Detecting Municipal Solid Waste Leachate Plumes Through Electrical Resistivity Survey And Physio-Chemical Analysis Of Groundwater Samples

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Abstract: A Direct Current electrical resistivity survey was carried out in Unguwan Dosa open dumpsite in Kaduna metropolis, North Western Nigeria. The dumpsite is the typical non-controlled waste facility that lack bottom liner. 8 vertical electrical soundings (VES) employing the Schlumberger electrode array were conducted with maximum electrode spacing of 100 m. Interpreted resistivities were obtained by iterative computer modeling of the apparent resistivity data. The VES data were plotted as pseudo and resistivity cross-sections in order to look at the spatial distribution of the contaminant plumes. The interpreted VES data measured inside the dumpsite showed contamination plumes as low zones with resistivity values ranging between 1 and 12.9 ohm-m extending from the surface down to the aquifer of shallow groundwater of less than 5 m. Calculated hydraulic conductivity ranges between 5.9×10^{-2} m/s and 3.7 m/s for shallow subsurface layers of interpreted VES points located inside and outside the dumpsite. This moderately conductivity value of the subsurface materials is believed to facilitate movement of the leachate plume through the soils and migration of the contaminants outside the dump and into the shallow aquifer in the study area. Elevation in concentrations of the measured parameters of the physio-chemical analysis of water samples from existing hand dug wells indicate contamination of the groundwater as a result of solid waste leachate accumulation, consequently, complimenting the geophysical data.
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Keywords: Open dump; electrical resistivity; Schlumberger; leachate; contamination; physio- chemical

1. Introduction

Groundwater resources are very important for public water supply most especially in the arid regions. Solid wastes are being produced every day by urban societies and in an attempt to dispose these materials; man has carelessly polluted the environment. The problems associated with municipal non-controlled dumpsites are of general concern, especially because of the hydraulic contact between the hazardous contents of the leachate plume and the groundwater. Poor water quality is a significant problem in many parts of the world and Kaduna metropolis with about 342 unsanitary open dumpsite(Ministry of Environment and Natural resources, Kaduna state, personal communication, 2008) is not immune from this environmental problem. Generally, electrical resistivity method provides economic and non destructive means to identify and delineate leachate contaminant plumes from dumpsite because the electrical conductivity of leachate tends to be higher than that of natural water. This is as a result of the leachate diminishing the electrical resistivity of the formation containing them (Martinho and Almeida, 2006). The use of resistivity method applied to landfills studies are well documented (Porsani et al., 2004; Karlik et al., 2000; Mukhtar et al., 2000;).The objective of the present work is to apply the Electrical resistivity technique to detect and delineate leachate plume from non-controlled solid waste dumpsite in Kaduna municipal, North- West, Nigeria. The addition of physio-chemical analysis of water sample is to compliment the results of the geophysical data and measure the level of accumulation of the contaminants.

2. Material and Methods.

Geologic and Hydrogeologic Settings of the study area

The survey area (Fig.1) is located on Abdullahi Bello road at co-ordinates $10^{0}34^{''}$ N and $07^{0}27^{''}$ E, in Unguwan Dosa, Kaduna North Local Government Area of Kaduna State, North West Nigeria. Geologically, the survey area lies entirely within the Basement Complex rocks of Northern Nigeria. These are undifferentiated basement rocks comprising mainly granites, gneisses, migmatite, quartzite and amphibolites. These basement rocks are mechanically competent and therefore respond to imposed strains by brittle fracture. Surface water percolates down through the fractures and the process of chemical weathering proceeds. In general, gneiss and migmatite weather more easily than granite (Olorunfemi et al., 1991). However, the weathering products of the gneiss and migmatite are richer in clay minerals and hence less permeable with attendant lower groundwater yield. The top soil varies in composition, colour and texture and in most places they are predominantly clayey sand and quartz grains (deep brown or reddish brown soil). GSN Unpublished report No. 1539. The study area has a typical Savannah climate with distinct wet and dry seasons. The dry season normally begins in October and ends in April while the rainy season occurs between May and September. Average annual rainfall for Kaduna is 1270mm Eduvie (2003). Rainfall generally reaches a peak in August. Temperatures vary between less than 15^{o}C around December/January and 32^{o}C in March/April. Concerning groundwater occurrence, geophysical investigations and borehole drilling reports have identified two major aquifers. These are the overburden weathered aquifer (clayey sand/sand) and the fractured crystalline aquifer (Eduvie, 2003; Dan-Hassan and Olorunfemi, 1999). The overburden aquifers usually contain great quantity of water largely exploited by hand dug wells for domestic water supply. At some locations, these aquifers are interconnected and form a hydrogeological unit of water table surface.

