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Evaluation of Leachate Spreading Post-Closure of Keputih Final Disposal Site (TPA) and Its Impact on Groundwater Quality

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ABSTRCT

The Keputih Final Processing Site (TPA) in Surabaya operated from 1970 to 2001. A key issue arising from its operations was the formation of leachate. After the closure of the landfill in 2001, leachate was detected at various points around the site. This study aims to investigate the distribution of leachate in the Keputih Landfill area after its closure and its impact on the surrounding groundwater quality. To achieve this, the study utilized the Active Directory Magnetotelluric (ADMT) method, which helps in obtaining variations in the impedance of different layers of rock beneath the ground surface. Additionally, shallow groundwater samples were taken from three locations: residents' wells, monitoring ponds at the landfill, and reservoirs near the Keputih Landfill area, to analyze the presence of leachate. Data processing was carried out using AIDU Prospecting, Surfer, and Voxler Software. The study's results revealed that the water flow direction in the area is towards the east, towards the sea. Leachate continues to spread into the shallow groundwater surrounding the landfill. This is evident from the high values of BOD5, COD, and TSS, which exceed environmental quality standards. The resistivity measurements of groundwater, which ranged from 8.23 – 9.81 Ωm, fall within the range for brackish water and leachate, indicating that the spread of leachate into deeper aquifers cannot be conclusively confirmed. This uncertainty arises due to the intrusion of seawater into the landfill area.

Keywords: Active Directory Magnetotelluric (ADMT), Groundwater Quality, Leachate, White Landfill.

INTRODUCTION

The waste problem is a significant challenge in many major cities in Indonesia, including Surabaya. As urbanization and economic activities increase, the volume of waste also rises, contributing to various environmental issues. Effective management of waste, particularly through Final Processing Sites (TPAs), is crucial to ensuring that waste is handled efficiently and safely (Sari & Darmawan, 2020). However, improper management of TPAs can lead to environmental pollution, especially in the form of leachate—a liquid formed when rainwater percolates through waste piles (Nugroho & Setiawan, 2021; Lestari et al., 2023). Leachate is of particular concern due to its potential to contaminate both surface and groundwater, presenting significant risks to environmental and public health (Sukarta et al., 2019).

The Keputih Landfill in Surabaya, operational from 1970 until its closure in 2001, provides a notable example of the environmental challenges posed by landfills. Despite its closure, leachate continues to be detected at various points around the site, indicating that the environmental impact of the landfill persists (Yuliana et al., 2021). The ongoing presence of leachate poses a potential risk of contamination to shallow aquifers, which serve as a primary source of drinking water for local communities. This highlights the need for a thorough evaluation of the spread of leachate and its long-term effects on groundwater quality (Putra et al., 2022).

In the field of education, studies on teacher competence and its impact on student learning outcomes provide relevant insights. For instance, Roesminingsih (2020) examined the influence of pedagogical competence and teacher motivation on student achievement in senior high schools in Mojokerto. The study found that both pedagogical competence and teacher motivation significantly affected student learning outcomes. However, the study did not differentiate between the effects of professional competence and pedagogical competence on student achievement. In contrast, Zevender (2020) investigated the impact of academic supervision by school principals, pedagogical competence, and professional competence of teachers on student achievement at MAN 5 Jombang. This study concluded that academic supervision by principals and pedagogical competence had a significant effect on student learning outcomes, whereas professional competence did not. However, it did not explore the role of professional competence in enhancing student achievement (Kusuma et al., 2018).

Building on these studies, the purpose of this research is to analyze the impact of both professional and pedagogical competence on student learning outcomes at SMP Negeri Subrayon 03 in Tanggamus Regency. The findings from this study are expected to provide empirical data that can inform the design of teacher competence enhancement programs, contributing to the development of more effective educational policies aimed at improving learning quality and student achievement.

RESEARCH METHOD

The research employed a mixed-methods approach, combining geophysical surveys with laboratory water analysis. The Active Directory Magnetotelluric (ADMT) method (Figure 1) was used to map subsurface resistivity and detect the distribution of leachate. This geophysical technique enabled detailed imaging of the subsurface, allowing for the identification of leachate pathways based on variations in resistivity.

