Subsurface characterization using electrical resistivity and MASW techniques for suitable municipal solid waste disposal site

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Abstract

Investigation of the subsurface becomes a compulsion before waste disposal site is developed. The content of this paper presents integrated geophysical methods in a basement complex terrain, southwestern Nigeria. The dumpsite is located at Oke Saje, Abeokuta, in Ogun state. This was done to investigate the leachate curtailment capacity (LCC) of the existing dumpsite by characterizing the subsurface. A clay overburden thickness of about 15 m which acts as leachate filter is a standard for determining the LCC of a dumpsite. Prior to this work, there is no documented record that such investigation had been done to reveal the LCC before establishment of the dumpsite. Vertical electrical sounding (VES), 2D electrical resistivity tomography (2D-ERT) and multi-channel analysis of surface waves techniques were adopted for the investigation on the existing dumpsite. Eighteen VES was carried out using Schlumberger configuration at 5–10-m intervals to obtain resistivity values and the respective lithological units of the subsurface and three electrical resistivity imaging using dipole–dipole array. MASW techniques were later carried out to ascertain the underlain materials by determining seismic wave arrival times which were processed to obtain the shear wave velocities (SWVs) of the subsurface. The 2D-ERT revealed clearer features of the subsurface as topsoil, weathered, fractured and fresh basement. The result of the VES revealed topsoil with resistivity values ranging from 18 to 1381 Ωm , weathered layer (clay) with resistivity values 15–84 Ωm , fresh basement and fractured layer with resistivity values 192/366–5585 Ωm . The thickness of the clay deposition ranges from 1.8 to 18.5 m. The MASW result using SWVs revealed topsoil, sandy clay, clayey sand and clay with rigidity modulus ranging between 42.4 and 160 N/m^2 at the depth of 30 m. The combined methods carried out at the dumpsites revealed the same lithological units. The waste disposal site is said to have a good LCC due to the presence of clay overburden thickness but not up to 15 m in some parts of the dumpsite.

Keywords Multi-channel analysis of surface waves · Vertical electrical sounding · Leachate curtailment capacity · Lithological units · Waste disposal site

1 Introduction

Over the years, dumpsites have been identified as one of the key threats to groundwater resources. Considering the population of developing country like Nigeria, there is massive increase in the rate of municipal waste generated on a daily basis [1, 17, 23]. The common waste disposal facility we have is the uncontrolled open dumpsite

which has appeared to be a major source of environmental pollution, especially groundwater. Perpetually, wastes are generated continually and disposed indiscriminately in rivers and dumps without recourse to the underground environment, local geology and their proximity to the living quarters [6, 33]. Leachate generated by decomposed wastes happens to be part of groundwater flow system as soon as it reaches the water table. Poor management

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of municipal solid waste materials leads to potentially devastating environmental and health hazards. Among health hazards that have resulted from lack of an effective disposal system are periodic epidemic and communicable diseases [4, 12]. Leachate migration in an open dumpsite involves simple advection which is the movement of contaminants in porous media along with flowing groundwater at the seepage velocity. It might also involve diffusion which is a molecular mass transport process in which solutes move from areas of higher concentration to areas of lower concentration. The ability to dependably predict the rate and direction of groundwater flow and contaminant transport is critical in planning and implementing groundwater remediation [2]. The need to investigate the available underlain geological materials arises in establishing a dumpsite to avoid groundwater contamination as permeable geological formations permit rapid movement of leachate unlike in less permeable formations [3, 27]. Based on different physical principles, some of the geophysical techniques can be used as non-destructive method for subsurface investigation. Methods like seismic refraction, ground penetrating radar and electrical resistivity have been found useful to discover subsurface information for exploration purposes. The electrical resistivity method is mostly used in environmental studies because the electrical resistivity of the earth materials is determined by environmental factors such as fluid, temperature, degree of fracture, porosity, rock type, permeability, grain size and the extent of weathering of such medium [15, 29]. Although there are limits to the information each method can be obtained, the integrated geophysical methods can produce rapid and profitable results. Electrical resistivity method has been adopted by various researchers like groundwater investigations which include the mapping of depth, aquifer thickness, location of groundwater migration paths as well as contaminant zones like salt water intrusion and leachate infiltration as they are electrically conductive [14, 29]. The 2D electrical resistivity tomography method is also an effective technique in subsurface study and has the capability of exploring and can identify subsurface characteristics [32]. It as well measures the resistivity distribution of the subsurface formations and anthropogenic contamination [20]. The MASW are also a non-destructive seismic refraction method for assessing stiffness of the subsurface. It is easy to perform and accurate as it gives insight to the subsurface structure, the velocities of body waves, the thickness of each layers and underlain geological materials [18, 22]. The MASW method is efficient in its capability to assess the modulus of the underlain geological materials using the shear wave and primary wave velocities. The acquired result of the technique is dependable under the company of greater modes of surface waves and diverse cultural noise. Due to some

