# Characterization of leachate distributions at Ngipik Municipal Solid Waste Disposal site

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**ABSTRACT:** The Municipal Solid Waste Disposal in Ngipik – Gresik (near Surabaya, in East Java Province, Indonesia) has become an overflowing landfill due to the indiscriminate dumping of solid waste at the site. Leachate migration away from the landfill boundaries creates serious environmental problems which include, and are not limited to vegetation damage, groundwater pollution and soil pollution. This present paper is meant to study the possible impact of the leachate percolation to the adjacent soil and groundwater. The soil samples and leachate samples were collected from this landfill-site and its surrounding area to study the possible impact of leachate percolation on soil characteristics. The geophysical (Electrical Resistivity Tomography – ERT) investigations were carried out on this landfill-site and its adjacent area, to better understand the sub-soil characteristics. The water quality data were collected to study the possible leachate penetration on the ground water. Concentration of various physicochemical parameters and engineering properties were then be determined. The study indicated that leachate percolation quantity has strongly affected the groundwater properties. There is a general change in groundwater properties which are attributed to the chemistry of leachate.

**Keywords:** leachate percolation, ERT method, groundwater pollution, Landfill.

## 1. INTRODUCTION

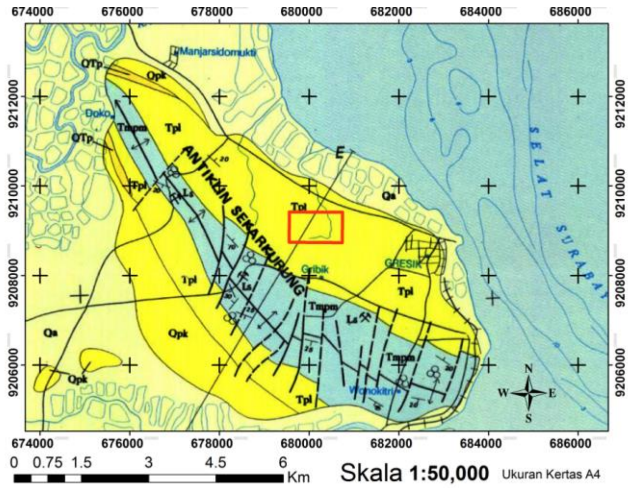
Ngipik Landfill is one of the landfills in East Java Province, Indonesia, which still applies the open dumping method for waste disposal (Figure 1). Although Ngipik landfill was designed for sanitary landfill in 2002, this landfill still applies the open dumping method until 2016. Recently, Ngipik landfill is shifting to be a controlled landfill. The amount of waste carried and dumped in Ngipik Landfill was around 624,72 $m^3$ per day or 187,42 tons per day with waste density 300 $kg/m^3$ (Agustina, 2012).

The common problem of landfills is the leachate deployment. Leachate means any liquid percolation through the deposited waste and emitted from or contained within a landfill. The leachate consists of many different organic and inorganic compounds that may be either dissolved or suspended. They will bring potential pollution issues for groundwater and surface waters in nature. The landfill leachate is a secondary contamination related to landfills (Monroe, 2001). Landfill deployment problems have been studied by several researchers such as Suparmanto et al (2006) in Benowo Landfill Surabaya and Endah and Pudjiastuti (1997) in Keputih Landfill Surabaya. They found out that the disposal method was the main cause of the groundwater contamination.

Sutra et al.(2016) found that water from the monitoring wells (Figure 1) has been influenced by the leachate from Ngipik Landfill. It means that the clay soil has also been contaminated due to the contaminant migration by the water. The increasing use and expanding of this site will seriously affect the quality of groundwater in the region besides the major influence on the air pollution.


