Environmental Challenges 6 (2022) 100415

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

Urban landfills investigation for leachate assessment using electrical resistivity imaging in Johor, Malaysia

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ARTICLE INFO

Keywords:
Landfill leachate
Electrical resistivity imaging
Leachate characterization
Contaminants

ABSTRACT

The use of the electrical resistivity imaging (ERI) approach has expanded dramatically in engineering applications over the years due to the efficiency of the technique in terms of time, expense, and data coverage. The assessment was carried out using ERI to assess the landfill leachate's pollution level at Simpang Renggam, Johor, Malaysia. The ERI survey was carried out in the research region, utilizing the ABEM Terrameter LS 2 equipment using the Schlumberger electrode configuration. Besides, seven (7) parameters of leachate characterization such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD5), Suspended Solid (SS), Power of Hydrogen (pH), Ammonia Hydrogen (NH3-N), Turbidity and Biodegradability Ratio (BOD5/COD) were also performed to identify and evaluate the current leachate condition of the landfill. Furthermore, the study, which involves the measurement of the apparent resistivity of the subsurface materials were able to determine the existence of chemical pollutants in the soil at 1.5 m to 4.0 m depth, with special reference to the chemically apparent resistivity linked with the low resistivity anomalies of 1 – 10 Ωm. Based on the investigations conducted, the physiochemical and microbial analysis of the Simpang Renggam leachate site was found to be 1633 mg/L (Chemical Oxygen Demand), 137.41 mg/L (Biological Oxygen Demand), 359.8 mg/L (Suspended Solid), 7.61 (Power of Hydrogen), 385.29 (Ammonia Hydrogen), 117.65 (Turbidity) and 0.07 (Biodegradability Ratio) which shows that all of the parameter's value exceeded the value as stated in the local standard which is Environmental Quality Act (1974) except for the pH value which is within the range value as stated in the standard. The leachate from dumps was thought to arise due to system failures in accepting and managing trash, which was exacerbated by the recent high rains. In hindsight, the ERI result was practical for identifying leachate and, therefore, can benefit the authorities in immediate action to halt the extensive water disturbance at the research region.

1. Introduction

In the last few years, the frequency of occurrence of natural disasters from around the world has been increasing fast with a consistent trend (Khanna et al., 2021; Oyedotun et al., 2021). Therefore, inappropriate disposal and buildup over long periods is a ticking time bomb, a significant ecological disaster that will lead to minerals leaching into the ground resulting from incorrect dumping can cause significant environmental degradation and negative impacts on individuals (Khanna et al., 2021). Owing to rapid urbanization (Karimi et al., 2021), the worldwide garbage creation rate is expected to rise by 72%, from 2.0 billion tonnes in 2016 to 3.50 billion tonnes in 2050. The United States is the largest MSW producer (0.63 million tonnes per day), followed by China (0.52 million tonnes per day), Brazil (0.15 million tonnes per day), and Japan (0.14 million tonnes per day). India ranks fifth in the world, with a cumulative waste production of 0.14 million tonnes (MT) every day (48.00 MT per year), of which approximately 91,153 tonnes are gathered, and approximately 25,885 tonnes are dumped at the landfill site (Tyagi et al., 2021). Internationally, 1.4 billion tonnes of MSW are generated each year (1.25 kg per capita per day), with this figure expected to rise to roughly 2.20 billion tonnes by 2025. With a population of 1.35 billion people, India is expected to generate over 55 MT of municipal solid garbage per year, with a 5% annual population rate (Tyagi et al., 2021).

Leachate is defined as any contaminated liquid or wastewater formed by stormwater runoff seeping through accumulated pollutants and waste disposal items and migrating into the subsoil and adjacent areas (Hamzah et al., 2014; Giang et al., 2018). Leachate (liquid waste) is generated from the degraded waste due to dissolved salts and greater conductance (Ganiyu et al., 2016; Zhang et al., 2021a; Zhang et al., 2021b; Feng et al., 2021). The content and level of the landfill leachate can differ considerably depending on the waste content and

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https://doi.org/10.1016/j.envc.2021.100415
Received 19 August 2021; Received in revised form 25 November 2021; Accepted 30 November 2021

water content, landfill type and age, and weather conditions. The ongoing influx of landfill leachate into ground conditions has been identified as a severe hazard (Park et al., 2016). In 2013, over 62 million m^3 of leachate were created in the United States alone (Feng et al., 2021). In 2018, China generated more than 24 million m^3 of leachate (Zhang et al., 2020). The quantity of leachate generated is projected to increase as the municipal landfill waste in the world keeps rising (Zhang et al., 2020). Almost 70% of waste materials may be compostable, with the remaining 10% leaving the landfill in the form of leachates (Jóźwiak et al., 2019). A fraction of the leachates could be properly controlled in the leachate rehab clinic, while the remainder would pass through the dump boundary, lodge in the ground, and leach into the aquifer. Leachates have a wide range of impacts on aquifers. Pollutant concentrations in landfill leachate would vary with time, precipitation, and the type of landfill garbage (Zhang et al., 2021a; Zhang et al., 2021b).

ERI is recognized as among the most effective tools for geological mapping and leachate assessment at waste disposal due to the contaminant of the leachate, which is abundant in soluble ions that will allow the transfer of an electric charge (Park et al., 2016; McLachlan et al., 2020). The mutuality of electrical properties of landfill leachate is much relatively low than that of clean underground water (Bai et al., 2021; Das et al., 2021), and variability (Park et al., 2016) in ERI may illustrate alterations, pollutants (Ganiyu et al., 2016; Gupta et al., 2015). Finally, the ERI offers a rapid, more straightforward (Osinowo and Falufosi, 2018), and more extensive coverage of larger areas (Hazreek et al., 2015) by obtaining reliable and specific data about the underlying materials (Osinowo and Falufosi, 2018). Various academics worldwide, particularly those working in geophysical and geological fields, have demonstrated that combining geological data with geological mapping can give valuable information and analysis for underlying profile classification (Day-Lewis et al., 2017; Crawford et al., 2018; Li et al., 2018; Demudu Babu et al., 2020; Marciniak et al., 2021; Rucker et al., 2021; Vásconez-Maza et al., 2021). Therefore the knowledge obtained from the previous study has been applied to assess the leachate in the study area.

Essentially, this investigation was carried out to confer onto those involved in the optimistic prediction of ERI as an approach in forensic leachate examinations and investigation of landfills. Numerous studies have been directed into using ERI in engineering properties and evaluated the use of ERI as a technique in analyzing landfill leachate globally. However, only a few studies were conducted by applying ERI in leachate assessment in Malaysia. The ideal combination of the ERI survey and leachate characterization test can prove the effectiveness of ERI in landfill leachate assessment which is energy-efficient and economical.

