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Investigation of Groundwater Aquifer Contamination due to Leachate Intrusion Using a High Resolution Real-Time Resistivity Technique at a Dumpsite around the University of Port Harcourt Environs, Choba, Rivers State, South-South, Nigeria

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ABSTRACT
An analysis of real time vertical electrical sounding (VES) resistivity data has been carried out in this study to investigate the pollution effect of a dumpsite on groundwater aquifer. The resistivity survey was implemented using ADMT 200S Digital Terameter and a ground sensor other than four moveable electrodes to measure resistivity vertically across the subsurface layers. This technique remotely transfers current, voltage and geometric data obtained by the instrument to a digital computer which utilizes the AIDU Resistivity Software to measure bed resistivities and generate high resolution real time 2D and 3D contour maps. In this study, the use of the Digital ADMT 200S Terameter and ground sensor significantly minimized the operational difficulties that would have been encountered if the conventional VES method that involves extensive layout of cables had been employed. As an added advantage, this instrument allowed us to implement the VES survey in a confined space around the dumpsite due to deep penetration of current into the depths of the subsurface. From our results, groundwater aquifers at depths of 40-70m and 100m, capped at the top and bottom by clay beds, were identified. These are zones of lower conductivities (higher resistivities) ranging from 10.3mS/m to 11.1mS/m at the 40-70m depth zone and 11.1 -11.5 mS/m at the 100m depth. A higher conductivity (lower resistivity) that permeated the subsurface layers from the topsoil through the different lithologic layers down to the depth of about 190m occurred within the subsurface. This conductivity pattern represents a deviation from normal conductivities for an uncontaminated lithology. It shows the effect of the dumpsite on the subsurface layers. The results we obtained clearly showed that a contaminant leachate plume percolated through the dumpsite and infiltrated the clay beds without a direct contamination of the delineated aquifers. Although the identified groundwater aquifers were not directly contaminated, the pollution effect of the plume on other sand aquifers within the subsurface around the dumpsite may need to be further investigated.
Keywords: Investigation, groundwater, aquifer, contamination, high, resolution, real-time

1.0 INTRODUCTION

Water is important for human consumption, domestic activities, agriculture, industrial processes, engineering projects and many other purposes. Most of the worlds' surface water is found to be polluted either by the anthropogenic activities of man or intrusion of salinity and other factors. These factors have necessitated the purification of surface water before consumption and other uses (Bashir et al, 2014). The exposure of surface water to uncontrolled pollution presents groundwater as a veritable option to meet the ever increasing demand for clean drinkable water. However, it is well documented in the literature that groundwater may sometimes be contaminated by intrusion of leachate and other chemical substances if the groundwater borehole is sited at or near a dumpsite, landfill and/or sewage disposal areas. Landfills/waste-sites are often massive sprawling dumps with few environmental safeguards. The problem is particularly acute in places of rapid urbanization and growing human population. McCall (1998) and Ding and Cheng (2012) report that over fifty large cities in China have major cases of groundwater contamination from landfills or improperly disposed industrial wastes. It is also reported that management of solid waste landfills has been a major problem of urban centres in Nigeria and other developing economies around world (Olisah and Obiekezie, 2020). In these urban centres, wastes are generated daily and disposed indiscriminately in rivers and landfills without regard to the environment, local geology and their proximity to residential areas (Olayinka and Olayiwola,2001;Tijani et al. 2004; Ariyo et al., 2013; Olisah and Obiekezie , 2020). Consequently, maintaining a potable groundwater supply that is free from microbial and chemical contaminants is far from reality in most urban centres in Nigeria, Africa and the developing parts of the world due to poor waste disposal and management practices (Mosuro et al, 2017). Disposal of waste into open landfills, which is the most common means of waste disposal in the developing countries, is likely to remain the conventional approach to waste disposal for the foreseeable future with its attendant health, safety and environmental consequences (Pugh, 1999; Olisah and Obiekezie, 2020). In the developed world, modern sanitary landfills include clay and plastic geomembrane barriers beneath the waste as well as leachate collection and processing systems that prevent leachate leakage into the depths of the subsurface. Unfortunately, most landfills in the developing world have no such barriers, which results in leachate seepage into the surrounding aquifers (Ding and Cheng, 2012).

