The Effect of Differences Leachate Concentration and Material Properties on Electrical Conductivity of Volcanic Deposits – Case Studies Piyungan Landfill Bantul Yogyakarta

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ABSTRACT. Monitoring at the contaminated subsurface soil, have been conducted by using the geophysical surface method, especially for geoelectrical resistivity method. Monitoring is commonly conducted by using geoelectrical resistivity through measuring the value of Electrical Resistivity (ER) or Electrical Conductivity (EC) of leachate contaminated soil layer. EC measurement value of soil is affected by many factors, among others, particle conduction of soil materials, surface conduction, fluid conduction in the pores as well as the effect of particle shape and soil materials. Piyungan landfill is the main disposal site of Yogyakarta municipal solid waste. This landfill located mainly on the tertiary rocks of volcanic rocks and its weathering products. In order to improve the accuracy of geoelectrical measurements on resistivity in monitoring soil layers from contaminated leachate on this area, this research conducted several measurements on physical properties of soil sample and electrical properties of leachate in the saturated soil samples. The measurement of physical properties includes: porosity, clay content, particle content, and cation exchange capacity (CEC) value. The soil samples were collected from 3 locations around Piyungan Landfill. Type of soils are taken from the alluvial deposits (Sample B), weathered tuffaceous sandstone-claystone (Sample D), and weathered andesitic breccia (Sample F). Samples were made in containers, saturated with aquades-leachate solution with 12 different concentration levels. Electrical conductivity (EC) was measured by using Soil Box Miller and Geoelectric Resistivity Oyo McOhm. According to results of physical properties analysis, the grain size of soils are dominantly sandy clayey silt in grain size distribution, with clay content ranging from 33.0--38.4 %, the CEC values ranging from 26.8--52.7 meq/100 gr, and the porosity of samples B, D and F is 58.85 %, 55.30 %, 59.24 %, respectively. Based on the experiments with 12 different leachate concentrations, there is a linear increase in EC of 0.718 μS/cm for every increase in electrical conductivity pore fluid (EC$_f$) 1 mg/l in samples B, while in samples D and F are 0.492 μS/cm and 0.284 μS/cm respectively. Plotting the data of EC vs EC$_f$ for each samples and ER vs EC$_f$, it can be concluded the slope of ΔEC/ΔEC$_f$ differ for each samples and the electrical conductivity value of different concentration of leachate is very sensitive for alluvial deposits compare to the weathered tuffaceous sandstone-claystone and weathered volcanic breccia deposits.

Keywords: Electrical conductivity · Cation exchange capacity · Leachate · Soil · Volcanic deposits.

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1 INTRODUCTION

Landfill is the most often used method for dumping disposal site in urban areas. How-

ever, the landfill often becomes a potential source of groundwater contamination because containing high concentration of chemical elements (Mac Farlane *et al.*, 1983; Rapti-Caputo *et al.*, 2006; Reyes-López *et al.*, 2008) . Therefore,in the landfill dumping site it is necessary to monitor the probability of leachate seepagein the soil and groundwater continuously in the surrounding area of the landfill.

Many soil and groundwater quality monitoring at the contaminated subsurface soil, have been conducted by using the geophysical surface method, especially for geoelectrical resistivity method. Monitoring is conducted by using geoelectrical resistivity through measuring the value of Electrical Resistivity (ER) or Electrical Conductivity (EC) of leachate contaminated soil layer (Abbaspour *et al.*, 2000; Meju, 2000; Porsani *et al.*, 2004). EC measurement value of soil is affected by many factors, among others, particle conduction of soil materials, surface conduction, fluid conduction in the pores as well as the effect of particle shape and soil materials. Electrical Conductivity of fluid (EC_f) is the dominant factor in measuring the EC value of soil, which is influenced by the chemical concentration and composition of pore fluid (McCarter, 1983; Kalinski and Kelly, 1994; Klein and Santamarina, 2003).

The purpose of this research to find the electrical characteristics of volcanic deposits saturated leachate as Piyungan landfill overlying such kind of lithology.Research conducted by Longo (2014) obtained ER value of volcanic deposits are between 4-20 Ohm-m (Longo *et al.*, 2014). On this research, samples were obtained from the volcanic deposits around Piyungan landfill. This layer consists of alluvial deposits, weathered andesitic breccia and weathered sandstone-tuffaceous claystone (Putra, 2001). Data of ER or EC values of soil layering and pore fluid filler is required as a binder to improve the accuracy of data interpretation of the soils layering lithology on the geoelectric resistivity measurements (Meju, 2000).

