Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 20, No 3, 2023, 633-643
Article available at homepage presipitasi

Regional Case Study

Two-Dimensional Modeling of Leachate Distribution in Batu Layang Landfill on Peat Soil using Geoelectric Method

Fitriana Meilasari[1*], Hendri Sutrisno[1], Arifin[2], Rizki Purnaini[2], Irda Dwi Utari[2]
[1] Department of Mining Engineering, Faculty of Engineering, Universitas Tanjungpura, Jalan Prof. Dr. H. Hadari Nawawi, Pontianak, Indonesia 78124
[2] Department of Environmental Engineering, Faculty of Engineering, Universitas Tanjungpura, Jalan Prof. Dr. H. Hadari Nawawi, Pontianak, Indonesia 78124
Corresponding Author, email: fitriana@untan.ac.id

Abstract

The open dumping system implemented by the Batu Layang landfill can produce leachate, contaminating groundwater around the landfill. Groundwater contaminated with leachate, if used by the community, can cause health problems. Therefore, management efforts were needed, such as subsurface leachate modeling. This study aims to model the distribution of subsurface leachate in 2 dimensions. The modeling of leachate distribution below the soil surface used the Wenner configuration geoelectric method. The number of geoelectric measurement paths was two paths. The length of each track was 195 m, with a distance of 5 m between the electrodes. Data obtained from resistivity values were analyzed using the Res2Dinv application. The calculation of leachate discharge used the water balance method. Based on the inversion results using the Res2Dinv software, the resistivity value of leachate-contaminated soil in line 1 was 1.19-9.43 Ωm, and track 2 was 0.5-10.2 Ωm. The leachate resistivity value was <10 Ωm because the leachate contains inorganic minerals (metals), so the resistivity value was low. Land contaminated with leachate was estimated to be spread as far as 195 m. The most profound leachate depth was estimated at 39.4 m. Batu Layang Landfill leachate discharge in Zone E averages 4 m^3/day.

Keywords: Batu Layang landfill, geoelectricity, leachate

1. Introduction

The human population was predicted to increase every year. The increase in the human population was directly proportional to the rise in the amount of waste produced (Aziz et al., 2019; Shah et al., 2022). Based on data from the National Waste Management Information System for 2022, the waste generation rate generated in Pontianak City was around 144,651.25 tons in 2021. Meanwhile, the waste generation rate generated in Pontianak City in 2022 was around 146,560.7 tons (Dinas Lingkungan Hidup Kota Pontianak, 2022). For one year, the increase in the waste generation rate was 1.3%.

Pontianak City waste comes from domestic and non-domestic waste. The waste was transported to the Batu Layang landfill. Waste generation characteristics at the Batu Layang landfill include 70% organic waste and 30% non-organic waste (Qadri et al., 2020). The Batu Layang landfill in waste management uses an open dumping system. The open dumping system has the potential to produce leachate, which can contaminate the environment and groundwater around the landfill (Apriasti et al., 2016).

Leachate is a liquid produced due to the entry of water from outside into the waste pile, dissolving and rinsing dissolved materials, including material resulting from the decomposition of waste or waste decomposition (Azis et al., 2018; Wu et al., 2021). The leachate generation rate is affected by rainwater, surface water flow, evapotranspiration, temperature, waste composition, and groundwater infiltration

(Fang et al., 2021). Leachate composition was influenced by the type of waste in the landfill and the age of the landfill. The concentration of chemical compounds in leachate is affected by temperature, pH, humidity, and the age of the waste pile (Hakim et al., 2014). Leachate contains dissolved organics, macro-inorganic, heavy metals, and xenobiotic compounds (Ael-Shafy et al., 2023; Fang et al., 2021). Leachate is toxic because it contains heavy metals and organic and inorganic substances in the leachate, which form carcinogenic compounds (Sari and Lucyana, 2021). Leachate was not appropriately managed, and it can cause groundwater contamination around the landfill (Abrauw, 2019). Some Batu Layang landfill communities use groundwater for toilet needs (Maryani et al., 2016). The distance of the settlement from the Batu Layang landfill was less than 1 km (Yatim and Mukhlis, 2013). The closer the settlement was to the landfill, the greater the potential for leachate to disperse into groundwater utilized by the community (Jaya et al., 2016). Groundwater contaminated with leachate, if used by the community continuously, will potentially interfere with health (Maryani et al., 2016). Therefore, it was necessary to deal with leachate below the ground surface. One of the efforts made was modeling leachate below the surface.