Data collection involved two primary techniques. First, geophysical data was collected using ADMT to survey the subsurface resistivity at various locations around the former landfill site. Second, shallow groundwater samples were taken from three distinct locations: residents' wells, monitoring ponds, and reservoirs located near the landfill. These samples were tested in the laboratory to measure physical and chemical parameters, including pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), N-total, mercury, and cadmium. The analysis of these parameters followed the standards outlined in the Minister of Environment and Forestry Regulation No. P.59 of 2016.

The data analysis was conducted using specialized software for geophysical data processing. AIDU Prospecting, Surfer, and Voxler were used to process the resistivity data and create both 2D and 3D models of the subsurface, which helped visualize the spread of leachate. For the groundwater analysis, statistical methods were used to assess the quality of the water based on the chemical and physical parameters measured in the laboratory. This multi-faceted approach allowed for a comprehensive understanding of the leachate distribution and its potential impact on the groundwater quality around the former landfill.

RESULTS AND DISCUSSION

Leachate Distribution Analysis at Keputih Landfill

In this study, to analyze the spread of leachate in the Keputih Landfill was carried out based on the value of material resistivity using the Active Directory Magnetotelluric (ADMT) method measurement. The results of the interpretation of the material layer used a 2D model on trajectory 1 (A-B), trajectory 2 (B-C) and trajectory 3 (C-A). After classification, in general, there are 6 layers of material with a range of resistivity values in Table 2. The resistivity value was determined based on references from several experts, namely Telford, et.al., (1990), Suyono (1978) and Halmer Helide (1984) and adjusted to the geological conditions of the research site. The geological conditions of most of the land of Surabaya City are dominated by alluvial (sedimentary soil), especially the northern and eastern parts of Surabaya City (Anjasmara et.al., 2017). The area formed from alluvial deposits has materials such as sand, sandstone, and clay (Bahri, S., et.al., 2012).

Table 1. Resistivity Value

No	Material	Resistivity Value (Ωm)	Resistivity Values in the Field (Ωm)
1	Leachate/ Brackish Water	0-10	8,23 -9,32
2	Alluvial Groundwater	10-30	10,20 – 29,37
3	Groundwater	30-50	30,55 – 49,85
4	Sand & Gravel	50-100	50,17 – 99, 98
5	Sand	100-120	101, 37 – 119,66
6	Sandy Clay	120-170	120,22 – 199,31

In the early part of track 1 (Figure 1), the length of the track is 0-20 m with a depth of about 120-180 m and the length of the track is 80-100 m with a depth of about 110-200 m, it can be seen that there is a zone with very low resistance, only ranging from 0-10 Ωm. Resistivity values that are well below the general range for soil or rock layers indicate that the zone is dominated by highly water-saturated al-material, such as water-saturated clay or even leachate layers. Leachate is a type of groundwater that has been contaminated by chemical, organic, or inorganic substances derived from the decomposition process of waste or waste. The high solute content in leachate causes its resistivity value to be very low.

Furthermore, on a 20-50 m trajectory with a depth of 20-200 m, there is a zone with higher resistivity, which ranges from 100-170 Ωm. This zone can be interpreted as a layer of sandy clay that is comparatively drier and less productive in terms of groundwater storage. The presence of zones with higher resistivity indicates a subsurface lithological variation, where in this area there is a layer dominated by sandy clay material that has lower porosity and permeability compared to other zones along the trajectory.