2 STUDY AREA

The areas of Piyungan Landfill and surrounding are covered by Quarternary and Tertiary rocks, which are the Young Merapivolcanicdeposits, Alluvial Deposits and the lower-middle
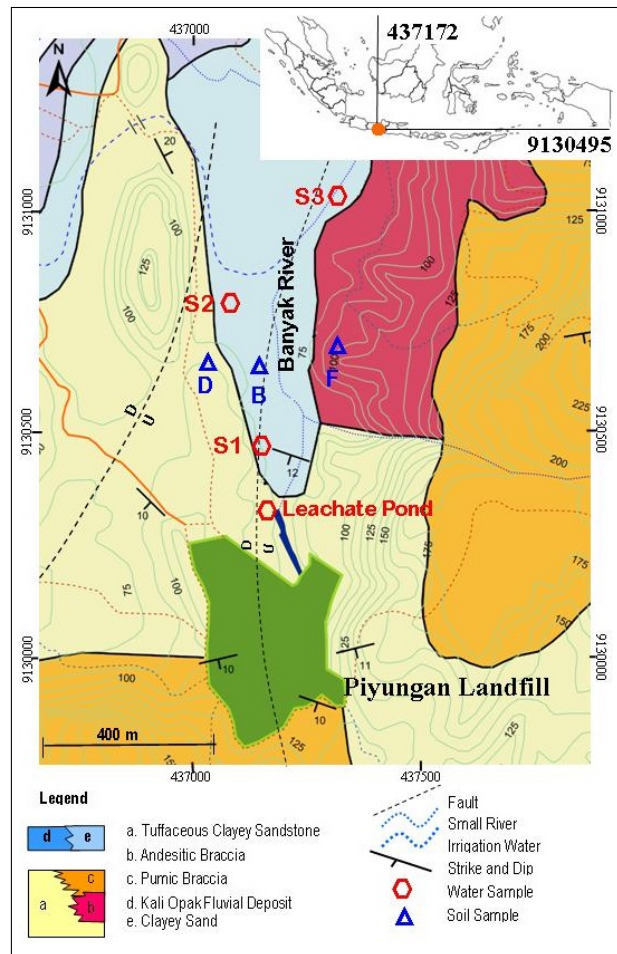

Figure 1: Geological map (Putra, 2001) and soil sampling locations (B1, B2, B3, B4, D and F), leachate pond sample location, and groundwater sample location from the dug well S1, S2 and S3.

Miocene rocks called as Semilir Formation (Raharjo *et al.*, 1995).

The lithology contained in the study area can be divided into five lithological units, namely; sandstone-tuffaceousclaystone unit, andesitic breccia units, breccia pumice unit pumice which is a product of the tertiary rocks, and Opak River's alluvial and fluvial deposition units and which is a quarternary deposit product (Putra, 2001). Banyak River is a disposal river for leachate from the Piyungan landfill, flowing across the alluvial deposits from the South to North (Figure 1).

3 THEORETICAL BACKGROUND

The Waxman and Smits Equation (Waxman and Smith, 1968; Sen *et al.*, 1998) explains the correlation between the EC of soil fluid (electrolyte)

with the electrical conductivity of clay material. EC material is represented by the Cation Exchange Capacity (CEC) value of the clay:

$$EC = \frac{1}{F}\left(EC_f + BQ_v\right) \qquad (1)$$

where F is related to the porosity ϕ with Arcie equation of $1/F = \phi^m$ in which m is the porosity exponent of Archie equation with a value of $m \approx 2$ and B is the equivalent counter ion mobilityof clay surface.

$$B = B_0\left[1 - 0.6\exp\left(-\frac{EC_f}{0.013}\right)\right] \qquad (2)$$

where EC_f is the electrolyte conductivity in S.m^{-1} and the maximum counterion equivalent mobility is given by the value of $B_0 = 4.78 \times 10^{-8}$ m^{2}s^{-1}V^{-1}. Meanwhile, the Q_v value shows the CEC with an equation:

$$Q_v = \rho_{mat}\frac{(1-\phi)}{\phi}CEC \qquad (3)$$

where ρ_{mat} is the matrix density in kg.m^{-3}.