2. Experimental examination

2.1. Study area

The study location is in the Simpang Renggam dump site in Simpang Renggam, Kluang, Johor, with the coordinates 1°53′41″N, 103°22′35″E, as illustrated in Fig. 1. The study area is about two (2) kilometres from Simpang Renggam town. The landfill which was exploited by the garbage dump, is six hectares in size, collects 450–600 tonnes of wet household waste every day from three localities, including Simpang Renggam, Kluang, and Batu Pahat is now has been operated for more than 13 years old and is used to monitor the leachate. The leachate at the dump is severe and has polluted the nearby river, which has become a source of freshwater for the population of Simpang Renggam. During monsoon season, the leachate at the landfill will overflow affecting, the nearby areas including, the palm oil plantation beside the landfill (Zailani et al., 2018).

Table 1
ERI Field Survey Information.

ERI Cable	Spacing (m)	Takeout Number	Length (m)
RC1	5.0	20	100
RC2	2.5	20	50
RC3	2.5	20	50
RC4	5.0	20	100
Total ERI Length (m)	300		

2.2. Electrical resistivity imaging (ERI)

2.2.1. Basic introduction

The ERI technique is one of several electrical resistivity techniques used throughout geophysics engineering that detect differences in electrical resistance of the subsurface (Day-Lewis et al., 2017; Crawford et al., 2018; Li et al., 2018; Demudu Babu et al., 2020; Marciniak et al., 2021; Rucker et al., 2021; Vásconez-Maza et al., 2021). The ERI approach was used for this study because of the ability of leachate particles to enhance current flow in the media.

2.2.2. Equipment description

The ERI apparatus comprises three (3) major parts: a record, an inducer, and a source (Abidin et al., 2017). A 12 volt DC battery powered the ERI supply. As a current inducer, a 61 steel electrode was utilized, and an ABEM Terrameter LS 2 was utilized to measure and display the perceived resistivity value. Lastly, the original data collected from the field survey was processed and elucidated via the RES2DINV program.

2.2.3. ERI field procedure

The research is divided into three stages: desk research, field measurements, and data analysis. Desk research begins with acquiring relevant data and information about the study location through maps and publications to acquire precise data, including geography, geological of the sites, and so on in worldwide and localized scales. The ERI was conducted utilizing the ABEM Terrameter LS 2 equipment set, with a total of two (2) spread lines of ERI survey (Resistivity Survey Line, RL1, and Resistivity Survey Line 2, RL2) at the landfill site that is still being used as a dumpsite as shown in Fig. 2. Table 1 shows the electrode separation and overall electrical investigation distance. The ERI's field configuration is depicted in Fig. 3. Following that, the actual measurements were carried out using ERI, and the data from the experimental measurements were evaluated and analyzed using RES2DINV software. Furthermore, the Schlumberger arrays were used during data collecting because fewer electrodes needed to be moved for each sounding, and the cable length for the potential electrodes was short. Schlumberger soundings also have higher resolution, more immense probing depth, and need less time to deploy in the field.

2.2.4. ERI data processing and inversion

The Schlumberger array can generate a clean image and an excellent vertical sharpness, making it suited for detecting activated leachate (Abidin et al., 2017). Subterranean potentials recorded due to direct current flow are used throughout this approach to calculate the resistivity and then used as essential data in inverse modeling to construct a subsurface accurate resistivity simulation (Marciniak et al., 2021; Rucker et al., 2021; Vásconez-Maza et al., 2021). It would be more precise whenever the 2D model of the subsoil has resistance variations in the vertical position along the line segment (McLachlan et al., 2020), and the 2D measurements using ERI are obtained in sequential sequence across profiles (Day-Lewis et al., 2017; Crawford et al., 2018; Li et al., 2018; Demudu Babu et al., 2020; Marciniak et al., 2021; Rucker et al., 2021; Vásconez-Maza et al., 2021). Furthermore, unprocessed data received from data capture after ERI field investigation were conducted were then analyzed using the commercially available RES2DINV program (Li et al.,

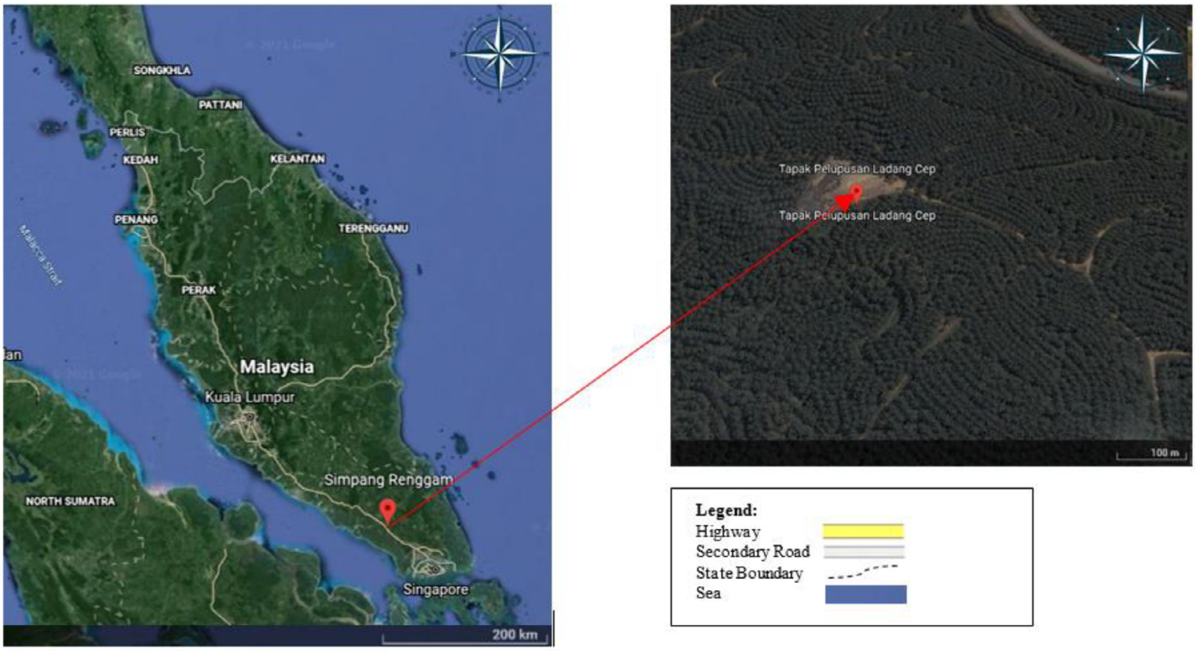

Fig. 1. Study location.

Fig. 2. RL1 and RL2 ERI area of investigation.

2018; Demudu Babu et al., 2020; Marciniak et al., 2021; Rucker et al., 2021; Vásconez-Maza et al., 2021) to create an inversion model that perfectly resembled the simple subsurface structure. The 2D resistivity models of the subsurface were acquired from the interface data measured by utilizing the RES2DINV code inversion, and the RES2DINV can take immediate designs from the resistivity input data using smoothness constrained least-squares method (Abidin et al., 2017). The total resistivity lines undertaken in the Simpang Renggam dump in Johor are depicted in Fig. 2.

