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Research Paper

3D Modeling of Leachate Distribution Around Zone E of Batu Layang Landfill, Pontianak, West Kalimantan, Indonesia Using the Geoelectrical Method

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Abstract

Open dumping systems as implemented by the Batu Layang landfill in Pontianak City, Indonesia can cause leachate pollution in the environment. The constituent soil condition affects the leachate distribution into the ground. One of the landfill constituents of the soil at the site of the Batu Layang landfill is peat soil, in which organic content (>75%), porosity, and permeability are high. Leachate that seeps below the earth's surface can cause soil and groundwater contamination. Meanwhile, people around landfills use groundwater for their daily needs and use the land around the landfill to grow papaya, banana, sugarcane, and taro. Therefore it is necessary to prevent and minimize leachate spread. One of the efforts that can be done is to model the leachate distribution. In this study, leachate distribution modeling was done with a geoelectric method, the Wenner configuration, with a smallest electrode distance of 5 m. There were six tracks, with a length of 195 m each. The model obtained from this study was a 3D resistivity section. 3D data processing was done using the inverse distance method. The results showed that a resistivity value ≤10 Ωm identified the soil layer contaminated with leachate. The contaminated soil layers were estimated to be peat, clay, and loamy sand. The leachate distribution is suspected of seeping up to 195 m south of the landfill. The leachate distribution into the soil was estimated from the surface to 33.8 m.

Keywords: *3D modelling; Batu Layang landfill; geoelectric method; leachate distribution; resistivity.*

Introduction

Based on data from the Pontianak City Environmental Service, it is known that waste generation in 2020 was 140,823.35 tons/year. In 2021 there was an increase in waste generation by around 2.65%. The amount of waste generated in 2021 was 144,651.25 tons/year [1]. One of the factors affecting the rate at which waste is generated is the increase of the population [2,3]. The composition of Pontianak City waste in 2020 consisted of food waste (83%), paper/cardboard (7.2%), wood/branches (1.5%), plastic (6%), metal (2%), rubber/skin (0.1%), and others (0.2%) [1]. Waste characteristics are influenced by waste composition. If waste is not managed correctly, it will cause environmental pollution [4-7].

One of the waste management systems is landfilling. The Batu Layang landfill is a final waste processing site in Pontianak City. It is located in Batu Layang Village, North Pontianak District, Indonesia. The Batu Layang landfill uses an open dumping system. The open dumping system has the potential to produce leachate, which can

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pollute the environment [8]. Leachate is a liquid formed from waste decomposition [9,10]. The rate of leachate generation is influenced by the composition of the waste in the landfill, the amount of waste in the landfill, and the intensity of rainfall [11]. Leachate is toxic [12]. Thus, leachate has the potential to cause environmental pollution, especially soil, groundwater, and surface water pollution, if it is not appropriately managed [10,13-19].

Prevention of the spread of leachate into the environment around the Batu Layang landfill is essential. Because the landfill does not use a geomembrane layer on the base layer of the soil, the potential for leachate to spread into the soil is quite large. In addition, one of the soils that make up the Batu Layang landfill is peat soil. Peat soil has an organic content >75% [20]. Significant organic content will affect the absorption of leachate into the soil. The porosity and permeability of peat soils are high [21]. The porosity of peat soils is 83.43 to 92.92%, and the permeability is 2.97×10^{-5} to 8.31×10^{-5} m/s, with a bulk density of 0.16 to 0.31 g/cm^3 [22]. The depth of the peat soil at the Batu Layang landfill site is around 4 to 4.5 m [23].

The Batu Layang landfill is near a settlement. The landfill distance from the settlement is about 300 meters. Most inhabitants use groundwater for their daily needs [24]. The community also uses the land around the landfill to grow consumer crops such as sugar cane, bananas, taro, and papaya. The soil and groundwater quality will decrease if contaminated with leachate. The closer the settlement is to a landfill, the greater the potential for the leachate to be dispersed into the soil, which will potentially contaminate the soil and groundwater [25]. If groundwater is used continuously by the community, it has the potential to cause a decrease in the quality of health. Therefore, it is necessary to have an appropriate intervention for preventing and minimizing the impact caused by leachate pollution on the environment. One effort that can be made is to model the distribution of leachate below the soil surface.

Modeling the leachate distribution below the soil surface can be carried out using a geoelectric method [26-38]. Geoelectric methods are geophysical methods to determine changes in the resistivity of rock beneath the soil surface by passing a high-voltage DC electric current into the ground [39]. The rock's resistivity differences can be used identify the leachate distribution below the soil surface [40]. The geoelectric method used in this study was the Wenner configuration. This method uses a system of constant spacing rules [41]. The advantage of the Wenner configuration is that the accuracy of reading the voltage at the potential electrode is better with relatively large numbers because the potential electrode is reasonably close to the current electrode. The Wenner configuration has been successfully applied to identify the leachate distribution below the soil surface in 2D and 3D [6,17,21,42-44].

Material and Methods

Research Location

The research area is located around Zone E of the Batu Layang landfill. The Batu Layang landfill is located in Batu Layang Village, North Pontianak District, Pontianak City (Figure 1). The research area covers 195 x 195 m^2 and is located in the Batu Layang landfill. Figure 1 shows the location of the Batu Layang landfill.

