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Integrated geophysical assessment of a municipal waste disposal site for its geological suitability in terms of the underlain material

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Abstract

Dumpsites are major sources of groundwater pollution as a result of leachates that drain out of the decomposed waste. If there are no underlain materials that could serve as a seal to stop the percolation of leachate, it finds its way to the groundwater. A properly designed landfill is expected to have a high leachate curtailment capacity to limit groundwater pollution. A suitable landfill is expected to have a specific thickness of clay which acts as a natural filter. This study aims to determining the subsurface material and the leachate curtailment of Oke–Diya dumpsites. Very low frequency-electromagnetic method was adopted as a reconnaissance survey, after which electrical resistivity and multichannel analysis of surface waves (MASW) methods were carried out. The resistivity values obtained were used to determine the lithological units of the study area while the MASW was employed to determine the seismic wave arrival times which was processed to obtain the shear wave velocities of the subsurface. The rigidity moduli were also obtained from the shear wave velocities, from which the lithological units of the subsurface were inferred. The integrated method appeared to be the ideal tool to characterize the dumpsite and adjudge the leachate curtailment capacity. The methods corroborated each other. Oke–Diya dumpsite, from the results, revealed the study area had low leachate curtailment capacity and should be evacuated.

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1. Introduction

The alarming rate of groundwater contamination and environmental degradation as a result of indiscriminate waste disposal needs urgent attention, especially in a developing country like Nigeria [1]. Leachate is the term used to describe a fluid that drains from municipal waste after it decomposes. If it finds its way to reach the subsurface, it migrates to contaminate the groundwater [2]. Landfill is known to be an important feature of the environment particularly in extremely populated cities where it becomes the major means of disposing of waste. In most cases, landfills are located in proximity to inhabited areas which pose threat to the populace [3–8] thus, the need to assess the suitability of the underlain geological material if it suits the purpose of waste dumping. There is a cause to protect the groundwater because it is a major part of water resources for all humans and animals [4]. Considering the type

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of waste disposal facilities practiced in this part of the world, the groundwater is said not to be protected until the needful is done before siting the disposal facility.

Open dumpsites is the major municipal waste dumpsite practiced in Nigeria without prior investigation before commissioning. The environmental monitoring agent is expected to investigate the subsurface to get information about the subsurface by studying the suitability of the underlain materials if it is good for use, because of the groundwater that human consumes. Previous geophysical investigations on the dumpsite did not involve mapping of the subsurface geology for its leachate curtailment capacities as confirmed from the authorities before embarking on this research. Therefore, this research was adjudged to be necessary in an attempt to provide useful information on the study area. The main geological material considered to serve as a good seal to prevent the percolation of leachate in a landfill is clay [5]. For a man-made landfill, synthetic liners are used and natural liners (clay) to seal the subsurface from leachate percolation. In the same vein, there are natural conditions that suites the condition for landfill suitability. The standard according to the Geological survey of Ireland [6], where a clay deposition of about 15 m above the water table is required to seal the subsurface (Figure 1). In the process of the clay curtailing the leachate, evaporation takes place which takes care of the leachate before finding its way to the aquifer. The low budget, attenuation capability and easy implementation of compacted clay liners make it a potential seal and more accepted than synthetic geomembranes in lining systems [7, 8]. Non-invasive integrated geophysical methods could be used as pre-investigation before landfill is situated. An integrated geophysical survey had been used by researchers to characterize the subsurface. Very Low-Frequency Electromagnetic method (VLF-EM) and Electrical resistivity had been adopted by Benson *et al*. and Benson *et al*. [9, 10] in finding characterizing the subsurface which they reported to have yielded great results in geological mapping. The VLF most times is adopted as a reconnaissance survey to locate conductive zones before the electrical resistivity method comes up to reveal the geoelectric section of the subsurface. Electrical resistivity techniques and seismic refraction methods have been applied on landfills by several authors to detect waste deposits and host formation and seismic to image the lowest limit of landfill thickness [11–13]. In this research, we aim at using integrated geophysical methods to map the subsurface and adjudge the leachate curtailment capacity based on the delineated lithology of the study area.

Figure 1 shows an illustration of suitable landfill. It is expected to a natural seal like clay that could curtail the leachate.

2. Description of the study area

The study area is located at Sagamu along the old Ikorodu road directly opposite West Africa Portland cement company, South-western Nigeria. Oke–Diya dumpsite falls in the Eastern Dahomey Basin and also lies within Ewekoro Formation (Figure 2). It spreads about 650 m^2 of the whole area. The study area is categorized by topography elevation of about 260 m above the sea level with longitude E $3^0 56' 057''$ - $3^0 56' 426''$ and latitude N $6^0 47' 340''$ - $6^0 47' 964''$. The study area is significantly influenced by climate and relief. The closeness of Sagamu and the study area to Lagos, together with the availability of well-constructed roads made the environs a good industrial hub of Ogun state. Moreover, the dumpsite had been in existence for about 20 years after a mechanic workshop was relocated from the site and it's the major waste disposal facility in the city.

3. Methodology

3.1. Data acquisition

Three (3) geophysical methods were adopted for this research work. Very low frequency-electromagnetic (VLF-EM), Electrical resistivity and Seismic refraction methods respectively. The purpose of the integrated geophysical methods was to obtain robust information about the subsurface and correlate the result for proper characterization. Although, the VLF-EM was adopted as a reconnaissance survey to locate conductive zones before carrying out the other two methods. Six VLF profiles were established at the study area with 5 m intervals at E-W geologic strike with lengths ranging from 100 – 250 m as space permits using ABEM WADI 2000 equipment. Twenty Vertical Electrical soundings (VES) were performed at the dumpsites and its environs with maximum half current electrode spacing (AB/2) of 100 m. The ABEM resistivity meter with its accessories was used for the survey. Three Profiles of the seismic refraction Multichannel Analysis of Surface Waves (MASW) were performed at the study area with the seismograph and 24 arrays of geophones. The space between each geophone was 3m and the shot to the first geophone offset was 5 m. After the proper setup, the seismograph was switched on and shots were taken when energy was discharged for the reverse, forward and intermediate shootings. Figure 3 shows the data acquisition map of the VES points.