Electrical resistivity survey and data processing

Eight Schlumberger vertical electrical soundings (VES) measurements were conducted with maximum electrode spacing (AB/2) of 100 m. Four of the VES points (1- 4) were located inside the dump. Based on the local groundwater flow and topography of the area (Fig 1), the remaining four (5-8) were located at the southern margin of the dump to observe any migration of the leachate outside the dump. The VES points were separated by 5 m intervals. The ABEM SAS 300C Terrameter was used to collect the VES data. Field resistivity structures of sounding data were determined by the software, IPIWIN (version 3.0.1) developed by the Geophysics Group Moscow State University for inverse interpretation. Data were interpreted in terms of three and four layer structure (Fig 2). The fit between model response and the field data for VES points outside the dump were generally lower than 10% while a maximum fit of 24. 4% was obtained for VES points located inside the dump. This high discrepancy is attributed to the large lateral variations between the materials on top of the dump and those surrounding the dump (Porsani et al., 2004). The interpretation of the VES curves aided by lithological logs from boreholes (Fig.3) enabled the derivation of maximum of four geologic sections. The topmost layer consists of clayey sand and lateritic clay. This formation is followed in succession by sandy clay/clayey sand/sand, weathered transitions zone/fractured layer, and the fresh basement. Qualitative interpretation indicates that the weathered/fractured basement constitutes the main aquifer unit. From the VES results, the depth of water table in the study area varies between 1.21 and 5.68 m. This is due to variations in the thickness of the weathered zone and intensity of weathering. The VES data were subsequently plotted as pseudo and resistivity cross-sections in order to look at the spatial distribution of the leachate plume (Figs 4 and 5).