Data Acquisition and Data Analysis

Six tracks were made, denoted by L1, L2, L3, L4, L5, and L6 (Figure 1). These six tracks were to the west of the Batu Layang landfill location. Creating a 3D model of the soil layers requires intersecting paths. Therefore, in this research, three trajectories were made, which intersected with the other trajectories. Each track stretched for 195 m. Tracks L1, L2, and L3 had the same track direction, namely N274°E, while tracks L4, L5, and L6 had a stretch direction of N188°E. Table 1 shows the coordinates of each track.

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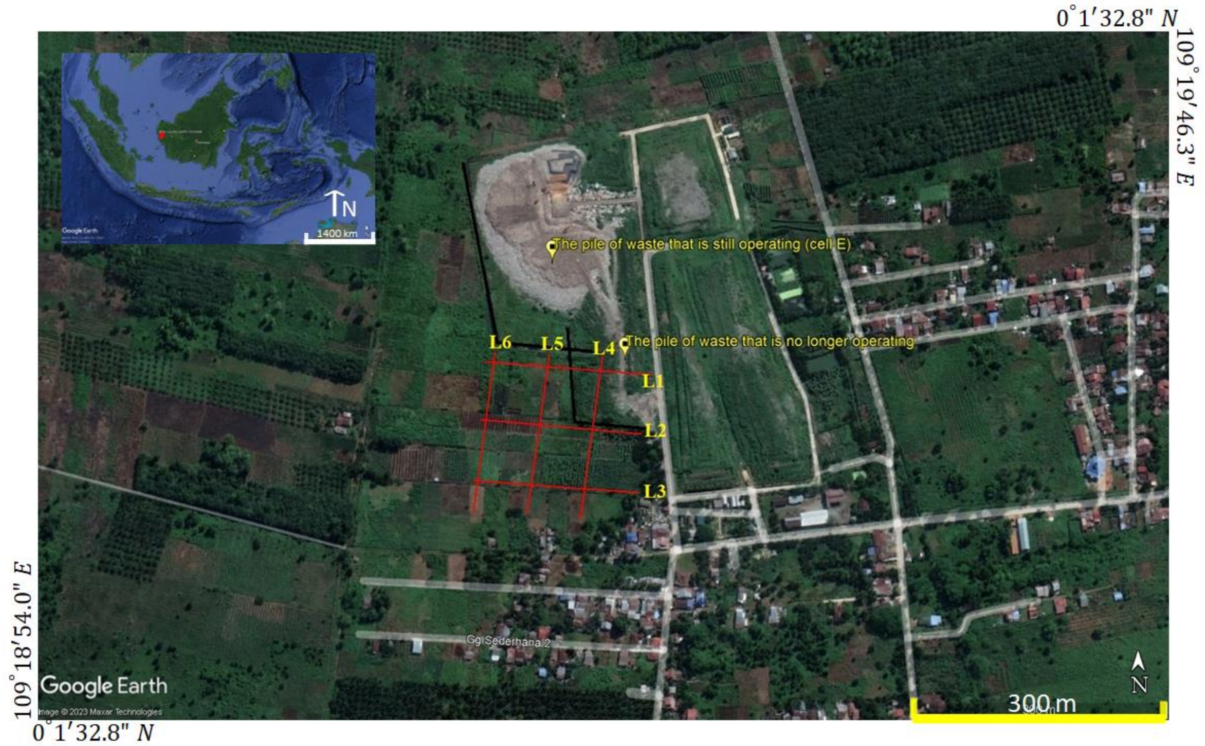

Figure 1 The research location, the Batu Layang landfill [45].

Table 1 Coordinates of the geoelectric trajectory.

Track	Track Coordinates	
	The starting point of the track	Track end point
L1	0°01’32.82” N 109°19’17.32”E	0°01’33.40” N 109°19’11.04” E
L2	0°01’30.65” N 109°19’16.77” E	0°01’31.22” N 109°19’10.49” E
L3	0°01’28.33” N 109°19’16.82” E	0°01’29.12” N 109°19’10.70” E
L4	0°01’33.46” N 109°19’15.45” E	0°01’27.22” N 109°19’14.33” E
L5	0°01’33.81” N 109°19’13.63” E	0°01’27.55” N 109°19’12.54” E
L6	0°01’33.76” N 109°19’11.37” E	0°01’27.51” N 109°19’10.45” E

Modeling of the distribution of leachate below the soil surface using the geoelectric method can also estimate the type of rock beneath the soil surface [46] and detect aquifers [47]. The rock resistivity measurements are influenced by water content, porosity, permeability, mineral content, rock homogeneity, and water content [15]. The geoelectrical method is carried out by flowing current into the earth through current electrodes and measuring the potential value on the earth’s surface using potential electrodes [48]. The configuration used in this study was the Wenner configuration. This configuration is often used in geoelectric exploration [49]. The advantage of the Wenner Configuration is that the data is more detailed in describing the lateral direction [21]. In this study, the smallest electrode distance used in the Wenner configuration was 5 m. The Wenner configuration had the same electrode arrangement between C1-P1, P1-P2, and P2-C2. The arrangement of the Wenner configuration electrodes is shown in Figure 2. C1 and C2 are current electrodes, while P1 and P2 are potential electrodes. If the electrodes are connected in the field, the data collection process started automatically, and a current was injected (I) at the ground surface. The ARES tool recorded the measured current (I) and the potential difference (ΔV). The ARES tool used had a power of up to 300 watts with a maximum current of 2 amperes and a current reading transmission of 0.3 seconds. In addition, on the ARES tool, the apparent resistivity value was calculated based on Eq. (1).

