IOP Conference Series: Materials Science and Engineering

Forensic assessment on landfills leachate through electrical resistivity imaging at Simpang Renggam in Johor, Malaysia

To cite this article: M S I Zaini *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **669** 012005

Forensic assessment on landfills leachate through electrical resistivity imaging at Simpang Renggam in Johor, Malaysia

M S I Zaini[1], M F Ishak[1] and M F Zolkepli[1]

[1] Faculty of Engineering Technology, Universiti Malaysia Pahang, 26300 Kuantan, Pahang, Malaysia

fakhrurrazi@ump.edu.my

Abstract. From years to years, the usage of electrical resistivity imaging (ERI) method dominated by geophysicist has increased tremendously in the application of geotechnical engineering owing to the effectiveness of the method in term of time, cost and also data coverage. The forensic assessment performed with respect to the particular reference to ERI in assessing the landfills leachate at Simpang Renggam, Malaysia. There were two lines of ERI performed at the study area using ABEM Terrameter LS 2 set of equipment based on Schlumberger protocol. Furthermore, the analysis made based on the electrical resistivity anomaly managed to detect the presence of chemical contaminants in the soil with particular reference to the chemicals resistivity values which was associated to low resistivity anomaly. Besides, the heterogeneous of the subsurface material presented in the paper by using integrated ERI analysis enabled forensic assessment of the leachate. The leachate from the landfills was believed to occur owing to the failure of the systems in accommodating and treating the waste which became worst with the present of heavy rainfall. In retrospect, the ERI result was applicable to be adopted in detecting the leachate and thus can assist the authority in taking immediate measure to prevent the frequent water disruptions at the study area.

1. Introduction

Over the past few years, the consequences and frequency related to the human activities and natural event around the whole world has increased rapidly with continuous trend. In engineering, forensic assessment is the investigation of structures, products, materials or breakdown components which may lead to property damage and cause injury [1]. As were already known, forensic engineering in geotechnical field is growing in most of the countries where the soil failures may lead to criminal action and even litigation [1, 2]. Related to the study, in most of the cases, some countries may have different soils but similar patterns of rainfall or some countries may have different rainfall but similar soils [3]. As stated by [4, 5], the main source of environmental problems is from the development of residential areas which resulted to the high production of domestic waste through daily activities. Lack of systematically efficient systems in developing countries to prevent the solid waste disposal problem leading to the open dumping areas which were considered as a cost-effective and speedy solution. The soil, surface water and lastly to the groundwater which are the areas normally surrounding the waste disposal sites will be polluted through the open dumping activities [4, 6].

The next point that need to be highlighted is solid waste are the production of the daily basis as a result of unescapable human activities. The increment volume of solid waste all over the world despite of current level of industrialization and global technological advancement occurred owing to the intensity of human's activities. Dumpsite or landfill acts as the important recipient of municipal solid waste. Theoretically, it is a common waste management employed by most of the nations in any parts of the world [7, 8]. Besides, the waste dump in this process causes a variety of public health and aesthetic problems which will also attracts rodents, insects and various disease vectors [7, 9, 10]. In this dumping process, the solid waste undergoes slow, anaerobic decomposition over a period of time and generate large amount of leachate with decomposing products such as heavy metals, leachate, landfill gas and varieties of hazardous contaminants which may seep into underground aquifers from the landfill site thus polluting the urban water resources [7, 11].

Based on [4] leachate is delineated as any liquid that is contaminated or wastewater which is produced from rain water percolating through accumulating contaminants, solid waste materials and moving into subsurface and surrounding areas. Owing to the presence of dissolved salts and has higher conductivity, leachate is formed which is in the liquid state from the decomposed waste [7]. Moreover, as stated by [12], leachate is an influence of surface run-off, precipitation and intrusion or infiltration of groundwater percolating through the landfill, inherent water content of wastes and biochemical processes in wastes cells themselves which is produced when liquid or water comes into contact with the wastes. The landfill leachate is a serious issue pointed out due to the continuous inflow of the leachate into subsurface materials [13]. Next, [13] also stated that the process of diffusion of the leachate occurs quickly and is extensive due to the increasing value in the groundwater flux following the heavy rain. On the other side of discussion, the landfill leachate possibly results in a groundwater contamination and the supply of surface water which can affects human health when migrating into neighbouring lands and waters occurring from the landfill [12].

Additionally, when dealing with the leachate analysis, certain number of complicated factors should be taken into account such as solid waste composition, operation of the landfill, age of the waste, hydrogeological conditions in vicinity of the site, temperature, moisture content, rate of the water movement through the waste, biological activities, landfill chemicals and seasonal weather variations which varies for four seasons country [12], [14-17]. The method of treatment and characterisation of landfill leachate have been developed for the past 40 years [7, 12], [18-21] and various techniques can be applied to describe the properties of the landfill, regional contamination from offsite seepage or leachate circulation [22].

