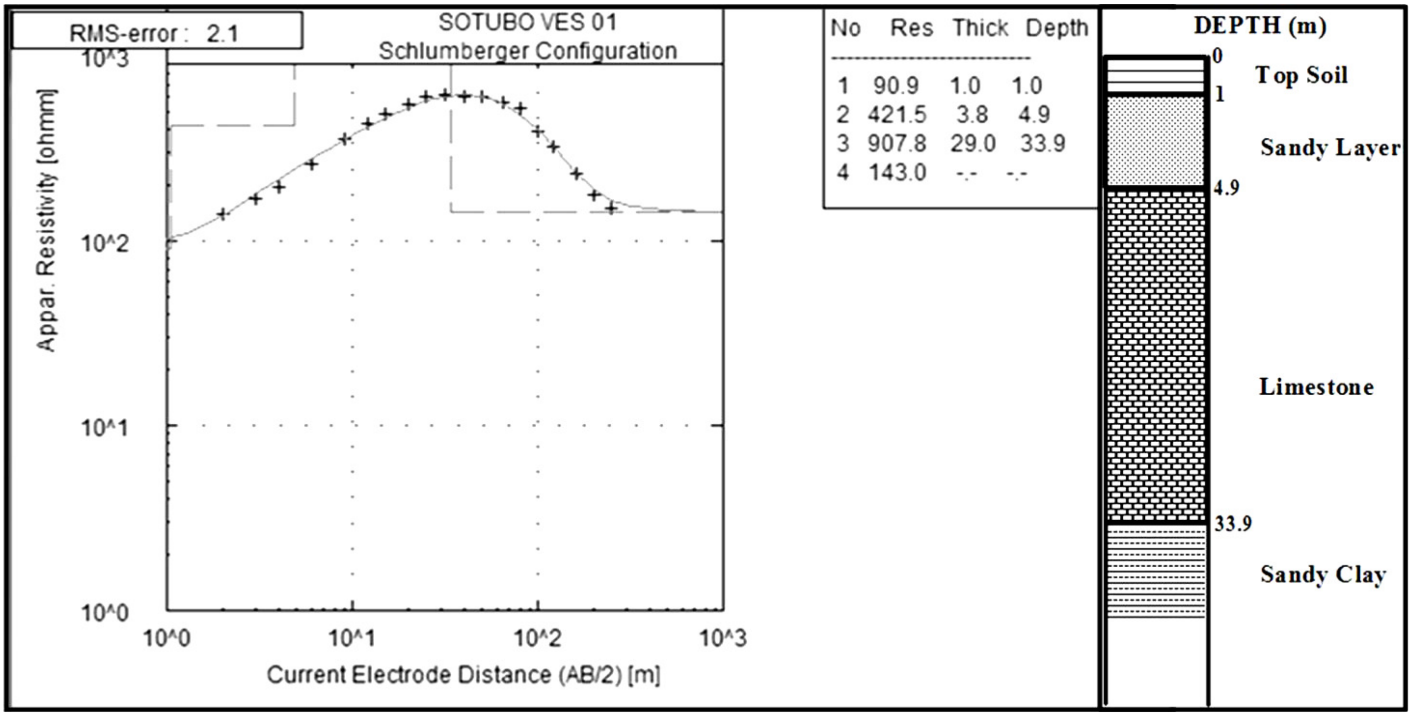

Figure 5. Plot for apparent resistivity against electrode spacing (AB/2) for the vertical electrical sounding. The inferred geoelectric section is shown on the eastern part of the figure.

results are presented in terms of resistivity, thickness and depth.

RESULTS AND DISCUSSION

Vertical electrical sounding (VES)

The VES revealed four (4) geo-electric layers; typical type K curve was obtained (Figure 5). The first layer is the top soil with resistivity of 90.9 Ωm and thickness of 1.0 m. It is underlain by sandy layer of ~421.5 Ωm and thickness of ~3.8 m. The third layer is limestone with thickness and resistivity of ~29 m and ~907.8 Ωm, respectively, the last layer is apparently sandy clay which has resistivity of ~143.0 Ωm (Figure 5). The high resistivity values obtained for the rock types at the VES station suggest that this part of the study area is not contaminated by the leechate.

Two dimensional (2D) pseudosection (Profiling)

Profile 1

The first profiling was measured along the road at the edge of the dumpsite. The 2-D pseudo section obtained from the constant separation traversing (CST) survey is shown in Figures 6 and 7. The high resistivity zone of 275 to 2548 Ωm existed at the depth of 7.50 to 20.0 m on the eastern part of the pseudosection; this zone is leechate-free. Low resistivity of 32.5 Ωm outside this zone is associated with the presence of the leechate, the contaminant occur at ~0.0 to ~19.8 m depth. The blue portion shows zone of low resistivity (contaminant leechate plume), purple portion shows zone of high resistivity which is apparently a limestone and the yellow to green portion shows zone of water bearing (sands). The migration of the contaminant leechate plume to the bottom implies either the leechate is denser or that the surrounding rocks are porous.