Figure 1. Location map of the Ngipik landfill site

Based on geological setting, the geological formation at Ngipik Landfill is in the Lidah Formation (Figure 2) with Quarter age, composed of clay, black and blackish, hard when dry, little fossil content and sandstone clay. Characteristics of the Lidah Formation are to have fairly thick clay content on the layer (Sukardi, 1992). This can be proved by drilling results, up to 30 m indicating that the research area is dominated by silt and clay. Detailed soil characteristics, will be discussed further in this paper.




| | | | |
|---|---|---|---|
| Tpl | : Lidah formation | Qal | : Alluvium |
| Tmpm | : Madura formation | Qpk | : Kabuh formation |
| QTp | : Pucangan formation | | : study area |

Figure 2. Geological map of the study area (Sukardi, 1992)

Generally, this paper is aimed to investigate the effect of Ngipik landfill site on groundwater by employing an integrated use geophysical method (Electrical Resistivity Tomography – ERT), soil samples and leachates samples.

The ERT is able to efficiently define the electrical properties of shallow layers. In environmental pollution investigations, ERT can survey pipeline or tank leak incidents, verify sewage leakage and define the scope and depth of landfill (Ayolabi et al, 2013; Awni T.B., 2005). The extensive application ERT method for mapping leachate movement is based on strong response of conductivity variations for leachate distribution (E.Al-Tarazi et al.,2008). Relatively, adding of conductive or resistive contaminants into groundwater through soil porosity, will increase in the concentration of inorganic and/or organic constituents. Eventually, the contaminants will change the electrical properties of surrounding soil and groundwater.

## 2. FIELD AND LABORATORY INVESTIGATIONS

### 2.1. Field Investigation

There were three field investigations conducted in this research, Boring test and Standard Penetration Test (SPT), 2D-resistivity measurements and groundwater level testing. SPT purposed to obtain the field density of the soil and to see the physical condition of the in situ soil. The SPT showed how many blows the landfill soil can bear for 30 centimetres lowering (ASTM D1586). It represented the compactness and related to the bearing capacity of the soil. The SPT was taken up to 30 meters depth in three Bore Holes (BH). BH-1 took place next to IPAL (Instalasi Pengolahan Air Lindi/ Leachate Process Installation) as well as the Monitoring Well 1 (MW-1), BH-2 was taken next to the office, Monitoring Well 2 (MW-2) and the waste mound, and one bore hole taken a bit far from landfill, to assess the initial uncontaminated soil. BH-3 is 250 meter away from the landfill. Locations of the three bore holes and lines of 2D-resistivity measurement shown in Figure 3.


Figure 3. Locations of bore holes and resistivity measurements

The application of 2-D resistivity is aimed to describe resistivity below the surface in 2 dimentional figures so that both vertical and horizontal distributions of resistivity values may be determined. The field resistivity measurement used equipment's, such as Resistivity-meter, 4 rolls of connecting cables, 4 rods of electrodes (consisting of 2 current electrodes and 2 potential electrodes), hammer, and some supporting equipment (GPS, Meter Gauge, Geological Compass, Communication Tools, and Data Sheets). In this study the method of 2-D resistivity measurement is employed using Wenner-Schlumberger electrode configuration. As explained by Loke (1999), the Wenner-Schlumberger configuration allows a relatively good vertical and horizontal resolution and the configuration must be used when we are not sure with the local geological condition.

The flow net map is a basic tool for groundwater flow dynamics investigation. A flow net is a 2D diagram of equipotential and flow lines (Braja, 2013). The flow net map can be used to estimate the quantity of recharge across site feeding front boundary, and contaminant load can be estimated from flow net map (Domenico and Schwartz, 1990). Flow net can show the topographic control of groundwater flow (Fetter, 1988). To construct a flow net map at this study site, water levels are measured in 3 boreholes and 2 monitoring wells and their surfaces are interpolated between measuring points.