Compare to groundwater resistivity, the leachate electrical resistivity is much lower and contaminants and pollutants released into the environment barely remains at the point of discharge. Most of them are transported via the porous media by four mechanisms such as molecular diffusion, advection, adsorption and mechanical dispersion [22-23]. Adsorption which determine the chemicals contribution in the soil water environment and affect the fate of chemicals in soils is one of the most influential transport mechanisms [22, 24]. The groundwater was polluted owing to the infiltration of contaminants and percolation of fluvial water via the soil in waste disposal sites [22, 25] where the leachate of the landfill is associated with high ion concentrations which resulted to low value of resistivity of the rock formations containing them [22, 26]. Electromagnetic and electric geophysical methods such as ERI have been broadly used for investigating and exploring various works especially in investigating the groundwater [7, 28], geological [19, 29-31] and environmental features [32, 33-36] Therefore, geoelectrical techniques or mostly known as geophysical methods are the most suitable for mapping the leachate contamination around the landfills [22, 27].

Geophysical methods play an important role in finding the hidden subsurface of a soil accurately and adequately without bore holing or drilling [37]. This method proves the fact that the electrical resistivity (reciprocal of electrical conductivity) of the landfill leachate is much lower than that of a clean groundwater by which small changes are detectable owing to the high data resolution [38-40] and variations in ERI may demonstrate changes in composition contaminant or layer levels [41]. ERI or Electrical resistivity tomography (ERT) is recognized [43] to be one of the best tool for site characterization at disposal site owing to the pollutant of the leachate which are rich in soluble ions that will facilitate the flow of an electrical current hence lowering the resistivity of the medium [44]. Last but not least, geophysical investigation offers a faster, cheaper [42] and has the ability to cover greater areas more thoroughly [45-46] by getting credible and detailed information about the subsurface [42]. Various researchers from all over the world especially in geophysics and geotechnical field have exposed that the integration of geotechnical data and geophysical survey can provide a useful data and interpretation for subsurface profile characterization [47-50]. Hence, a forensic assessment is conducted on landfills by ERI at Simpang Renggam in Johor, Malaysia. Basically, this study was conducted aiming to bestow to those related parties on the good anticipation of ERI as an alternative method in forensic leachate of the landfill investigations and exploration.

2. Methodology

The ERI method is classified into the group of geoelectrical methods commonly used in geophysical engineering which measures the differences in electrical resistivity of the ground [17, 52-54].ERI method was chosen in this research owing to the abilities of the leachate ions to facilitate the current movement in the medium. The study involves three phases which are through desk study, field measurement and data processing. Desk study starts with gathering necessary information and data regarding the study area thru maps and journals in order to obtain early information such as topography, geology of the sites, etc. in global and localize scale as presented in subsection 2.1. Later, the field measurement was conducted by using ERI and finally raw data from the field measurement was analyzed and processed by using RES2DINV software as illustrated in subsection 2.2. In this method, subsurface potentials that was measured owing to the passage of direct current are utilized in calculating the apparent resistivity and later applied as inputs in inverse modeling to construct a subsurface true resistivity model [51]. It is more accurate when the 2D model of the subsurface having the resistivity changes in the vertical direction along the survey line [55] and the 2D measurements via ERI should be taken along profiles in chronological order [48].

2.1. Study area and geologic setting

The study area was located at Simpang Renggam landfill site which was located in Simpang Renggam, Kluang, Johor, with the coordinate of 1°53'41"N, 103°22'35"E as shown in Figure 1. The location of the study area is about two kilometres away from Simpang Renggam town. With a total of six hectares in size, the landfill receives 400-500 tonnes of wet solid wastes per day which is from three different areas such as Simpang Renggam, Batu Pahat and Kluang. Based on the previous research conducted by the othe researchers, it was claimed that the leachate at the landfill is severe and disturbed the nearest river which became the sources of water supply to the residents of Simpang Renggam.