3.2. Data analysis and interpretation

Analysis of each data acquired from the methods were analyzed and interpreted appropriately. For the VLF technique, the data was processed and simplified relating to the physical property of the subsurface geological structure by plotting the filtered real and filtered imaginary components against the distance along the profile; which most times are used to interpret the fractures or conductive zones. The data was finally subjected to the Karous-Hjelt filtering process to reduce noise and improve signal [14, 15]. It simply calculates the current source at a given depth called the current density. The interpretation was based on the filtered real part which always shows a positive peak above the conductor [**?**]. The VES data were analyzed by using the log-log graph sheet

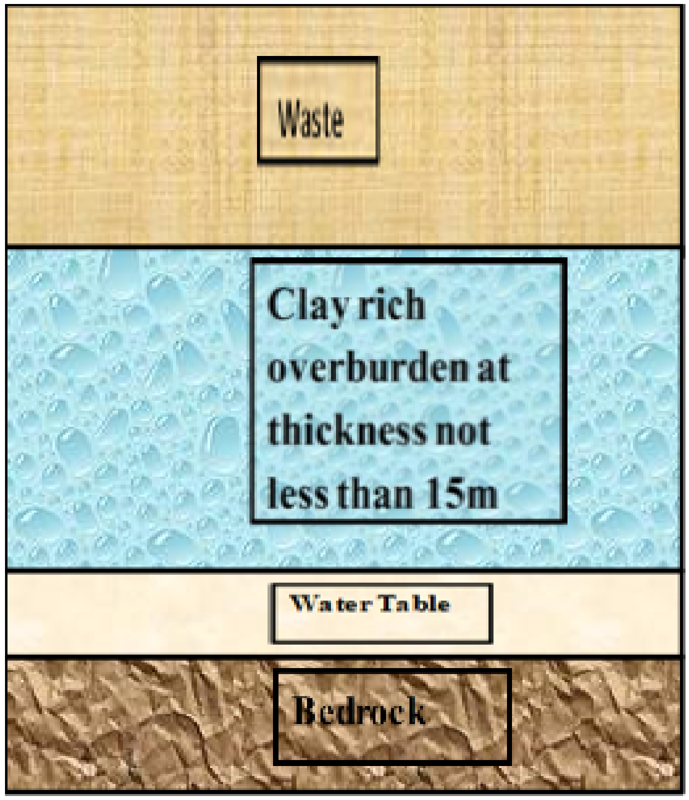

Figure 1. Modified schematic diagram of a landfill model [?].

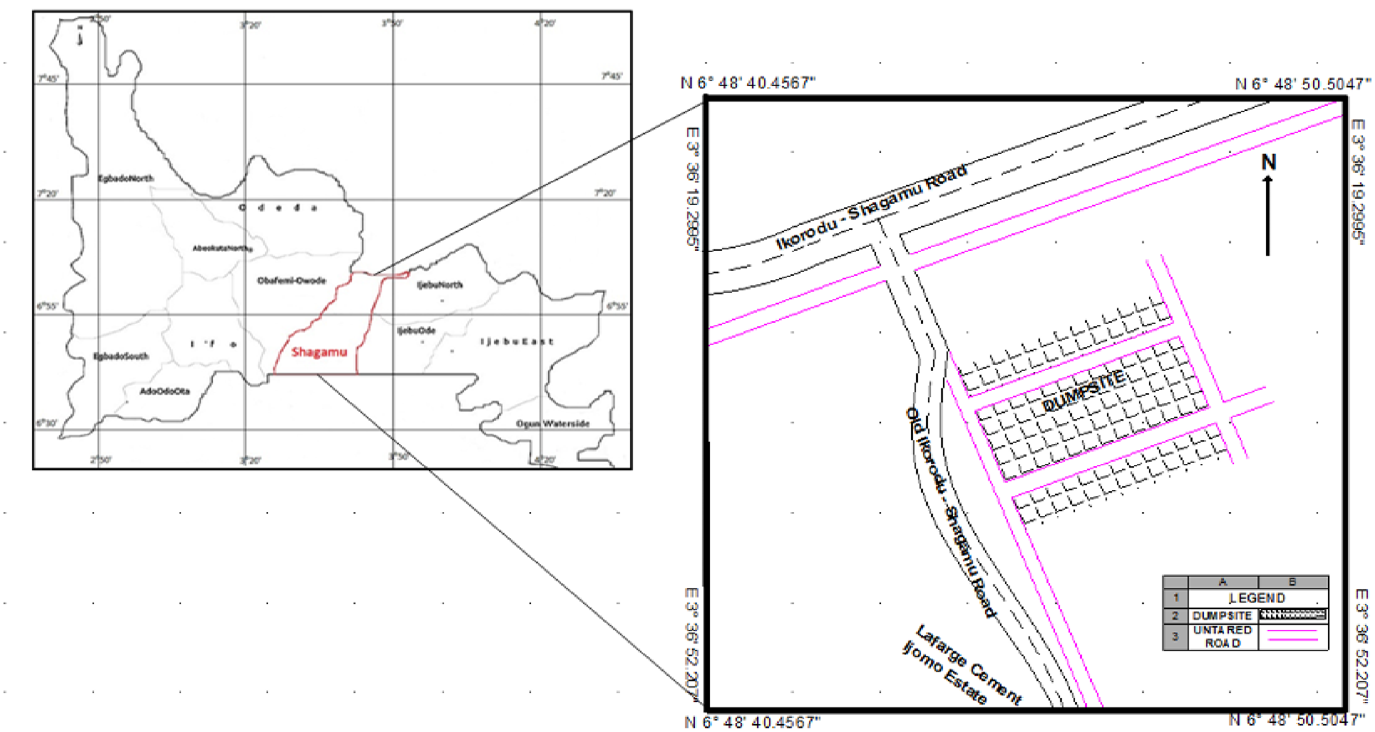

Figure 2. Location map of the study area (Oke–Diya Sagamu).