Modeling leachate distribution in the subsurface at the Batu Layang landfill can be identified using the Wenner configuration geoelectric method (Arrazi and Usman, 2021). Geoelectricity is a geophysical method to determine the nature of subsurface electricity flow based on the nature and physical condition of the specific gravity value of rocks in the earth and based on the electrical properties of rocks (Amien, 2016; Arman, 2012). The advantages of this geoelectric method are that it does not pollute the environment, easy and fast operation, lower costs compared to using other geophysical methods, and identifies depths up to several 50 feet below the ground surface (Miswar, 2017). Many studies have used the geoelectric method to study the distribution of leachate below the soil surface, including the Estimation of Leachate Distribution with the Geoelectrical ERT Method (Ramadhan et al., 2019); Application of the Wenner mapping configuration geoelectric method to determine leachate seepage at Talang Gulo Jambi landfill (Pratiwi et al., 2018) and Identification of the direction of leachate seepage using the resistivity geoelectric method of dipole-dipole configuration around the Sekoto landfill, Kediri district (Ratih et al., 2021). Therefore, the geoelectrical method is needed to indicate the leachate distribution below the soil surface. Leachate distribution modeling can be used to determine the appropriate landfill management if leachate seepage exceeds the radius selected based on Indonesian national standard No. 03-3241-1997. This study aims to model the distribution of subsurface leachate in 2 dimensions. The limitation of modeling the potential distribution of leachate below the ground surface in 2 dimensions using geoelectricity is that it cannot describe how much leachate is below the ground surface. Therefore, this research is supported by analyzing leachate discharge calculations using rainfall. Rainfall is one of the factors that influences the amount of leachate in the landfill. The more rainfall, the more leachate is produced. Research that links potential leachate distribution modeling with leachate discharge analysis is very few/limited.

2. Methods

2.1 Research Location

Geoelectric method measurements were conducted near zone E of the Batu Layang landfill. Zone E of the Batu Layang landfill was a landfill that was still operating and an active cell. Zone E of the Batu Layang landfill was administratively located at Jalan Kebangkitan Nasional, Batu Layang, North Pontianak sub-district, West Kalimantan. Geoelectric measurements consist of 2 tracks. Track 1 was before the accumulation of waste and close to a small ditch with coordinates 0°01'30.65"N, 109°19'16.77"E to 0°01'31.22"N, 109°19'10.49"E. Track 2 was on a pile of garbage with coordinates 0°01'33.46"N, 109°19'15.45"E to 0°01'27.22" N, 109°19'14.33"E. The measurement picture of the geoelectric method can be seen in Figure 1.

Figure 1. Wenner configuration geoelectric method measurement location

2.2 Research Equipment

The measurement of the geoelectrical method used equipment such as 1 unit of Resistivity meter Brand ARES (Company that manufactures Resistivity meter Brand ARES (Automatic Resistivity System): GF Instruments, s.r.o.), 40 electrodes, two current cables, two potential difference cables, 4 meters, 1 GPS (Global Positioning System) unit, and 1 Res2DInv Software version 3.54.44 (Res2DInv software manufacturer: Geotomosoft).

2.3 Research Methods

2.3.1 Measurement of Geoelectric Method

Geoelectric measurements consisted of 2 tracks with the length of each track of 195 m. The basis for determining the size of the track was the distance from the landfill to the settlement of about 200 m. The distance between electrode spacings was 5 m. The configuration used in the geoelectric method in this study was the Wenner configuration. The advantages of the Wenner configuration were an excellent vertical resolution and high sensitivity to lateral changes but weak current penetration to depth (Asmaranto, 2012; Hakim and Manrulu, 2016). The distance between the current and potential electrodes in the Wenner configuration was the same. It was intended that the results obtained were symmetrical or by the calculations (Telford et al., 1990). The potential electrode distance in the Wenner configuration was 1/3 of the current electrode distance (Asmaranto, 2012).

2.3.2 Data Processing

After measuring the geoelectric method, the next step was data processing, interpretation, and analysis. Data processing from geoelectric measurement results uses Res2Dinv software. The stages in data processing include: (1) Calculating the value of the geometry factor (K), the midpoint value, and the Rho Apparent value (ρ). Geoelectric measurement data processing output using Res2Dinv software was a 2D cross-sectional image (Simanjuntak and Surbakti, 2021). Color imaging was interpreted as the study area's rock/material/soil resistivity value. The 2D cross-sectional obtained from data processing using

Res2Dinv software showed depth (h) and leachate distribution below the soil surface. Data interpretation and analysis were based on the study area's geological, hydrogeological, and topographical conditions.

The arrangement of the electrodes determines the geometry factor k. For the Wenner configuration, it can be formulated as equation (1).

$$k = 2\,\pi\,a \quad (1)$$

After obtaining the geometric factor value, calculate the midpoint value. The midpoint value for the distance was the distance from C1 to C2 divided by two. The midpoint value for the depth was 1\5 from the distance from C1 to C2.

For data interpretation, values were based on the resistivity value by calculating the apparent Resistivity value (ρ_a) as equation (2).

$$\rho_a = 2\pi a\,\frac{V}{I} \quad (2)$$

Description:

k = Geometry factor (m)

ρ_a = resistivity value (Ωm)

I = current (A)

ΔV= Potential difference (V) (Telford et al., 1990).