2.3. *Soil characterization*

The soil samples are collected at the Simpang Renggam leachate site, with four (4) samples collected up to 3 m depth. There are four (4) types of laboratory testing conducted to characterize the properties of the soil samples collected at the leachate site, which includes mechanical sieve analysis to regulate the particle size of the samples, pycnometer test to determine the relative density of the specimens, Atterberg limit test to regulate the plastic limit, liquid limit and plasticity index of the soil sample and standard compaction test to regulate the optimum

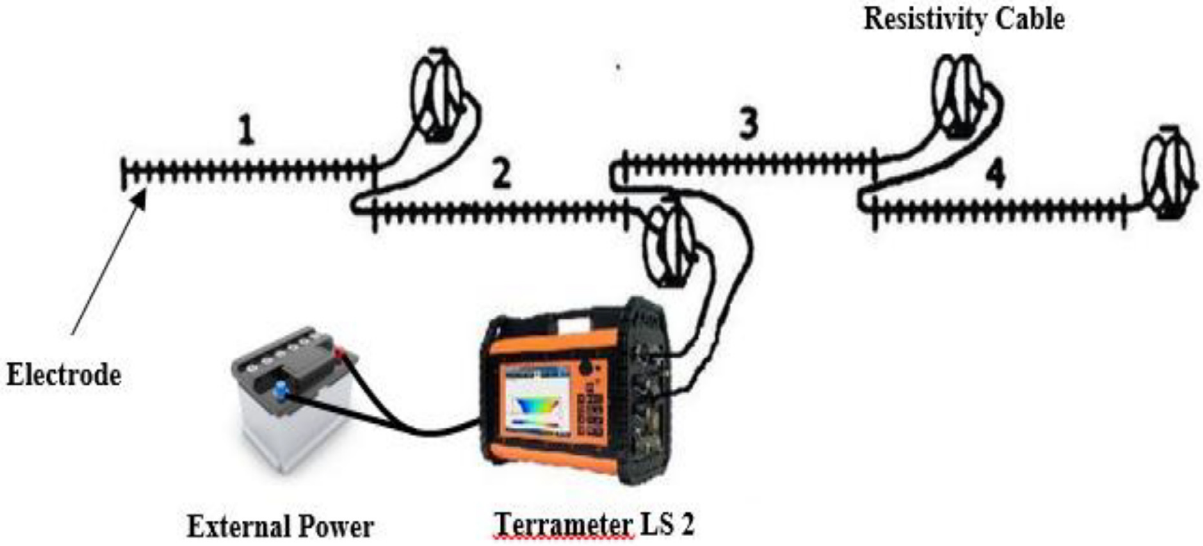

Fig. 3. ERI four cables field survey.

moisture content (OMC) and maximum dry density (MDD) of the soil sample.

The physical sieve analysis is carried out in line with BS 1377: Part 2: 1990. The particle size of the leachate soil sample was determined using this assay. The hydrometer test or fine analysis was conducted in line with BS 1377: Part 2: 1990. This laboratory test aims to determine the surface structure that has passed through a 63 μm sieve. In this laboratory test, 50 g of the residual sample in the sieved pan was used.

The relative density of the soil samples was calculated using the small pycnometer method following BS 1377: Part 2: 1990. The test employed 10 g of an oven-dried specimen that passed through a 2 mm BS sieve and was done twice until the findings differed by no more than 0.03 Mg/m^3.

The soil sample's Atterberg limit was calculated following BS 1377: Part 2: 1990. A liquid limit (LL) was measured using the cone penetration approach with a test specimen weighing at least 300 g and passing through 425 μm. The plastic limit (PL) was established by rubbing roughly 20 g of the produced test collected from the LL sample. The test was performed to differentiate between silt and clay.

2.4. *Soil chemical composition*

The chemical oxide composition of the soil sample was tested using Bruker S8 Tiger X-Ray Fluorescence (XRF) analyzer and was fully compliant with the ASTM E1621 - 13 standard. For this test, 10 g of the soil sample at the Simpang Renggam leachate site were collected and kept in a sealed lock plastic bag before sending it to the laboratory for testing. The 10 g soil sample was then placed in the XRF equipment to analyze the chemical composition of the soil samples. The analysis was crucial to determine the presence of the contaminants in the soil sample based on the chemical composition of the soil.

2.5. *Leachate sampling*

In this study, the sampling method used to collect the leachate sample was by grab sampling at four (4) different points. A clean high-density polyethylene (HDPE) 30-L volume container was used to collect a sample of leachate wastewater from the SRL site. The obtained samples were taken directly to the wastewater laboratory and stored in a cold storage room at room temperature to prevent additional chemical changes during scenario represents. The experimental process and analysis were conducted under American Public Health Association's guidelines (Standard, 2012). Our study looked into seven (7) metrics from the Simpang Renggam landfill site, including Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Suspended Solids (SS), Power of Hydrogen (pH), Ammonia Hydrogen (NH3-N), Turbidity, and BOD5/COD ratio.

3. Results and discussion

3.1. *Electrical resistivity result*

The RES2DINV tool was used to invert two (2) resistivity spread lines data obtained on the profiles during field measurement, as illustrated in Fig. 2. The lines are oriented in the direction of North-East to South-West for RL1 and in the direction of South-West to North-East for RL2 in the research area, covering the side half of the dump and even a portion of the nearby oil palm cultivation. On average, the spread of resistance values measured in both inverse models varies from 0.5 Ωm to around 130 Ωm, describing the leachate area with a resistivity value less than 10 Ωm or unpolluted area with a resistivity value of more than 10 Ωm containing soil and freshwater from the top to a maximal depth of approximately up to 35 m below the surface of the ground.

Essentially, the resistance dispensation may be divided into three (3) primary zones interconnected by strong apparent resistivity ranging from 45 Ωm to 110 Ωm, indicating the disintegrated trash or waste piles buried with soil at a depth of 0–3.0 m. It should be emphasized that in regions far from the landfill that RL2 illustrates, the high resistivity value at the upper surface could be associated with the sandy areas above the groundwater. A region with much lower apparent resistivity with a range of 1 Ωm to 10 Ωm at a depth of 0 m - 5 m below ground corresponds to loamy sand and clayey soils (Bai et al., 2021). In comparison to groundwater resistance (Park et al., 2016; Bai et al., 2021), the resistivity value of leachate is substantially lower, and toxins discharged into the atmosphere scarcely linger at the point of disposal. Most particles travel through porous materials via three (3) different phases: molecular diffusion, advection, and mechanical dispersion (Giang et al., 2013). The groundwater was contaminated due to the pollutant incursion and fluvial water percolation through the soil in dumpsites (Giang et al., 2013). The landfill's leachate is linked with increased electrolyte concentration,