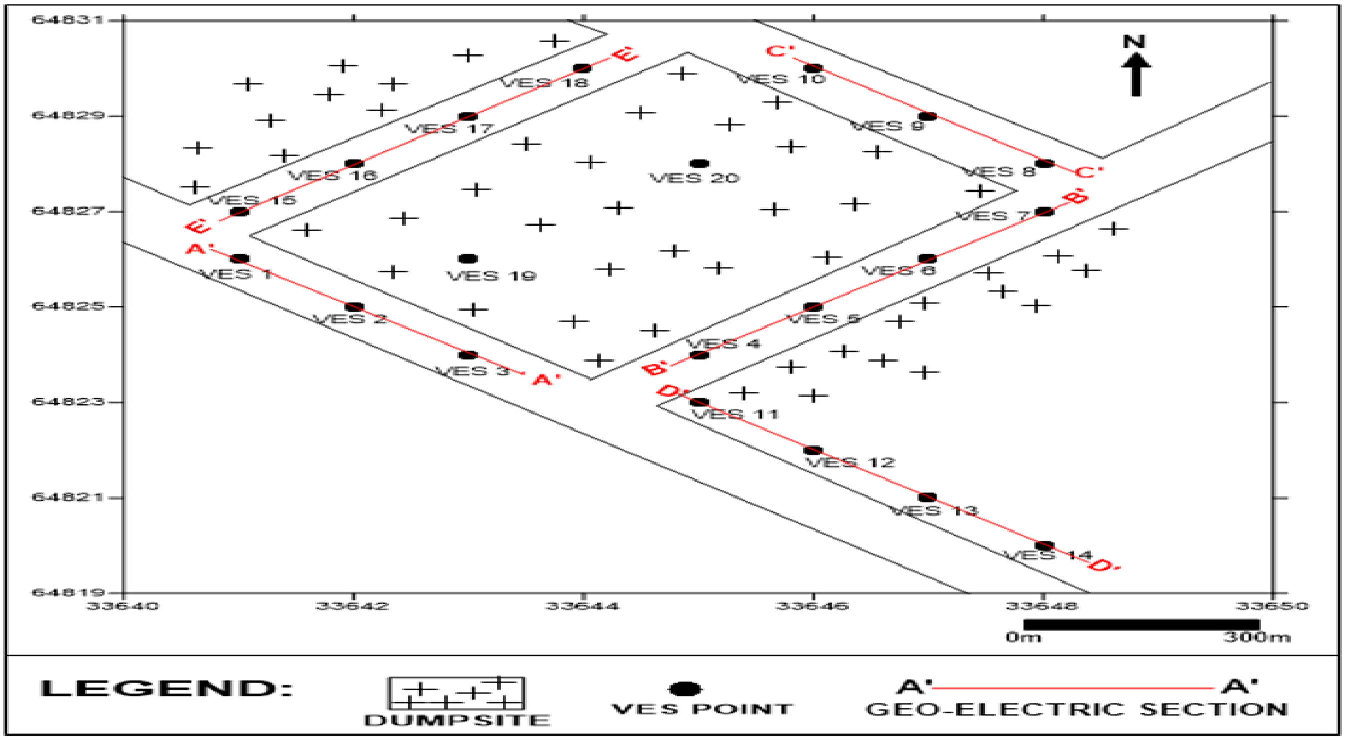

Figure 3. Data acquisition map of the VES points.

to plot the curves before generating the layered parameters with the use of WinResist software for iteration; this was done until an acceptable model was obtained. The adjusted layer parameters obtained from the curves iteration were quantitatively summarized and interpreted using tables. A qualitative interpretation was done with the aid of geo-electric sections to simulate a cross-sectional view of the subsurface geology of the area, strictly along established profiles. The data acquired using MASW technique was analyzed using seisImager which picked the first arrivals and also the pickwin and Geoplot software. Before acquiring the seismic refraction plot, the first arrival times were picked right before saving the first arrivals.

4. Result and discussion

4.1. VLF Result

4.1.1. Oke–Diya profile 1

This shows the VLF-EM profile and its corresponding Karous–Hjelt pseudo section (Figure 4). This profile is 120 m long, carried out in the EW direction. The profile passes through the centre of the dumpsite from the entrance. The value of filtered real ranges from -10.4 to 20.4 while those of filtered imaginary varied from -9.1 to 7.1 across the profile. There are many points on the profile showing the point of inflection of the filtered real and filtered imaginary which is an indication of a shallow overburden. The only point showing a few conductive zones is around the distance of 50 – 60 m corresponding to the Karous–Hjelt pseudo section.

4.1.2. Oke–Diya Profile 2

] This shows the VLF-EM profile and its corresponding Karous–Hjelt pseudo section (Figure 5). This profile is 130 m long, carried out in the EW direction. The profile passes through the centre of the dumpsite to the extreme end. The value of filtered real ranges from -39.8 to 53.4 while those of filtered imaginary varied from -27.2 to 19.3 across the profile. Along the profile is a high-tension pole at around point 55 – 60 m. There are many points on the profile showing the point of inflection of the filtered real and filtered imaginary at points 30 – 85 m which is an indication of a shallow overburden. The few points showing conductive zone are around the distance of 70 – 100 m corresponding to the Karous–Hjelt pseudo section which is showing red colour, this is an indication of the presence of permeable materials that may allow the passage of leachate to the subsurface.

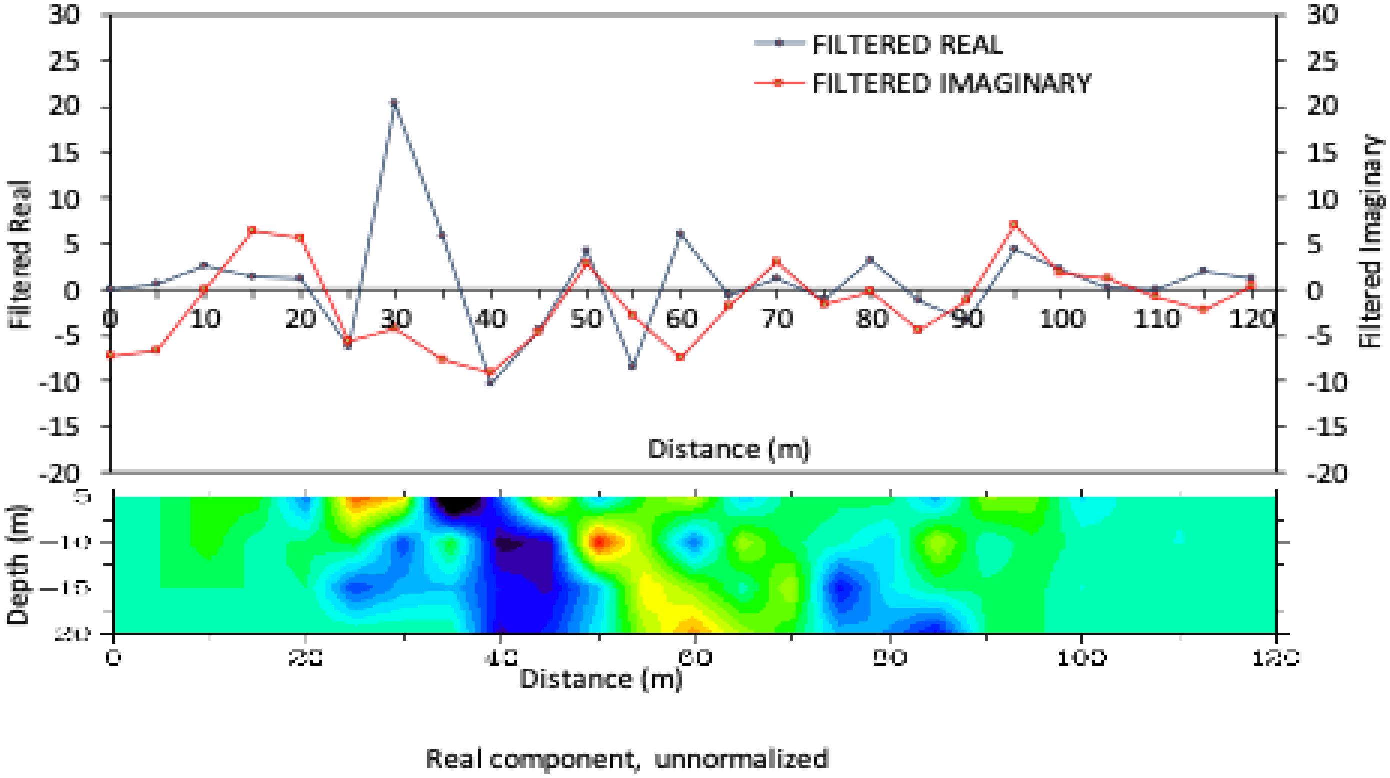

Figure 4. Conductivity profile and its corresponding Karous-Hjelt pseudo section of the VLF-EM at Oke–Diya (Sagamu) profile 1.