2.3.3 Leachate Flow Calculation

Leachate flow analysis was calculated using the annual rainfall and runoff approach. The terms of the approach using this method are:

- The rainfall data used is the annual average rainfall data for ten years (2012-2021).
- The results of empirical research show that 40% of rainfall will be surface runoff and 60% will be infiltration. Leachate discharge analysis uses the percentage of infiltrated rainfall.
- The formula used to calculate leachate flow was equations (3) and (4) (Direktorat Pengembangan Penyehatan Lingkungan Permukiman, 2018)

$$Q = L \times A \quad (3)$$

$$L = C \times 60\% \quad (4)$$

Description:

Q: Flow or leachate rate (m^3/day)

A: Area (m^2)

C: Annual average rainfall (mm/day)

L: leachate (m/day)

Leachate flow analysis uses rainfall data for 2012-2021. Rainfall data for ten years were obtained from the Segedong rainfall station belonging to the Kalimantan River and Regional Office I (BWSK 1). The area data used in this analysis is the landfill area data in zone E. The area designated by zone E is 1.2 Ha.

3. Result and Discussion

3.1 Analysis of the Distribution of Leachate Below The Soil Surface Based on Resistivity Values

Based on the inverse modeling software Res2DInv results, the resistivity values on track 1 ranged from 1.19 to 13.3 Ωm (Figure 2). The error rate (RMS error) in the processing of geoelectric measurement data using the Res2Dinv software on track 1 was 1.67%.

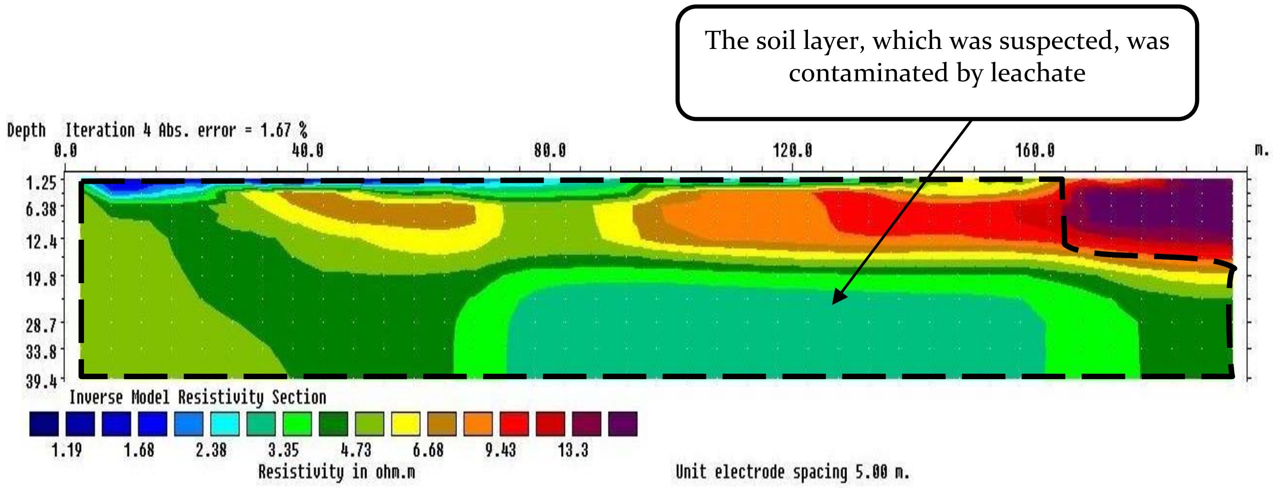

Figure 2. The 2D cross-section of track 1 resistivity

Figure 2 shows the leachate distribution modeling below the ground surface on track 1. Resistivity values obtained from processing data using Res2Dinv software were 1.19-13.3 Ωm with an RMS error value of 1.67%. The resistivity value of 1.19-9.43 Ωm was identified as leachate-contaminated soil. It was to the research of Apriasti et al. (2016), which states that the leachate resistivity value was < 10 Ωm (Apriasti et al., 2016).

The leachate resistivity value was <10 Ωm because leachate contains a lot of inorganic mineral content (metals), so the resistivity value was low (Sukisna and Toifur, 2019). Low resistivity values and high conductivity values indicated heavy metal content in leachate. The content of heavy metals in leachate affects the resistivity and conductivity values. The leachate resistivity value was small, and the conductivity value was high. The higher the resistivity value, the lower the conductivity value and the less heavy metal content. Vice versa, the lower the resistivity value, the higher the conductivity value and the heavier the metal content. Vice versa, the lower the resistivity value, the higher the conductivity value and the heavier the metal content. Leachate in the study area was thought to have spread as far as 195 m. The deepest underground seepage of leachate was estimated to be 39.4 m. Factors influencing leachate distribution were the research area's geological and hydrogeological conditions (Padilah et al., 2021). The geology of the study area consists of alluvium rock formations. The alluvium formation was composed of alluvial and swamp deposits (Suwarna and Langford, 1993). The Batu Layang landfill was in the Pontianak groundwater basin. In addition to geological and hydrogeological factors, other factors influence the distribution of leachate, namely the condition of the landfill not operating, leachate from zone E that enters the ditch may overflow during the rainy season, and the habit of scavengers in piling up waste around the geoelectrical measurement site.