intrinsic properties of subsurface wave, resolution of the result is restricted by the size of the anomaly [5]. MASW being a surface wave technique have been adopted in geomorphologic studies and a tool for characterizing near surface layers, and the result shows the accuracy of the technique [13]. MASW can also provide information regarding variations of elastic properties in the vertical direction.

Integrated geophysical methods have been applied by many researchers to characterize the subsurface and had yield a great result [8, 11, 16, 24]. Integrated geophysical methods are suitable and capable of characterizing the subsoil, the contaminant pathway and waste materials compatibility [7, 10, 16, 25]. Many factors had contributed to groundwater and environmental pollution arising from municipal solid waste disposal. These include inappropriate siting of the disposal site, such as not studying the underlain geological material to ascertain its ability to curtail leachate, and presence of fractures and joints could also be a factor as it serves as conduit for leachate infiltration. There are no records to show that studies to check the natural underlain geological materials were done by the government before the establishment of the investigated dumpsite, which calls for the need to carry out this work. The combination of the methods gave assenting information on the subsurface structural features of the study area. The objective of this research work is to use integrated geophysical method to characterize the subsurface of the existing dumpsite to ascertain its suitability on its ability to curtail leachate generated on the dumpsite.

2 Geology of the study area

The study area is composed of metamorphic rocks of the gneiss family which are grouped into porphyroblastic gneiss, quartzite schist, banded gneiss and biotite–hornblende granite. The porphyroblastic gneiss covers modest percent of the area and was established at the central part of the area. Porphyroblastic gneiss is not completely foliated as the light band forms larger phenocryst that is aligned in the same direction but not completely stretched. They include both mafic and felsic minerals like quartz, biotite, muscovite and plagioclase feldspar. In addition, the quartzite schist is mainly composed of quartz with some mica and/or tourmaline. They constitute good aquifer whenever they are found, especially in basement areas. The banded gneiss is foliated metamorphic rocks, and the felsic and mafic minerals form a distinct band of colors from which the name banded gneiss is derived. They occur in bands of dark- and light-colored minerals. They are highly rich in quartz, biotite, muscovite and feldspar.

The hornblende–biotite granite occurs in the eastern part and also the western part of the study area [9, 26, 28].

The location of the study area is at Oke Saje, Abeokuta, in the Southwestern part of Nigeria with latitude $7^{\circ} 05' - 07^{\circ} 07' \text{ N}$ and longitude $03^{\circ} 21' - 03^{\circ} 24' \text{ E}$ with prominent settlement. A major road from NNPC mega station at Magbon close to Kuto in Abeokuta cut across the map of the study area, and there are also various footpaths and minor roads that lead to the whole area. The topographic map and the geological map of the area are shown in Figs. 1 and 2.

3 Materials and method

Integrated geophysical exploration methods comprising of electrical resistivity method (vertical electrical sounding and 2D electrical resistivity tomography) and multichannel analysis of surface waves (MASW) techniques of the seismic refraction method were used for the study. The methods were adopted for characterizing the subsurface for the suitability of the waste disposal site.

Fig. 1 Topographic map of the area

Fig. 2 Geological map of southwestern Nigeria showing the study area

3.1 Fundamental principles of electrical resistivity method

Electrical resistivity method basically utilizes current from a direct commutated or low-frequency alternating current of electromotive force to depict the earth content, and according to Ohm's law, a proportional relationship exists between the resulting potential difference (V) between the potential electrodes pair and the magnitude of current (I) transmitted via the current electrode with the constant of proportionality of these two parameters being the resistance (R) of the earth material along the path followed by the current. The distribution of current and voltage in a homogenous earth is shown in Fig. 3.