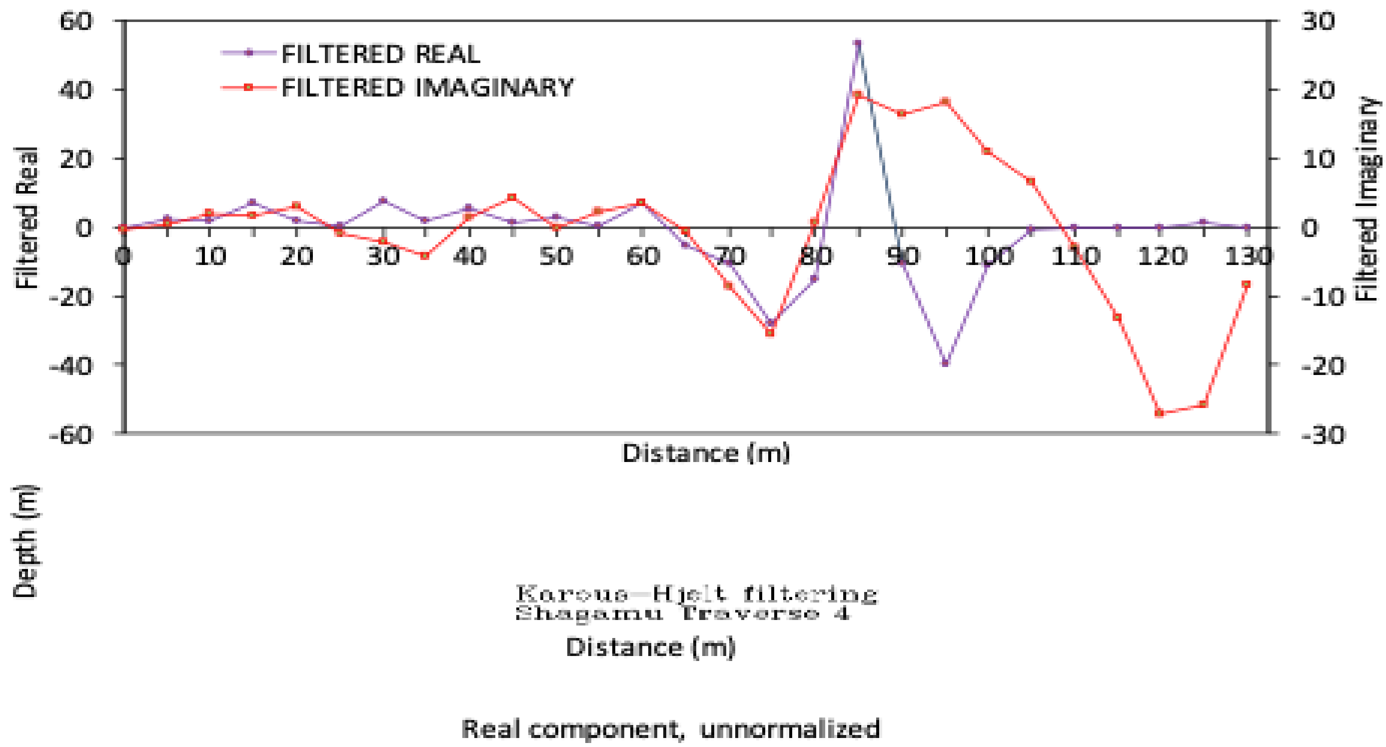

Figure 5. Conductivity profile and its corresponding Karous–Hjelt pseudosection of the VLF-EM at Oke–Diya (Sagamu) profile 2.