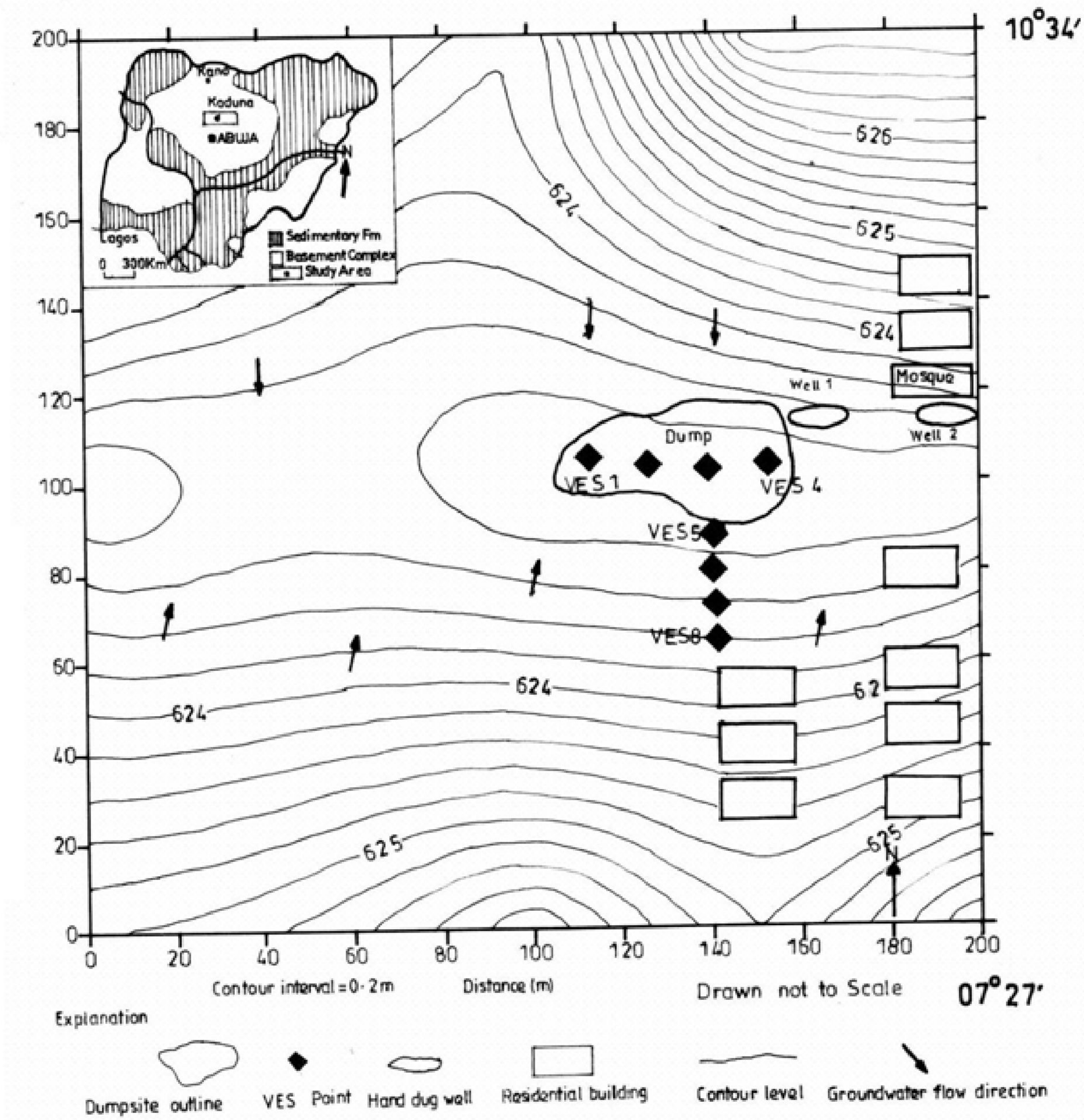
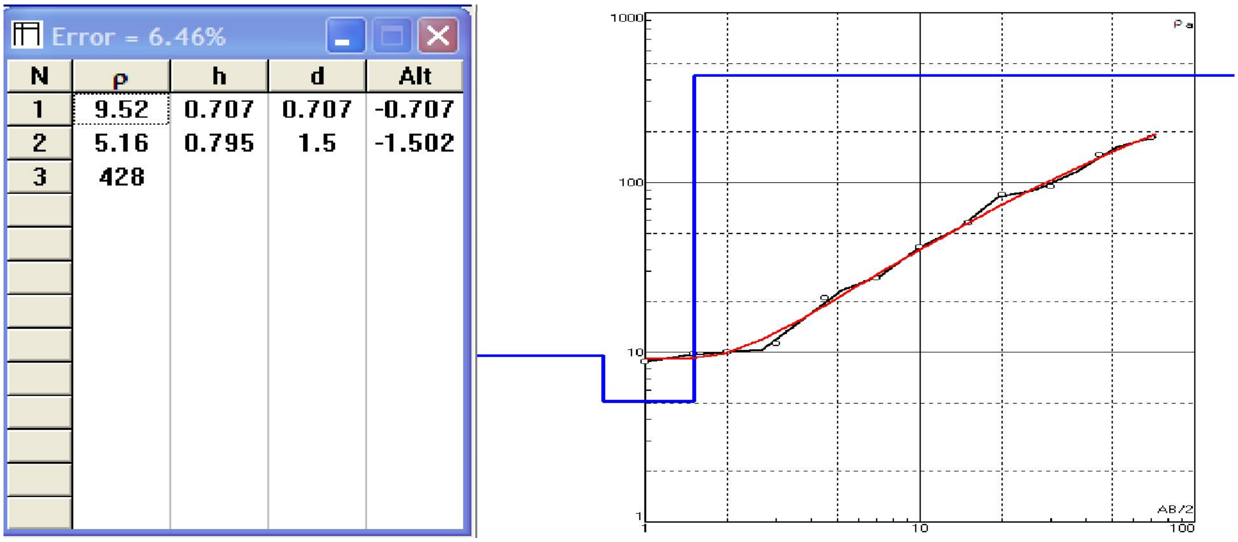


Fig.1: Genealised map of the study area(Modified after Osazuwa and Abdullahi,2008)