Infiltration of rainfall into a landfill/dumpsite together with the biochemical and chemical breakdown of the wastes produces leachate that is high in suspended solids and varies in organic and inorganic contents (Desa et al. 2009). The leachate accumulates various chemical ions in solution as it percolates through the landfill/dumpsite and finally migrates into underlying groundwater aquifers, resulting in pollution. It typically forms a plume that may contain dissolved carcinogens (which include the heavy metals such as lead, mercury, chromium, cadmium, arsenic, etc.), volatile organic compounds (such as benzene, ethylbenzene, toluene, etc.) and less harmful inorganic ions (such as sodium, calcium, iron, sulphate, and chloride, etc.). The leachate plume moves outward and downward, that is laterally and vertically within the subsurface into the surrounding and underlying aquifers. As it migrates through the ground, it follows preferential flow paths due to the heterogeneity of the earth's subsurface materials coupled with hydraulic forces that contribute to its lateral and vertical migration. With the presence of the sodium, calcium, iron, sulphate and chloride ions as the key components, the leachate contaminant can cause measurable decrease in resistivity of groundwater due to their electrolytically conductive property. In addition, the fact that these components are not greatly affected by geochemical processes such as absorption, precipitation or redox processes implies that the leachate can travel long distances through groundwater without suffering great attenuation and thereby causing anomalous increase in the conductivity of the groundwater (Jaana, 2001). The presence of the plume in and around a sand aquifer therefore produces a remarkable variation pattern in the characteristic resistivity of the aquifer as well as in the resistivity pattern of contaminated clay layers.

Although various methods can be used to map or image a contaminant plume, the anomalous increase in electrical conductivity or decrease in resistivity along flow paths of the plume makes the resistivity method an efficient and attractive technique in studies involving groundwater contamination by leachate infiltraton. The flow of electric current in a subsurface medium follows the path of least resistance, which is controlled more by porosity and water resistivity than by the resistivity of mineral particles. This is because most of the rock-forming mineral particles are not electrically conductive. Current conduction therefore relies more on electrolytic process in which the fluid contents of the pore spaces and the matrix porosity of the rock determine the amount of current that can pass through a medium (Meju, 2000). The classical Archie's (1942) law shows that both resistivity and porosity are inversely proportional. In other words, the more porous a rock type is, the greater is its conductivity and the smaller is its resistivity. High porosity brings about low resistivity in water-saturated rocks. Since conduction is dominated by ions through the earth's subsurface materials, it then follows that the presence of contaminants in groundwater would drastically alter (increase) the electrical conductivity of aquiferous zones which are otherwise naturally characterized by high resistivity (or low conductivity) response due to low concentration of conductive ions in these zones.

This objective of this study is to investigate leachate infiltration into groundwater and clay layers at a dumpsite in Choba, Rivers State, Nigeria, around the University of Port Harcourt environs, using a high resolution real-time resistivity technique. The method involves electrical resistivity sounding, but rather than the conventional use of moveable potential and current electrodes, the compact digital terameter used for the geophysical survey utilizes a ground sensor placed firmly on the earth's surface to implement the sounding. Vertical electrical sounding (VES) uses direct current (DC) injected into the ground to investigate the subsurface electrical resistivity (Vladimir et al.2006). During sounding, apparent resistivity of the subsurface materials is measured as a function of depth. The VES carried out in this study was used to measure variation in resistivity with depth enabling us to investigate and determine possible contaminant intrusion into the aquifer and clay beds at the dumpsite. Again, unlike most VES surveys that utilize moveable electrodes, the method adopted for this study excludes moveable electrodes and incorporates the use of a ground sensor to produce a high resolution real-time image of the subsurface for detection of any infiltrating leachate plume in and around the underlying aquifer(s). Kearey et al.(2003) reports that the depth of penetration of current in a VES survey must be such that the ground is sufficiently energized to the required depth. Although the instrument we have used does not involve the use of current electrodes, the instrument's sensor is capable of injecting current to a 200m depth but must make firm contact with the ground surface.