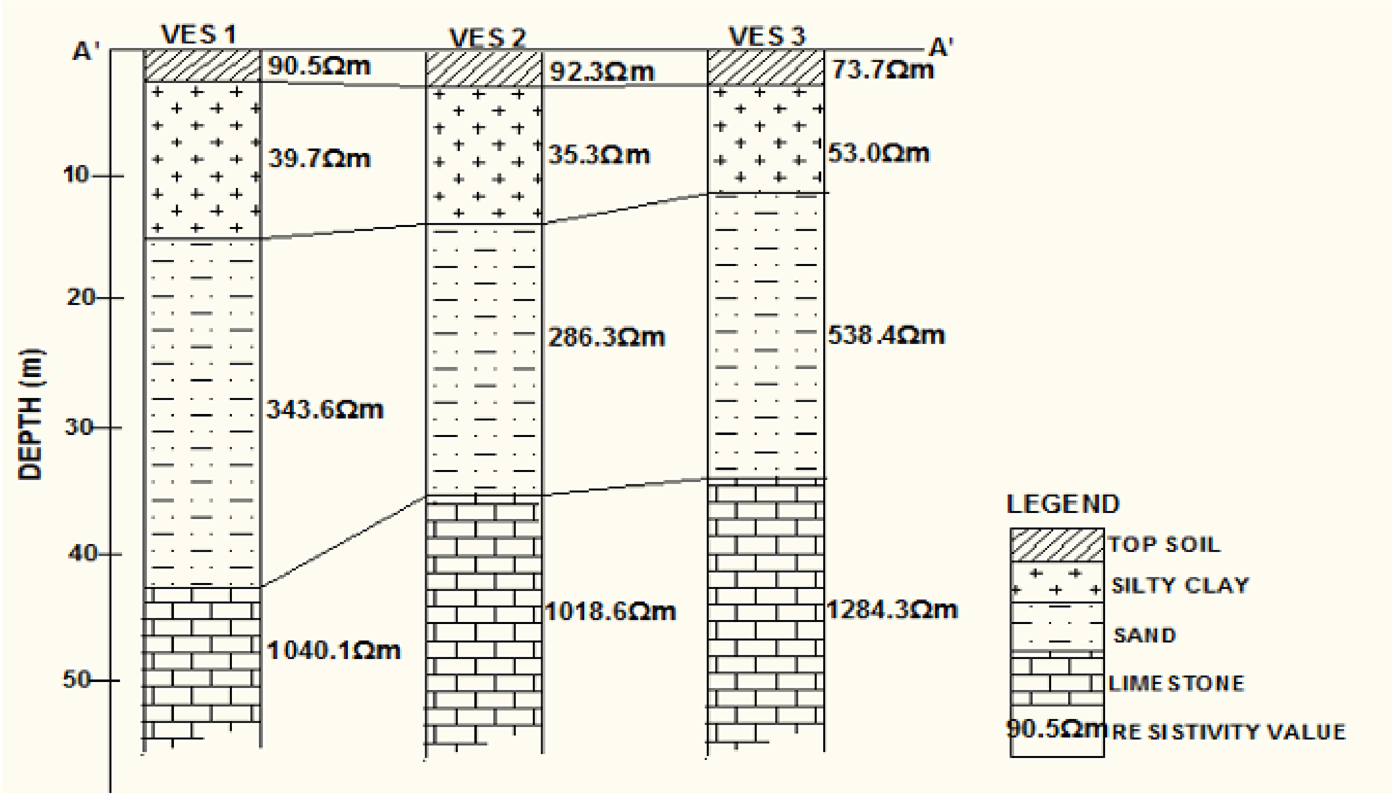

Figure 6. Geo-electric sections for profile 1 (VES 1, 2 and 3).

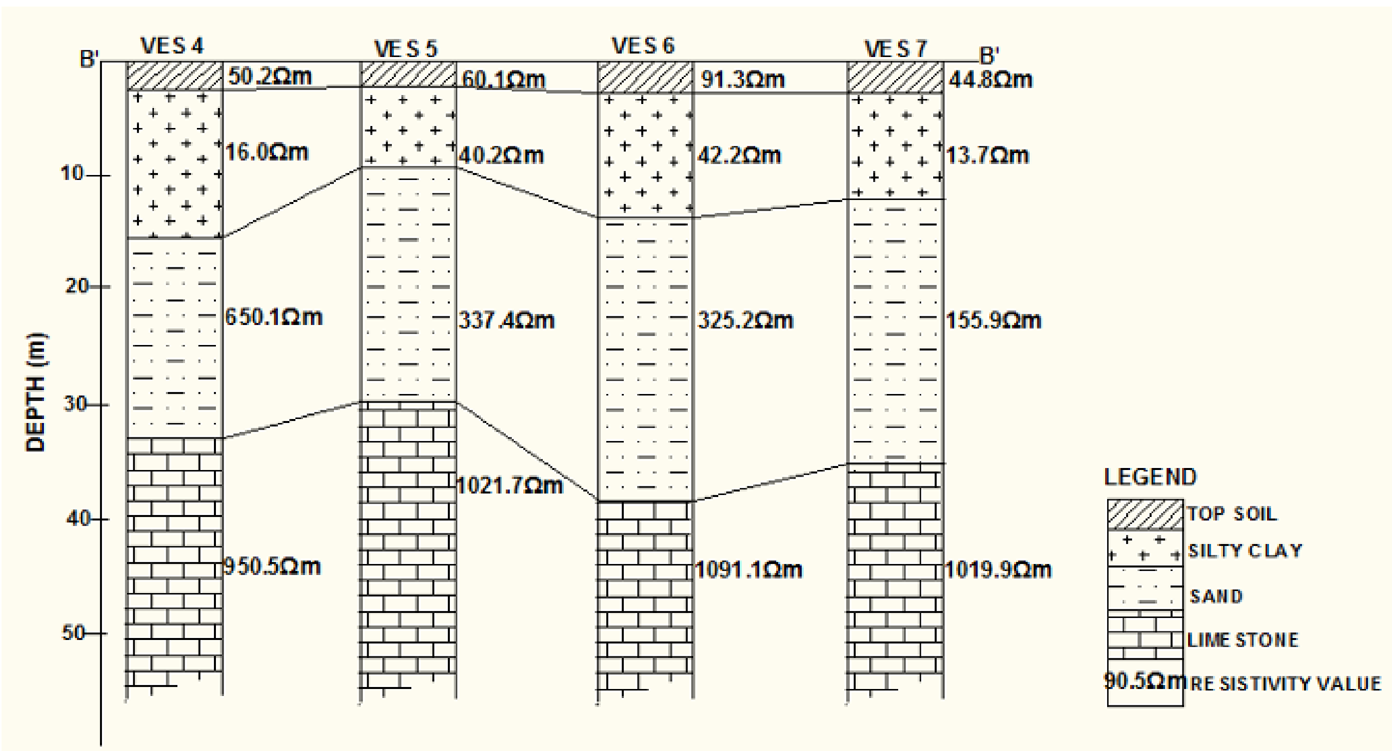

Figure 7. Geo-electric sections for profile 2 (VES 4, 5, 6 and 7).