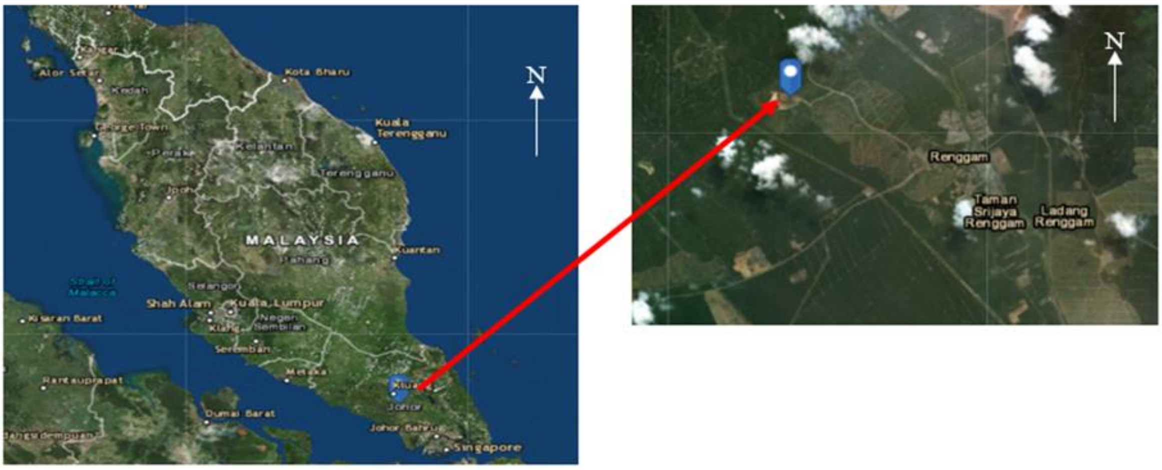

Figure 1. Study area

2.2. Equipment

The ERI equipment consists of three main components such as record, inducer and source [1]. The ERI source was set up by using a DC battery of 12 volt. A 61 of steel electrode was used as a current inducer and ABEM Terrameter LS 2 was used to record and plot the apparent resistivity value and finally the raw data obtained from the field measurement was analysed and clarified by using RES2DINV software.

2.3. Data acquisition and processing

By using ABEM Terrameter LS 2 equipment set, the ERI was conducted with a total number of two (2) spread lines of ERI survey were conducted (Resistivity Line, RL1 and Resistivity Line 2, RL2) at the study area as shown in Figure 2. The test configuration of the equipment was conducted based on the Schlumberger array by using four (4) resistivity cables, sixty one (61) numbers of electrode and sixty four (64) numbers of jumper cable. Electrode spacing and total electrical survey length are illustrated in Table 1. The field arrangement of the ERI was illustrated in Figure 3. Besides, the Schlumberger array was used during the data acquisition owing to the ability of the protocol to provide dense near-surface data of the resistivity.

Table 1. Electrode spacing and total electrical resistivity length

Resistivity Cable	Electrode Spacing (m)	Takeout Number	Total Length (m)
Cable 1 (C1)	5.0	20	100
Cable 2 (C2)	2.5	20	50
Cable 3 (C3)	2.5	20	50
Cable 4 (C4)	5.0	20	100
Total ERI Length (m)			**300**

Figure 2. Entire location of resistivity lines (spread lines) conducted at Simpang Renggam Landfill, Johor.

As exposed by [57], the Schlumberger array can give a clear image and can provide a good vertical resolution which is suitable to be used to detect the leachate of the landfill. Additionally, raw data obtained from the data acquisition were being processed by using commercialize RES2DINV software of [51] to present an inverse model that closely shown the actual subsurface structure. From the input resistivity data which is by using the inversion code of RES2DINV, the 2D inverse resistivity models of the subsurface was obtained and the RES2DINV can automatically determines the 2D resistivity models from the resistivity data input by using smoothness constrained least squares method [53-57]. Figure 2 shows the location of the entire resistivity lines (spread lines) conducted at Simpang Renggam landfill, Johor.

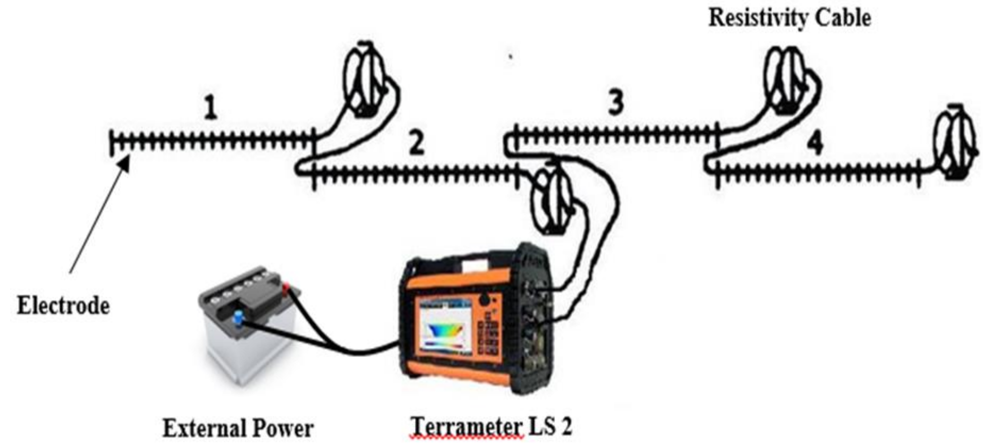

Figure 3. Four cables configuration of field arrangement in electrical resistivity imaging (ERI).