Physio- chemical survey

In order to assess the level of groundwater contamination by the solid waste leachate, water quality analysis was conducted on water samples from two hand dug wells, one located 2 m from the dumpsite(Named well1) and the other at 16 m from the dumpsite near a mosque (Named well 2). The two hand dugs are located at the northern margin of the dump and the static water level of the hand dug wells are 2.55m for well 1 and 2.44m for well 2.The water samples were analysed for physical parameters{Temperature, pH, Conductivity, Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total dissolved solids (TDS), and Chloride (Cl^-)} at the Water Resources Department, Ahmadu Bello University, Zaria while the chemical analysis was conducted for five (5) trace elements at National Research Institute for Chemical Technology (NARICT), Basawa, Zaria. Water samples collected were stored in well-drained clean polythene bottles already rinsed out with same water samples from each hand dug well. The water samples collected for chemical analysis were acidified with dilute nitric acid and stored in a refrigerator prior to analysis. Analysis of all the physical parameters were done using the various standard methods for water analysis (APHA, AWWA & WPC, 1985) while preserved water samples were analysed for cations and anions using Atomic Absorption Spectrometer (AAS) method.. The results of the physio-chemical analysis are presented in table1.



(a) (b)

Fig 2: (a) Model description and (b) DC Curve interpretation for VES 1

Table 1. Physio-chemical analysis of Hand dug wells

Parameter	Unit	Well 1 (Dump)	Well 2 (Mosque)	WHO (1992)
Conductivity	μs	1024	283	100
pH		6.63	6.72	6.5-8.5
TDS	mg/l	1000	400	500
COD	mg/l	902	742	80.0
BOD	mg/l	480	395	<40
Chloride	mg/l	433	298	250
Chromium	mg/l	0.4970	0.1778	0.0500
Cadmium	mg/l	0.0330	0.0270	0.0030
Lead	mg/l	0.929	0.0618	0.0100
Iron	mg/l	1.5561	0.7754	0.3000

3. Results

Figs 4a and 4b show the pseudo and the resistivity cross-sections for VES points located inside the dump (VES 1 – 4). The pseudo cross-section (Fig 4a) shows a low resistivity zone (1 – 12.9 ohm-m) for AB/2 spacing of 1- 4.5 m extending vertically at VES 3 and narrowing laterally at VES 4. This is attributed to contamination of the top soil as a result of accumulation of leachate. The lower limit (black color scaling /2 ohm-m) established around VES 3 indicates that most of the waste are dumped there. A horizontal horizon made up of green, grey, yellow and pink colour scaling observed at AB/2 spacing of 4.5 m - 15 m (equivalent to maximum depth of 6 m) is the water bearing zone. The resistivity of this layer depends on the sand to clay ratio and saturation, hence the wide range of colours. The low resistivity end (< 80 ohm-m) could be attributed to contamination of the groundwater as a result of invasion of the leachate. The resistivity cross – sections (Fig 4b) revealed a sequence of three geo-electric sections of H (VES 3) and A (VES1, 2 & 4) types. The low resistivity value of the second layer at VES 3 is an indication of downward migration of the leachate. The bedrock has a resistivity that exceeds 1000 ohm-m but where it is fractured and saturated (VES2); the resistivity reduces to less than 1000 ohm-m (Olayinka and Olorunfemi, 1992). The fractured zone constitutes a major aquifer component in a Basement Complex area. The hydraulic conductivity of the first and second layer was estimated in order to provide an insight into the mode of contaminant movement in the formations. Sing (2005) established a non–linear relationship between hydraulic conductivity (K) and apparent resistivity (ρ) given by $K = 0.0538\,e^{-0.0072\rho}$ where ρ equals the apparent resistivity of the formation. The calculated hydraulic conductivity of the first and second layer is 5.9×10^{-2}m/s and 3.3×10^{-1}m/s respectively. These moderately low conductivity values are characteristic of the resistivities of the layers which vary between 1.89 and 326 ohm-m corresponding to leachate accumulation or due to clay material.