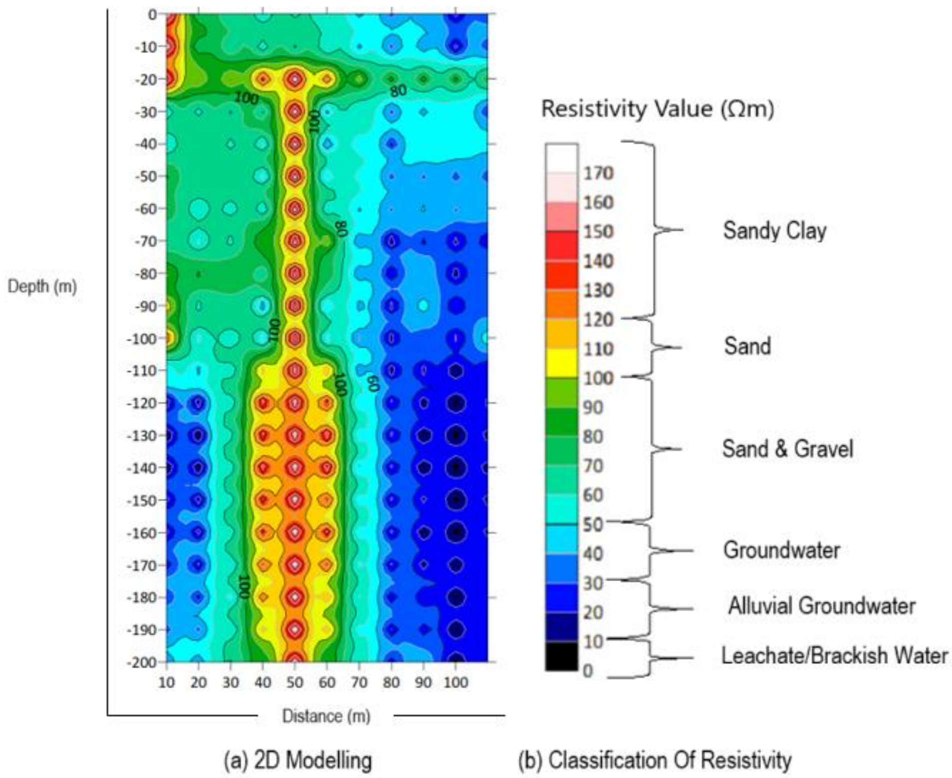

Figure 1. Track 1 (a) & (b)

Track 2 (B-C) (Figure 2) at a track length of 0-30 m and a depth of 120-200 m, there is a zone with very low resistivity, only ranging from 0-10 Ωm. Resistivity values that are well below the general range for these layers of soil or rock indicate the presence of highly water-saturated materials, such as water-saturated clays or leachate accumulations. In the context of hydrogeology, these low-resistance zones can indicate the presence of contaminated aquifers or impermeable layers saturated with contaminated groundwater.

The appearance of a zone with very low resistivity at a depth of 120-200 m at the beginning of this trajectory can indicate the presence of leachate or groundwater pollution from a source of pollution on the surface. In hydrogeological systems, leachate is a type of groundwater that is contaminated by chemical, organic, and inorganic substances derived from the decomposition process of waste or waste. The high solute content in leachate causes the resistivity value of this zone to be very low, well below the normal resistivity value for the geological layer (Rahman et al., 2020; Prasetyo & Arifin, 2022).

At a trajectory length of 30-50 m and 80-100 m, with depths ranging from the surface to 200 m, there are zones with a predominantly high resistivity, ranging from 100-170 Ωm. In the context of geology and hydrogeology, these zones with high resistivity can be interpreted as a layer of sandy clay that is relatively drier and less productive in storing groundwater.