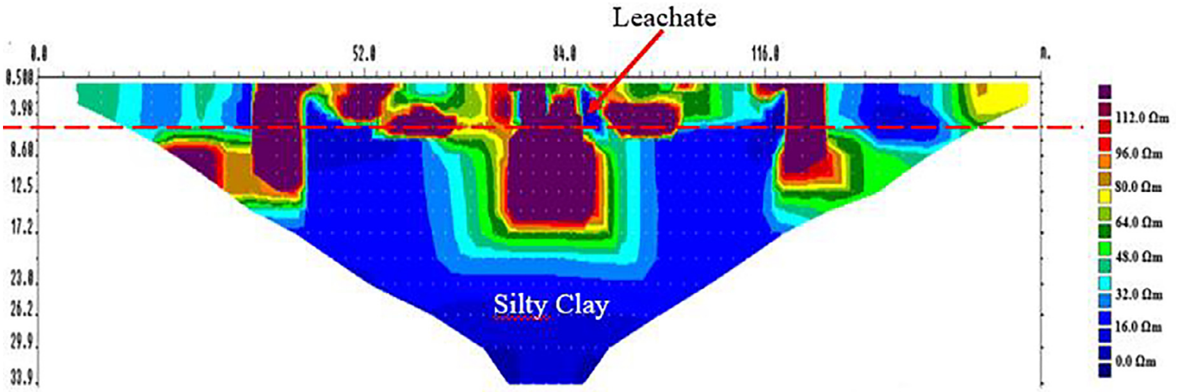

Fig. 4. The ERI inverse model for resistivity survey line 1 (RL1).

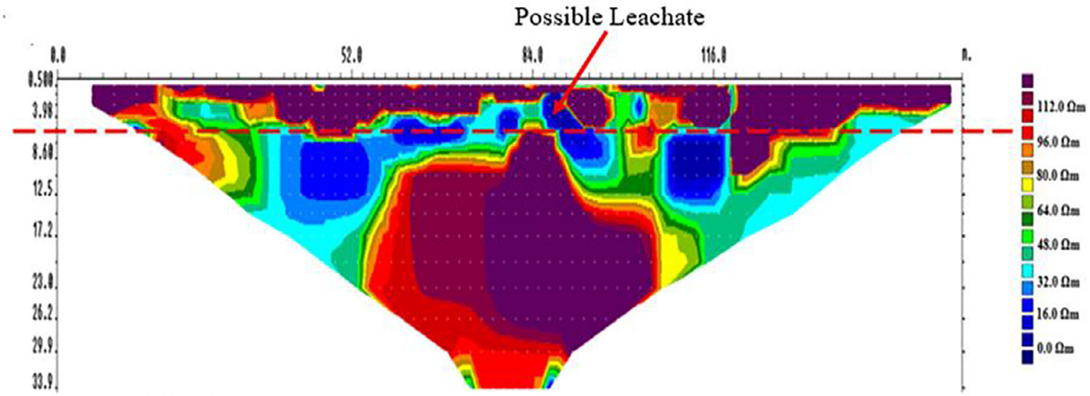

Fig. 5. The ERI inverse model for resistivity survey line 2 (RL2).

resulting in low resistivity values of the geological formations containing them (Giang et al., 2013).

Figs. 4 and 5 illustrate the inverted model of resistivity of RL 1 and RL 2. The dotted line in Figs. 4 and 5 depicts the level of the investigation for the landfill leachate, which ranges from 0.5 m to 5.0 m. Furthermore, significant leachate levels are always characterized by much smaller apparent resistivity, less than 10 Ωm (Park et al., 2016; Maurya et al., 2017; Moretto et al., 2017; Chu et al., 2017; Ansari et al., 2021). Variances influence variations in the low resistivity anomaly arrangement in the ionic strength of landfill leachate (Maurya et al., 2017). Furthermore, the ERI approach can measure low and high resistivity ranges, with areas with low resistivity less than 10 Ωm identifying the presence of leachate concentration zones (Moretto et al., 2017). Leachate can also impact the electrical conductivity, pH, and sulfate content (Ansari et al., 2021). They discovered that the increasing value in pore water conductivity, pH, and sulfate concentration in pore water resulted in a significant decrease in sample electrical resistivity. Moreover, the leachate, which contains a variety of chemical and heavy elements, can lower the resistivity value of the soil sample (Chu et al., 2017). The inclusion of metals in soil pore liquid can diminish the resistivity values. The resistivity of heavy metal-polluted soils diminished with the increase in water content (Chu et al., 2017).

As a result, the powerful oxidizing leachate zone was barely detectable in the inverted modeling on both line segments performed in clay regions where the electrical resistivity of the leachate and clay were relatively similar. Depending on the resistivity data reported in RES2DINV along RL1, it is possible to see the existence of leachate with resistivity values ranging between 2.0 Ωm - 9.5 Ωm in resistivity simulations of profiles RL1 assessed across these sections of the effective landfill towards the southwest boundaries of the oil palm cultivation. The leachate was discovered at a depth of 1.5 m to 4.0 m at a distance of 85.0 m to 90.0 m.

Outside of the landfill site in the oil palm cultivation, one line (RL2) of resistance mapping was performed. According to the resistance obtained values in RES2DINV along RL2, it is possible to see the existence of leachate with resistance values ranging from 1.5 Ωm to 9.5 Ωm in resistance simulations of profiles RL2 recorded throughout the outer of the operational landfill towards the northeast boundaries of the landfills. The leachate was discovered at a depth of 1.5 m to 5.0 m and a distance of 88.0 m to 90.0 m. RL2 was conducted out along the sewer into which landfill wastewater was discharged. Fig. 5 depicts the leachate observed in the inverted simulation of RL2 resistivity.

3.2. *Physical properties of soil*

A laboratory testing for physical characterizations has been carried out on the soil sample at the Simpang Renggam leachate site and at other Simpang Renggam sites which are not associated with the leachate. The main physical property was soil classification which influenced several aspects such as the specific gravity, Atterberg limits, and particle size analysis. The summarization of the laboratory test result for soil characteristics of soil materials at Simpang Renggam leachate site and Simpang Renggam natural soil were presented in Table 2.

3.2.1. *Specific gravity*

According to Table 2, the mean specific gravity of the soil specimens taken at the Simpang Renggam leachate site is 2.73. Most of the region in Malaysia is rich in residual tropical soil. Because of the incredible variety in mineralogy, the specific gravity of tropical residual soils can be either extraordinarily low or extremely high (Hasan et al., 2021). As

Table 2.
Physical characteristics of soil.