The resistivity value of 9.43-13.3 Ωm was identified as sandy loam. It was supported by the research of Muliadi et al. (2019), which states that one of the soil types found in the Batu Layang landfill was suspected of sandy loam (Muliadi et al., 2019). The resistivity value of 1.19-13.3 Ωm was interpreted as peat soil. The estimation of the resistivity value was supported by the research of Muhardi et al. (2020). The depth of peat soil was up to 4.5 m below the surface (Muliadi et al., 2019). Based on the regional geological map of the Singkawang sheet in 1993, the Batu Layang landfill was composed of alluvial and swamp sedimentary rock formations, where one of the rock/soil types found in these formations was peat, silt, sand, and gravel (Suwarna and Langford, 1993).

The resistivity value on track 2 (L2) obtained from processing the results of geoelectrical measurements using the Res2Dinv software was 0.5-564 Ωm (Figure 3). The error rate (RMS error) in the processing of geoelectric measurement data using the Res2Dinv software on track 2 was 24.2%. The error

rate (error RMS) on track 2 was greater than 10% due to the geoelectrical measurement of the Wenner configuration on track 2 being in a pile of plastic and other waste, making the electrode challenging to plug in. In addition, the condition of this pile of garbage was c
and challenging to conduct electricity. Hot weather conditi
surface high.

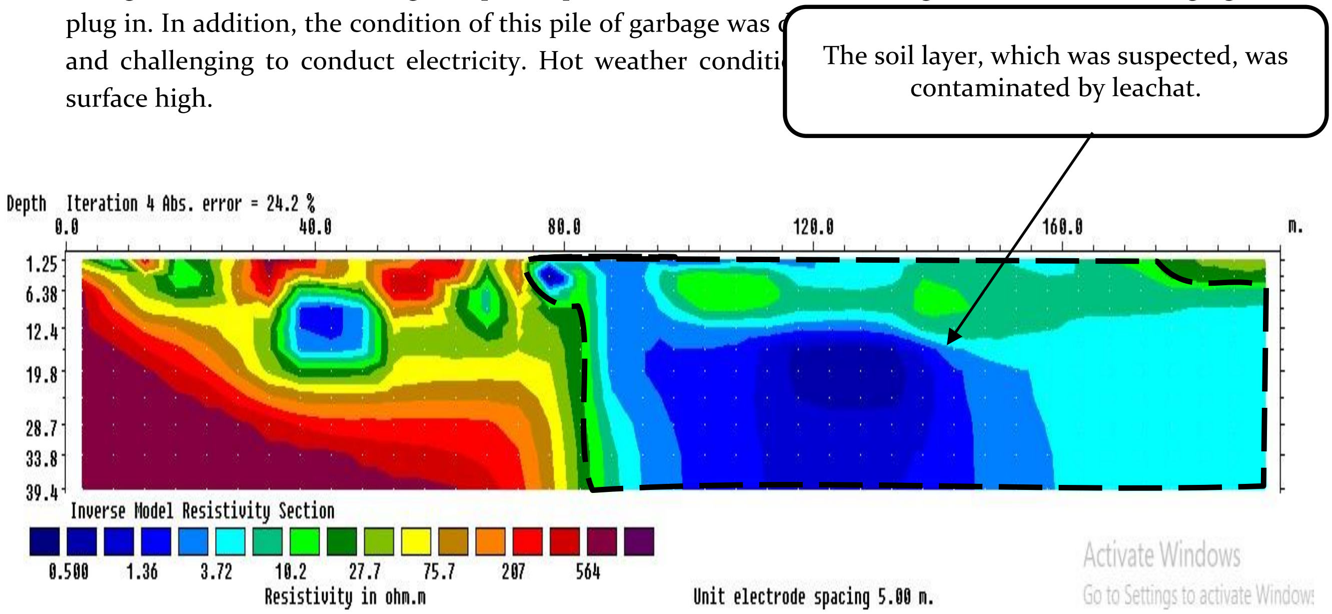

Figure 3. The 2D cross-section of track 2 resistivity

Figure 3 shows the results of the leachate distribution modeling below the ground surface on track 2. The resistivity value obtained from data processing using Res2Dinv software was 0.5-564 Ωm. The resistivity value of 0.5-10.2 Ωm was identified as leachate-contaminated soil. It was supported by the research of Muhardi et al. (2019) (Muhardi et al., 2020), which states value estimation. Leachate contaminated soil resistivity of 0.152-13.3 Ωm. Leachate was thought to spread horizontally up to 195 m. The deepest leach seepage was estimated at 39.4 m below the ground surface.