The apparent resistivity value (ρ_a) of the Wenner configuration can be written as follows:

$$\rho_a = 2\pi a \frac{\Delta V}{I} \quad (1)$$

where ρ_a represents resistivity (Ωm), *a* is the smallest electrode spacing (*m*), Δ*V* is the potential difference (*V*), and *I* is the current flowing in the medium (*A*). In Eq. (1), there is a Wenner configuration factor of k = *2πa*. This geometry factor has units of *m*.

If the apparent resistivity value has been obtained, the following process is inversion to obtain a 2D resistivity section. The inversion method used was the least squares inversion method. After obtaining the 2D resistivity section, the data was stored in 3D format (X, Y, and Z). The 3D data input was in the form of distance in the X-axis direction, distance in the Y-axis direction, depth (Z), and the resistivity value of the inversion result. The data for each track were then combined and reconstructed into a 3D view. The method used to interpolate the 2D resistivity sections into 3D resistivity displays was the inverse distance method. The 3D model created aimed to see the distribution of leachate-contaminated soil more comprehensively. An isosurface boundary was made between the suspected leachate-contaminated and non-contaminated soils from the results of the 3D model interpolation to see the distribution of leachate contaminating the soil. The resistivity value used for the isosurface was 10 Ωm [50]. Using an isosurface boundary to analyze leachate that contaminates soil has been carried out successfully in [51] and [50]. The resulting 3D models also succeeded in describing the distribution of leachate in landfill areas [50,51].

In addition to collecting geoelectrical data, water samples were also taken in the research area. This water sample was then tested in a laboratory to determine the biochemical oxygen demand (BOD) and conductivity. This parameter was used to determine the spread of leachate in the study area. In addition, this data was used to validate the model and interpret the 2D and 3D resistivity sections. Water sampling was located at three points, namely points P1, P2, and P3 (Figure 2). Point P1 was close to a pile of garbage that was still operational in the research area. Point P1 was outside the research area but was still in the Batu Layang landfill. Points P2 and P3 were located in the research area and were near piles of waste that were no longer operational.

Table 2 Air sampling point coordinates.

Water sample point	Coordinates
P1	0°1'33.96" N 109°19'14.20" E
P2	0°1'31.09" N 109°19'13.84" E
P3	0°1'29.66" N 109°19'15.55" E

Results and Discussion

The 2D resistivity depicts the layers beneath the surface of the study area. The resistivity cross-section is obtained from the inversion of the apparent resistivity value. The cross-sections of the resistivity lines L1-L6 were combined to form a 3D cross-section (Figure 2). The resulting model had a resistivity value of 0.5145 to 474.14 Ωm. The resulting model had a depth of 33.8 m.

From the 2D resistivity data, a 3D resistivity model was obtained using the inverse distance method (Figure 3a). The 3D resistivity model describes the soil layers covering the study area. This resistivity model also shows the direction of the leachate spreading from the Batu Layang landfill.

From Figure 3, the resistivity value on lines L1 and L4 was greater than that on lines L2, L3, L5, and L6 because the two lines passed through a pile of garbage. Tracks L1 and L4 passed over piles of rubbish at a distance of 0 to 80 m. The resistivity value in the trash pile area was greater than in the non-trash pile area. This is because the waste in the research area was in the form of plastic waste and other inorganic waste. When collecting data, the trash that was visible on the surface of the pile of plastic waste was dry, which gives the waste a higher resistivity value, making it less able to conduct electricity. The resistivity value of the garbage pile was 29.6 to 474.14 Ωm. If it rains, this pile of waste will also produce leachate, which will flow into the ditch and the surrounding area.