Composition	Simpang Renggam Leachate Soil	Simpang Renggam Natural Soil
Natural Moisture Content (%)	17.95	17.86
Gravel (%)	4.2	3.9
Sand (%)	27.9	27.4
Silt (%)	45.1	44.7
Clay (%)	22.8	22.5
[a]LL (%)	70.0	38.0
[b]PL (%)	31.0	30.0
[c]PI (%)	39.0	37.0
[d]SG (G_s)	2.73	2.70
[e]V.R (e)	0.69	0.64
Porousness (n)	0.41	0.39
[f]B.D (g/cm^3)	1.99	1.97
[g]D.D (g/cm^3)	1.67	1.65

[a] Liquid Limit.
[b] Plastic Limit.
[c] Plasticity Index.
[d] Specific Gravity.
[e] Void Ratio.
[f] Bulk Density.
[g] Dry Density.

Table 3
Chemical compositions of natural soil and leachate soil.

Toxic Metals	Natural Soil (g/kg)	Leachate Soil (g/kg)
Iron (Fe)	126.4	143.6
Chromium (Cr)	0	0.236
Arsenic (Ar)	0	0.395
Lead (Pb)	0	0.059
Copper (Cu)	0.108	0.204
Zinc (Zn)	0.267	1.256

Based on Table 3, the presence of toxic metals in both of the soils can be observed. Table 3 clearly shows the increment in the chemical contents of iron, copper, and zinc from 126.4 g/kg, 0.108 g/kg, 0.267 g/kg (Hasan et al., 2021; Aja et al., 2021) to 143.6 g/kg, 0.204 g/kg, and 1.256 g/kg respectively in Simpang Renggam landfill soils as compared to the natural soil. Besides, the presence of three (3) toxic metals in the leachate soils (Cr, Ar, and Pb) with a value of 0.236 g/kg, 0.395 g/kg, and 0.059 g/kg clearly explained that the current soil at the landfill is polluted.

Table 4
Chemical compositions of Simpang Renggam Wastewater Leachate as compared to the EQA regulations.

Toxic Metals	Wastewater Leachate (mg/L)	EQA Regulations (Government of Malaysia 1974)
Iron (Fe)	8.457	5.00
Chromium (Cr)	0.453	0.20
Arsenic (Ar)	0.054	0.05
Lead (Pb)	0.110	0.10

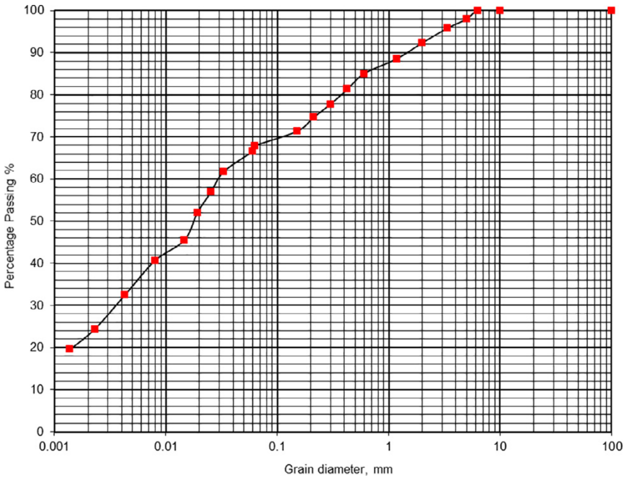

Fig. 6. Particle size analysis of Simpang Renggam soil.

shown in Table 2, the leachate did not significantly influence the value of the specific gravity of the soil at Simpang Renggam as the different margins of the leachate soil and natural soil is small with a different margin value of 0.03.

3.2.2. Atterberg limits

According to Table 2, the Atterberg Limit of the soil samples collected at the Simpang Renggam leachate site was 70.0 percent, the plastic limit (PL) was 31.0 percent, and the Plastic Index (PI) = LL-PL = 39.0 percent. According to the British Soil Classification System (BSCS), the soil at the field experiment can be classified as SILT of high plasticity (MHS). As what can be observed from Table 2, the leachate also did not greatly affect the value of the Atterberg limits of the soil at Simpang Renggam as the different margin of liquid limit, plastic limit, and plasticity index of the leachate soil and natural soil are small with a different margin value of 0.02%, 0.01%, and 0.01% respectively.

3.2.3. Particle size analysis

Fig. 6 depicts the particle size study at the Simpang Renggam leachate site. The residual soils were classed as very high plasticity of sandy SILT (MVS) soil by the British Soil Classification System (BSCS). The grain size from a piece of 100 g soil specimen comprised 4.2 percent greater than 2 mm (gravel), 27.9 percent within 2 mm and 0.063 mm (sand), 45.1 percent within 0.063 mm and 0.002 mm (silt), and 22.8 percent less than 0.002 mm (clay). Fig. 6 depicts the mean different particle size distributions detected and reported from several sources of collected soil generation at the study area.

From Table 2, the leachate did not give significant influence to the value of the particle size of the soil at Simpang Renggam as the different margins of the gravel, sand, silt, and clay of the soil samples are small with a different margin value of 0.3%, 0.5%, 0.4%, and 0.3% respectively. However, the leachate soil is coarser compared to the leachate soil.

3.3. Soils chemical content analysis

Landfill leachate is notorious for harming the soil by containing harmful materials such as metals, chromium, arsenic, lead, copper, and zinc, which are rapidly unstable and can desalinate water and soil (Khanna et al., 2021; Mohd-Salleh et al., 2020; Li et al., 2019). Malaysia is already on the correct route by enacting the Environmental Quality Act 1974: Second Schedule (Regulation 13). According to this act, the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009 were enacted to exercise powers converse provided by sections 21, 24, and 51 (Mohd-Salleh et al., 2020). Table 3 compares the chemical composition at the Simpang Renggam leachate site with the natural condition of soil without contaminants. In contrast, Table 4 shows allowable leachate discharge conditions in Malaysia compared to the current condition of the Simpang Renggam landfill leachate discharge.

The analysis for toxic substances only provided for Fe and Cr from (Abd. Kadir et al., 2014) investigations. The 2014 chemical composition for Fe and Cr is 16.10 mg/L and 0.623 mg/L, correspondingly (Abd. Kadir et al., 2014). Based on the investigations, the level of heavy metals was falling throughout the year. Notwithstanding the decreased accumulation of heavy metals in the leachate specimen, it was still higher than the Malaysia discharge guidelines, particularly for iron (Fe) and overall chromium (Cr), which were 8.46 mg/L and 0.45 mg/L, correspondingly. Toxic chemicals may develop in biological systems and

Table 5
Simpang Renggam leachate characterization.

Parameters	Units	Result	EQA (1974) (Government of Malaysia 1974)
COD	mg/L	1633	400
BOD5	mg/L	137.41	20
SS	mg/L	359.8	50
pH	N/A	7.61	6.0 – 9.0
NH3-N	mg/L	385.39	5
Turbidity	NTU	117.65	–
BOD5/COD	N/A	0.07	–

become a significant source of hazard (Khanna et al., 2021). Based on the comparison, most heavy metal concentrations did not meet the discharged level with large concentrations. Because the sample taken was unprocessed, it was sensible and made sense for most of the variables to be unable to fall below the reasonable level (Aja et al., 2021). As a result, to assure the efficacy of the rehabilitation, the produced leachate must be handled via its type and content.