3. Results and Discussions

A total of two (2) resistivity spread lines were modelled by using RES2DINV software as shown in Figure 2. At the study area, the lines are randomly located occupying the side part of the landfill as well as certain part of the nearest oil palm plantation. The interpretation of the inverse resistivity models are basically based on the resistivity values of the mixture between leachate with clay, clayey sand and sandy clay experimentally measured by previous researcher in a small scale laboratory studies. Generally, the range of resistivity values observed and recorded in both of the of the inverse models differ from 1.0 Ωm to about 120 Ωm which describe the contaminated (less than 10 Ωm) or uncontaminated (more than 10 Ωm) soil and groundwater from the surface to a maximum depth approximately about 34 m in the ground.

Basically, the resistivity distributions can be grouped into three (3) different major zones interrelated with high resistivity values which is between 50 Ωm to 100 Ωm that represent the decomposed waste or waste pile covered with soil at the depth of 0-2.5 m. Noted that, in the areas that is away from the landfill which is at resistivity line 2 (RL2) located in the palm oil plantation, the high resistivity top layer can be correlated to the dry soil situated above the water table. Next, a zone with much lower resistivity value was observed with a range of value of 1 Ωm to 10 Ωm at a depth of 0-5 m below the surface coincide to sandy clay and clay soils based on [53].

Figure 4 and Figure 6 shows the inverse model of resistivity of RL 1 and RL 2 respectively which is in sync with the graph of resistivity (Ωm) versus distance (m) at a certain depth of 0.5 m, 4.5 m, 2.5m, 4.0 m and 5.0 m as shown in Figure 5 and Figure 7 respectively. The dotted line in Figure 4 and Figure 6 represents the depth of the study for the leachate at the landfill which is starting from 0.5 m until 5.0 m depth. Besides, high leachate contents is always described by a much lower resistivity values as stated by previous researcher which is lower than 10 Ωm. Therefore, the high concentrated leachate zone could barely detected in the inverse model from both of the survey lines conducted in clay areas where both the leachate and clay have quite similarity in resistivity values. Based on the resistivity value obtained in RES2DINV along RL1, it can be observed that there is a presence of the leachate with resistivity values around 2-9.5 Ωm in resistivity models of profiles RL1 measured across some parts of the active landfill towards the southwest borders of the oil palm plantation. The leachate was detected at a distance of 86.0 m to 91.0 m and at the depth of 1.5 m to 4.0 m. Figure 5 shows the resistivity value plotted against the distance of the ERI survey by taking the depth of exploration into consideration for RL1. The graph (Figure 5) was correlated with the inverse model plotted with RES2DINV software as shown in Figure 4.

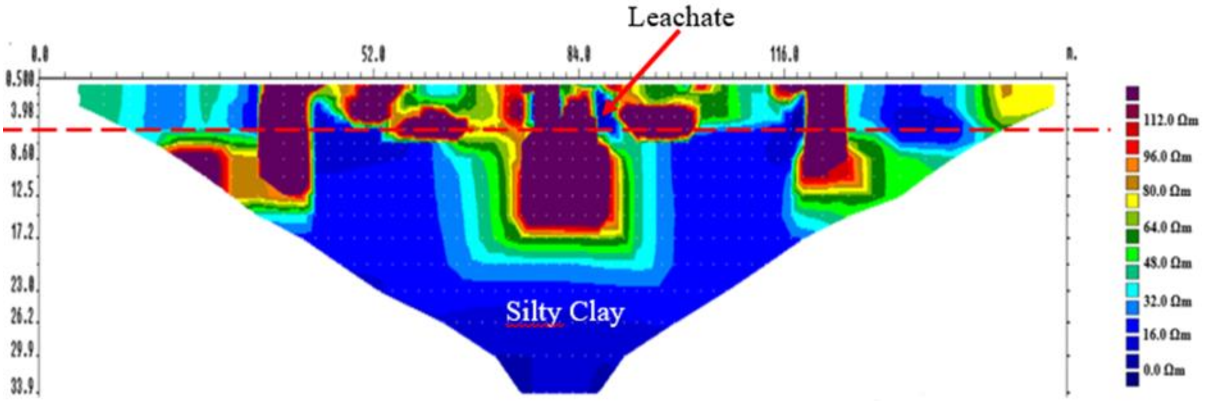

Figure 4. The inverse model of resistivity for Resistivity Line 1 (RL 1).