2.0 MATERIALS AND METHOD

2.1 The Study Area

The study was conducted at a landfill in Choba Town around the University of Port Harcourt environs, Rivers State, South-south in the eastern Niger Delta of Nigeria. The University of Port Harcourt, Choba lies on latitude 4^{o}54′ and longitude 6^{o}55′ (Fig. 1) and forms part of the coastal plain of southern Nigeria. The landfill has been used over the years for open indiscriminate dumping of refuse and has piled up to become a massive heap with no environmental control or regard to the hydrogeology of the area (Fig.2). The continuous heaping of wastes on the landfill is a typical pointer to the poor waste disposal and management system in Nigeria. Although the dumpsite is located somewhat around the three campuses of the University of Port Harcourt (the Choba Park, Delta Park and Abuja Campus), it is closer to the Abuja Campus than the parks, and can be accessed easily from Abuja Campus Gate, as one traverses across East-West Road from the gate (Fig.1).

The underlying sediments at the dumpsite forms part of the stratigraphic sequence of the Niger Delta lithology. Reports on the stratigraphy of the Niger Delta shows that its subsurface lithology comprises an upper sandy Benin Formation, an intervening unit of alternating sandstone and shale known as the Agbada Formation and a lower shaly formation called the Akata Formation. These three delta facies extend across the whole delta and are typically environments of depositions. The depositions constitute the sequences of subsurface elastic sediments which range in thickness from 9km to12km (Ofodile, 1992). Most boreholes drilled near or around dumpsites in the Niger Delta have been found to produce contaminated water due to the intrusion of leachate plume into the underlying sand aquifers (e.g Bello et al.2017), with the aquifer depths ranging from 20m to 60m or more (Aweto et al. 2017; Bello et al. 2017; Agbalagba et al. 2019).