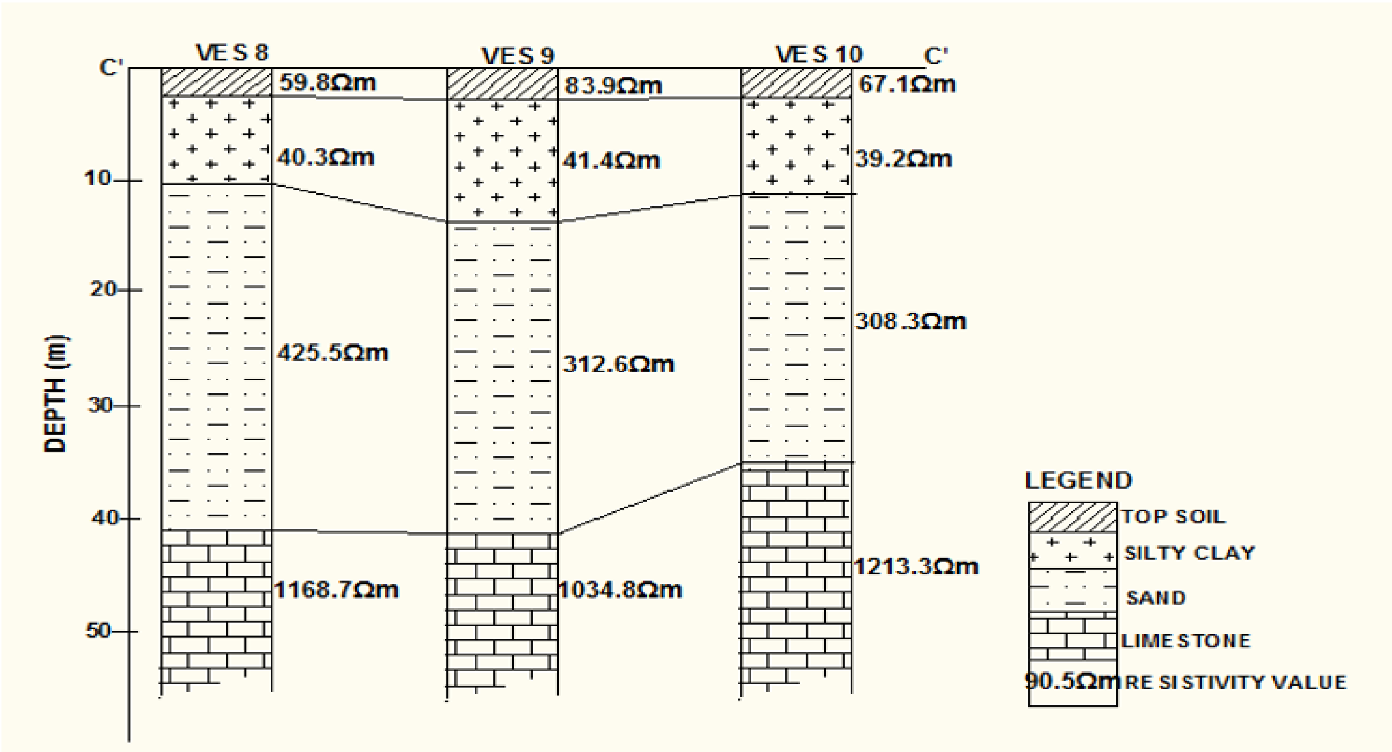

Figure 8. Geo-electric sections for profile 3 (VES 8, 9, and 10).

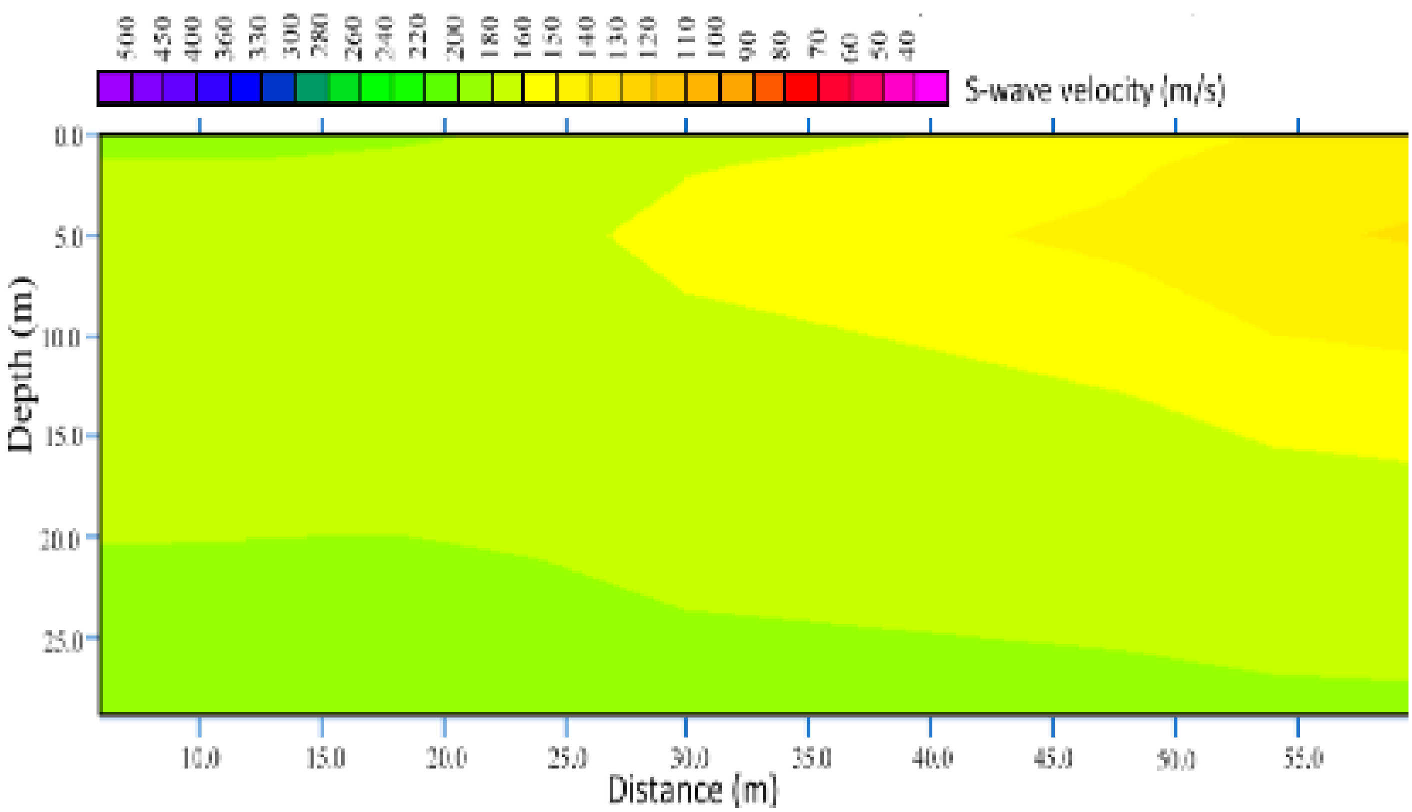

Figure 9. Typical shear wave velocity line 1 at Oke–Diya, Sagamu.