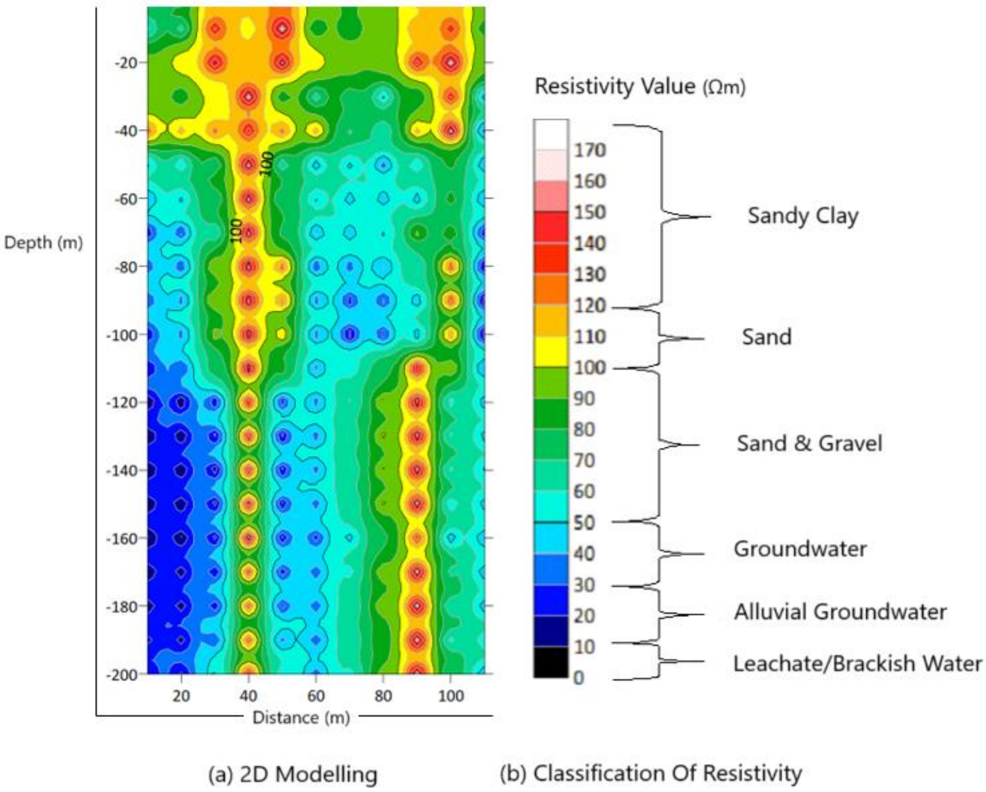

Figure 2. Track 2 (a) & (b)

Track 3 (C-A) in Figure 3 with a track length of 80-100 meters, detected a zone with a very low resistivity value, which is only 0-10 Ωm, at a depth of 100-200 m. The resistivity value in the range of 0-10 Ωm indicates the presence of highly water-saturated materials, namely leachate collected in the zone. The appearance of this low resistivity zone indicates the potential for the accumulation of contaminated leachate in this area. This zone of low resistivity on a trajectory of 80-100 m is enclosed by a layer with a higher resistivity value, ranging from 30-60 Ωm, which extends from the surface to a depth of 200 m. Based on the table, resistivity values in this range can be interpreted as a layer of groundwater in alluvial or groundwater that is quite productive as an aquifer. Meanwhile, at a trajectory length of 0-60 m, zones with higher resistivity values are seen, ranging from 70-170 Ωm. Referring to table 2, the resistivity value in this range can be interpreted as a layer of sand and gravel, as well as sandy clay which is relatively more compact and less productive as an aquifer. The presence of zones with higher resistivity indicates a significant difference in lithological and hydrogeological characteristics compared to the low resistivity zones in the middle of the trajectory.

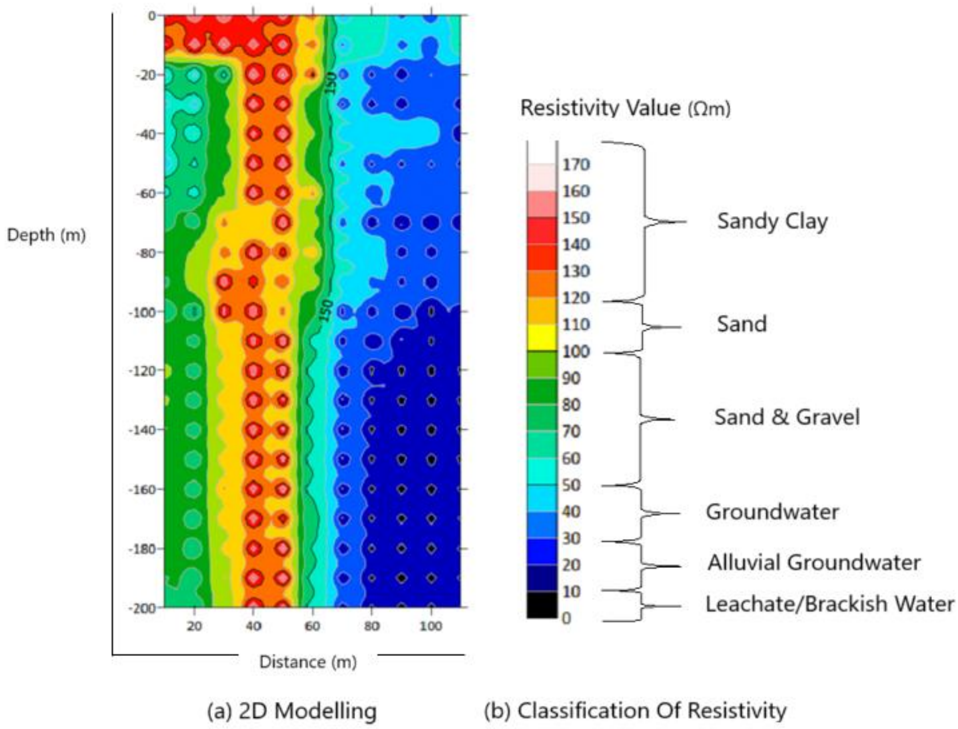

Figure 3. Track 3 (a) & (b)