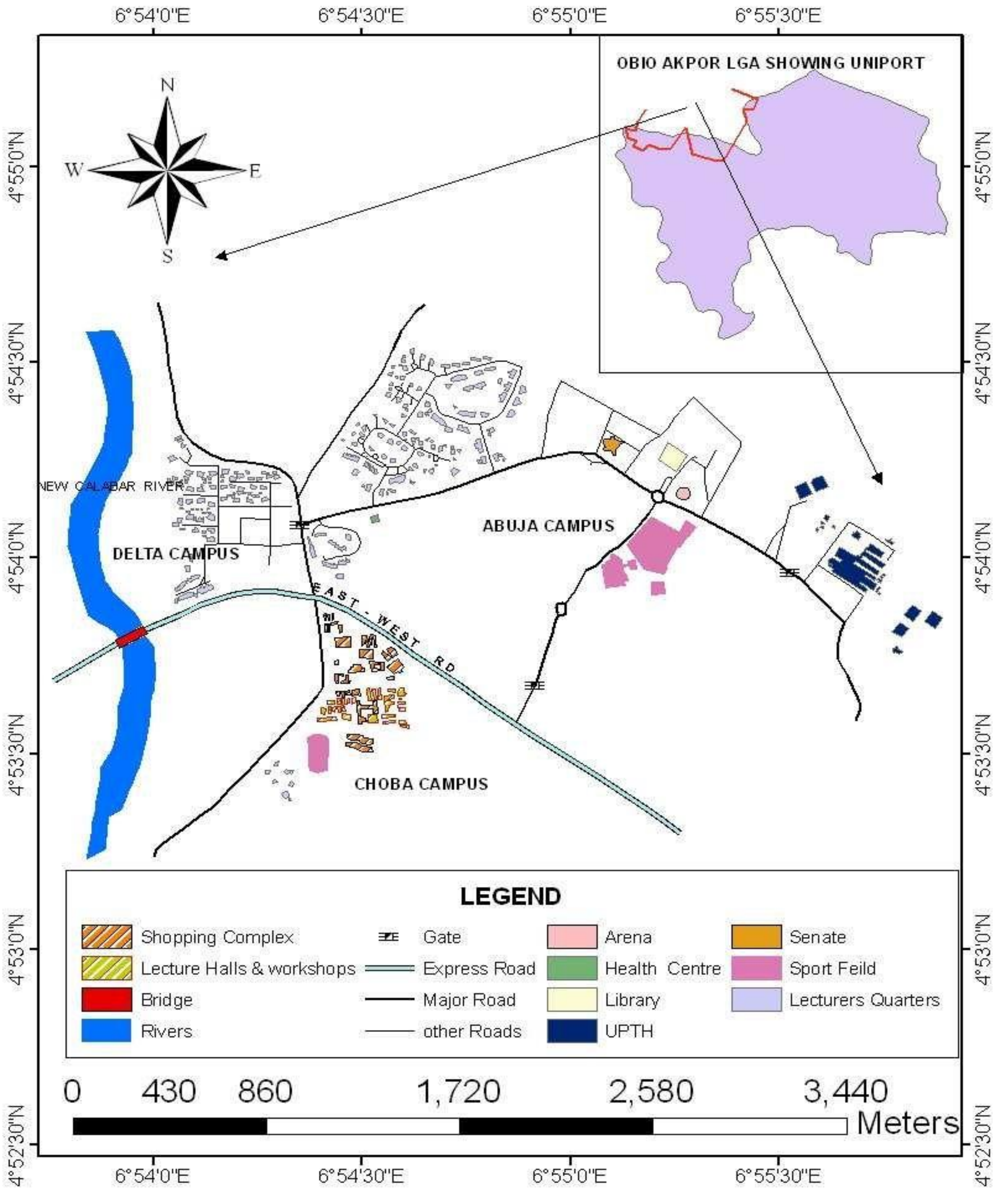

Fig.1: Map of University of PortHarcourt, showing the Abuja Campus, the Abuja Campus Gate and East-West Road across which the Dumpsite can be accessed (Chima and Ofodile, 2015)

Fig.2: The Dumpsite in the Study Area where the Resistivity Survey was Conducted. The Dump can be accessed from the University of PortHarcourt Abuja Campus Gate as one traverses across East-West Road from the Gate (Field Photograph)

2.2 Method

This study involves the investigation of leachate infiltration into the groundwater at a dumpsite using a high resolution real-time resistivity technique. The method involves vertical electrical sounding (VES), but rather than the conventional use of moveable potential and current electrodes, the digital terameter used for the survey utilizes a rectangular box-shaped ground sensor, placed firmly on the ground surface, to implement the sounding (Fig.3).The vertical electrical sounding uses direct current (DC) injected into the ground to investigate the subsurface electrical resistivity. During the sounding, the apparent resistivity of the subsurface earth's materials was measured as a function of depth. The VES carried out in this study was used to measure variation in resistivity with depth because the intrusion of a contaminant plume into sand and clay beds significantly alters (increases) the electrical conductivity of the beds (Aristedemou and Thomas-Betts, 2000; Kirsch, 2006). With the use of the digital terameter and ground sensor, we were able to generate a high resolution real-time image of the subsurface that enabled us to detect if there was an infiltrating leachate plume in and around the underlying aquifers. Kearey et al.(2003) reports that the depth of penetration of current in a VES survey must be such that the ground is sufficiently energized to the required depth. The ground sensor-coupled terameter employed in this survey is capable of injecting current to a depth of 200m.

The ADMT 200 Series Digital Terameter is a portable, compact and robust equipment that consists of a battery-powered current-transmitting and receiving system (known as the mainframe) which produces a current output that sufficiently energizes the ground. The equipment can be operated compactly with the use of the mainframe and the ground sensor alone, to provide operational convenience in comparison to conventional VES methods that involve extensive layout of cables (Fig.3).