The CEC values for some clay minerals are available in Table 1, ranging from 3-150 (meq/100gram) from Eslinger and Pevear (Ismadji *at al.*, 2015).

Table 1: The CEC values for some clay minerals. The CEC values of clay ranging from 3--130 meq/100g, from Eslinger and Pevear (Ismadji *et al.*, 2015)

Clay mineral	CEC, meq/100 g
Allophane	70
Kaolinite	3–15
Halloysite	5–10
Sodium Montmorillonite	80–130
Calcium Montmorillonite	40–70
Hectorite	80–130
Palygorskite	30–40
Sepiolite	30–40
Illite	10–40
Vermiculite	100–150

4 Materials and Methods

Materials

Soil samples were collected from 6 locations around the Piyungan landfill, Yogjakarta (See Figure 1). Sampling were taken at a depth of 40-50 cm, except for the samples in location B that were taken from four different locations and depths. Point B1, B2, B3 and B4 are derived from a single point location with a depth of 1.0 m, 1.5 m, 2.5 m and 3.0 m, respectivley. Point B1, B2, B3, and B4 are in alluvial deposit. Point D is located at the location of the tuffaceous sandstone-claystone deposit, while point F is located at andesitic breccia unit. Each samples were made into two parts for the measurements of physical and electrical properties of the sample. Groundwater samples were collected from dug well S1, S2 and S3. Leachate sample was collected from the leachate pond.

Measurements of physical and electrical properties of the samples

a. Measurements on the physical properties of the soil; density, porosity, grain size distribution and the value of the CEC, conduct with the pycnometer, hydrometry and percolate distillation methods. The tests were conducted in the laboratory of Institute for Agricultural Technology (BPTP) of Yogyakarta.

b. The measurement on the resistivity value of the sample was conducted in the laboratory of Environmental Geological Engineering of Gadjah Mada University of Yogyakarta. Each sample was dried for 3×24 hours. Each type of samples was then put into the 12 different sample containers with the same weight. Each sample was saturated with the aquades-leachate solution with 12 different levels concentration. The leachate was obtained from the leachate pond of Piyungan landfill. 11 samples used an aquades-leachate solution ranging from 10 mg/l to 350 mg/l and 1 sample used ground water. The samples were stirred evenly until the soil samples were saturated based on the standard (ASTM-G57a, 1995). There were 72 containers of saturated samples were then left for 24 hours to ensure saturation of samples. The saturated samples were then put into the soil box Miller (sketch in Figure 2), compacted evenly, and then measured for its EC values (Kowalzczyk *et al.*, 2014).

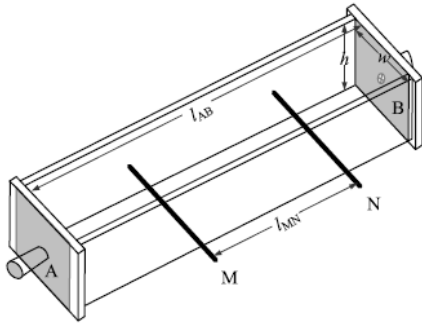c. Electrical Resistivity (ER) values measurements used a Geoelectric Resistivity Oyo

Figure 2: Soil box Millers scheme, A and B are the electrodes of electric current, M and N are the electrodes of electric potential. Electrodes A and B are made of stainless-steel fragments, with a thickness of 1 mm, and distance of 22cm. Electrodes M and N that are made of 4mm-diameter copper nails, with a length of 5cm, are made in a distant of 12 cm (ASTM-G57a, 1995).

McOhm. By using four electrodes method, 2 current electrodes and 2 potential electrodes, the current is conducted through the electrodes A and B that are made of stainless-steel fragments with a thickness of 1mm, and a distance of 22 cm. M and N electrodes that are made of 4 mm-diameter copper nails, with a length of 5 cm, are made in a distance of 12 cm. The data of sample resistivity were analyzed through graphics of the relationship of the effect of the level of EC change due to the increase of TDS concentration level of the pore fluid filler.