### 2.2. Laboratory Investigation

The soil samples from the drilling result are then taken to the laboratory for physical and mechanical properties tested. The properties of soil examined are physical properties including the physical properties: volumetry & gravimetry (ASTM D 2216-71; ASTM D 854-72), Atterberg Limit (ASTM D4318-00), and grain size distribution including the hydrometer (ASTM D2487; D422); the mechanical properties: Standard Compaction Proctor (ASTM D698); and soil strength properties: Unconfined Compressive Strength (ASTM D 3080-72).

Finding the characteristic of soil resistivity functioning as water content or leachate content in the research location requires a laboratory resistivity measurement over undisturbed sample of soil. The soil samples were collected from BH-3. Samples from the depth above 2 m were used in the laboratory experiment. The resistivity of the soil samples was measured using the four-electrode cell.

In an effort to study the extent of the groundwater contamination 3 groundwater sampling was taken from boreholes. Since the landfill site was not equipped with a leachate collector, the leachate collected at the base of the landfill. The tests was held in two laboratories, Laboratory of Environmental Quality, Environmental Engineering, ITS and TAKI Laboratory in Chemical Engineering, ITS.

## 3. RESULTS OF MEASUREMENTS

### 3.1. Soil characteristics

The in-site geotechnical measurements that have been conducted include boring and measuring Standard Penetration Test (SPT) for 30 m depth. From SPT, until 5 meters soil still classified as very soft clay, and the next depth varied from medium to stiff clay in 10 to 30 meters depth. The results of sieve analysis of soil samples resulting from sieve drilling indicate that in general the soil at the surveyed site consists of loam soil (SC) dominated by brown color. The following Figure 4 show parameter of soil in the surveyed location respectively, based on water content test and gravimetry-volumetric test, degree of saturation ($S_r$), specific gravity ($G_s$), unit weight of soil ($\gamma_t$), and void ratio (e).

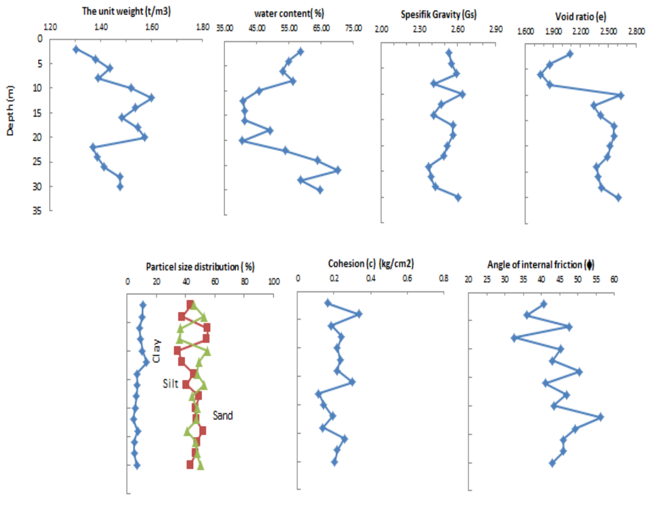
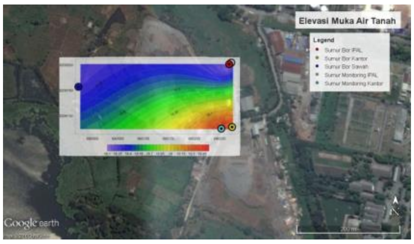



Figure 4. Soil parameter from surveyed area

The liquid limit (LL) values for soil samples from BH-1, BH-2 and BH-3 are 77,69%, 69,36% and 86,05%, with the Plasticity Index (PI) 55,69%, 46,68% and 57,22%, respectively. These values are chategorized as high plasicity clay. The higher plasticity index gives a lower value of hydraulic conductivity. (Daniel, 1987; Arifin, 2001). The void ratio (e) for BH-1, BH-2 and BH-3 are 1.299, 1.148 and 1.635, respectively. These values correspond to the density value of each BH. BH-3 has the lowest density among three boreholes, 1.62 tons/m$^3$.