The apparent bed resistivities are measured automatically on a digital computer that is remotely connected to the mainframe and uses the AIDU Resistivity Software to generate 2D and 3D contour maps that give high resolution resistivity information in real time, revealing any plume intrusion into the water aquifers within the subsurface. Only one (1) VES station was occupied during the survey, with our measurements consisting of six (6) sounding points along the profile line.

Fig.3: The Compact Digital Terameter (ADMT 200S) cabled to the Rectangular Box-shaped Ground Sensor Used for the VES Resistivity Survey for Detection of Leachate Intrusion into the Aquifer (Field Photograph)

3.0 RESULTS

Fig. 4 is a 2D contour section obtained in real time showing a cylindrical well bore that indicates drillable positions cutting across zones of potable drinking water at depths of 40-70m and 100m. These are zones of lower conductivities (higher resistivities) ranging from 10.3mS/m to 11.1mS/m at the 40-70m depth zone and 11.1 -11.5 mS/m at the 100m depth, which have been identified with blue colourations. A high conductivity pattern (identified with red colouration) that permeates the subsurface layers from the topsoil through the different lithologic layers down to the depth of about 190m can also be observed on the map. This conductivity pattern represents a deviation from normal conductivities for an uncontaminated lithology. It shows the effect of the dumpsite on the subsurface clay beds. It is clear that a contaminant leachate plume has percolated through the dumpsite and infiltrated the clay beds near the aquifers as depth increases.