3.4. Leachate analysis

Many prior research investigations show the differences in leachate conditions between landfills (Zailani et al., 2018; Mohd-Salleh et al., 2020; Aopreeya et al., 2013; Detho et al., 2020). Table 5 presents the leachate properties used in this investigation. As indicated in Table 5, the leachate has a significant concentration of NH3-N and COD. The COD and BOD5 levels are 1633 mg/L and 137.41 mg/L, correspondingly. Table 5 shows that a fresh specimen of leachate effluent has a biodegradability ratio (BOD5/COD) of 0.07. The study revealed that the COD and BOD5 values suggest that the leachate is effectively stabilized. The amount of COD (<3000 mg/L) and NH3-N (>400 mg/L) in stabilized leachate is significant, although the percentage of BOD5/COD is minimal (Zailani et al., 2018; Mohd-Salleh et al., 2020; Detho et al., 2020). The pH content of leachate ranges from 7.50 to 9.00, with a mean of 8.25, and it steadily increases over time (Zailani et al., 2018; Detho et al., 2020). According to a prior study, the pH level of a stabilized leachate is greater than 7.5. (Zailani et al., 2018; Mohd-Salleh et al., 2020; Abd. Kadir et al., 2014; Detho et al., 2020).

3.4.1. Analysis of chemical oxygen demand (COD)

Whereas the COD measure, which reflected the organic strength of the leachate, decreased in intensity as the landfill aged. The COD result in our study was collected from the Simpang Renggam landfill Site (SRLS), which ranges at a mean of 1633 mg/L. The COD levels were between 13,166 mg/L and 13,500 mg/L, with a mean of 13,333 mg/L (Daud et al., 2013). The best COD levels were between 9839 mg/L and 15,680 mg/L, with a mean of 25,519 mg/L (Fatihah, 2015). Other authors' COD values, such as (Zailani et al., 2018; Mohd-Salleh et al., 2020; Detho et al., 2020), with COD values of 1993 mg/L, 2343.4 mg/L, and 1712 mg/L, demonstrate minimal differences in the value of COD as the value began to drop in 2018. The data demonstrate that the level falls from 2015 to 2017 owing to landfill ages (> 10 years). The COD content in the leachate was still over the discharge requirement of 400 mg/L before it could be released into the environment. This was because as the landfill aged, the leachate's properties changed as well (Mohd-Salleh et al., 2020; Detho et al., 2020).

The data inaccuracy for the COD concentration of the leachate wastewater was shown in Fig. 7. The diversity of the data is exhibited for COD content data from multiple studies from 2013 to 2021. The experimental values in the figure suggest a significant variation in the COD level of the leachate wastewater from 2013 to 2015 since the standard errors are not substantially overlapping and are significant. Furthermore, there is no noticeable difference in the COD level of the leachate wastewater from 2018 to 2021 since the standard errors are heavily overlapping and the error margins are high.

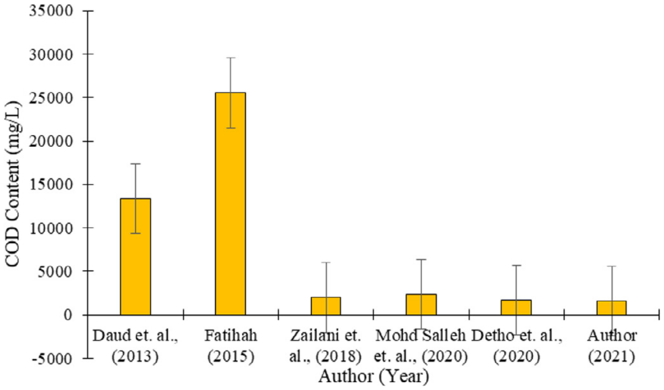

Fig. 7. COD content trending from 2013 - 2021.

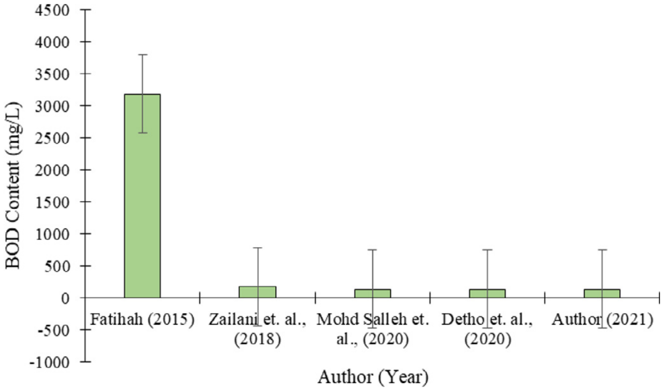

Fig. 8. BOD content trending from 2013 - 2021.

3.4.2. Analysis of biological oxygen demand (BOD)

In comparison to previous, current research on Biological Oxygen Demand, the value assessed in the current study was 137.41 mg/L. (BOD). The average value obtained of BOD was 3183 mg/L (Fatihah, 2015). The BOD value for mature landfills ranges from 100 mg/L to 200 mg/L (Mohd-Salleh et al., 2020). The BOD value is derived from SRLS and is reported in the 100 mg/L to 200 mg/L range. There is a significant difference in BOD values between 2015 and the subsequent years, with BOD values of 170 mg/L, 139.57 mg/L, 138.66 mg/L, and 137.41 mg/L in 2017, 2018, 2020, and 2021, respectively. The landfill is classified as mature based on the obtained results. By comparative analysis to EQA (1974) (Government of Malaysia 1974), most of the results produced by various scientists from 2015 to 2021 surpass over 50 mg/L, confirming the necessity for a better treatment to minimize the BOD content. There is a significant association between COD and BOD5 values, which could be utilized as an early indication to characterize the pollution levels in wastewater (Mohd-Salleh et al., 2020).

The data inaccuracy for the BOD concentration of the leachate effluent is shown in Fig. 8. The variance of the data is noticed for BOD concentration data from multiple studies from 2015 to 2021. The error bar in the figure suggests a considerable difference in the BOD concentration of the leachate effluent from 2015 to 2018, as the standard errors are not substantially overlapped and are significant. Furthermore, there is no noticeable difference in the BOD concentration of the leachate effluent from 2018 to 2021 since the standard errors are heavily overlapping and the error margins are enormous.

3.4.3. Analysis of suspended solid (SS)

The level of SS ranged from 270 mg/L to 1200 mg/L, with a mean value of 735 mg/L (Daud et al., 2013). Fatihah (Fatihah, 2015), on the other hand, exhibited the maximum of SS between 1200 mg/L and

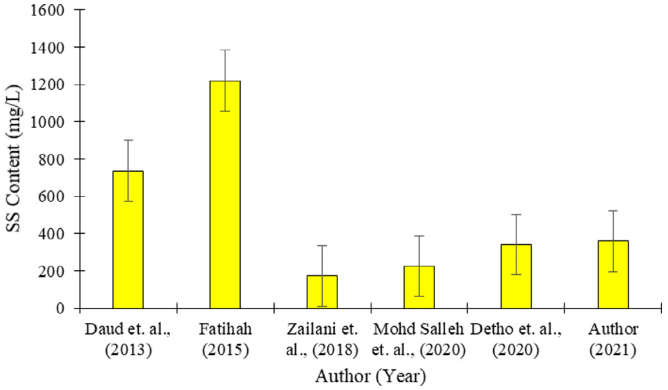

Fig. 9. SS content trending from 2013 - 2021.