The resistivity value of 1.36-564 Ωm was interpreted as peat soil, sandy loam, and sand. This statement is by the research of Muhardi et al. (2020) (Muhardi et al., 2020). The estimation of the resistivity values of peat, sandy loam, and sand in the research by Muhardi et al. (2020) is in the range of 0.152 to 3132 Ωm. Another study that supports the estimation of the resistivity value of peat soil is Fajania et al. (2021), which states that the resistivity value of peat soil is in the range of 18.8-126 Ωm (Fajania et al., 2021). Ramadhaningsih and Sampurno's research (2017) also states that the resistivity interpretation value on peat ranges from 17.6-69.9 Ωm (Ramadhaningsih and Sampurno, 2017). The depth of peat soil in Batu Layang landfill was estimated to be up to 4.5 m below the soil surface (Muhardi et al., 2020). Peat soil contains organic matter (Muhardi et al., 2020). The peat soil color was yellow to dark brown. The level of biodegradation influences the color of peat soil, the amount of plant fiber, and sediment (inorganic). Peat soils were porous and had low nutrient content. Peat soil pH ranges from 2.7 to 5.0 (Wibowo, 2010). Peat soil has a high porosity value (Sampurno et al., 2018). Peat soils have high porosity and permeability, so they are water-saturated (Muhardi et al., 2020; Zulkifley et al., 2013). Peat soils saturated with water can make it easier for leachate to fill pore spaces and contaminate groundwater around the landfill, causing groundwater to mix with leachate (Muhardi et al., 2020). Peat soil has a permeability value of 2.97×10^{-5}-8.31×10^{-5} m/s, porosity of 83.43-92.92%, and bulk density of 0.16 - 0.31 g/cm^3 (Jakarius et al., 2021). Porosity determines the amount of water that can be contained in the rock. The grain shape of the constituent rock material, the arrangement of the constituent rock grains, the filling of the spaces between the grains by cement, and the size of the constituent rock material affect porosity. The number of different sizes in the subsurface rock arrangement also affects porosity. It can be seen that below the soil surface, there were rocks of different sizes (large and small), and the tiny particles could fill the voids between the large particles.

Peat decomposition levels were divided into 3: fibric, hemic, and sapric. Based on research by Jakarius et al. (2021), the value of hemic peat soils has a porosity value of 86.27% (0.21 g/cm³) and 87.74% (0.21 g/cm³). Porosity values in fibric-type peat soils were 92.92% (0.16 g/cm³), 83.43% (0.31 g/cm³), and 91.85% (0.18 g/cm³) (Jakarius et al., 2021) Fibric peat soil has a permeability value that exceeds the permeability value of hemic peat soils (Jakarius et al., 2021). Peat formation comes from plant residues that have not yet fully decomposed, and this formation process experiences a low level of fertility because it contains high organic acids (Jakarius et al., 2021). Peat soils have high porosity and permeability, absorbing and storing water more than other mineral soils (Zulkifley et al., 2013). The water content in peat soil was identified as 300-3000% (Astuti et al., 2020). Peat characteristics cause peat soils to be quickly saturated with water. This results in leachate having the potential to quickly fill the pore space of peat soil, potentially causing soil and groundwater pollution.

The recommendation for control efforts to minimize leachate pollution to the environment, especially surface water and groundwater, is to use a barrier. The barrier functions as a barrier for pollutants (leachate) so they do not seep into the ground so they do not contaminate groundwater. An example of a barrier is a layer of geomembrane and clay. The geomembrane layer is a geosynthetic material that protects soil and groundwater from leachate contamination. The clay barrier serves as a barrier between leachate and soil and groundwater. The clay functions as a natural geological barrier. The flow of inorganic and organic pollutants, especially in industrial and domestic waste, makes clay soil membranes a readily available waste treatment tool. The existence of this membrane property prevents harmful inorganic and organic pollutants from flowing further into the groundwater; besides that, the nature of the membrane also responds to a solution concentration gradient, namely a lower concentration of a solution (lower water activity) and higher concentration of a solution (higher water activity). The choice of clay barrier as a leachate pollution prevention technique is based on the large availability of Clay in Pontianak City, making it easier to process. In addition, effectiveness is also a concern in determining recommendations to minimize leachate pollution to the environment. A clay barrier serves as an impermeable layer to inhibit pollutants, which do not need to use the addition of hazardous chemicals to achieve the desired composition, so it is safe for the environment.

3.2 Leachate Flow Calculation

The leachate flow was influenced by the rainfall of an area and the size of the catchment area. The amount of annual rainfall used is for at least the last ten years. The minimal data used aims to obtain accurate and representative information about rainfall patterns in an area. The calculation of leachate flow has been carried out for the last ten years using a fixed area from 2012 to 2021. The results of leachate flow calculations for the last ten years can be seen in Table 1.