### 3.2. The Flow net

Groundwater level measurements also have been conducted from same shallow wells that distributes at surveyed area. The depth of the groundwater in the study site is very shallow at less than 2 m. It is obvious that the groundwater flow within the study area is controlled by topographic (Figure 5). The direction of groundwater flow or the flow net in the Ngipik Landfill is mainly to the North.



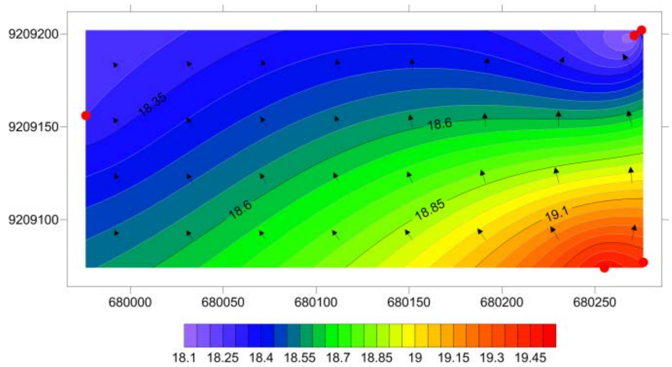




Figure 5. Local flow net map of unconfined aquifer (water table) based on wells in the study area

### 3.3. Effect of Leachate movement through aquifer

The leachate composition affects the chemistry of groundwater, as it percolates through the soil horizon reaching the subsurface groundwater aquifers. Therefore, three wells (two wells from boreholes and one well from monitoring well) have been selected to show the effect of the leachate contamination on the quality of groundwater.

The target of the quality of groundwater testing was through the basic laboratory experiment to analyze and realize the characteristic of leachates. In the laboratory analyses total suspended solids (TSS), pH, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) of leachate were analyzed. Also the chemical composition of leachate sample such as nitrite, nitrate, ammonia, N-total and cadmium were determined. According to the analysis experiment of selected parameters to make a table to concentrated present the whole results (Table 1).

Based on Indonesian Ministry of environmental and Forestry Regulation No. 59 (2016) for effluent standard for leachate, the threshold of physical and chemical parameters required for leachate is presented in column 2 (Table 1). From comparison of measurement results of landfill leachate with values of effluent standard, and then obtained all parameters (TSS, COD, BOD and N total) exceeds the threshold, up to 3 – 17 times.

The pH of landfill leachate is 8,05, which is present weak alkaline. The high of COD and BOD in landfill are producing from the organic matter of domestic biological waste. The relatively high value of TDS indicated the presence of inorganic material. The high concentration of ammonia nitrogen (N –Total $NH_3$) in landfill indicates that it is still active in the decomposition of organic material.

The concentration of Cd (one of heavy metal ionic) is low. The amount of heavy metals is related to industrial level of local urban and how much industrial waste will be land-filling. The domestic waste only contains heavy metal is low. Generally, based on physical and chemical parameters of landfill leachate then leachate generated from Ngipik landfill is the leachate of young landfill (above 3 – 5 years) (Alloway & Ayres, 1997).

Based on Indonesian Government Regulation No. 82 (2001) for quality standard for drinking water/clean water, the maximum physical and chemical parameters required for clean water is presented in column 1 (Table 1). From comparison of measurement results of wells BH-1, MW2 and BH-3 with values of quality standard, then obtained almost all parameters exceeds the quality standard threshold. These high values obtained for the underground water near the landfill is an indication of its effect on the water quality.

TDS indicates the general nature of water quality or salinity. The range of TDS at all sites higher than 860 mg/L. As per the classification of Rabinove et al. (1958) based on TDS, one sample (BH 3) was non-saline and other samples were slightly saline. The high value of TDS may be due to the leaching of various pollutants into the groundwater (Suman Mor, et al, 2006).