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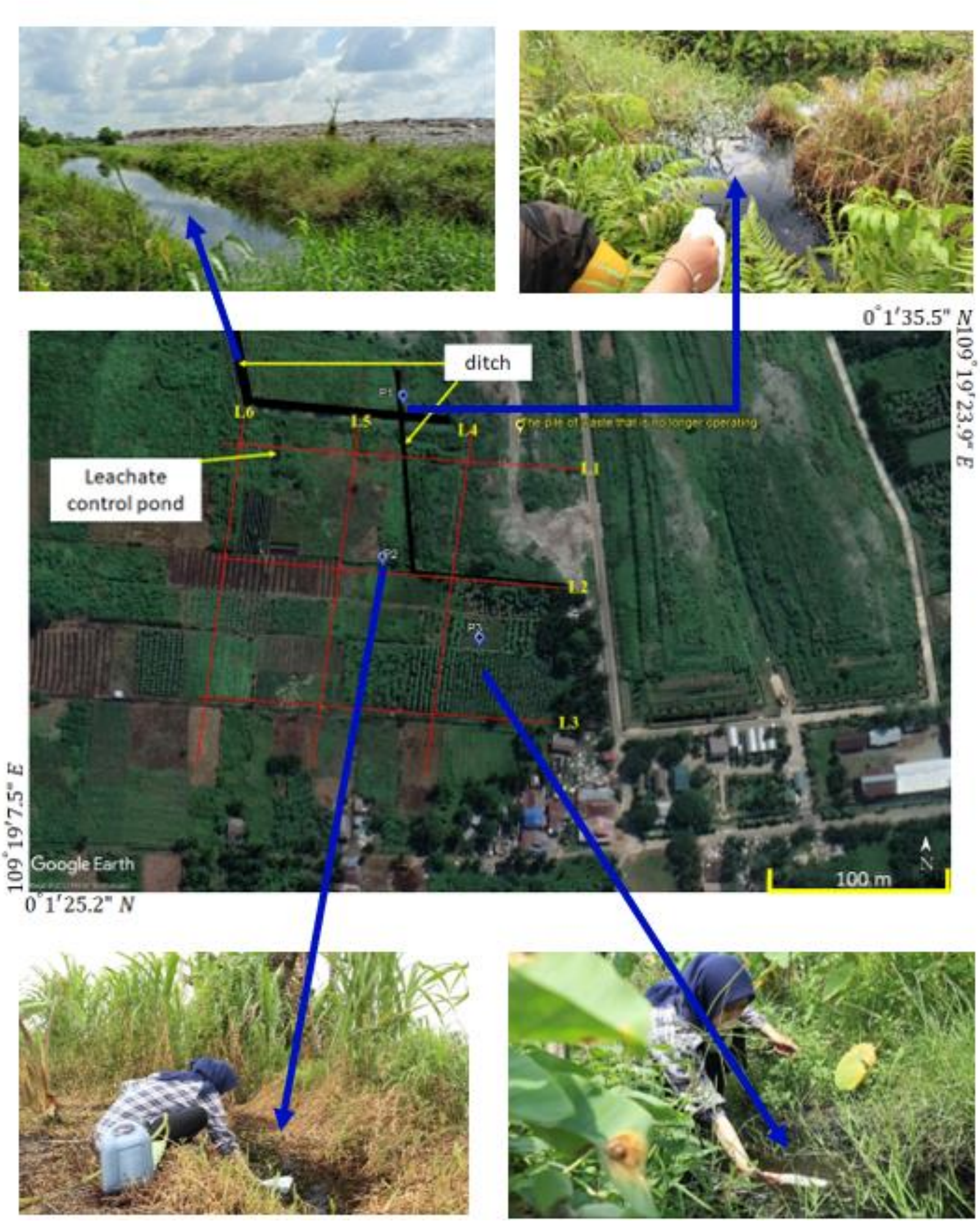

Figure 2 Water sample points in the research area.

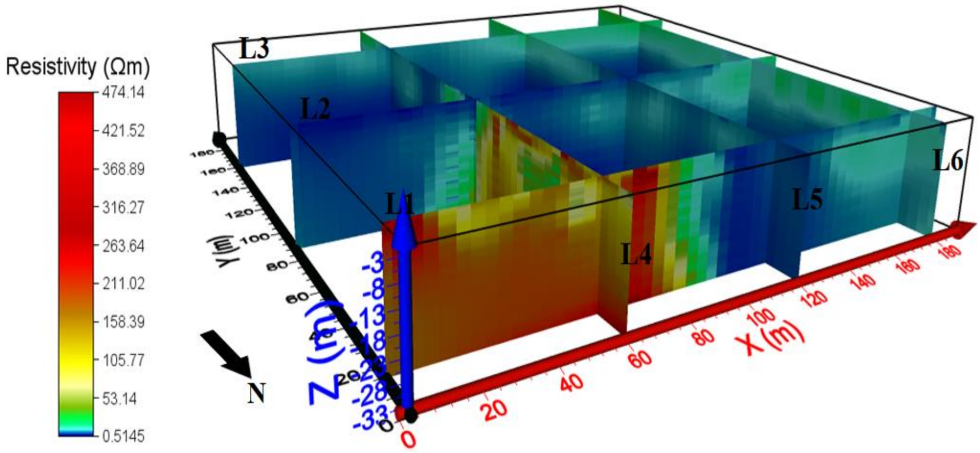

Figure 3 3D resistivity sections L1 to L6 at the study site.

Figure 4 illustrates the condition of the layers at the research location in 3D. The method used to obtain this 3D view was the inverse distance method. From the 3D resistivity model, the area of garbage heaps in the study area can be seen. The results of the 3D resistivity model also show that the waste pile area had a high resistivity value of 29.6 to 474.14 Ωm. This resistivity model was considered suitable for describing the subsurface conditions in the study area, so that this model could provide a 3D description of the leachate distribution in the study area. Figure 6b shows the appearance of the research location in Google Earth. The X and Y arrows indicate the direction of the increase in track length.