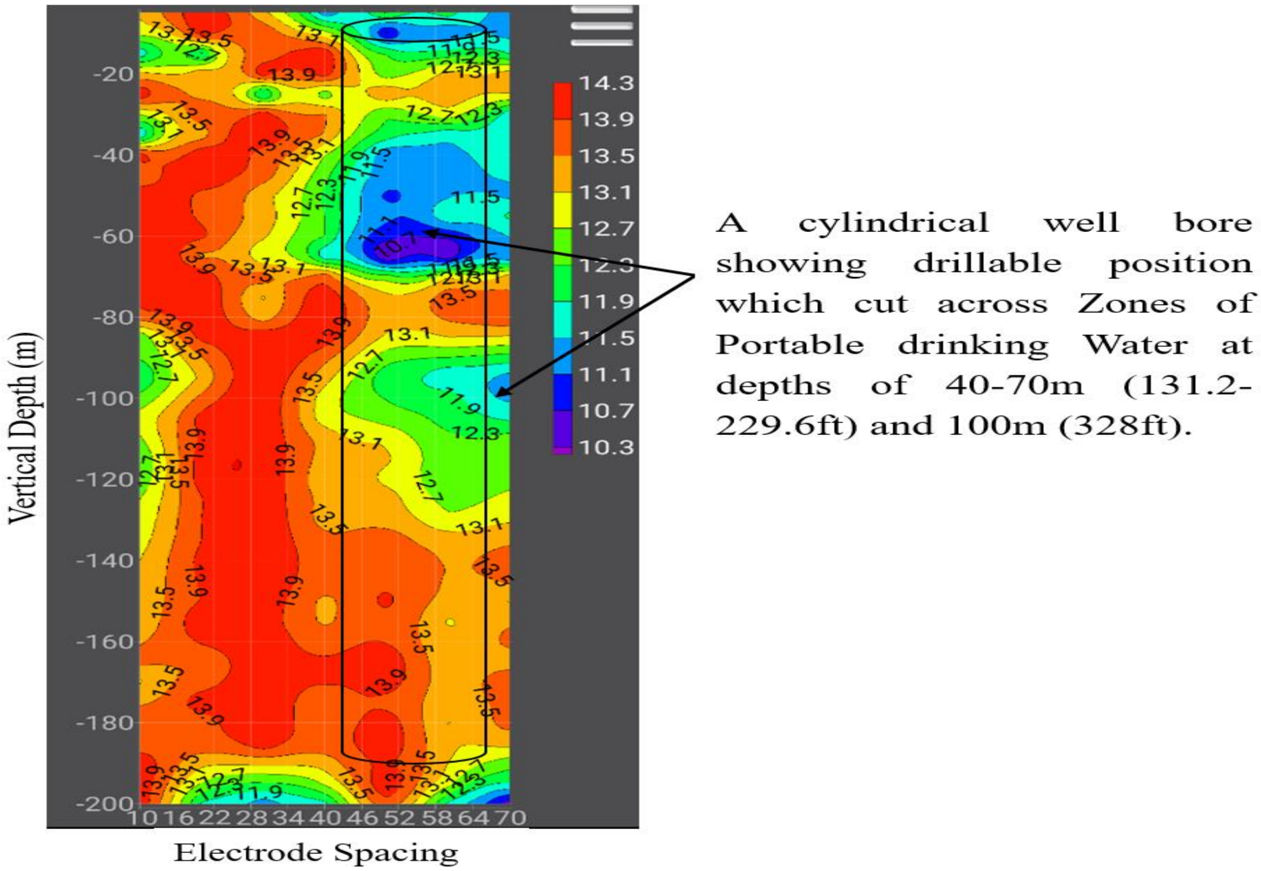

Fig. 4: The 2D Contour Section Obtained in Real Time Showing the Infiltration and Migration of a Contaminant Plume from the Topsoil Vertically down the Subsurface Beds. The Travel of the Plume through the Layers is Indicated with Red Coluration.

Fig.5 is the top view of a 3D model obtained in real time showing zones of potable groundwater at depths of 40-70m within the sand beds, capped at the top and bottom by clay beds. The effect of the dumpsite on the subsurface lithologic layers can be observed. A contaminant leachate fluid from the dumpsite (identified with the red colouration) can be found migrating as a high conductivity pattern through the clay beds near the aquifer as the depth of investigation increases. Although the groundwater aquifer is not directly contaminated, the effect of the plume on other sand aquifers within the subsurface may need to be investigated further by increasing the survey profiles around the dumpsite.