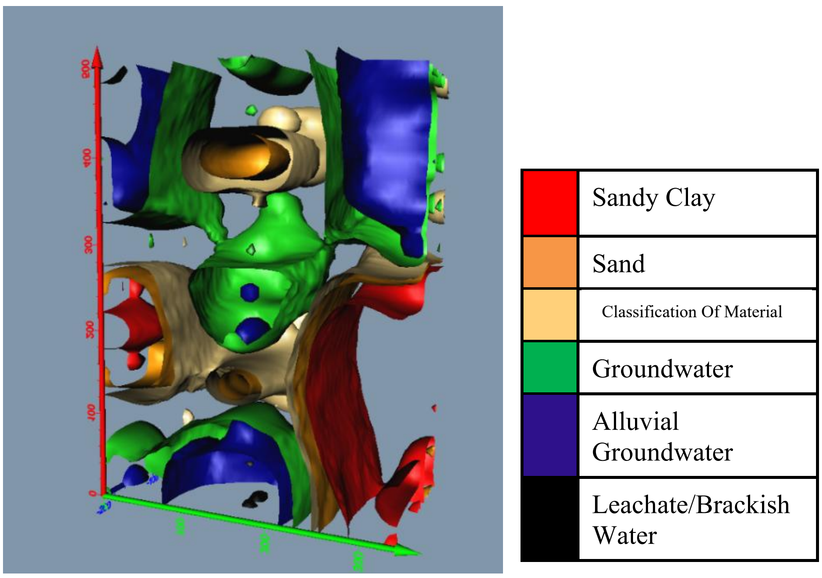

Figure 4. 3D Modelling

Referring to table 1 and figure 4 after data analysis was carried out, it is known that the resistivity values of leachate and brackish water have the same resistance value range, which is 0-10 Ωm, supported by research from Tarallo, D., et.al., (2023) that brackish water is also shown with a resistivity value of 2 to 5 Ωm. From the results of the study, it cannot be confirmed that the water found at a depth of 100-180 m and concentrated between trajectory 1 (A-B) and trajectory 2 (B-C) is leachate or brackish water. To determine whether it is leachate or brackish water, further research needs to be carried out by conducting several activities such as taking water sampling at a depth of 100-180 m with an analysis of Environmental Quality Standards in accordance with the "Regulation of the Minister of Environment Number 59 of 2016 concerning Leachate Quality Standards for Waste Disposal Businesses and/or Activities" such as pH parameters, BOD, COD, TSS, N Total, Mercury, Cadmium.

Based on the results of the research, it is possible that leachate no longer exists at the Keputih Landfill location after closure. This is supported by the period after the closure of the Keputih Landfill until now it has reached 24 years. The longer the life of the landfill, the more organic matter decomposes and the leachate becomes more stable. In young landfills, leachate contains a lot of organic matter that is easily degraded and has a greater impact on the environment. In intermediate landfills, decomposition takes place further, and leachate may begin to contain more heavy metals. Meanwhile, in stable landfills, leachate has lower quality with a very low concentration of organic matter (Azis, S.Q, 2013).

In addition, groundwater also has a natural property called self-purification. Water has the ability to cleanse itself of some pollutants through natural processes such as dilution, precipitation, filtration, oxidation, and the activity of microorganisms (Amiri & Nakhaei, 2021).

In connection with the information that leachate or brackish water is at a depth of 100-180 m from the ground level, it is known that the pattern of leachate water flow or brackish water from the west to the east is known, namely the sea. This statement is supported by the research of Ariyanto, G, (2016) that the flow direction starts from the western Su-rabaya area to the east covering various areas in the districts of Karangpilang, Gayungan, Jambangan, Wonocolo, Tenggilismejoyo, Gununganyar, Rungkut, Sukolilo, Tegalsari, Gubeng, Mulyoreji, Genteng, Tambaksari, Simokerto, Bulak and Kenjeran. so that this condition indicates that the groundwater at the Keputih Landfill location after the closure is affected by the seawater instructions. Seawater intrusion in coastal areas is a process of infiltration of saltwater from the sea into freshwater on land (Ariyanto, G, 2016). Based on the results of the classification of groundwater vulnerability to seawater intrusion, the Keputih Landfill is included in the medium vulnerability level (Masitoh & Saifanto, 2024). This is information that water that is indicated for leachate can be brackish water.