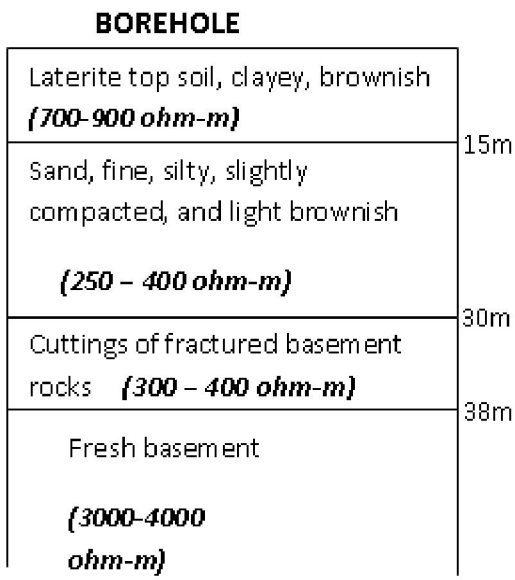


Fig.3**:** Borehole lithology and interpretation modified from Aboh (2001).

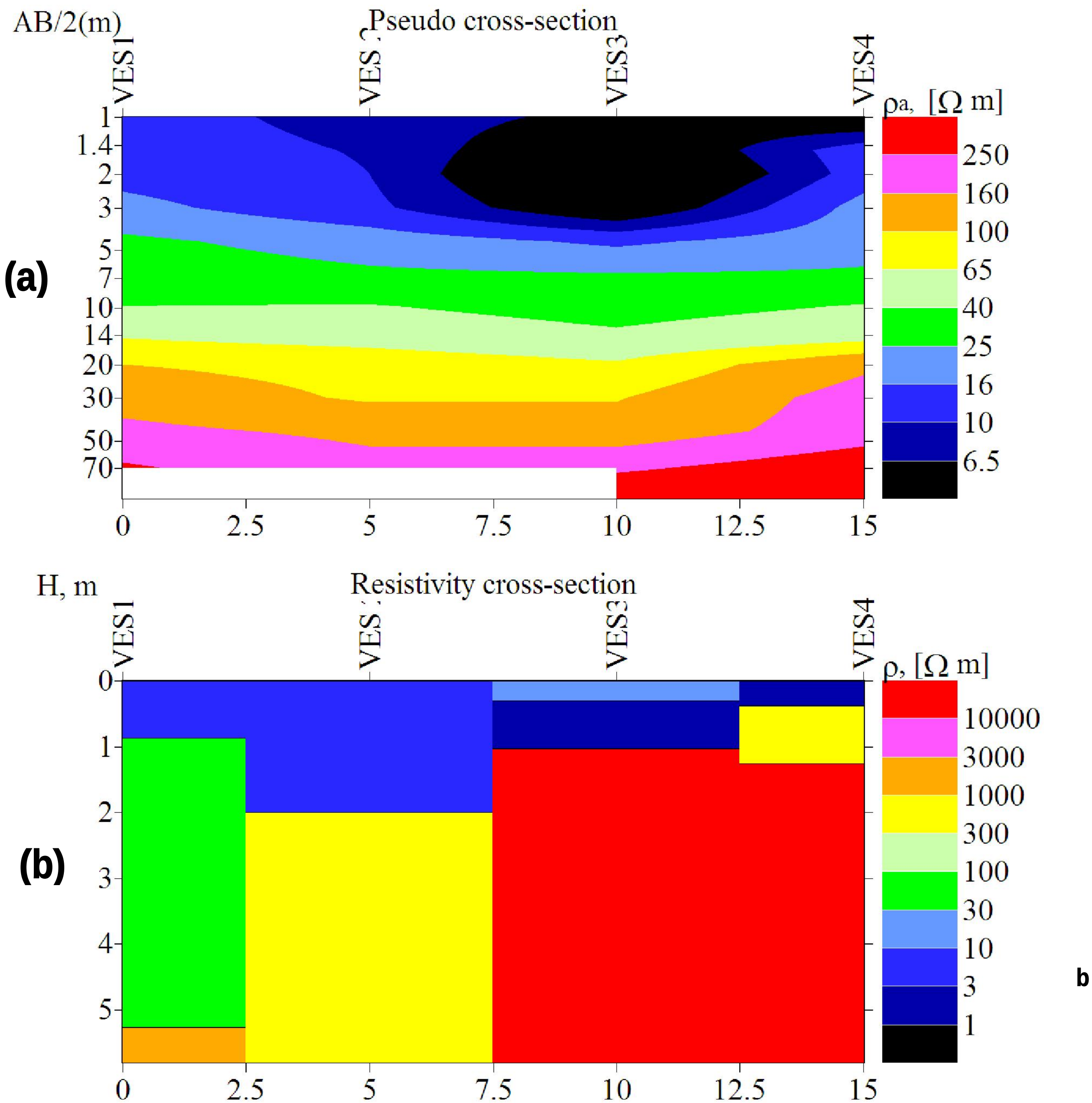


Fig.4: (a) pseudo cross-section and (b) resistivity cross-section of VES 1- 4.

Fig 5a shows the pseudo cross-section for VES points 5-8. The resistivity at the AB/2 spacing of 1- 4.5 m varies between 168 ohm-m and 367 ohm-m and is representative of clayey sand. The water bearing zone has colour scaling consisting of blue and green with a maximum resistivity of 263 ohm-m. This zone occurs at AB/2 spacing of 4.5 m to 20 m. The low resistivity values recorded in this zone could be an indication of accumulation of leachate and the contamination of the saturated sand. Fig.5b is the corresponding resistivity cross-section. The curve type consists of H (VES 1, 2 and 3) and HA (VES 4) and the basement rocks are competent (resistivity > 1000 ohm-m). The second layer for all the VES points, show low resistivity values (26 – 121 ohm-m) which could be attributed to contamination of the groundwater as a result of leachate accumulation or the presence of in situ weathered clay material. The former is favoured as the dumpsite is situated in a seasonally water surplus climate and therefore, leachate generation and migration from the dumpsite can be expected. Furthermore, the high calculated hydraulic conductivity of the second layer, 3.7 m/s is representative of sand and this may possibly be responsible for the migration of the leachate outside the dump. The calculated hydraulic conductivity of the topmost layer is 4.4×10^{-1} m/s which is typical of sandy clay.