1240 mg/L, with an overall mean of 1220 mg/L. The SS value observed at Simpang Renggam landfill Site (SRLS) varied at a mean of 359.8 mg/L in this study. According to Fig. 9, the SS value decreased dramatically between 2015 and 2018, with SS values of 1220 mg/L and 173 mg/L, correspondingly. The SS value will then progressively increase from 2018 to 2021, as initially disclosed by academics. Compared to EQA (Government of Malaysia 1974), the SS value is greater than the allowed limit of 50 mg/L. In the leachate investigation, the SS factor is one of the variables associated with the biological colloid particles (Mohd-Salleh et al., 2020; Detho et al., 2020).

The data inaccuracy for the SS concentration of the leachate wastewater was shown in Fig. 9. The variety of the dataset is seen for the SS contents collected by various investigators between 2013 and 2021. The graph's experimental values suggest a significant variation in the SS concentration of the leachate wastewater from 2013 to 2015 because the standard errors are not significantly overlapping and are significant. Furthermore, there is no discrepancy in the SS concentration of the leachate wastewater from 2018 to 2021 since the standard errors are heavily overlapping and the error margins are enormous.

3.4.4. *Analysis of power of hydrogen (pH)*

The antiquity of the landfill could be used to forecast the sort of leachates produced. The transformation from a more minor to a lengthier waste breakdown period reveals two distinct phases: acidity and fermentative (Zailani et al., 2018; Mohd-Salleh et al., 2020; Detho et al., 2020). The pH value recorded from Simpang Renggam Dump Site (SRLS) was 7.61 on the mean. Previous findings were achieved in 2013, with pH values ranging between 8.31 to 8.47 (Daud et al., 2013). With a pH of more than 7.5, leachate is categorized as ancient (Mohd-Salleh et al., 2020). According to the acidity and alkalinity assessments, the pH of leachates remains in the alkali region (above 8.0), depending on the analysis of the sample characteristics (Table 5). The pH value in leachate effluent discharge is an important indicator that could describe the biochemical processes of waste materials. Compared to EQA (Government of Malaysia 1974), the pH values obtained ranged from 6.0 to 9.0, deemed acceptable. As a result, leachate can be released without further pH correction.

The data inaccuracy for the pH value of the leachate wastewater was shown in Fig. 10. The variance of the data is seen for pH value data from multiple scientists from 2013 to 2021. The experimental values in the chart suggest that there is no substantial difference in the pH of the solution of the leachate wastewater from 2013 to 2015 because the error margins are heavily overlapping and huge. Furthermore, the standard errors are not significantly overlapping and are large, showing a significant change in the pH value of the leachate outflow from 2015 to 2018 and from 2018 to 2020.

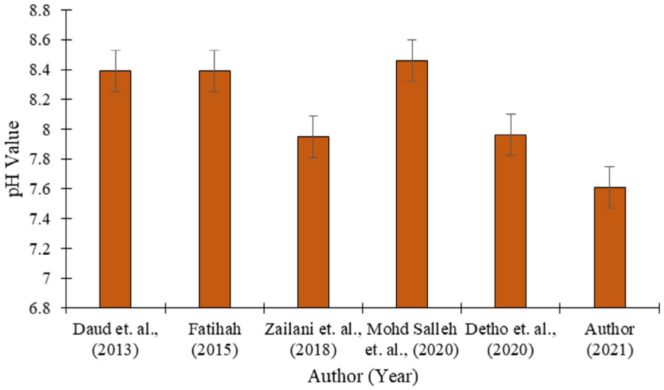

Fig. 10. The pH value trending from 2013 - 2021.

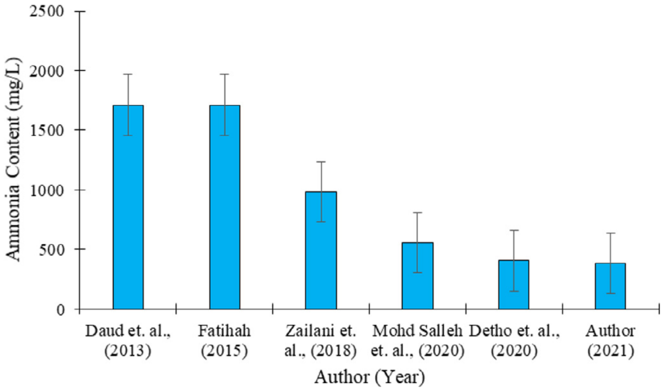

Fig. 11. Ammonia content trending from 2013 - 2021.

3.4.5. *Analysis of ammonia hydrogen (NH3-N)*

The higher acid content of leachate has made it a particularly toxicant for living beings. There was a slight variation between the results for the ammonium indicator, indicating a decrease in level throughout the year. The average value from Simpang Renggam Land-fill Site (SRLS) was 385.39 mg/L. Daud et al. (2013) (Daud et al., 2013) performed research and discovered that the ammonia content ranged from 200 mg/L to 1000 mg/L, with an estimated value of 1712.5 mg/L. It has no negative impact on anaerobic processes. As a result of the earlier study presented by the researchers in (Mohd-Salleh et al., 2020), which reveals a greater level of ammonia nitrogen in 2013 ranging from 755 mg/L to 2670 mg/L, bioremediation is not advised for SRLS sites. The fall in acidic nitrogen content is caused by a lack of organic compounds (Detho et al., 2020). Compared to EQA (Government of Malaysia, 1974), the resultant ammonium level is expected to be higher than the permitted limits (5 mg/L). To meet specified discharge limitations, ammonia nitrogen can be reduced using various methods, including physicochemical treatment. The present overall mean for ammonium concentration is 385.39 mg/L, and this level must be reduced to less than 5 mg/L to meet the acceptable amount of outflow requirement.

The data inaccuracy for the Ammonia concentration of the leachate wastewater was shown in Fig. 11. The variety of the data is exhibited for the data of Ammonia percentage collected by several researchers between 2013 and 2021. The experimental values in the data suggest that there is no notable change in the Ammonia percentage of the leachate wastewater from 2013 to 2015 and from 2018 to 2021 because the error margins are heavily overlapping and huge. Furthermore, the standard errors are not substantially overlapping, and the error margins are broad, indicating a significant variation in the Ammonia concentration of the leachate wastewater from 2015 to 2018.