Analysis of the Impact of Leachate Spread in the Keptih Landfill on Groundwater Quality

Several studies have suggested that leachate contains heavy metals in the form of ions. This is what causes leachate to contaminate groundwater, making soil conditions more conductive due to the presence of heavy metal ions that produce resistance values. If the presence of leachate is less and less, it will produce a low resistivity value (Tampubolon et al., 2020).

Further analysis to determine the condition of water quality around the current location of the Keputih Landfill area by using laboratory test results data for water sampling at 3 (three) location points. The water samples taken were taken from residents' wells, Keputih Landfill monitoring ponds and reservoirs with a groundwater level depth of about 0.5 – 1 m and obtained test results in accordance with table 2

Table 2. Water Laboratory Test Results

No	Parameter	Unit	Point 1 Result (People's Well)	Point 2 Result (Monitored Pool)	Point 3 Result (Dam)	BML Leachate[1)]	Method
1	PH	-	8,29	10,1	8,20	6,0-9,0	SNI 6989.11:2019
2	BOD_5	mg/L	15,6	393,5	10,2	150	SNI 6989.72:2009
3	COD	mg/L	38,7	979,0	25,1	300	SNI 6989.2:2019
4	TSS	mg/L	7,00	339,0	3,00	60	SNI 6989.3:2019
5	Cadmium (Cd)	mg/L	<0,0876	<0,0876	<0,0876	0,1	IKM.AXO-46 (AAS)
6	N Total	mg/L	21,6	0,665	10,2	60	IKM.AXO-41
7	Hg	mg/L	<0,0006	<0,0006	<0,0006	0,005	SNI 6989.78:2019

Information:
1) BML is an Environmental Quality Standard in accordance with the Regulation of the Minister of Environment
2) Living Number 59 of 2016 concerning Quality Standards of Leachate for Businesses and/or Waste Final Processing Site Activities"

Based on the results of the ADMT analysis, the existence of leachate or brackish water is currently at a depth of 100-180 m. The test results showed that the water of the well at point 1 and the reservoir at point 3 was below the leachate quality standard which indicated that the shallow groundwater quality in the two scattered locations was not affected by the spread of leachate. The location of sampling well water point 1 is in a plantation area owned by residents, around the well there are several plants such as bananas, and other wild plants. Meanwhile, the location of the water sampling point 3 is in a reservoir close to residents' housing.

Furthermore, the sampling location at point 2 is in the monitoring pond of the Keputih Landfill after the closure. This pond is an open pond and, in the area, where this monitoring pond is located there are no significant activities, but it has an open area and there are other green plants.

The results of laboratory tests showed that the values of pH, BOD5, COD and TSS were very high (above the environmental quality standards for leachate). In this regard, it is most likely caused by the accumulation of biologically and chemically decomposed organic matter, as well as the high concentration of suspended particles. High BOD5 and COD indicate the presence of excessive organic matter content from the water. Such as organic waste that has not been fully decomposed and plant or animal remains. The process of decomposition of organic matter by microorganisms requires oxygen so that high BOD can cause a decrease in dissolved oxygen levels in water. Furthermore, COD measures all organic matter that can be oxidized, both biologically and chemically, so its value is usually higher than BOD5.

Tchobanoglous & Kreith (2002), Handbook of Solid Waste Management explain that even if landfills are closed, active anaerobic zones can still produce degradation reactions, especially if the zone still receives moisture or organic matter remains. High TSS values in monitoring ponds are most likely influenced by sediment resuspension, microbial growth, and surface water runoff, rather than solely from active leachate flows. The picture of taking water sampling is shown in figure 5.

Figure 5. Water Sampling

CONCLUSION

The study concluded that the water flow around the Keputih Landfill after its closure flows eastward toward the sea, based on analysis using the Active Directory Magnetotelluric (ADMT) method. However, the resistivity obtained from the study could not distinguish between leachate and brackish water at depths of 100-180 meters. Additionally, the spread of leachate continues in the shallow groundwater at the landfill site, as indicated by BOD, COD, and TSS values exceeding environmental quality standards. The resistivity values in deep groundwater, ranging from 8.23 – 9.81 Ωm, fall within the range for both brackish water and leachate, but the spread of leachate in deep aquifers cannot be confirmed due to the intrusion of seawater into the landfill area. Future research could focus on further investigating the deep aquifers and using more advanced techniques to accurately differentiate between leachate and brackish water.

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