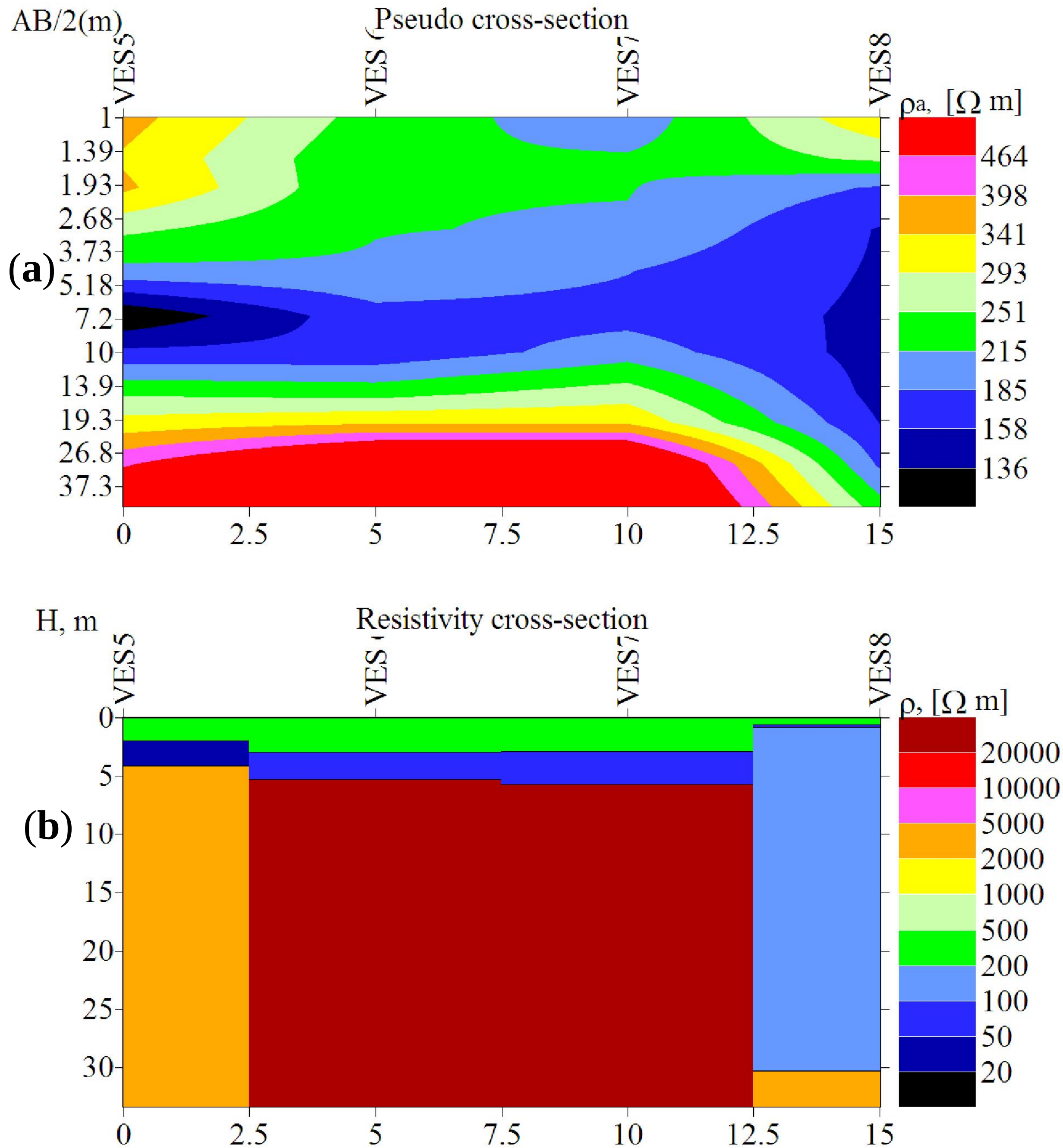


Fig.5: (a) pseudo cross-section and (b) resistivity cross-section of VES 1- 4.

In the light of WHO standards, it could be inferred from the results of the physiochemical analysis (Table 1) from the two laboratories, the values of the different parameters showed pollution of the groundwater. High electrical conductivities are attributed to contaminant fluids rich in total dissolved solids. High BOD concentration is an indication of high concentration of biodegradable organic substances from the dumpsite while elevated COD concentration indicates pollution from both oxidizable organic and inorganic pollutants. High concentrations of the trace metals are possibly due to the effect of the leachate migrating from the waste body facilitated by the high conductivity of the geo-electric layers. High concentration of iron in the groundwater is probably due to the leaching of iron scraps which constitute a reasonable part of the waste. The high concentration of chloride, iron and zinc ions is an indication of toxic or hazardous substances in solid forms in the leachate Meju (2000). The high concentrations of these substances (chloride, iron and zinc) and detrimental substances (Lead, Chloride and Chromium) observed in both wells call for urgent concern because according to Bashir. (2001) this may cause central nervous system and kidney/liver effects.

4. Discussions