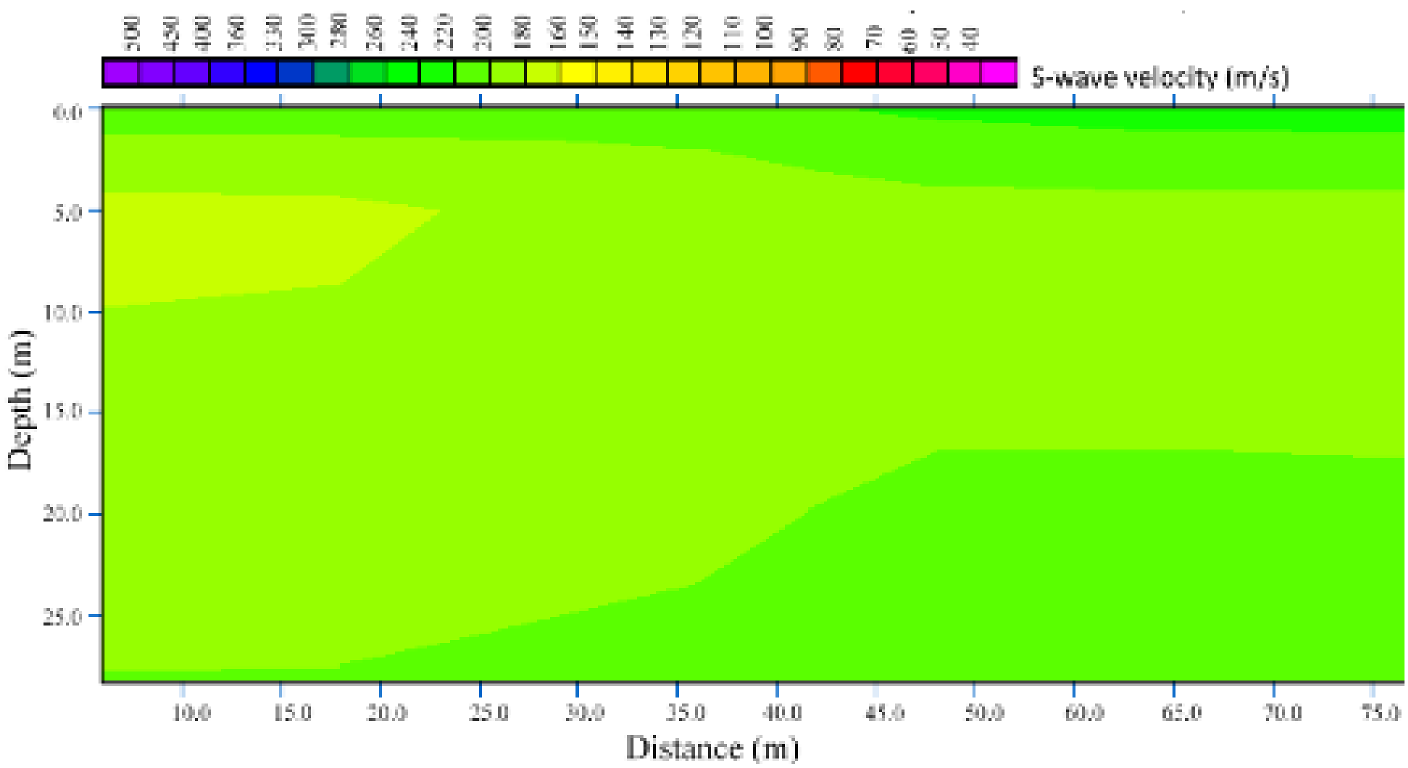

Figure 10. Typical shear wave velocity line 2 at Oke–Diya, Sagamu.

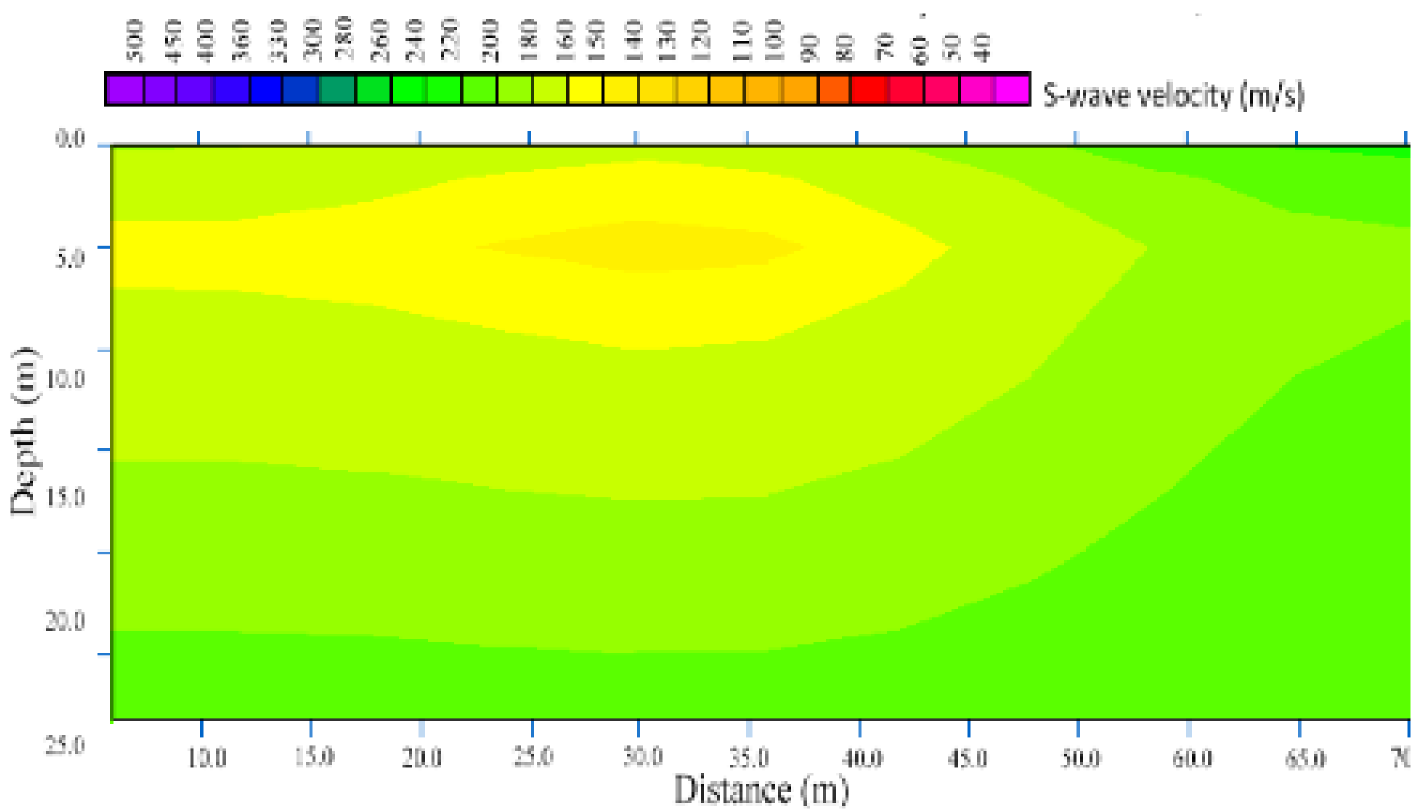

Figure 11. Typical shear wave velocity line 3 at Oke–Diya, Sagamu.

Table 1. MASW Inferred lithology for the Oke–Diya dumpsite.

Depth (m)	Vs (m/s)	Inferred Lithology
0-5	118 -160	Topsoil
5-10	160-180	Sand (partially saturated with leachate)
10-20	180-200	Sandy clay
20-25	>200	Clayey sand

4.2. Results of the electrical resistivity method (Vertical electrical sounding technique)

The acquired VES data was evaluated using the quantitative and qualitative approaches. The WinResist iterative computer programme assisted to generate parameters like the true resistivity, layer thickness and depth which were used to deduce the lithological inferences for the observed pattern of the geo-electric layer section. The results are presented in geo-electric sections below.

Profile 1 (Figure 6) consists of VES 1, 2 and 3. The resistivity of the topsoil ranges between 73.7 to 90.5 Ωm which is inferred as topsoil. The second layer with resistivity values ranges 39.7 to 53.0 Ωm is inferred as silty clay while the third layer of 286.3 to 538.4 Ωm is inferred as sand. The last layer with resistivity values ranges 1040.1 to 1284.3 Ωm is inferred as limestone with an undeterminable thickness extending to infinity. From the inferred lithology, this traverse does not seem to have any sealing material like clay that could prevent leachate from percolating into the underground water.