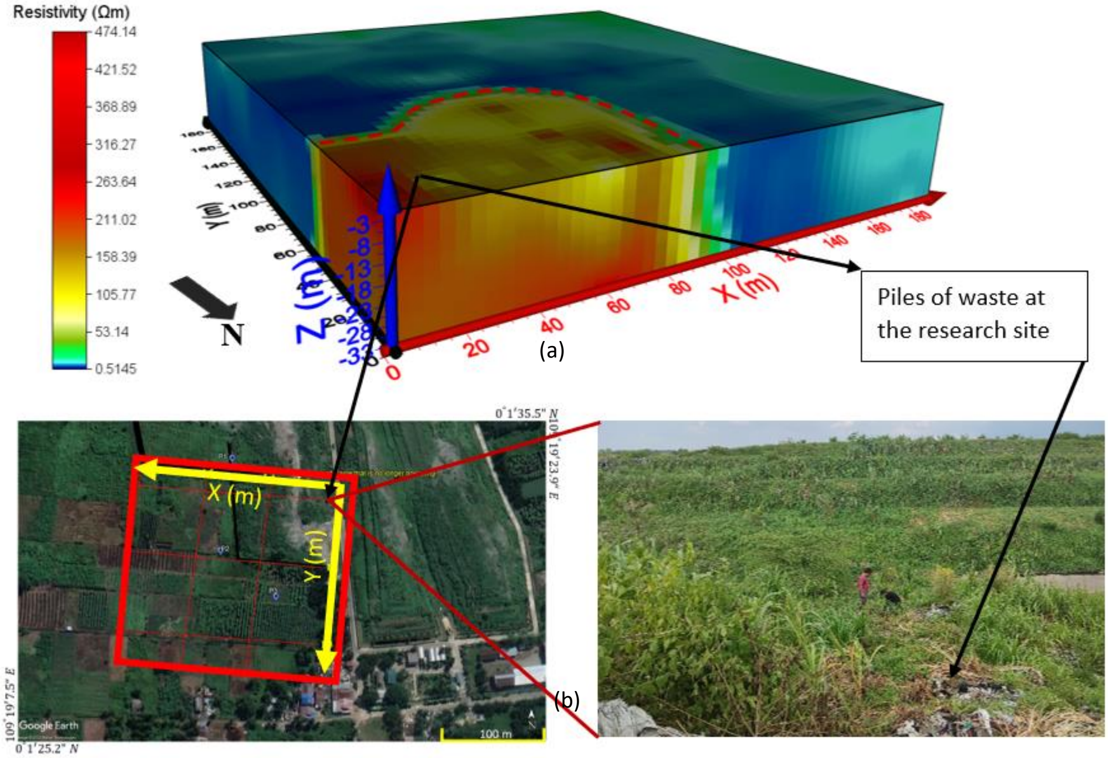

Figure 4 (a) 3D resistivity model of the research location; (b) the research location at the Batu Layang landfill.

The layers of soil in the study area are peat, soft clay, and sand. According to Muliadi et al. (2019), the peat soil near the Batu Layang landfill location has a depth of 4 to 4.5m [23]. Peat soil is a soft type of soil. The layer beneath the peat layer is thought to be a layer of soft clay from a depth of 4 to 20 m. The soft clay layer is also classified as a type of soft soil. According to Naim et al. (2016), in Pontianak City, soft soil is still present to a

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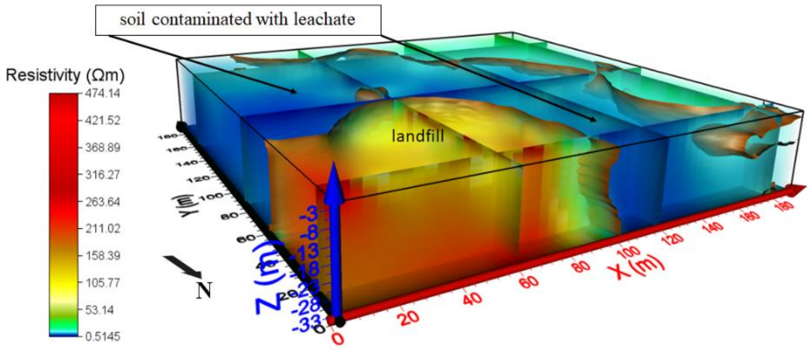
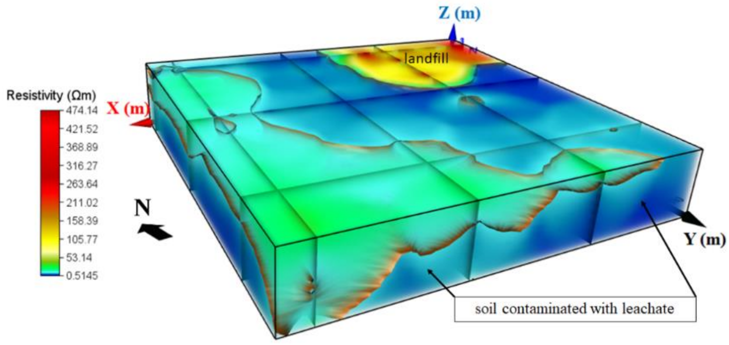
depth of 18 m [52]. The layer underneath the soft clay from a depth of 20 to 33.8 m is thought to be a layer of sand mixed with clay. Naim et al. (2016) state that from a depth of 24 to 35 m there is sand mixed with clay [52]. Geologically, the types of soil found in the study area include alluvial deposits in the form of silt, sand, gravel, and organic waste (peat) (*x*). In the results of this study, it is difficult to distinguish this layer from the resistivity value on some paths. This is presumably because the soil in the research area has been contaminated with leachate.

The soil contaminated with leachate is thought to have a resistivity value of 0.5145 to 10 Ωm. From the 2D resistivity section and the 3D resistivity model, it is suspected that the leachate is distributed up to a distance of 195 m. The soil is suspected to be contaminated from the surface to a depth of 33.8 m. The leachate distribution can be analyzed by looking at the resistivity values laterally at a certain depth. Based on the 2D interpretation, the soil contaminated with leachate had a resistivity value of 0.5145 to 10 Ωm. Therefore, in this study, the resistivity value of 10 Ωm became the limiting value between leachate-contaminated soil and non-leachate-contaminated soil. The resistivity value is contoured and displayed in the form of a brown interface in Figure 5. This interface boundary states that the connected surfaces have the same resistivity value of 10 Ωm.