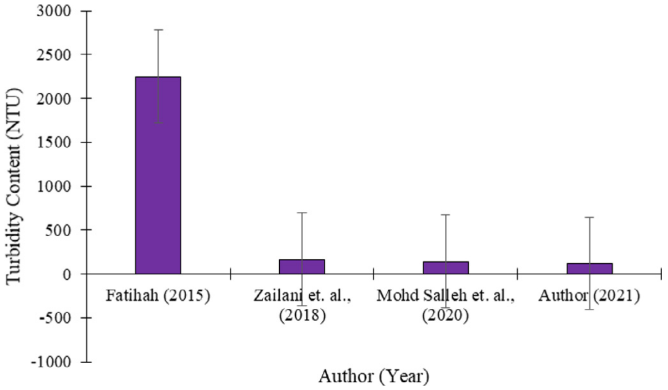

Fig. 12. Turbidity content trending from 2015 - 2021.

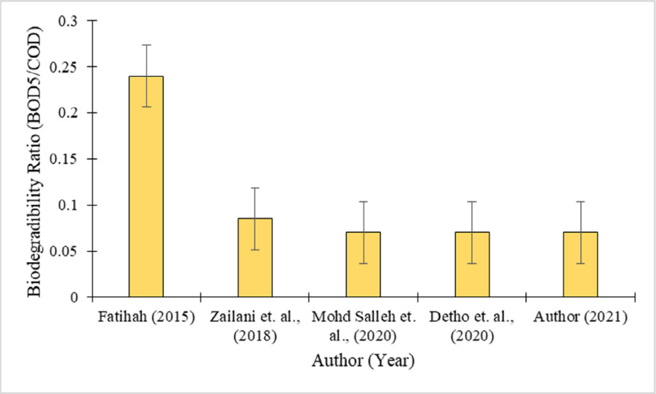

Fig. 13. Biodegradability ratio trending from 2015 - 2021.

3.4.6. *Analysis of turbidity*

The turbidity measurement was 2250 NTU based on preliminary data collected in 2015. The turbidity measurement obtained from the SRL site in 2018 is falling at 2064 NTU. The turbidity value from 2018 to 2021 is the same, ranging between 117 and 142 NTU. The antiquity of the landfill and the stability of leachate might induce alterations in the escalation of turbidity values.

The data inaccuracy for the turbidity concentration of the leachate wastewater was shown in Fig. 12. The heterogeneity of data is shown for turbidity level data from multiple studies from 2015 to 2021. The experimental values in the graph suggest a significant variation in the turbidity percentage of the leachate wastewater from 2015 to 2018, as the standard errors are not significantly overlapping and are significant. Furthermore, the standard errors are heavily overlapping, and the error margins are high, indicating no discrepancy in the turbidity contents of the leachate wastewater from 2018 to 2021. The difference in turbidity content between 2018 and 2021 is narrowing.

3.4.7. *Analysis of biodegradability ratio (BOD5/COD)*

The biodegradability ratio (BOD5/COD) has been utilized to calculate landfill age (Zailani et al., 2018; Mohd-Salleh et al., 2020; Detho et al., 2020). It differs at an acceptable range of 0.07 according to the Simpang Renggam Landfill Site (SRLS). The leachate is classed as aged (stabilized) leachate effluent with a BOD5/COD value of 0.1, depending on the outcomes. As a result, the proportion of BOD5/COD falls as landfill ages (Detho et al., 2020). The characterization of biodegradable ratio is often regarded as the best option for determining biological and chemical breakdown at SRLS. The increased COD value compared to BOD5 indicated that more chemicals might be oxidized chemically rather than physiologically. A low BOD5 result herein suggested that the created leachate had a small value of biodegradability, which was incompatible with the physiological treatment method (Mohd-Salleh et al., 2020). The average value for BOD5 and BOD5/COD were 137.41 mg/L and 0.076, correspondingly.

The data inaccuracy for the biodegradability ratio of the leachate wastewater was shown in Fig. 13. The heterogeneity of results is shown for biodegradability ratio data from multiple studies from 2015 to 2021. The figure's experimental values indicate a clear distinction in the biodegradability ratio of the leachate wastewater from 2015 to 2018, as the standard errors are not widely overlapping and are significant. Furthermore, there is no noticeable difference in the biodegradability ratio of leachate wastewater from 2018 to 2021 since the error bars are heavily overlapping, and the error margins are enormous. Furthermore, beginning in 2018, the margins between the biodegradability ratio got narrower than in 2015.

Based on the data obtained in Figs. 7–13, it can be concluded that the courses of changing the concentration of the parameters (COD, BOD, SS, pH, NH3-N, turbidity, and BOD5/COD) over the nine (9) years period starting from 2013 to 2021 which shows a decreasing trend has been affected by the age of the landfill site which is more than ten (10) years and directly affects the changes in the leachate's properties. With the current parameters' current concentration exceeding the local standard, the leachate may seep and contaminate nearby soil and groundwater. It is commonly understood that leachate overflows into water bodies such as rivers, lakes, and groundwater will reduce the quality of the water and so affect ecological systems.

4. Conclusions

The 2D ERI performed at Simpang Renggam, Johor, demonstrated the presence and transport of leachate from the landfill into the nearby soil and water. According to the investigation results, the leachate also impacted the surrounding oil palm cultivation, which was located southwest of the landfills. In general, the tremendous leachate penetration was found 1.5 to 4.0 m vertically beneath the soil's base and 80 m horizontally away from the SRL site. In both inverse models of resistance, resistivity values ranging from 1 to 10 Ωm were discovered to represent the most polluted zone (RL1 and RL2). Lastly, by establishing the validity of leachate under the soil, it can be verified that the ERI technique is one of the most effective methods for assessing the existence of leachate due to the clear image of analysis obtained from RES2DINV software, cost-saving and environmentally friendly, which the other previous researchers have also proved. Based on the studies conducted, it can be concluded that the leachate did not greatly affect the physical properties of the soil at Simpang Renggam landfill as the value of specific gravity, Atterberg limits, and particle size of the leachate soil sample have a small margin of difference as compared to the natural soil of the landfill site. In terms of soil chemical content analysis, the content of Fe, Cr, Ar, Pb, Cu, and Zn in the leachate soil is higher compared to the natural soil, and the content of Fe, Cr, Ar, and Pb in the leachate samples also exceeded the values stated in the EQA regulations which confirm that the level of heavy metal may develop in the biological systems and become a significant source of hazard. In terms of wastewater leachate characterization, except for the pH measurements, the parameters such as COD, BOD, SS, NH3-N, turbidity, and BOD5/COD show a decrease in values in 2021 as compared to 2015 but still exceeding the values stated in the EQA (1974) regulation.

Acknowledgements

The authors wish to thank Universiti Malaysia Pahang (UMP) for funding this project via the Postgraduate Research Grant Scheme (PGRS), Project Number PGRS2003185. All parties participating in this project have been highly cooperative.

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