Profile 2

This profile was done along the N-S direction through the dumpsite perpendicular to profile 1. The pseudosection revealed low resistivity value of <5.95 Ωm attributed to the presence of highly conductive leechate which indicates that the area has been highly contaminated. The blue section shows zone of low resistivity (contaminant leechate plume), the red portion in the southern portion from the surface to depth of 2.5 m is composed of a lateritic top soil which presumably inhibit the percolation of leechate. Consequently, two zones were observed on the profiles; they are the zones of high and low resistivity. Contaminant leechate plume was identified in 2-D resistivity profile as the section of low resistivity zone represented by blue contour. The observed contamination is consistent with the earlier work (Ehirim et al., 2009; Esmail et al., 2008; Samsudeen et al., 2006; Olayinka and Olayiwola, 2001).

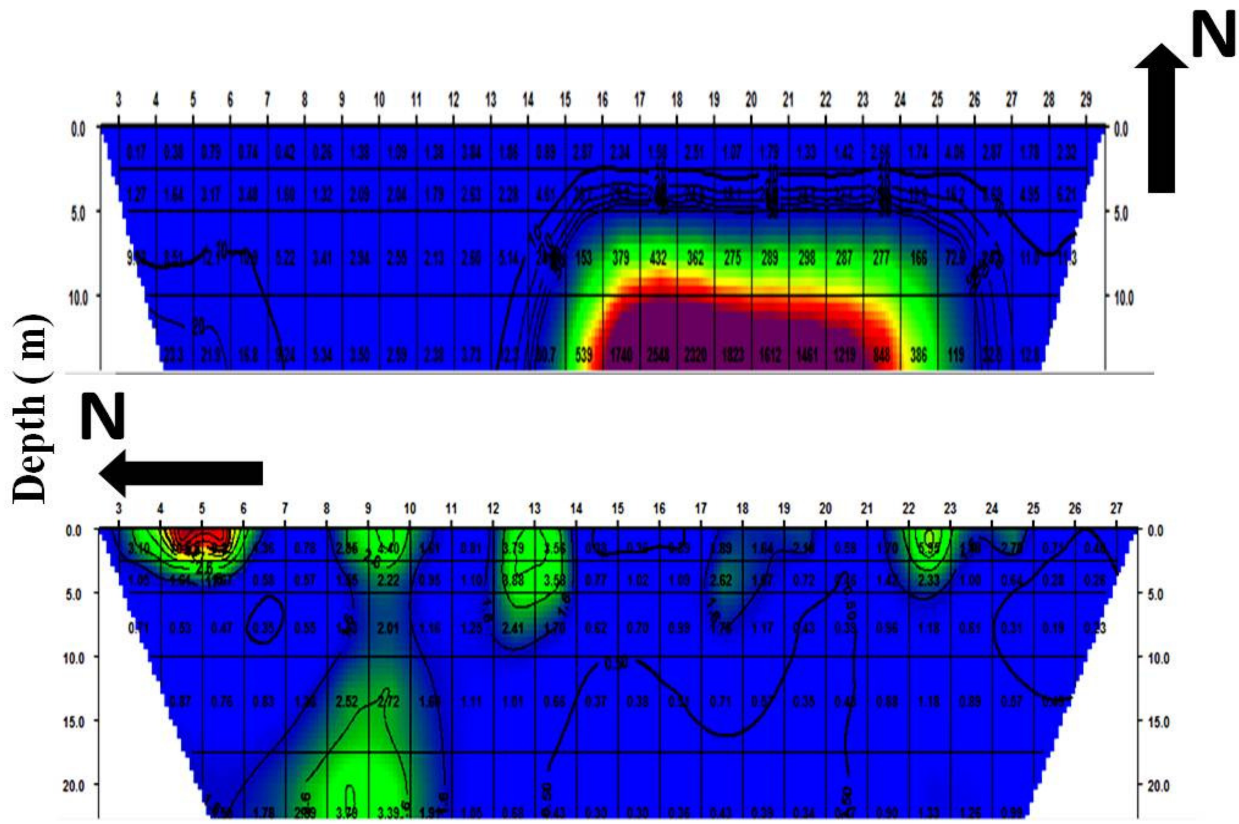

Figure 6. Resistivity pseudosection for profiles 1 and 2. The resistivity values are contoured using different colors.