(a)



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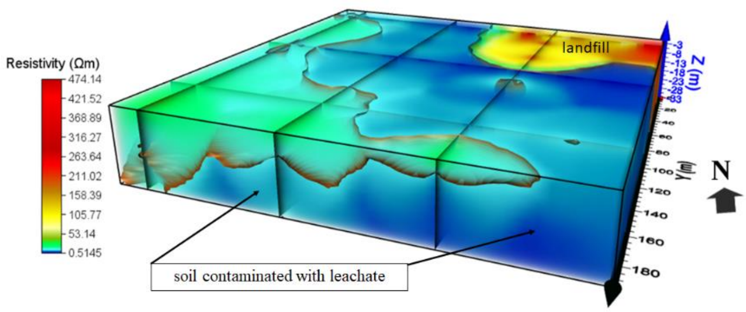

(c)

Figure 5 3D model overlay, the interface of leachate-contaminated soil layers, and the cross-section of L1 to L6 (a) seen from the northeast, (b) southwest, and (c) southeast.

Figure 5 also shows an overlay of the 2D resistivity cross-section with the 3D resistivity model and the leachate-contaminated soil interface. This image was created by making the 3D resistivity model transparent. The objective of the 3D resistivity model was to make it transparent to show the leachate-contaminated soil interface in the study area so that the distribution of leachate can be seen vertically and laterally. From this model, it can be seen that the soil was contaminated with leachate from the surface to a depth of 33.8 m and as far as 195 m to the south of the Batu Layang landfill. The layers contaminated with leachate are layers of peat, soft clay, and clay sand. Leachate that seeps into the soil makes the soil layer conductive. Soil contaminated with leachate accumulates in pore spaces in the peat, soft clay, and sand. Leachate is an electrolyte liquid resulting from inorganic waste such as metal materials. At the Batu Layang landfill, organic and inorganic materials are stacked into one pile at the stacking location.

On the L1 and L4 tracks at a distance of 80 m, there are ditches that serve as drainage and a place for leachate to be collected. The location of this ditch can be shown in Figure 4. From this ditch, it is suspected that the leachate has spread to a depth of 33.8 m. The leachate storage pond on the L1 track is located at a distance of 165 m, so it is suspected that the distribution of leachate as far as 195 m is caused by the holding pond. Moreover, the research location is on peatland. In addition to collecting geoelectrical data, this research also took water samples near or in the research location area. Water samples were taken at three points in the ditch in the study area. Point P1 was in a bigger ditch than points P2 and P3 (Figure 4).

These three water samples were subjected to laboratory tests. The parameters tested were biochemical oxygen demand (BOD) and conductivity. Table 3 shows the results of laboratory tests of the three samples. From the results of the three laboratory tests, it was suspected that the water samples in the ditch in the study area were contaminated with leachate. The BOD values of the water samples at points P2 and P3 exceeded the standard leachate limits. This data supports the interpretation of the leachate distribution based on the geoelectrical data. The BOD values of the water samples at point P2 were more significant than at point P3. Point P2 was in a ditch directly connected to the main ditch (Figure 4), so point P2 was more contaminated with leachate than point P3. The results of the laboratory tests and analysis were used as a control in identifying leachate distribution in the study area. From Table 3, the resistivity values of the water samples were from 1.67 Ωm (P2) to 5.78 Ωm (P3). This resistivity value was also used as validation data for interpreting the leachate distribution from the 3D resistivity model. From the results of the laboratory tests, the resulting model was validated. This resistivity value supports the 3D model made at points P2 and P3, including areas contaminated with leachate based on the 3D model (Figure 6a). The resistivity value of the water sample at point P2 was higher than at point P3 because the ditch at point P2 is directly connected to the ditch that limits the Batu Layang landfill.

Table 3 Results of water quality inspection in the research area, Batu Layang landfill.

Parameters tested	**Unit**	**P1**	**P2**	**P3**	**Leachate Standard** [1]
BOD	mg/L	378	347	158	150
Conductivity	S/m	0.417	0.6	0.173	-

Leachate that contaminates the soil in the study area can be analyzed based on the resistivity model laterally at a certain depth. The distribution of leachate at a certain depth can be seen laterally as shown in Figures 6 to 10. Figure 6a shows the soil resistivity values at the soil surface (0 m) and the presence of water sample points P2 and P3. The 3D resistivity model also shows that points P2 and P3 had a resistivity value of <10 Ωm and are suspected to be leachate-polluted areas (Figure 6a). The laboratory test results showed that at points P2 and P3, the water samples were polluted, because the BOD values exceeded the water standard limits. At this depth, leachate-contaminated soil was identified with a resistivity value of 0.5415 to 10 Ωm. This resistivity value is shown in blue and light turquoise. Areas with a resistivity value of >10 Ωm are suspected to not have been contaminated with leachate. The waste pile area had a resistivity value of >10 Ωm and was a source of leachate. The piles of waste in the research area were no longer operational, but still, when the rainy season arrives, leachate will be generated by these piles of waste, which collects in the ditches surrounding the piles of waste in the Batu Layang landfill area.