Table 1 Calculation of leachate discharge for the last ten years (2012-2021)

Years	Rainfall	Infiltration	Flow	Flow
	mm/years	m/years	L/d	m^3/day
2012	1708.7	1.0251995	0.39010636	3.37051892
2013	1792.4	1.07545968	0.40923123	3.53575785
2014	1246.6	0.74795789	0.28461107	2.45903963
2015	1135.8	0.68148475	0.25931688	2.24049781
2016	1755.5	1.05330197	0.40079984	3.46291058
2017	2159.9	1.29595594	0.49313392	4.26067705
2018	2341.9	1.4051232	0.53467397	4.61958312
2019	2208.6	1.32513926	0.50423868	4.35662224
2020	3638.0	2.18280485	0.83059545	7.17634471
2021	2696.8	1.61805341	0.61569764	5.31962764

Table 1 shows the calculation of the leachate flow for the last ten years (2012-2021), which has fluctuated. The highest leachate flow in 2020 was 7.18 m^3/day, and the lowest in 2015 was 2.24 m^3/day. Based on leachate flow data for the last ten years, it can be estimated that the leachate flow generated in zone E of the Batu Layang Landfill is 4 m^3/day. The leachate flow produced over the last ten years has fluctuated. It is caused by the influence of rainfall, which differs each year (Dzulfahmi et al., 2019).

Leachate generated from Zone E will easily infiltrate into the soil. Because the Batu Layang Landfill does not use a liner in its cell layer, the water that enters the landfill will be forwarded into the ground vertically and horizontally. In addition, infiltration into the soil was influenced by the type of rock that makes up the soil. The more porous and permeable the constituent rocks are, the easier they become saturated with water (permeable). The coarser the grain of the soil, the greater the volume of leachate that enters the soil. Leachate that flows vertically and horizontally into the soil contains pB and Cd metals. The content of these heavy metals in the Batu layang landfill area has exceeded the Indonesian National Standard 06-6992-3-2004 threshold. The distribution of leachate that needs to be managed correctly will potentially cause soil and groundwater pollution (Purba and Kamil, 2015).

The content of dissolved organics, macro-inorganic, heavy metals, and xenobiotic compounds found in leachate differed at certain times. During the rainy season, the intensity of rainfall is also high. It impacted increasing the resulting leachate flow and decreasing the concentration of leachate. In the dry season, the leachate value is less and has a high concentration and a blackish-brown color because there is no dilution during the rainy season. The high concentration of leachate in the dry season is due to the stability of the water flow rate so that precipitation occurs quickly compared to the rainy season, where the water flow rate becomes faster due to rain (Biaggi, 2022).

4. Conclusions

Based on the Res2DInv inverse modeling software results, the resistivity value of leachate-contaminated soil on track 1 was 1.19-9.43 Ωm. Meanwhile, the resistivity value of leachate-contaminated soil on track 2 is 0.500-10.2 Ωm. Leachate resistivity value < 10 Ωm. However, on line 2, the leachate resistivity value is > 10 Ωm. It was because the measurement conditions on track 2 were in plastic and other waste piles. The condition of this pile of garbage is dehydrated, making it more resistant and difficult to conduct electricity. The leachate-contaminated soil was thought to have spread as far as 195 m. The distribution of the deepest leachate is up to a depth of 39.4 m. Batu Layang Landfill leachate discharge in Zone E averages 4 m^3/day. The highest leachate discharge in 2020 was 7.17634471 m^3/day. Meanwhile, the lowest leachate discharge in 2015 was 2.24049781 m^3/day. The suggestions for further research are research on the environmental impact on the distribution of leachate in the research area and appropriate countermeasures for the distribution of leachate.

Acknowledgement

The researcher's gratitude goes to the Environmental Agency, Batu Layang Landfill, Kalimantan River Basin I, which has supported and assisted in providing data and information for the benefit of this research. The Institute of Research and Community Services (LPPM), Tanjungpura University, which has assisted in funding this research DIPA.

References

Abdel-Shafy, H.I., Ibrahim, A.M., Al-Sulaiman, A.M., Okasha, R.A., 2023. Landfill leachate: Sources, nature, organic composition, and treatment: An environmental overview. Ain Shams Engineering. Journal. 102293.

Abrauw, A.E.S., 2019. Studi Operasional Pengelolaan Limbah Cair Lindi (Leachate) Pada Tpa Control Landfill Koya Koso. J. Din. 1, 1–10.

Amien, S., 2016. Penyelidikan Hidrogeologi Dengan Metode Geolistrik Schlumberger di Kecamatan Hamparan Perak, Deli Serdang, Sumatera Utara. Journal of Electrical Engineering Volume 1

Apriasti, E.R., Marsudi, Utomo, kiki P., 2016. Pola Sebaran Air Lindi Di Tpa Batu Layang Pontianak Dengan Metode Geolistrik Wenner-Schlumberger. Jurnal Teknologi Lingkungan Lahan Basah 4, 1–10.