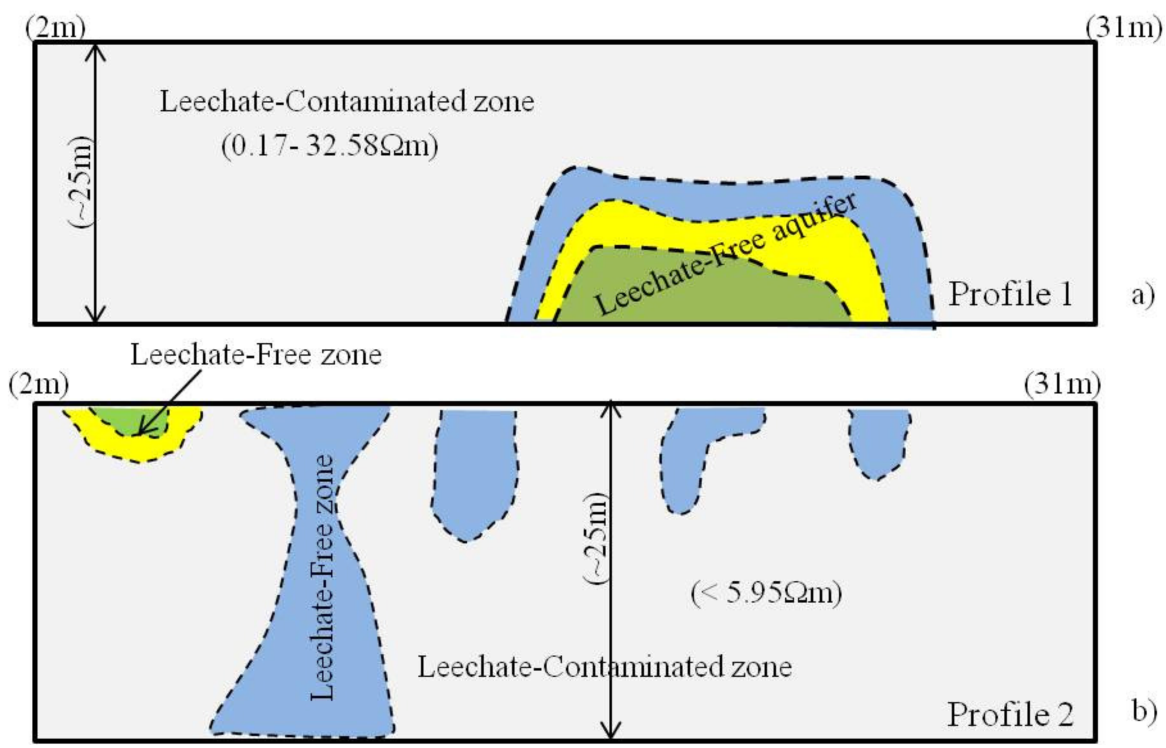

Figure 7. Geological model for the resistivity pseudosection for profiles 1 and 2 respectively.

Conclusion

The result of the electrical resistivity investigation of solid waste using VES and 2-D profiling imaging at the study area has made it possible to establish contamination of the subsurface environment by leechate. At the VES station, the stratigraphy of the study area was established, with the resistivity values suggesting no leechate contamination. However, the profiling shows that the contaminants occur to depth of 25.0 m with resistivity value of <32.5 Ωm in sandstone and limestone layers. The contaminant is dominant in the northern and South western part of the study area. Consequently, soil and shallow sandstone aquifer have been polluted by the leechate. The apparent high porosity and permeability of sandstone layers may enhance the percolation of the contaminant to deeper aquifers. The degree of contamination is moderate at depth but with increasing and continuous dumping of refuses in the area, the contaminant may reach deeper depth with time.

Sotubo dumpsite is a non-engineered landfill. It neither has a bottom liner nor leechate collection and treatment system. Therefore, the leechate generated finds its way into underground water system. Feasibility studies should be done prior to choosing a landfill site. Retrofitting techniques for the existing, old sites, like Sotubo, would be cumbersome and expensive. Some of the measures for limiting the infiltration of the effluent through the landfill cover should include:

1. Increasing the evapo-transpiration rate by providing vegetation cover over the landfill.
2. Provision of waterproof base such as an impermeable clay cover.
3. Enactment of laws by the government to prevent indiscriminate dumping of refuse.
4. Provision of well engineered landfill design and other means of solid waste disposal technology by the government.
5. Monitoring of leechate contamination in existing dumpsite to safeguard future contamination of the ground water system.
6. When drilling borehole in these environments, shallow aquifers should be ignored and the borehole should be screened in order to restrain the infiltration of contaminated water into them.

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