Along profile two (Figure 7), VES 4, 5, 6 and 7 were correlated to produce a geoelectric section revealing a range of four geoelectric layers inferred from topmost to nethermost as topsoil, silty clay, sand and limestone. The resistivity of the topsoil ranges from 44.8 to 91.3 Ωm. The resistivity of the second layer ranges between 13.7 to 42.2 Ωm. The third layer ranges between 155.9 to 650.1 Ωm. The last layer has resistivity values of 950.5 Ωm to 1021.7 Ωm with an undeterminable depth and thickness. This traverse also does not possess any sealing material like clay that could prevent the percolation of leachate.

Along profile three (Figure 8), VES 8, 9 and 10 were correlated to produce a geoelectric section revealing a range of four geoelectric layers inferred from topmost to nethermost as topsoil, silty clay, sand and limestone. The resistivity of the topsoil ranges from 59.9 to 83.9 Ωm. The resistivity of the second layer ranges between 39.2 to 41.4 Ωm. The third layer ranges between 308.3 to 425.5 Ωm. The last layer has resistivity values of 1034.8 to 1213.3 Ωm with an undeterminable depth and thickness. This traverse also does not possess any sealing material like clay that could prevent the percolation of leachate.

4.3. Seismic refraction method (Multichannel analysis of surface waves) results

The data acquired for the MASW technique was analyzed and presented in shear wave velocity profiles to reveal the lithological units of the study area. Table 1 shows the summary of the results based on the shear wave velocities and the inferred lithology.

The profile is located in the southeastern part of the dumpsite. Figure 9 shows the MASW result for the first profile at Oke–Diya Sagamu. Four layers were delineated from this profile having a shear wave velocity Vs ranging from 139-194 m/s with a maximum depth of about 25 m and density gradient ranges 1.35 - 1.37. The modulus of rigidity value varies between 25.1 - 52.7 MN/m^2. The first layer is characterized by a shear wave velocity of 139 m/s with a thickness of 5m inferred as Topsoil. The underlying layer has Vs value of 170 m/s with a thickness of 5 m delineated to be sandy clay. The third layer has a Vs value of 160 m/s with a thickness of 10 m which extends to a depth of 20 m and is inferred to be sand. The fourth layer has a Vs value of 194 m/s which extends to a depth of 25 m with a thickness of 5 m and is inferred to be sandy clay. The profile cannot be taken to have materials that can protect the aquifer from being polluted.

The profile is located at the northwest part of the dumpsite. Figure 10 shows the result of the MASW for this profile. Three layers were delineated with shear wave velocities ranging between 165 – 208 m/s with a maximum depth of 25 m/s and density gradient of 1.34 - 1.43. The modulus of rigidity value varies between 16.5 - 60.5 N/m^2. The first layer is characterized by a shear wave velocity of 165 m/s with thickness of 10 m inferred as Topsoil. The underlying layer has a Vs value of 180 m/s with thickness of 5 m is indicative of a sandy clay material extending to a depth of 5 m. The last layer also has a Vs value of 208 m/s extending to a depth of 25 m with 10 m thickness. The layer is delineated to be clayey sand taken as a fairly competent material due to some percentage of sand in the layer which cannot hold the infiltration of leachate.

The profile (Figure 11) is taken kilometres away from the site. It serves as the control profile for other profiles. The MASW processed result for this profile is presented in Figure 11. Three layers were delineated on this profile with shear wave Vs ranges 155 - 227 m/s with depth ranges 0 – 25 m and density gradient of about 1.35 - 1.40. The modulus of rigidity value varies between 27.3 - 72.1 N/m^2. The first layer is characterized by Vs of 155 m/s with thickness of 10 m inferred to be Topsoil. The second layer has a Vs value of 183 m/s with thickness of 15 m is indicative of sandy clay material. The last layer has Vs value of 227 m/s which extends to a depth of 25 m indicating a clayey sand material which is not a completely competent material for the purpose of waste disposal facilities.

4.4. Evaluation of the integrated methods

The purpose of these integrated geophysical methods is to assess the subsurface formation of the study area to detect if there are geological underlain materials that could serve as a seal to prevent the percolation of leachate on and around the waste disposal

Table 2. Summary of the Integrated methods.

Depth (m)	Vs(m/s)	Inferred lithology	Resistivity(Ωm)	Depth(m)	Inferred lithology
0-5	118-160	topsoil	44-88	1.2-2.7	Topsoil
5-10	160-180	sand	13-53	4.2-10.5	Silty clay
10-20	180-200	Sandy clay	155-538	11.7-41.4	Sand
20-27	>200	Clayey sand	950-1284	-	Limestone

facility. From the summary of the methods in Table 2, it shows that the methods corroborated each other and gave layer-to-layer information. The inferred lithology of the study area reveals topsoil, sand (partly saturated with leachate), silty /sandy clay and limestone. The shear wave velocity was deduced from the MASW result to determine the sediment with depth as well as the retentive capacity of the available underlain materials. The rigidity moduli range between 25.1 - 60.5 N/m^2.

Table 2 shows the inferred lithology of the study area using the integrated methods. From the results, the methods corroborated each other.

5. Conclusion

In this research work, three geophysical methods were integrated involving very low-frequency electromagnetic method which was adopted as a reconnaissance survey to locate possible conductive zones. After, the electrical resistivity method and MASW; a technique of seismic refraction method was carried out. These were done to successfully characterize the subsurface in order to adjudge the leachate curtailment capacity of the dumpsite and its environs. The data from the fieldwork exercise aided in getting subsurface information about the study area.

At Oke–Diya dumpsite (Sagamu), the result of the 20 VES revealed four geoelectric layers; topsoil, silty clay, sand and limestone with resistivity values ranging from 26.1 - 90.5 Ωm, 16 - 155.7 Ωm, 155.9 - 445.5 Ωm respectively. Seismic refraction method (MASW) inferred topsoil, sand, sandy clay and clayey sand with shear wave velocity ranging between 118 – 160 m/s, 160 - 180 m/s, 180 - 200 m/s and > 200 m/s. Results from the integrated methods at Oke-Diya dumpsites show that the underlain materials are not competent to serve as seals to prevent the migration of leachate into the subsurface. The available materials are permeable materials which are not recommended underlain geological material that could serve as seals to protect the groundwater. The available materials could harbor leachate and thus pollute the environment at large. Although from the result so far, the entire parts of the dumpsite are not polluted yet, especially the Northeastern part, leachate will gradually migrate to the entire part as time goes on. Several activities are going on at the dumpsites, so it is advised that the dumpsites be evacuated and a well-engineered waste disposal facility should be constructed. Finally, geotechnical investigation is also recommended on the dumpsite. The soil samples can be taken at various depth to further the research on the compaction strength of the underlain materials.

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