The soil on the surface is peat. This soil has high porosity and high permeability. The leachate contained in the ditch seeps into the peat layer through pore spaces and seeps through the connected pores. Sampurno et al. (2018) state that the porosity of peat soils in Pontianak City is 77.23 to 95.18% [53]. Jakarius et al. (2021) showed

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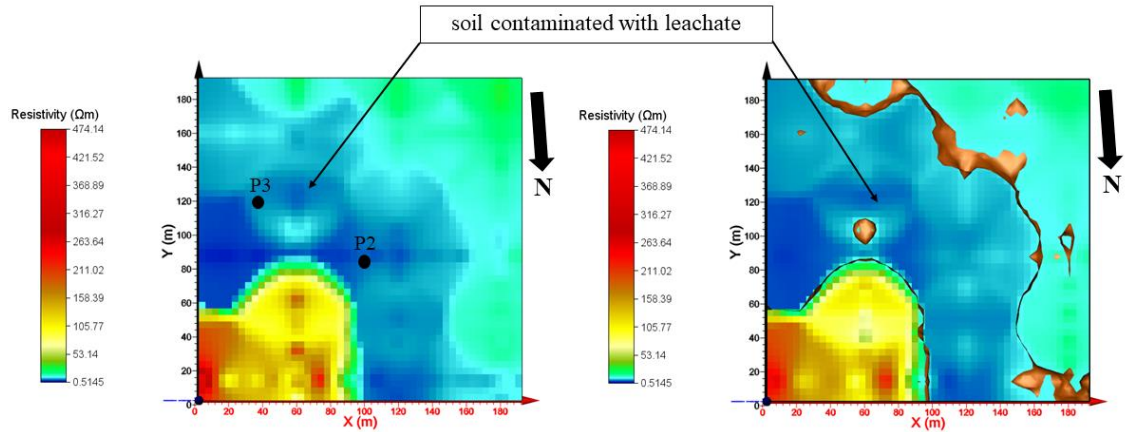
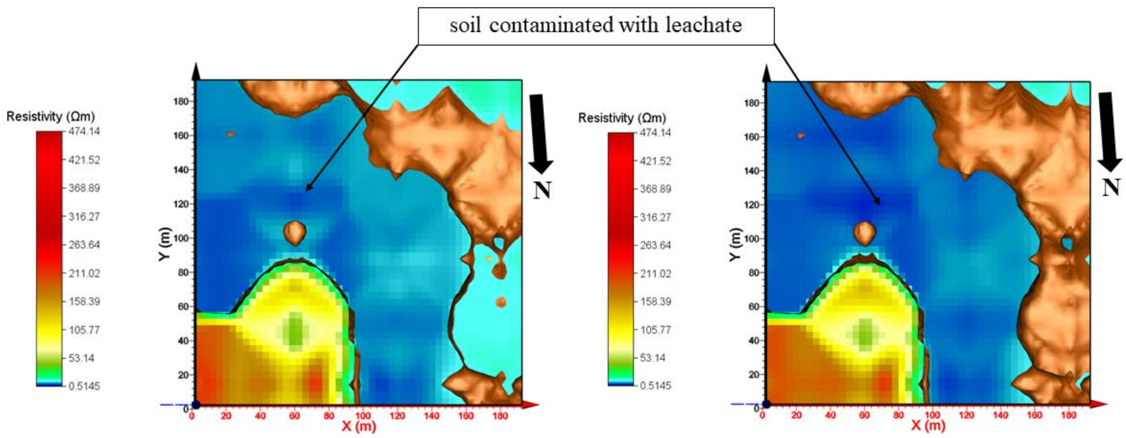
that the porosity in the Batu Layang landfill is 83.43 to 92.92% [22]. Peat soil has a very high porosity value and is a very good place to store groundwater and leachate. Due to the high purity of peat soil, it is suspected that leachate spreads and contaminates the peat soil as far as 195 m to the south. In addition, the distribution of the leachate is also influenced by the small ditches in the research area. Based on the distribution of resistivity values on the surface, further from the Batu Layang landfill, namely to the southwest, the peat soil is presumably not contaminated. This is presumably due to the existence of embankments made to limit the movement of leachate. In addition, the elevation of the study area, which is almost flat and gently sloping, causes insignificant leachate movement to the southwest.

From the peat soil layer, the leachate spreads and seeps down into a layer of soft clay with a resistivity value of < 10 Ωm. Muhardi et al., (2020) state that the clay layer beneath the peat soil was also contaminated with leachate, which spread eastward from the Batu Layang landfill [50]. In this layer, the southwest of the study area is suspected to be uncontaminated leachate with a resistivity value of >10 Ωm. The contaminated soft clay layer is estimated to have a depth of 20 m. From this layer of soft clay, the leachate spreads to a layer of clay sand with a resistivity value of <10 Ωm. At a depth of 20 m, it can be seen that the contaminated soil is spread and evenly distributed in all directions in the study area, as indicated by the blue color. This layer has a more conductive layer than the soft clay layer, because leachate accumulates in this layer.