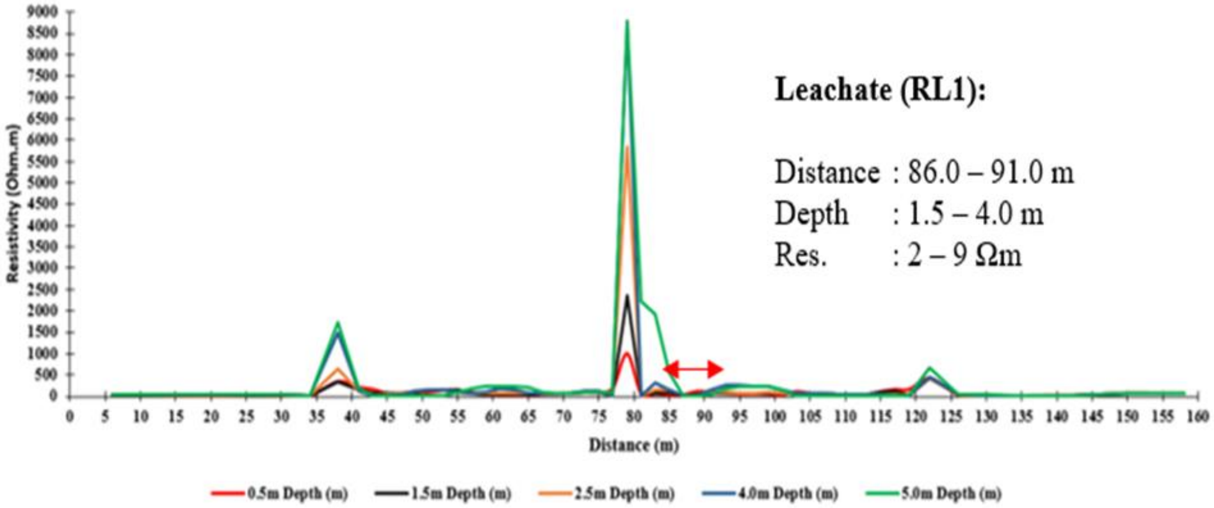

Figure 5. Graph of resistivity (Ωm) versus distance (m) at a certain depth of 0.5 m, 4.5 m, 2.5m, 4.0 m and 5.0 m for Resistivity Line 1 (RL 1).

One line (RL2) of resistivity imaging was carried out outside of the landfill area which is situated in the oil palm plantation. Based on the resistivity value obtained in RES2DINV along RL2, it can be observed that there is a presence of the leachate with resistivity values around 1.5-9.5 Ωm in resistivity models of profiles RL2 measured across outside of the active landfill towards the northeast borders of the landfills. The leachate was detected at a distance of 87.0 m to 89.0 m and at the depth of 1.5 m to 5.0 m. RL2 was carried out near the drainage which the water from the landfill was discharge. Figure 6 shows the leachate that was detected in the inverse model of the resistivity of RL2. Figure 7 shows the resistivity value plotted against the distance of the ERI survey by taking the depth of exploration into consideration for RL2. The graph (Figure 7) was correlated with the inverse model plotted with RES2DINV software as shown in Figure 6.

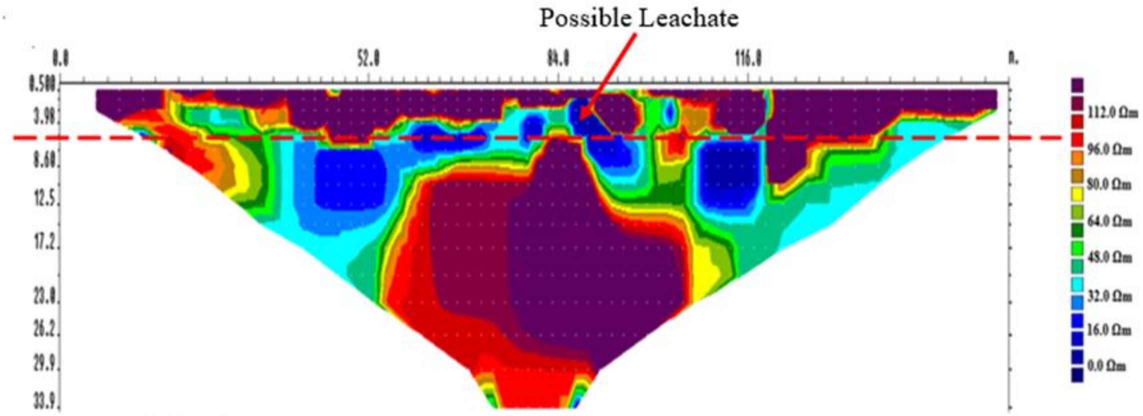

Figure 6. The inverse model of resistivity for Resistivity Line 2 (RL 2).