5 RESULTS AND DISCUSSION

Physical properties

Physical properties of the sampless how on Table 2. According to the percentage value of the grain size, sample B, D and F are classified as sandy clayey silt. All samples had a total porosity of greater than 55 %. Weathered andesitic brecciashas a porosity of 59.24 %, alluvial deposits 58.85 % and weathered tuffaceous sandstone-claystone 55.30 %, respectively. Alluvial deposit samples contain higher clay percentage compare toweathered andesitic breccia and weathered tuffaceous clay sandstone.

However, the clay contain seem to be not linear to the CEC value (see Figure 3). The CEC values are ranging from 26.8–52.7 meq/100gr.

Table 2: The physical parameter of lithology around Piyungan landfill (CEC in meq/100gr).

Soil Sam- ple	ρ (gr/cc)	ϕ Total (%)	Sand >50μ (%)	Silt 2–50μ (%)	Clay <2μ (%)	CEC
B	2.48	55.30	14.50	46.70	38.80	32.94
D	2.53	58.85	18.67	44.67	36.67	26.60
F	2.48	59.24	26.67	40.33	33.00	36.40

B: Alluvial deposit
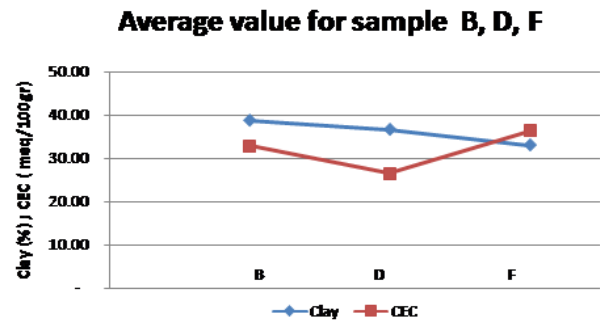CD: Weathered tuffaceous sandstone-claystone
F: Weathered andesitic breccias

Figure 3: The graphic of average clay content percentages and CEC values of volcanic deposits around Piyungan landfill. The CEC values are in meq/100g and clay content in %.

The highest CEC value measured on sample F of weathered andesitic breccia, and the lowest CEC measured from sample D of weathered tuffaceous sandstone-claystone.

Electrical conductivity measurements

The electrical conductivity values of samples with different combination of leachate concentration is show in Table 3. The groundwater samples used in the measurements was from a dug well located approximately 650 m downstream from waste processing disposal of Piyungan landfill. The dug well has been classify as contaminated by leachate from Piyungan landfill (Phonhalath, 2012). The EC_f value of this ground water is equal to the EC_f value of aquades-leachate fluid that is 410 μS/cm at the same TDS concentration of 200 mg/L. However, the EC of the ground water-saturated soil sample has a lower value than the aquades-leachate saturated sample. It is probably due to effect of different types of ions in the ground water containing ions in the

aquades-leachate fluid that result in different EC values (Parhusip, *et al.*, 2016).

From the measurements, it can be obtained that the leachate-aquades solution with TDS values ranging from 10 mg/l to 350 mg/l has an EC value ranging about 30 μS/cm to 710 μS/cm. There is an increase in EC linearly with the average increase of 0,82 μS/cm for every additional leachate TDS of 1 mg/l (Table 3). Concentration of TDS from 10 mg/l to 350 mg/l wi have EC of samples D and F are about 347 μS/cm to 796 μS/cm than samples B around 1027 uS/cm -1473 uS/cm. From Table 3, the value of ER can be calculated as ER is reciprocal value of EC. ER sample D, F and B are 19.3–28.8 Wm, 12.6–22.9 Wm 6.8–9.7 Wm, respectively. And if sample saturated with ground water ER for D, F and B are 17.2 Wm, 24 Wm, and 7.5 Wm, respectively. All of the samples that were saturated by fluid aquades-leachate or by groundwater have increases in EC linearly due to the increase of EC_f (Figure 4 and Table 4).

Table 3: The electrical conductivity values of samples B,D and F, after being saturated by aquades-leachatefluids with 12 different levels of TDS concentration.

Fluid (Aquades+leachate)		Electrical Conductivity Sample (Aquades+leachate+soil)		
TDS mg/L	EC_{mud} μS/cm	B μS/cm	D μS/cm	F μS/cm
10	30	1105	437	347
20	70	1027	520	370
50	110	1088	486	358
70	160	1043	575	377
100	210	1100	551	424
150	310	1312	593	436
200	410	1360	687	447
220	450	1462	667	466
250	500	1376	718	509
300	610	1405	769	549
350	710	1473	796	517
200*	410	1333	582	416

*)groundwater

In Equation 1, it shows that EC is a function of the EC value of the electrolytes in the pores, where the density, porosity and CEC values of the samples are the constant magnitude as seen in Figure 4a. The graphic of the change of resistivity values of the sample towards the increase in EC_f (Figure 4b) shows that the slope of the

Table 4: The equation of the graphs of EC value change versus the increase of EC_f value and DEC/DEC_f value.