(a) (b)

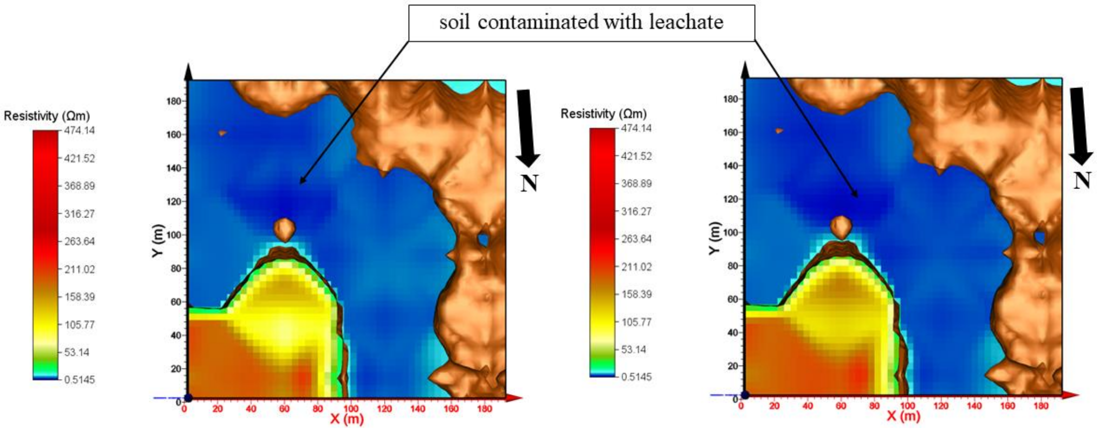
Figure 6 Resistivity image at ground level (0 m), and (b) 5 m deep.



(a) (b)

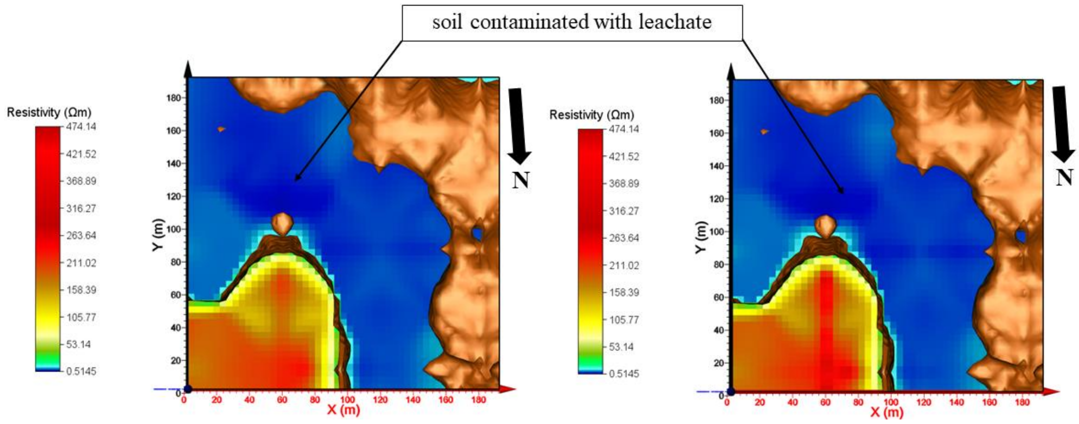
Figure 7 Resistivity image at ground level (a) 10 m, and (b) 15 m deep.

The clay sand layer is a layer that has good porosity and can become an aquifer layer and accommodate water as well as leachate. The pore space of a clay sand layer that is filled with leachate makes this layer more conductive than the other layers, both the peat layer and the soft clay layer. Leachate that has accumulated and contaminates the clay sand layer is thought to have reached a depth of 33.8 m. From Figures 8, 9, and 10, the leachate spreads dominantly in all directions, both south and west of the Batu Layang landfill, as far as 195 m.



(a) (b)

Figure 8 Resistivity image at ground level (a) 20 m, and (b) 25 m deep.



(a) (b)

Figure 9 Resistivity image at ground level (a) 30 m, and (b) 33.8 m deep.

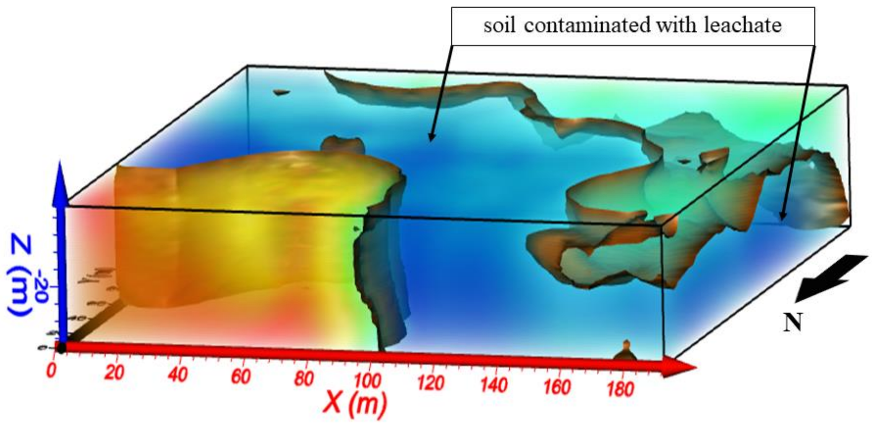


Figure 10 3D model of leachate contaminated soil.

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Conclusions

The 2D and 3D resistivity models in the research area had a resistivity value of 0.5415 to 474.14 Ωm. Resistivity values ≤10 Ωm identified soil layers contaminated with leachate. The leachate content in the soil makes the soil layer conductive. The contaminated soil layer is thought to be a layer of peat, clay, and clay sand. The condition of the soil layers around the Batu Layang landfill affects the distribution of the leachate horizontally and vertically. The leachate distribution is suspected of seeping up to 195 m south of the Batu Layang landfill. This is thought to be caused by the condition of the small ditches around the study site. Leachate distribution in the soil is estimated from the surface to a depth of 33.8 m. The leachate is thought to have accumulated in layers of clay-sand soil from 20 m to 33.8 m.

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