Mathematically, Ohm's law can be expressed as:

$$V \propto I \text{ or } V = IR; \text{ or } R = V/I.$$

Resistivity is the ability of a material to impede the flow of electrical current through it [19]. Mathematically, the resistivity ℓ is of a cylindrical material to its cross-sectional area A , length l and resistance R to current flow through the material. The system international unit of ℓ is Ωm .

$$\ell = \frac{\delta R \delta A}{\delta L}$$

3.2 Multichannel analysis of surface waves (MASW)

The MASW technique of the seismic refraction method is very useful in acquiring the modulus of base underlain geological material and subgrade materials. It employs the dispersive properties of surface waves. Dispersion is the process in which the phase and group velocities of a surface wave are dependence on the frequency. In the case of a layered media, the frequency of a surface wave is correlated with the elastic and physical properties of such material. The wave propagates through diverse depths and a certain phase velocity. The major equipment used for the survey which is the geophones records a wave train produced by waves of different frequencies arriving at different times. The amplitudes recorded are function of the frequencies produced within the layered media. Since surface waves are generated as a result of P and S waves' interference, the suitable dispersion curve is selected from the multichannel shot record of the propagating surface waves. It is afterward inverted to obtain the P and Vs wave velocities as a function of depth [21]. The dispersion curve gives an insight of the different modes or harmonics of the surface wave as it propagates through a particular media.

Fig. 3 Distribution and current and voltage in a homogenous earth

4 Data acquisition

The electrical resistivity methods adopted are vertical electrical sounding using Schlumberger array because of its ability to observe variation of resistivity with depth and 2D electrical resistivity tomography (ERT). Eighteen vertical electrical sounding profiles were carried out right on the dumpsite and meters away from it that serves as control for comparing the result (data acquisition map shown in Fig. 4). ABEM resistivity meter and its accessories were used for the survey to acquire the apparent resistivity of the probed medium at appropriate distances as space permit. In addition, electrical resistivity imaging survey was also carried out using the dipole–dipole array both and outside the dumpsite. This was done to give clearer information of the subsurface and lithological delineation using the same equipment.

The instruments used for the MASW techniques are ABEM Seismograph Terralock mark8 weight drop, metal plate, geophones, GPS and connecting cables.

The connections were made to the seismograph which recorded the signals by the array of geophones, and energy was discharged through the weight drop hammer (50 kg) and the 0.5-mm-diameter plate. The 12 V battery supplies energy to the seismograph. The 24 geophones were laid out in a split spread approach that the end was connected to the hammer via the cable. The spacing between each geophone was 3 m, 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 the intermediate shootings. The data were taken adequately and saved on the seismograph to be accessed for processing and interpretation after the field work. The process was repeated so as to acquire lots of data at various offsets of 3 m apart.

Fig. 4 Data acquisition map of the study area showing the points of data acquisition of the VES and 2D ERT

5 Data processing

The data acquired for the VES were firstly plotted on a log–log graph sheet where the apparent resistivity curves were plotted and smoothened and later standardized using partial curve matching approach. The layering parameters obtained from the curve matching were subjected into the WinResist software for iteration until an acceptable model was achieved. The layered parameters from the iterated curves were summarized and presented in geoelectric sections to simulate a cross-sectional view of the subsurface geology of the established traverses. Making of pseudosection on the adopted 'DIPPRO 4.1' software from resistivity tomographic data requires the input of the array adopted, number of stations, station starting number, station number increment and the layer model. The standardization and validation of the pseudosection were done using the second-order inversion with five cycles of iteration to produce the resulting 2D resistivity structure which was interpreted using relative distribution of resistivity contour values. Contour values within a specific resistivity range correspond to a geological unit with distinct electrical properties.

The MASW data acquired were analyzed using SeisImager software; the pickwin of the SeisImager was used to pick the first arrival of the primary seismic wave. The results obtained were processed to indicate the subsurface shear wave velocity (V_s) and the primary wave velocity (V_p) with the depth and thickness of each layer. The stiffness property of the soil to obtain the retentive capacity of the underlain materials called the modulus of rigidity (μ) was estimated using the equation [30, 31]

$$\mu = V_s^2 \rho \quad (1)$$

where ρ is the density of the medium and μ is the modulus of rigidity.

6 Results and discussion

6.1 VES results

The table presented as (Table 1) summarizes the layering parameters of the eighteen (18) iterated vertical electrical sounding curves obtained in the study area.