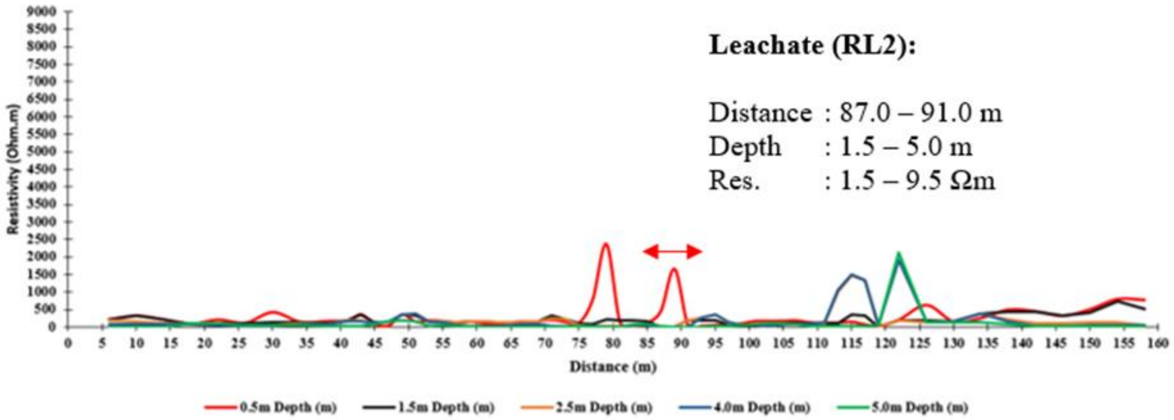

Figure 7. Graph of resistivity (Ωm) versus distance (m) at a certain depth of 0.5 m, 4.5 m, 2.5m, 4.0 m and 5.0 m for Resistivity Line 2 (RL 2).

4. Conclusions

The 2D electrical resistivity imaging conducted at Simpang Renggam, Johor managed to prove the existing and the leachate movement from the landfill into the surrounding of soil and water. Based on the analysis conducted the leachate also affected the nearby oil palm plantation which was situated southwest of the landfills area. Generally, the maximum leachate infiltration was detected at 1.5 to 4.0 m depth vertically below the surface of the soil and 80 m laterally away from it. From 1 to 10 Ωm of the resistivity values observed which described the most contaminated zone in both of the inverse model of resistivity (RL1 and RL2). Finally, by detecting the presence of the leachate under the ground, it can be confirmed that the ERI technique or 2D electrical resistivity imaging is among the effective technique for detecting the presence of the leachate.

References

[1] Abidin M H Z, Madun A, Tajudin S A A and Ishak M F 2017 *Forensic Assessment on Near Surface Landslide Using Electrical Resistivity Imaging (ERI) at Kenyir Lake Area in Terengganu,Malaysia* In Procedia Engineering. https://doi.org/10.1016/j.proeng.2017.01.354

[2] Poulos H G 2008 *A Framework for Forensic Foundation Engineering*, in: *Proc*. International Conference on Forensic Engineering: From Failure to Understanding, London, pp. 247.

[3] Nordiana M M, Azwin I N, Nawawi M N M and Khalil A E 2017 *Slope failures evaluation and*

landslides investigation using 2-D resistivity method. NRIAG Journal of Astronomy and Geophysics. https://doi.org/10.1016/j.nrjag.2017.12.003

[4] Hamzah U, Jeeva M and Ali M N A 2014. *Electrical resistivity techniques and chemical analysis in the study of leachate migration at Sungai SEDU landfill*. Asian Journal of Applied Sciences. https://doi.org/10.3923/ajaps.2014.518.535

[5] Keller E A 2000 *Environmental Geology.* 5th Edn., Merrill Publishing Co., Ohio, USA.

[6] Martinho E and Almeida F 2006 *3D behaviour of contamination in landfill sites using 2D resistivity/IP imaging: Case studies in Portugal.* Environmental Geology. https://doi.org/10.1007/s00254-005-0151-7

[7] Ganiyu S A, Badmus B S, Oladunjoye M A, Aizebeokhai A P, Ozebo V C, Idowu O A, and Olurin O T 2016 *Assessment of groundwater contamination around active dumpsite in Ibadan southwestern Nigeria using integrated electrical resistivity and hydrochemical methods* Environmental Earth Sciences. https://doi.org/10.1007/s12665-016-5463-2

[8] Singh B J and S 2009 *CHARACTERISTICS OF LEACHATE FROM BHALASWA LANDFILL SITE, AND GROUNDWATER SAMPLES FROM NEARBY LOCATIONS* Concentration in groundwater sample at radial distance from landfill facility. World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering.

[9] Olayinka A I and Olayinwola M A 2001 *An integrated use of geoelectric Imaging and hydrogeochemical methods in delineating limits of polluted surface and groundwater at a landfill site in Ibadan area, Southwestern, Nigeria*. J. of Mining and Geology, Vol 37 (1): pp 53-68.

[10] Adeyami O, Oloyede O B and Oladiji A T 2007 *Physicochemical and microbial characteristics of leachate- contaminated groundwater.* Asian. J. Biochem, 2: 343- 348.

[11] Bhuiya M A H, Huq N E and Hossain M M 2002 *Unplanned waste disposal and its possible impacts on subsurface environment of Dhaka City, Bangladesh*. In Bangladesh Environment 2002. Vol 2(ed) pp 7231- 7331.