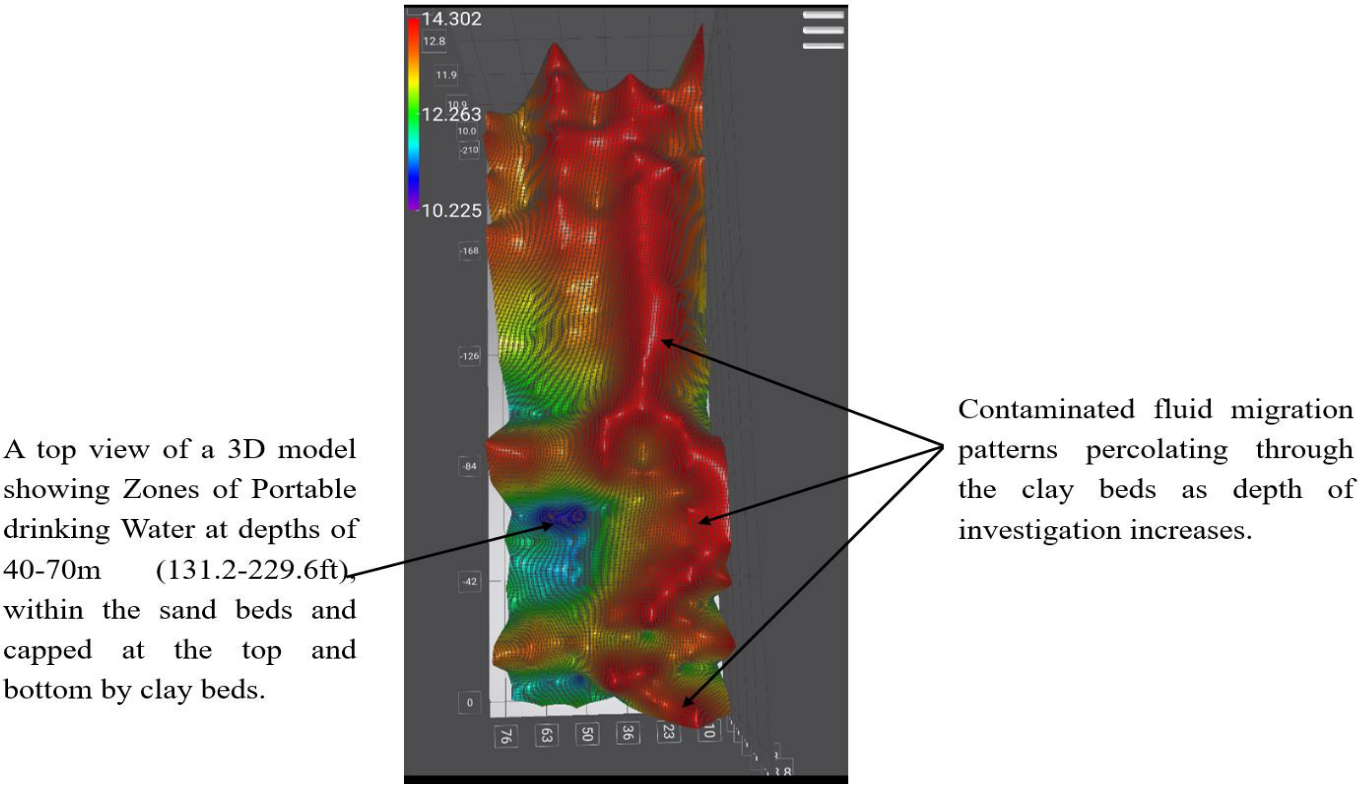

Fig.5: Top View of a 3D Real Time Model Showing Contamination of the Clay Beds, Indicated by a Red Conductivity Pattern

Fig.6 is a 3D map showing a geometrical structure of the aquifer and a trapping mechanism of aquifer fluid by clay beds. The aquifer which is not directly contaminated by the leachate plume is found encased at the top and bottom by clay layers.