Table 1 Summary of the obtained layered parameters

Ves no.	Layer number	Resistivity (Ω m)	Thickness (m)	Depth (m)	Curve type	Inferred lithology
1	1	31	2.5	2.5	A	Topsoil
	2	112	4.8	7.3		Sandy clay
	3	1737	–	–		Fresh basement
2	1	54	1	1	A	Topsoil
	2	128	2.8	3.8		Sandy clay
	3	1078	–	–		Fresh basement
3	1	77	1.1	1.1	H	Topsoil
	2	42	8.0	9.1		Clay
	3	326	–	–		Fresh basement
4	1	58	1.7	1.7	H	Topsoil
	2	26	7.7	9.4		Clay
	3	690	–	–		Fresh basement
5	1	61	2.5	2.5	H	Topsoil
	2	15	5.0	7.5		Clay
	3	1217	–	–		Fresh basement
6	1	105	0.4	0.4	KH	Topsoil
	2	782	1.8	2.2		Laterite
	3	192	21.6	23.8		Fractured basement
	4	1340	–	–		Fresh basement
7	1	272	0.4	0.4	KH	Topsoil
	2	1545	1.1	1.5		Laterite
	3	58	5.2	6.7		Clay
	4	2400	–	–		Fresh basement
8	1	18	0.4	0.4	A	Topsoil
	2	71	18.5	18.9		Clay
	3	615	–	–		Fresh basement
9	1	105	2.4	2.4	H	Topsoil
	2	36	10.4	12.8		Clay
	3	968	–	–		Fresh basement
10	1	254	0.8	0.8	H	Topsoil
	2	25	6.1	6.9		Clay
	3	604	–	–		Fresh basement
11	1	150	1.5	1.5	H	Topsoil
	2	23	5.7	7.2		Clay
	3	1529	–	–		Fresh basement
12	1	220	1	1	H	Topsoil
	2	22	4	5		Clay
	3	706	–	–		Fresh basement
13	1	1381	1.2	1.2	H	Topsoil
	2	150	10.2	11.4		Sandy clay
	3	1174	–	–		Fresh basement
14	1	623	0.5	0.5	KH	Topsoil
	2	1477	0.8	1.3		Laterite
	3	84	4.7	6.0		Clay
	4	827	–	–		Fresh basement
15	1	1082	1.3	1.3	H	Topsoil
	2	64	4.7	6.0		Clay
	3	1607	–	–		Fresh basement

Table 1 (continued)

Ves no.	Layer number	Resistivity (Ω m)	Thickness (m)	Depth (m)	Curve type	Inferred lithology
16	1	90	1.6	1.6	H	Topsoil
	2	26	2.5	4.1		Clay
	3	2493	–	–		Fresh basement
17	1	102	1.4	1.4	H	Topsoil
	2	23	2.9	4.3		Clay
	3	5585	–	–		Fresh basement
18	1	198	1.4	1.4	H	Topsoil
	2	31	3.7	5.1		Clay
	3	1231	–	–		Fresh basement

Generated parameters include the true resistivity value, layer thickness and depth; all of which quantitatively and qualitatively aid the designation of meaningful lithological inferences for the observed pattern of geoelectric layers succession.

6.2 Geoelectric section

Summarized Table 1 was used to obtain the geoelectric section. The lithology revealed 3 to 4 lithology, namely topsoil, weathered layer (clay/sandy clay) and fractured/fresh basement based on the values of their corresponding resistivity. The study area is majorly characterized with low and high resistivity values at diverse depths. The zones with low resistivity correspond to high conductive materials, and zones with high resistivity values correspond to low conductive materials.

The geoelectric sections shown in Fig. 5a–c are the interpreted result of the vertical electrical sounding which revealed basically three to four geoelectric layers which are topsoil, weathered layer (which is mostly composed of clay), fractured/fresh bedrock with their respective resistivity values. The dominant curve type is the 'H' type which covers up to 60 percent of the entire study area. Qualitative interpretation of the VES results delineates a clay-dominated overburden partially capped by sandy clay within and outside the dumpsite. The predominance of clay and sandy clay directly beneath the topsoil would effectively impede the downward infiltration of leachate into the subsurface and environment at large. On this basis, bulk of the contamination is predicted to remain restrained to the topsoil (as shown in the isoresistivity map of the topsoil in Fig. 6), while the thick occurrence of clay inevitably diminishes the specific yield of the weathered layer. The clay does not only serve as a seal but also filters the leachate produced by the waste, and during the process of evaporation, the liquid portion of the leachate vanishes.