[12] Giang N V, Kochanek K, Vu N T and Duan N B 2018 *Landfill leachate assessment by hydrological and geophysical data: case study NamSon, Hanoi, Vietnam.* Journal of Material Cycles and Waste Management. https://doi.org/10.1007/s10163-018-0732-7

[13] Park S, Yi M J, Kim J H and Shin S W 2016 *Electrical resistivity imaging (ERI) monitoring for groundwater contamination in an uncontrolled landfill, South Korea*. Journal of Applied Geophysics. https://doi.org/10.1016/j.jappgeo.2016.07.004

[14] Matias M S, Marques da Silva M, Ferreira P and Ramalho E 1994 *A geophysical and hydrogeological study of aquifers contamination by a landfill.* J Appl Geophys 32: 155- 162.

[15] Abudeif A M 2015 *Integrated electrical tomography and hydrochemical analysis for environmental assessment of El-Dair waste disposal site, west of Sohag city.* Egypt Environ Earth Sci 74(7): 5859- 5874. https://doi.org/10.1007/s12665-015-4610-5

[16] Bhalla G, Kumar A and Bansal A 2011 *Assessment of groundwater pollution near municipal solid waste landfill.* Asian J Water Environment Pollut 8(1): 41- 51.

[17] Sharma P V 1997 *Environmental and engineering geophysics Cambridge University Press*, Cambridge.

[18] Hoang V Y, Vasel J L and Le V C 2009 *Application of data analysis and experimental planning method to study partial nitrification in treatment of ammonium in landfill leachate in Vietnam.* 20th international waste management and landfill symposium, Sardinia, p 8.

[19] Chambers J C, Kuras O, Meldrum P I, Ogilvy R D and Hollands J 2006 *Electrical resistivity tomography applied to geologic, hydrogeologic, and engineering investigations at a former waste disposal site.* Geophysics 71(6): B231- B239.

[20] Khanh N H 2007 *Research and comparison of landfll leachate treatment system Vietnam and the world to choose suitable one to meet level of Vietnamese standard for landfll site NamSon in Hanoi*, report of the project, Institute of Environmental Technology, VAST.

[21] Paul T I, Debra R R, Marja E, Roger G, Nitin G B H, Sreeram J, Timothy G T and Ramin Y 2007

Review of state of the art methods for measuring water in landflls. Waste Manag 27:729–745.

[22] Giang N V, Duan N B, Thanh L N and Hida N 2013 *Geophysical techniques to aquifer locating and monitoring for industrial zones in North Hanoi.* Vietnam Acta Geophys 61(6):1573–1597. https://doi.org/10.2478/s11600-013-0147-8.

[23] Marylyn V Y 1990 *Modeling microbial transport in soil and groundwater.* Vol 56. No. 6.

[24] Kah M and Brown C D 2007 *Change in pesticides adsorption with time at high soil to solution ratio.* Chemisphere 68 1335-1343.

[25] Abdullahi N K, Osazuwa I B and Sule P O 2011 *Application of integrated Geophysical techniques in the investigation of groundwater contamination.* A case study of municipal solid waste leachate. Ozean Journal of Applied Science 4 (1), 7-25.

[26] Cristina P, Cristina D, Alicia F and Pamela B 2012 *Application of Geophysical methods to waste disposal studies, municipal and Industrial waste disposal.* Dr Xian-Ying Yu (Ed) ISBN 978-953-51-0501-5. In Tech.

[27] Bernstone C and Dahlin T 1999 *Assessment of two automated DC Resistivity Data acquisition systems to landfill location surveys.* Two case studies "Journal of Environmental and Engineering Geophysics. 4(2): 113-121.

[28] Gupta G, Patil J, Maiti S, Erram V C, Pawar N, Mahajan S and Suryawanshi R 2015 *Electrical resistivity imaging for aquifer mapping over Chikotra basin*, Kolhapur district, Maharashtra. Environ Earth Sci 73:8125–8143.

[29] Bernstone C, Dahlin T, Ohlsson T and Hogland W 2000 *DC-resistivity mapping of internal landfll structures: two pre-excavation surveys.* Environ Geol 39(3–4):360–368.

[30] Cardarelli E and Fischanger F 2006 *2D data modelling by electrical resistivity tomography for complex subsurface geology.* Geophys Prospect 54:121–133

[31] Kumar D 2012 *Efcacy of ERT technique in mapping shallow subsurface anomaly.* J Geol Soc India 80:304–307.

[32] Pantelis S, Nikos P, Ilias P, Maria K, Filippos V, Apostolos S and Thrassyvoulos M 2010 *Application of integrated methods in mapping waste disposal areas.* Environ Geol 53:661–675. https://doi.org/10.1007/s00254-007-0681-2.

[33] Guerin R, Begassat Ph, Benderitter Y, David J, Tabbagh A and Thiry M 2004 *Geophysical study of the industrial waste land in Mortagne-du-Nord (France) using electrical resistivity*. Near Surf Geophys 3:137–143.

[34] Porsani J L, Filhob W M, Vagner R E, Shimelesa F, Douradob J C and Moura H P 2004 *The use of GPR and VES in delineating a contamination plume in a landfll site: a case study in SE Brazil.* J Appl Geophys 55:199–209.