The main aim of the present work is to determine contamination of groundwater as a result of municipal solid waste leachate accumulation within the study area. The integration of vertical electrical soundings and physio-chemical analysis of water samples from existing hand dug wells; geologic logs and the local geology have been successfully used for the detection of groundwater contamination due to municipal solid waste in the study area. From the VES data, the thickness and resistivity values of the layers were determined. The VES interpretation revealed a maximum of four geologic units beneath the VES stations. The geologic sections revealed the various lithological compositions of various layers delineated. The generated pseudo and resistivity cross-sections showed leachate plumes extending below the water table, thus polluting the groundwater: a conclusion supported by the water quality analysis from existing hand dug wells which showed concentrations of organic/inorganic parameters exceeding permissible limits. The high concentration of detrimental heavy metals (lead, cadmium and chromium) is an indication of toxic or hazardous substances in the leachate. This is a major threat to human population, especially those within the area. The calculated hydraulic conductivity of the topmost layers of the subsurface outside the dump (4.4×10^{-1} m/s & 3.7 m/s) are higher than those inside the dump (5.9×10^{-2} m/s & 3.3×10^{-1} m/s).This signifies that the uppermost layers of the resistivity models in the study area consist of loose permeable sediments. Hence, the contamination of the hand dug wells indicated by the water quality analysis is believed to be as a result of transportation of the leachate plume outside the dumpsite through the pore spaces of the subsurface materials which are interconnected.

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