6.3 2D ERT result

The processed data of the 2D ERT are presented in pseudosections with colorations indicating the resistivity units with distinct resistivity contour range.

The 2D ERT result also delineates almost the same lithology with VES showing the availability of clay deposition in the probed site. It is shown that there is correlation between the two methods as it both infers top to bottom, contaminated topsoil, weathered layer (mostly composed of clay), partially weathered/fractured bedrock and the fresh basement. It can be concluded from both methods that larger section of the overburden is mostly composed of impermeable clay on the western part of the study area. In particular, the interpreted 2D resistivity structures along the various traverses delineate the disposition and geometry of lithological units constituting the heterogeneous weathered layer. The part of the study area with the presence of clay above 15 m envisaged areas are free from leachate pollution as the clay would serve as seal, preventing the aquifer from contaminants. Thus, leachate curtailment capacity can be inferred from both results based on the presence of clay. It can be apparently shown that a strong correlation exists between both results. Integration of the two results infers from top to bottom, a contaminated topsoil, weathered layer (majorly constituted by clay), partially weathered/fractured bedrock and the fresh basement. It can be concluded from both methods that larger section of the overburden is mostly composed of impermeable clay on the western part of the study area. In particular, the interpreted 2D resistivity structures along the various traverses delineate the disposition and geometry of lithological units constituting the heterogeneous weathered layer. The part of the study area with the presence of clay above 15 m envisaged areas are free from leachate pollution as the clay would serve as seal, preventing the aquifer from contaminants. Thus, leachate curtailment capacity can be inferred from both results based on the presence of clay. It can be apparently shown that a strong correlation exists

Fig 5 a–c The geoelectric sections of the study area

Fig. 6 Isoresistivity map of the topsoil

between both results. Integration of the two results infers from top to bottom, a contaminated topsoil, weathered layer (majorly constituted by clay), partially weathered/fractured bedrock and the fresh basement (Fig. 7a–c).

6.4 MASW results

Three profiles of MASW are carried out in the study area, both near and far off the dumpsite. MASW were adopted to measure shear wave velocities with a plan to establish the lithological units and the retentive capacity of the underlain geological materials. The V_s values were used to characterize the subsurface layers (Table 2).

6.4.1 MASW line 1

The line is located at the southeast part of the dumpsite. Figure 8 shows the MASW seismic result obtained on the profile. Four seismic layers were delineated at the dumpsite area with shear wave velocities distribution ranging between 165 and 350 m/s with maximum depth of about 27 m and density gradient ranges from 1.35 to 1.47. The modulus of rigidity value varies between 42.4 and 160 MN/m². The first layer is characterized with shear wave velocity of 174 m/s with thickness of 5 m inferred to be topsoil. The second layer is an indicative of clayey sand material with V_s value of 250 m/s having a thickness of 5 m which extends to the third layer delineated to be clay with V_s value of about 344 m/s and thickness of 10 m which is suspected to be a competent material. The fourth layer beneath is suspected to be a competent underlain material having a

Fig. 7 a–c 2D dipole–dipole electrical resistivity imaging for traverses 1, 2 and 3. The pseudosection is showing the inferred lithology and their resistivity values

high shear wave velocity of 350 m/s, and it is delineated to be a clay material with a thickness of 17 m. The layer delineated is said to have good competency based on the V_s range of values.

6.4.2 MASW line 2

The line is located at the southeast part of the dumpsite. Figure 9 shows the MASW seismic result for this line. Four seismic layers were delineated on this line at the dumpsite area with shear wave velocities distribution ranging between 178 and 330 m/s with maximum depth of about 27 m and density gradient ranges from 1.36 to 1.46.