COD is a measure of oxygen equivalent to the organic matter content of the water susceptible to oxidation by a strong chemical oxidant and thus is an index of organic pollution. The COD level in the groundwater samples higher than 24 mg/L, indicating the presence of organic contaminants in the water and can be used as organic indicators to assess the groundwater pollution caused by landfill (Suman Mor, et al, 2006).

The N total ($NH_3$) and Cd concentration was also found to be remarkably high at all samples. The Cd is one of heavy metal that undesirable metal or toxic in drinking water. Thus, it can be said that the groundwater around the landfill could not be used for drinking water purposes and likely indicate that groundwater quality is being significantly affected by leachate percolation. Strictly speaking one should avoid using groundwater drawn from the wells located in proximity of the landfill sites.

Table 1. Physical and Chemical parameters of groundwater

| No | Parameters | Unit | BH-1 | MW2 | BH-3 | Leachate | 1 | 2 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | - | 7,15 | 7,35 | 7,75 | 8,05 | 6-9 | 6-9 |
| 2 | TSS | mg/L | 20 | 202 | 90 | 280 | 50 | 100 |
| 3 | TDS | mg/L | 3040 | 1380 | 860 | 3750 | 1000 | - |
| 4 | COD | mg/L | 44 | 44 | 24 | 2480 | 10 | 300 |
| 5 | BOD | mg/L | 25 | 26 | 14 | 1512 | 2 | 150 |
| 6 | Nitrite ($NO_2$) | mg/L | 0,921 | 6,241 | 0,135 | nd | 0.06 | - |
| 7 | Nitrate ($NO_3$) | mg/L | 8,8 | 6,15 | 0,86 | 1058 | 10 | - |
| 8 | Ammonia ($NH_3$) | mg/L | 1,53 | 127,25 | 26,85 | 1020,44 | - | - |
| 9 | N Total ($NH_3$) | mg/L | 11,25 | 140,35 | 27,84 | 1031,02 | 0,5 | 60 |
| 10 | Cadmium (Cd) | mg/L | 0,04 | 0,04 | 0,04 | 0,08 | 0,01 | 0.1 |

| | |
|---|---|
| 1 | Indonesian Government Regulation No.82, 2001 |
| 2 | Indonesian Ministry of Environment and Forestry No.59, 2016 |
| nd | Not defined |
| BH | Bore Hole |
| MW | Monitoring Well |

### 3.4. Laboratory resistivity measurement

A laboratory-scaled resistivity measurement is carried out on some samples of undisturbed soil to find out the characteristics of soil resistivity as a function of water content (fresh water and leachate). The resistivity measurement on some soil samples is adjusted with the targeted depth of the 2D resistivity measurement in the field.

The soil sample used is the soil samples from BH-3 near the 6th 2D-resistivity path. The parameters used in making the sample are listed in Table 2.

Table 2. Parameters of resistivity sample preparation

| $\gamma_d$ (gr/cm³) | $W_w$ (g) | $W_s$ (g) | $W_{c\ opt}$ (%) | $W_t$ (g) | d (cm) | t (cm) |
|---|---|---|---|---|---|---|
| 1.32 | 31.91 | 104.62 | 30.50 | 136.53 | 3.72 | 7.27 |

where $\gamma_d$ is the dry unit weight that obtained from the test proctor of the soil sample used. The sample volume made has a diameter of 3.72 cm and a height of 7.27 cm. From the dry weight unit and the known volume of the sample, it can be determined the weight of the soil to be made. The soil weight, Wt consists of the sample weight Ws and the water weight Ww. The weight of water is obtained from the optimum water content value to the optimum dry weigh unit of sample.

Soil sample resistivity ($\rho$) can be calculated by multiplying resistance value (R) with geometric factor ($k = 2\pi a$) where a = 1 cm. A curve of correlation between resistivity ($\rho$) to water content ($w_c$) on each fluid (clean water and leachate) can be seen on Figure 6.