Arman, Y., 2012. Identifikasi Struktur Bawah Tanah di Kelurahan Pangmilang Kecamatan Singkawang Selatan Menggunakan Metode Geolistrik Resistivitas dan Inversi Lavenberg - Marquardt. POSITRON 2, 6–11.

Arrazi, H.F., Usman, 2021. Interpretasi Lapisan Bawah Permukaan TPA Muara Fajar Untuk Mengetahui Pola Sebaran Lindi Dengan Menggunakan Metode Geolistrik Konfigurasi. Wenner. Repos. Umr. 1–9.

Asmaranto, R., 2012. Identifikasi Air Tanah (Groundwater) Menggunakan Metode Resistivity (Geolistrik With Ip2win Software). Fakultas Teknik Universitas Brawijaya.

Astuti, Y., Astiani, D., Herawatiningsih, R., 2020. Pengaruh Pembakaran Berulang Pada Lahan Gambut Terhadap Beberapa Karakteristik Tanah Di Desa Rasau Jaya Umum Kabupaten Kubu Raya Kalimantan Barat. JURNAL HUTAN LESTARI 8, 668–681.

Azis, A., Yusuf, H., Badaruddin, S., 2018. Efektivitas Kolom Pasir Pada Waduk Resapan Sebagai Penyangga. pp. 43–48.

Aziz, R., Ihsan, T., Permadani, A.S., 2019. Skenario Pengembangan Sistem Pengelolaan Sampah Kabupaten Pasaman Barat dengan Pendekatan Skala Pengolahan Sampah di Tingkat Kawasan dan Kota. Jurnal Serambi Engineering. 4, 444.

Biaggi, M.., 2022. Pengaruh Hujan Terhadap Konsentrasi Logam Dalam Sedimen Sungai Code. Universitas Islam Indonesia.

Dinas Lingkungan Hidup (DLH) Kota Pontianak, 2022. Jumlah Timbulan Sampah Tahun 2022. Pontianak.

Direktorat Pengembangan Penyehatan Lingkungan Permukiman, 2018. Tata Cara Perencanaan dan Pembangunan Tempat Pemrosesan Akhir (TPA) Sampah. Jakarta.

Dzulfahmi, D., Ivansyah, O., Zulfian, Z., 2019. Monitoring Pergerakan Lindi Menggunakan Metode Geolistrik Time-Lapse Di Sekitar Pemukiman Tempat Pembuangan Akhir Batu Layang Pontianak. Prism. Fis. 7, 251.

Fajania, R., Arman, Y., Muhardi, M., 2021. Pendugaan Ketebalan Lapisan Gambut Di Sekitar Jalan Reformasi Kota Pontianak Menggunakan Metode Geolistrik Tahanan Jenis. Jurnal GEOCELEBES 5, 16–22.

Fang, D., Wang, J., Cui, D., Dong, X., Tang, C., Zhang, L., Yue, D., 2021. Recent Advances of Landfill Leachate Treatment. Journal of the Indian Institute of Science. 101, 685–724.

Hakim, A.R., Susilo, A., Maryanto, S., 2014. Spread Indication of Underwater Surface Contaminants Using Magnetic Method (Case Study: TPA Supit Urang, Malang). Natural-B 3, 281–289.

Hakim, H., Manrulu, R.H., 2016. Aplikasi Konfigurasi Wenner dalam Menganalisis Jenis Material Bawah Permukaan. Jurnal Ilmu Pendidikan Fisika Al-Biruni 5, 95–103.

Jakarius, Muliadi, Zulfian, 2021. Studi Sifat Fisika Pada Tanah Gambut di TPA Batu Layang Berdasarkan Tingkat Kematangan Tanah Gambut. Prism. Fis. 9, 166–171.

Jaya, A.E.S., Suarna, I.W.I.W., Aryanta, I.W.R., 2016. Studi Kualitas Air Tanah Dangkal Dan Pendapat Masyarakat Sekitar Tempat Pemrosesan Akhir Sampah Suwung Kecamatan Denpasar Selatan, Kota Denpasar. ECOTROPHIC Jurnal Ilmu Lingkungan, 62.

Maryani, I., Marsudi, Nasrullah, 2016. dentifikasi Penggunaan Sumber Air Baku oleh Penduduk di Sekitar TPA Batulayang Pontianak. Jurnal Teknologi Lingkungan Lahan Basah 4.

Miswar, 2017. Metode Geolistrik Resistivitas Di Kawasan Industri Makassar (KIMA). UIN Alauddn Makasar.

Muhardi, M., Muliadi, M., Zulfian, Z., 2020. Model 3D Sebaran Lindi pada Lapisan Tanah di Area TPA Batulayang Pontianak Berdasarkan Nilai Resistivitas. Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Univ. Lambung Mangkurat 17, 72.