Sample	Y	R^2	DEC/DEC_f (%)
B	$0.718\,X + 1018$	0.852	71.8
D	$0.492\,X + 4519$	0.917	49.2
F	$0.284\,X + 3405$	0.889	28.4

graphic of samples D and F is higher than of samples B. The slope of the graphic B is also greater than the graphic D and F. It is mean that the measurements of EC in the contaminated soil layers B, are more sensitive compare to the soil layers of D and F.

Comparing the physical properties of soils and results of the experiments (See Table 2 and Figure 4). It can be seen that the value of EC or ER have linear relationship with the clay content but not with CEC. The relationship is the highest the clay content, the highest the EC value, but for ER value, the highest the clay content, the lowest the ER value. This fact shows how important the existing of clay content on the value of EC and or ER measurement.

6 CONCLUSION

Based on the experiments, it reveals that the change of EC value of the contaminated soil is more sensitive on the soil of alluvial depositsthan soil from weathered tuffaceous sandstone-claystone and from weathered andesitic breccia. It means that the increased conductivity of soil saturated leachate, will be higher in the alluvial depositscompared with the weathered tuffaceous clay sandstone and weathered andesitic breccia.

This condition will affect the electric resistivity value of soils during the geoelectrical survey in the field. Different value of resistivity will be measured on the field of leachate contaminated area on different type of soils/rocks. Therefore, the data and results on this research can be used in the field as references to predict the contamination the leachate-saturated soil layer in the study area.
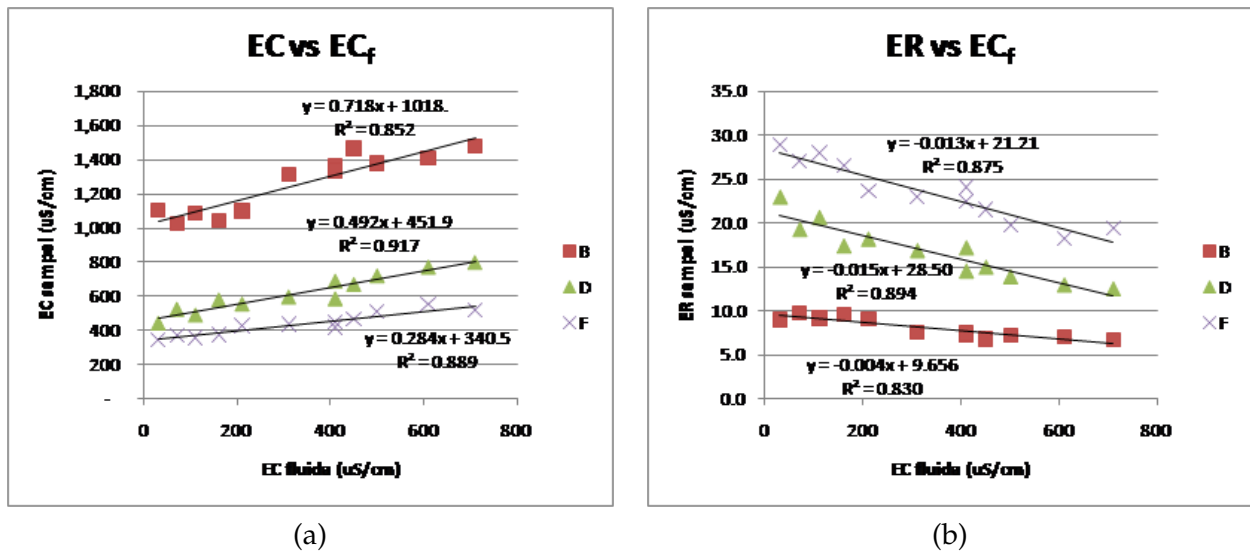
Figure 4: (a).The graphic of the change in EC values towards the increase of ECf.values. (b). The graphics of the change in ER values towards the increase in ECfvalue.

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