From the figure below (Figure 6), soil resistivity can be clearly distinguished between the contaminated soil and the soil that has not been contaminated with leachate. The soil contaminated leachate is worth less than 2.4 ohm m. This data will be used to interpret resistivity measurement results in the field

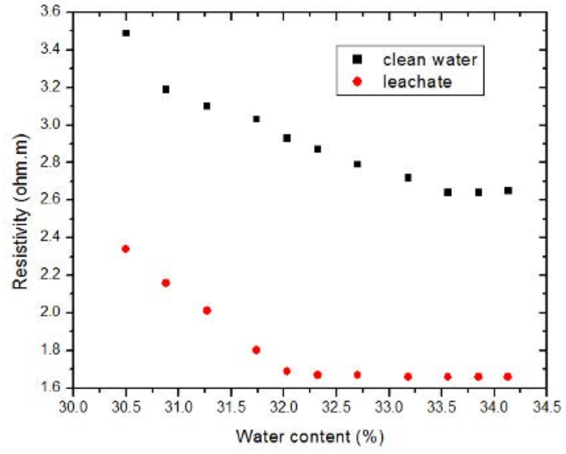



Figure 6. Curve of resistivity correlation ($\rho$) vs water content ($w_c$)

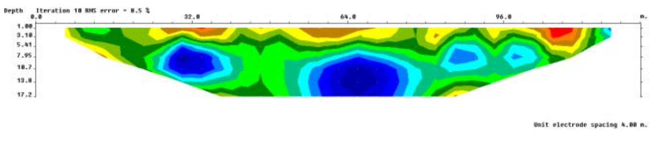
### 4.4. 2D-resistivity measurement

The resistivity measurement was conducted on five lines with varieties of seven length in the surveyed location (see Figure 3). Measurement in each line was conducted in the dry season (August 2017).

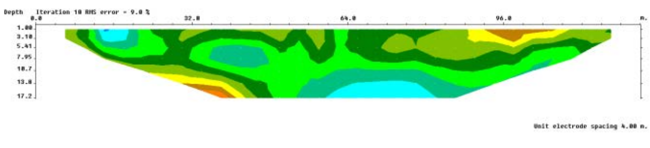
The result of resistivity measurement is obtained through data processing and topographical correction using the Res2Dinv ver. 3.56 Software (Figure 7). Based on the data, the Root-Mean-Squared (RMS) error is less than 10% with 10 iterations. However, the addition of iterations on the data processing does not result in significant change against reduction of RMS errors. Hence, the resistivity model to choose is the one on the 10th iteration. Distribution of resistivity value (2-D resistivity tomography) measured from the surface down to the depth of 20 m for all lines ranges from 0.1 Ωm to 29.2 Ωm.

In the cross section of the inversion of the line 1 to the line 7 there is a zone with a low resistivity value (Figure 7). Low resistivity values range from 0.1 - 1.7 Ωm. Based on the results of laboratory scale resistivity measurements, the value is indicated as the accumulation of leachate (which is characterized by blue). From all measurement lines, it was found that leachate water leakage was at a depth of 5 meters to 10 meters.