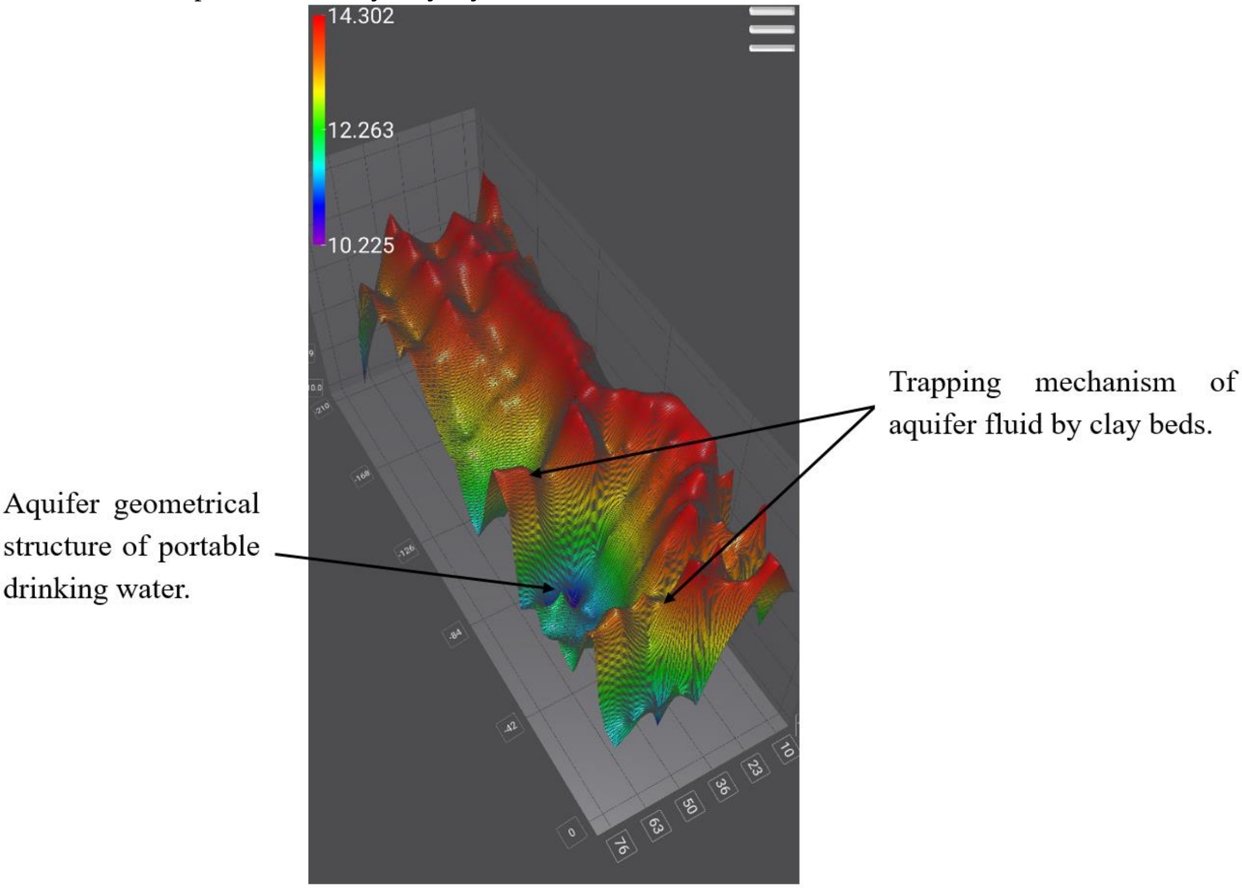

Fig.6: A 3D Map Showing a Geometrical Structure of the Aquifer and a Trapping Mechanism of the Aquifer Fluid by Clay Beds.

4.0 DISCUSSION OF RESULTS

A real time VES resistivity survey has been carried out in this study to investigate the pollution effect of a dumpsite on groundwater aquifer. Our results reveal the presence of groundwater aquifers at depths of 40-70m and 100m, capped at the top and bottom by clay beds. These are zones of lower conductivities (higher resistivities) ranging from 10.3mS/m to 11.1mS/m at the 40-70m depth zone and 11.1 -11.5 mS/m at the 100m depth, which have been identified with blue colourations (Figs 4-6). A high conductivity (identified with a red colour pattern) that permeates the subsurface layers from the topsoil through the different lithologic layers down to the depth of about 190m occurred within the subsurface. This conductivity pattern represents a deviation from normal conductivities for an uncontaminated lithology. It shows the effect of the dumpsite on the subsurface layers. From our results, it is obvious that a contaminant leachate plume percolated through the dumpsite and infiltrated the clay beds near the aquifers as the depth of investigation increases. However, the groundwater aquifers are not directly contaminated, but the pollution effect of the plume on other sand aquifers within the subsurface may need to be investigated further by increasing the survey profiles around the dumpsite. Furthermore, the use of the ADMT 200S Digital Terameter which utilized a ground sensor for this study significantly minimized the operational difficulties that would have been encountered if the conventional VES method that involves extensive layout of cables had been employed. This instrument can also be used in a very confined space to implement VES survey as it allows deep penetration of current into subsurface depths without moveable electrodes. Apart from the operational convenience this method offers in contaminant studies, it adds the advantage of producing high resolution results in real time.

5.0 CONCLUSION

A VES resistivity survey has been carried out in this study to investigate the pollution effect of a dumpsite on groundwater aquifer. Using the ADMT 200S Digital Terameter and a ground sensor, real time 2D/3D resistivity maps were obtained. The results obtained show a high conductivity pattern that permeated the subsurface layers from the topsoil through the different lithologic layers down to the depth of about 190m, revealing the migration of a leachate plume through the subsurface beds, although the groundwater sand aquifers present at depths of 40-70m and 100m were not directly contaminated. We have also demonstrated that the VES resistivity technique employed in this study is one that provides operational convenience during field work in addition to the advantage of producing high resolution results in real time.

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