Muliadi, M., Zulfian, Z., Muhardi, M., 2019. Identifikasi Ketebalan Tanah Gambut Berdasarkan Nilai Resistivitas 3D: Studi Kasus Daerah Tempat Pembuangan Akhir Batu Layang Kota Pontianak. POSITRON 9, 86.

Padilah, H., Widyaningrum, Y., Kurniawan, widodo budi, 2021. Identifikasi Sebaran Air Lindi (Leachate) Menggunakan Metode Geolistrik Self-Potential (SP) Di Tempat Pembuangan Akhir (TPA) Parit Enam Kota Pangkalpinang. Jurnal Riset Fisika Edukasi dan Sains 2, 15–24.

Pratiwi, D.P., Susanti, N., Dewi, I.K., 2018. Penerapan Metode Geolistrik Konfigurasi Wenner Mapping Untuk Mengetahui Rembesan Air Lindi Di TPA Talang Gulo Jambi. JoP 4, 18–22.

Purba, D.C.V., Kamil, I.M., 2015. Analisis Pola Penyebaran Logam Berat Pada Air Tanah Dangkal Akibat Lindi Di Sekitar Tempat Pemrosesan Akhir (TPA) Jatibarang, Semarang. Jurnal Teknologi Lingkungan 21, 149–158.

Qadri, U., Wahyuni, R., Listiyawati, L., 2020. Inovasi Manajemen Pengelolaan Sampah yang Berwawasan Lingkungan di Kota Pontianak berbasis Aplikasi. Eksos 16, 144–160.

Ramadhan, F., Prasasti D.R, F., Firizqy, F., Nugroho Adji, T., 2019. Pendugaan Distribusi Air Lindi dengan Geolistrik Metode ERT di TPA Piyungan, Bantul, DIY. Majalah Geografi Indonesia 33, 1.

Ramadhaningsih, L., Sampurno, J., 2017. Identifikasi Struktur Lapisan Bawah Permukaan Lahan Gambut di Desa Arang Limbung Kecamatan Sungai Raya Kabupaten Kubu Raya dengan Metode Resistivitas Konfigurasi Dipole-Dipole. Physics Community. 1, 29–35.

Ratih, Y.I., Suaidi, D.A., Hidayat, S., 2021. Identifikasi arah rembesan lindi menggunakan metode geolistrik resistivitas konfigurasi dipole-dipole di sekitar tempat pembuangan akhir (TPA) sampah sekoto kabupaten Kediri. Jurnal MIPA dan Pembelajarannya 1, 624–633.

Sampurno, J., Muid, A., Zulfian, Latief, F.D.E., 2018. Characterization The Geometry Of The Peat Soil Of Pontianak Using Fractal Method. Journal of Physics: Conference. Series 1040, 012044.

Sari, E.K., Lucyana, L., 2021. Evaluasi Instalasi Pengolahan Air Lindi Di Tempat Pembuangan Akhir Sampah (TPAS) Simpang Kandis Kabupaten Ogan Komering Ulu. J. Deform. 6, 33.

Shah, A. V., Singh, A., Sabyasachi Mohanty, S., Kumar Srivastava, V., Varjani, S., 2022. Organic solid waste: Biorefinery approach as a sustainable strategy in circular bioeconomy. Bioresource Technology 349, 126835.

Simanjuntak, H.R., Surbakti, A., 2021. Penentuan Sebaran Lindi Dengan Menggunakan Metode Geolistrik Konfigurasi Wenner Dan Uji Geokimia Di TPA Muara Fajar. Universitas Riau.

Sukisna, Toifur, M., 2019. Penentuan Konduktivitas Air Baku Proses Desilinasi di Baron Teknopark dengan Metode Regresi Linier. J. Mater. dan Pembelajaran Fis. 9, 127–131.

Suwarna, N., Langford, R.., 1993. Peta Geologi Lembar Singkawang. Bandung.

Telford, W., Geldart, P., Sheriff, E., Keys, A., 1990. Applied Geophysics. Cambridge University Press, New York.

Wibowo, H., 2010. Laju Infiltrasi pada Lahan Gambut yang Dipengaruhi Air Tanah (Study Kasus Sei Raya Dalam Kecamatan Sei Raya Kabupaten Kubu Raya). Jorunal of Belian 9, 90–103.

Wu, C., Chen, W., Gu, Z., Li, Q., 2021. A review of the characteristics of Fenton and ozonation systems in landfill leachate treatment. Science of the Total Environment. 762, 143131.

Yatim, E.M., Mukhlis, 2013. Pengaruh Lindi (Leachate) Sampah Terhadap Air Sumur Penduduk Sekitar Tempat Pembuangan Akhir (Tpa) Air Dingin. Jurnal Kesehatan Masyarakat. 7, 54–59.

Zulkifley, M.T.M., Ng, T.F., Raj, J.K., Hashim, R., Ghani, A., Shuib, M.K., Ashraf, M.A., 2013. Definitions and engineering classifications of tropical lowland peats. Bulletin of Engineering Geology and the Environment. 72, 547–553.