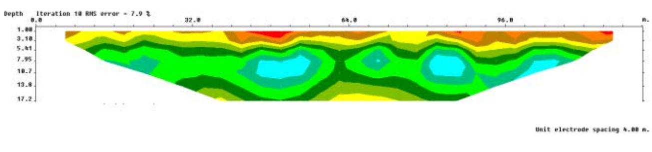
a. Line 1



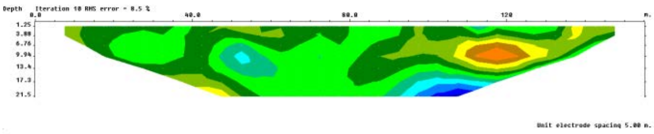
b. Line 2



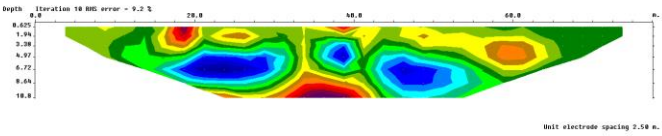
c. Line 3



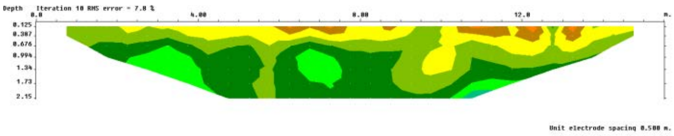
d. Line 4



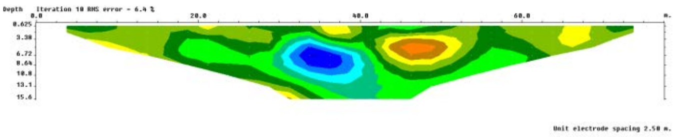
e. Line 5



f. Line 6



g. Line 7



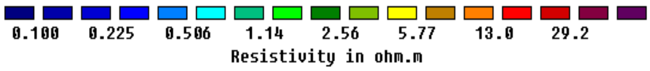



Figure 7. The 2D resistivity tomography on line 1 – line 7

Furthermore, from the inversion 2D resistivity results, 3D cross-section is made by displaying only the target resistivity value which is a low anomaly that is the presence of considerable water content in the soil (leachate water flow). The 3D result (as illustrated in figure. 8) combined with the direction of the aquifer stream (figure 3), shows that the leachate plume follows the aquifer stream.

This indicates that the leachate distribution pattern that occurs from the overloaded area of eastern garbage, the leachate spreads to the lower groundwater level that is towards the Southeast - Northwest.

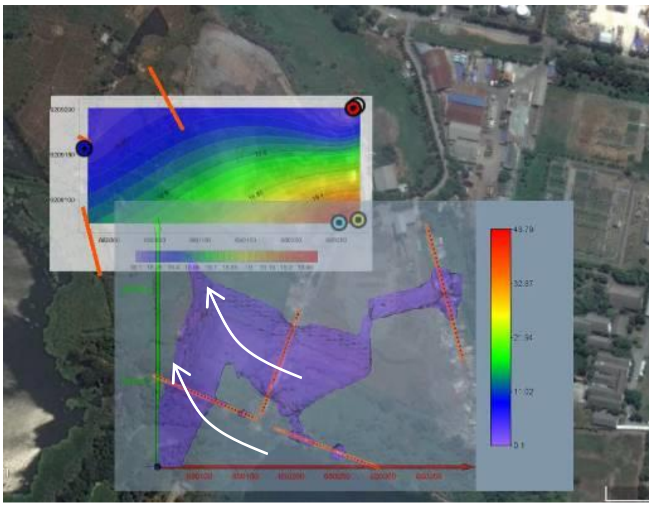


Figure 8. The 3D perspective view of leachate plumes

## 4. DISCUSSION AND CONCLUSION

From the groundwater testing and resistivity measurement, it is clearly seen that the leachate generated from the landfill site is affecting the groundwater quality in the adjacent areas through percolation in the subsoil. The leachate plume occurs at a maximum depth of 10 m on the 2-D inverse models of resistivity with an average depth of infiltration being 5 m in the study area.

It can be obviously seen that physical and chemical parameters of groundwater are greatly and strongly affected by the leachate. All groundwater physical and chemical parameters exceed the standard value of Indonesian Ministry of Environment and Forestry No. 59 , 2016.

Furthermore, a multidisciplinary technique of geotechnics, hydrogeological, geochemical and geophysical techniques should be adopted on the dumpsite to be able to holistically assessed and interpreted.

## 6. ACKNOWLEDGEMENTS

The authors would like to thank PMDSU Program from Indonesian Ministry of Research and Higher Education for the scholarship and research grant.

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