[35] Maillet G M, Rizzo E, Revil A and Vella C 2005 *High resolution electrical resistivity tomography (ERT) in a transition zone environment: application for detailed internal architecture and inflling processes study of a Rhône River paleo-channel.* Mar Geophys Res 6:317–328. https://doi.org/10.1007/s11001-005-3726-5.

[36] Martinho E and Almeida F 2006 *3D behaviour of contamination in landfll sites using 2D resistivity/IP imaging: case studies in Portugal*. Environ Geol 49:1071–1078.

[37] Sk M, Ramanujam N, Champoil V, Biswas S K, Rasool Q A and Ojha C 2018 *Identification of Groundwater in Hard Rock Terrain Using 2D Electrical Resistivity Tomography Imaging Technique: Securing Water Scarcity at the Time of Seasonal Rainfall Failure* South Andaman. International Journal of Geosciences, 9, 59-70. https://doi.org/10.4236/ijg.2018.91004.

[38] Buselli G and Lu K 2001 *Groundwater contamination monitoring with multichannel electrical and electromagnetic methods.* J. Appl. Geophys. 48, 11–23.

[39] Hagrey S A a and Petersen T 2011 *Numerical and experimental mapping of small root zones using optimized surface and borehole resistivity tomography*. Geophysics 76, G25–G35.

[40] Slater L and Sandberg S 2000 *Resistivity and induced polarization monitoring of salt transport under natural hydraulic gradients.* Geophysics 65, 408–420.

[41] Telford W M and Sheriff R F 1984 *Applied Geophysics. Cambridge University Press*.

[42] Osinowo O O and Falufosi M O 2018 *3D Electrical Resistivity Imaging (ERI) for subsurface evaluation in pre-engineering construction site investigation.* NRIAG Journal of Astronomy and Geophysics. https://doi.org/10.1016/j.nrjag.2018.07.001.
[43] Batayneh A T and Barjous M O 2005 *Resistivity surveys near a waste-disposal site in the Qasr Tuba area of central Jordan.* Bull. Eng. Geol. Environ., 64: 287-294.
[44] Aristodemou E and Betts A T 2000 *DC resistivity and induced polarisation investigations at a waste disposal site and its environments*. J. Applied Geophys., 44: 275-302.
[45] Hazreek Z A M, Rosli S, Chitral D C, Fauziah A, Azhar A T S, Aziman M and Ismail B 2015 *Soil Identification using Field Electrical Resistivity Method*, Journal of Physics: Conference Series. 622 1-7.
[46] Khatri R, Shrivastava V K and Chandak R 2011 *Correlation between vertical electric sounding and conventional methods of geotechnical site investigation*, Int. Journal of Advanced Engineering Sciences and Technologies. 4 042-053.
[47] Almalki H, El-Werr A K and Abdel-Rahman K 2011 *Estimation of near-surafce geotechnical parameters using seismic measurements at the proposed KACST expansion site*, Riyadh, KSA, Arabian Journal of Geosciences. 4 1131-1150.
[48] Sudha K, Israil M, Mittal S and Rai J 2009 *Soil characterization using electrical resistivity tomography and geotechnical investigations*, Journal of Applied Geophysics. 67 74-79.
[49] Oh S and Sun C G 2008 *Combined analysis of electrical resistivity and geotechnical SPT blow counts for the safety assessment of fill dam*, Environmental Geology. 54 (2008) 31-42.
[50] Hack R 2000 *Geophysics for Slope Stability*, Surveys in Geophysics. 21 423-448.
[51] Loke M H, Acworth I and Dahlin T 2003 *A comparison of smooth and blocky inversion methods in 2D electrical imaging surveys*. Explorat. Geophys., 34: 182-187.
[52] Keller G V and Frischknecht F C 1966 *Electrical methods in geophysical prospecting*. Pergamon Press Inc., Oxford.
[53] Loke M H and Barker R D 1996 *Rapid least squares inversion of apparent resistivity pseudosections by a quasi-Newton method*. Geophys Prospect 44:131–152.
[54] Smith R C and Sjogren D B 2006 *An evaluation of electrical resistivity imaging (ERI) in Quaternary sediments*, southern Alberta, Canada. Geosphere 2(6):287–298.
[55] Loke M H 2000 *RES2DINV version 3.44 for windows 95/98 and NT: rapid 2D resistivity and IP inversion using the least squares method*. Advanced Geosciences Inc., Austin.
[56] Sasaki Y 1992 *Resolution of resistivity tomography inferred from numerical simulation.* Geophys. Prospect, 40: 453-464.
[57] Hamzah U, Yaacup R, Samsudin A R and Ayub M S 2006 *Electrical imaging of the Groundwater Aquifer at Banting, Selangor, Malaysia*, Environmental Geology. 49 1156-1162.

Acknowledgements

The authors would like to thanks University Malaysia Pahang owing to the provided funding (RDU1703205) throughout this project.