(c)

Fig. 7 (continued)

Table 2 The MASW inferred lithology obtained for the Oke Saje, Abeokuta

Depth (m)	V _s (m/s)	Inferred lithology
0–5	144–165	Topsoil
5–10	180–200	Sandy clay
10–20	200–250	Clayey sand
20–27	250–350 and above	Clay

The modulus of rigidity value varies between 83.8 and 149.7 MN/m². The first layer is characterized with shear wave velocity of 250 m/s with thickness of 5 m inferred to be the topsoil. The second layer is an indicative of material with V_s value of 250 m/s at the thickness of 10 m inferred to be clay material. The third layer extends to the depth of about 25 m with V_s value 327 m/s having thickness of 10 m delineated to be a competent material inferred to be clay material. The fourth layer is also characterized by a high V_s value of about 340 m/s which extends to the depth of 27 m at about 2 m thickness. The layer is taken to possess a good competent material that serves as a mineral seal.

6.4.3 MASW line 3

The line is taken at kilometers away from the dumpsite. It serves as the control line for other lines on the site. The result of the MASW is presented in Fig. 10. Three layers were delineated in line with shear wave velocities V_s distribution that ranges from 177 to 350 m/s with maximum depth of about 27 m and density gradient between 1.34 and 1.47. The modulus of rigidity value varies between 64.7 and 160 MN/m². The first layer is characterized with shear wave velocity of 177 m/s at the thickness of 10 m as the topsoil, and the second layer is an indicative of material having V_s value of 215 m/s inferred to be clayey sand with a thickness of 10 m delineated to be a fairly competent mineral seal. The underlain layer at depth of 25 m has a high value of 348 m/s with 5 m thickness inferred as clay material. The layer is said to possess a competent sealing material for the purpose of waste disposal which is unlikely to pollute the groundwater and environment at large (Fig. 11).

Fig. 8 Typified shear wave velocity line 1 at Oke Saje, Abeokuta

Fig. 9 Typified shear wave velocity line 2 at Oke Saje, Abeokuta

6.5 Comparison of the methods

The aim of these integrated methods is to characterize the subsurface and see whether there are natural geological underlain materials that could curtail the infiltration of leachate into the subsurface and probably terminates the aquifer. Using the VES and 2D ERT, the inferred lithology of the study area reveals topsoil, sand, weathered layer (which is mostly clay), fresh/fractured bedrock. Integrating with the MASW, the technique was used to estimate the shear wave velocity for characterizing the subsurface and the inferred sediment with the depth, also to determine the retentive capacity of the available materials. The

shear wave velocity gradients obtained were consistent with the VES and ERT results obtained. And the deduced rigidity modulus between 42.4 and 160 N/m² shows that the clay material has a moderate retentive capacity. All the acquired results from the methods revealed the presence of clay (Table 3) which is a good and acceptable material that could serve as seal to prevent leachate from contaminating the subsurface.

Fig. 10 Typified shear wave velocity line 3 at Oke Saje, Abeokuta

Fig. 11 A typical raw data of MASW measurement by the seismogram

Table 3 Summary of the integrated geophysical methods

Depth (m)	V_s (m/s)	Inferred lithology	Resistivity (Ω m)	Depth (m)	Inferred lithology
0–5	144–165	Topsoil	14.6–525.5	0.5–2.3	Topsoil
5–10	180–200	Sandy clay	8.5–183.4	2.7–22.5	Weathered layer (clay)
10–20	200–250	Clayey sand	283.3–2781	–	Fresh bedrock
20–27	250–300	Clay	32.6–562.2	–	Fractured bedrock

7 Conclusion

The integrated geophysical methods revealed that there is presence of a natural geological underlain material that could curtail leachate from contaminating the subsurface and the environment. The methods gave information about the resistivity distribution, thickness variation and the retentive capacity of the materials. The presence of clay deposition is an indication that the subsurface is protected even though the fact that the topsoil is contaminated is inevitable. The available clay from the combined results shows that the clay is not evenly distributed throughout the study area; the clay is not up to the required 15 m thickness (which is a standard for suitable landfill) in the southeastern part of the dumpsite, so it can be considered not suitable for the purpose of waste disposal. But the northwestern part of the dumpsite has a clay thickness greater than 15 m which makes the overburden protected from contamination. It is recommended that thorough study of any waste disposal be done before operation so as to know whether the aquifer is naturally sealed or not and a site without impermeable material like clay should be discouraged. In a situation where there is no clay deposition either naturally or artificially deposited, those locations are prone to groundwater pollution as the underlain materials will serve as pathways for leachate. Therefore, it is essential to carry out geophysical investigations before siting waste disposal facility.

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Compliance with ethical standards

Conflict of interest The authors declared they have no conflict of interest.

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