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Underground Leachate Distribution Based on Electrical Resistivity Tomography in Piyungan Landfill, Bantul

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Abstract This research was conducted in Piyungan Landfill, this research aims to identify areas that experience groundwater pollution and spread direction of leachate to the surrounding area caused by leachate movement, and to develop a leachate management model. This research uses Electrical Resistivity Tomography (ERT) survey in order to identify the distribution of electrical resistivity in polluted areas. The results show that groundwater contamination has occurred in the research area, as indicated by very low electrical resistivity in aquifer zone, i.e. 3-9 Ωm. Such low electrical resistivity is caused by increased ions in groundwater as the results of leachate migrating downward into groundwater. The increased ions will trigger an increase in electrical conductivity (EC), i.e. up to 1,284 μmhos/cm, and a decline in electrical resistivity. The leachate spreads westward and northward at a depth of 6-17 m (aquifer) with a thickness of pollution between 4-11 m. The recommended landfill management model, emphasizing on leachate movement, include base lining (liner), leachate collection channel, geomembrane cap, and leachate treatment.

Keywords: Piyungan Landfill, Groundwater, Leachate, Electrical Resistivity, ERT

Abstrak *Penelitian ini dilakukan di Tempat Pembuangan Akhir (TPA) sampah Piyungan,dengan tujuan mengidentifikasi daerah yang mengalami pencemaran airtanah dan arah persebaran yang diakibatkan oleh pergerakan lindi, serta membuat model pengelolaan air lindi. Metode yang digunakan dalam penelitian ini yaitu survei electrical resistivity tomography (ERT). Hasil penelitian menunjukkan bahwa telah terjadi pencemaran terhadap airtanah ditandai dengan adanya nilai resistivitas yang sangat rendah di zona akuifer antara 3-9 Ωm. Rendahnya nilai resistivitas ini disebabkan oleh adanya peningkatan ion-ion dalam airtanah yang disebabkan masuknya air lindi ke dalam airtanah. Meningkatnya ion-ion ini akan memicu terjadinya peningkatan daya hantar listrik (DHL) hingga mencapai 1284 μmhos/cm dan menurunkan tingkat resistivitas. Pola penyebaran air lindi adalah ke barat dan utara pada kedalaman akuifer 6-17 meter, dengan ketebalan pencemaran antara 4-11 meter. Model pengelolaan yang terkait dengan pergerakan air lindi dilakukan dengan membuat pelapisan dasar, membuat saluran lindi, melakukan penutupan akhir menggunakan geomembran dan pengolahan lindi.*

Kata kunci: *TPA Piyungan, Airtanah, Lindi, Resistivity,ERT*

1.Introduction

Groundwater flow is a media that has a continuous influence on the surrounding underground environment. Poor and polluted water quality affects the environment negatively. Leachate fuses into groundwater, flowing from one place to another, in order to erase the energy difference between leachate and groundwater. It is found at the bottom of landfill. It seeps through the under lying soil layers. When it seeps through them, many chemical and biological elements that iniatially present in it will be released into the surrounding soil layers through filtration and absorption whose rates depend on the characteristics of the soil. In order to identify areas that experience leachate-contaminated groundwater, this research uses Electrical Resistivity Tomography [Cyril Chibueze Okpoli, 2013].

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One of many factors that frequently cause problems in landfills is leachate, which is alarmingly mobilized into soil layers and aquifer layers. Piyungan Landfill is constructed to accommodate the disposal of wastes from Yogyakarta City, Sleman Regency, and Bantul Regency. The overland flow that passes through landfills and potentially dissolves organic and anorganic materials in a high concentration is referred to as leachate.

The most likely emerging environmental problem is leachate migration from landfill to soil layer and groundwater. Leachate is a liquid waste produced by water flowing from external sources into the piles of waste, which then rinses and dissolves the materials inside the piles; therefore, leachate has varied organic and inorganic pollutant content. When rainwater comes into direct contact with waste, most of its water content converts to runoff and experiences evapotranspiration. The remaining water infiltrates into a pile of wastes. Leachate occurs when the capacity of waste materials to retain water (field capacity) is exceeded.

Leachate is a liquid material that has a high concentration of organic contents originating in landfill through which rainwater passes. Aside from the high organic contents, the environmentally harmful nature of leachate is also caused by the presence of metallic substances (e.g., Cr+6) [Irhamni et al.,2017]. A poor treatment leads to the infiltration of leachate into the ground and groundwater pollution in the surrounding area. Leachate is a potential problem because it spreads both laterally and vertically depending on the characteristics of the surrounding materials. The quantity (discharge) and quality of leachate fluctuate significantly because they depend on rainfall and the character of waste materials. The relationship between the amount of rainwater and the discharge of leachate is necessary to understand in order to design the capacity of leachate treatment facility as well as the pollutant load of related leachate.

2.The Methods

The Electrical Resistivity Tomography (ERT) method in this research applies Wanner Array electrode to obtain primary data from direct measurement at the field [Oladapo et al., 2013]. It firstly determines five measuring points, which are located on the north, west, east, and center of the landfill. The measuring points provide information on areas with the greatest and smallest pollutant anomaly by interpreting the difference of electrical resistivity levels acquired from geo-electrical sounding [G. Tamma Rao et al.,2013].

The electrical resistivity of clean water is between 10-100 ohm-m [Loke, 2000], which is the base value for determining which point has the greatest or the smallest pollutant anomaly and for identifying the spread direction of leachate. The tools used in this research are GPS Garmin Vista, compass, roll-up tape measure, and ERT Geoelectric Instrument. ERT is utilized for assessing the layers of materials beneath the land surface based on the characters of their electrical resistivity [Telford et al., 2004].

Electrical resistivity (ρ) is based on electrical current (I) and electrical potential difference (V), which are obtained from direct measurement at the field [Okan Evans Onojasun, 2015]. Electrical current and electrical potential difference are acquired through injecting electrical current underground using pairs of current electrodes (C1, C2) and potential electrodes (P1, P2) [Loke, 2012; Vincent Bichet, Elise Grisey, Lotfi Aleya, 2016].

Data Acquisition

Electrical current is injected through a set of electrodes arranged in Dipol-Dipole configuration [Loke, 2000] (Figure 2). Electrical current flows through a circuit, as illustrated in Figure 2. Current electrode pairs (C1, C2) are placed in a wider distance than potential electrode pairs (P1, P2). The distance between the current electrode pairs (AB or L) is wider in order to measure the electrical resistivity of deeper materials. When electrical potential difference becomes difficult to measure, the sensitivity of the measuring instrument decreases; hence, the distance between potential electrode pairs (MN or a) has to be widened. The electrical current and electrical potential difference for every distance formed between current electrodes and potential electrodes is observed in order to calculate the pseudo-electrical resistivity of the materials of the research area. Data acquisition is conducted at five

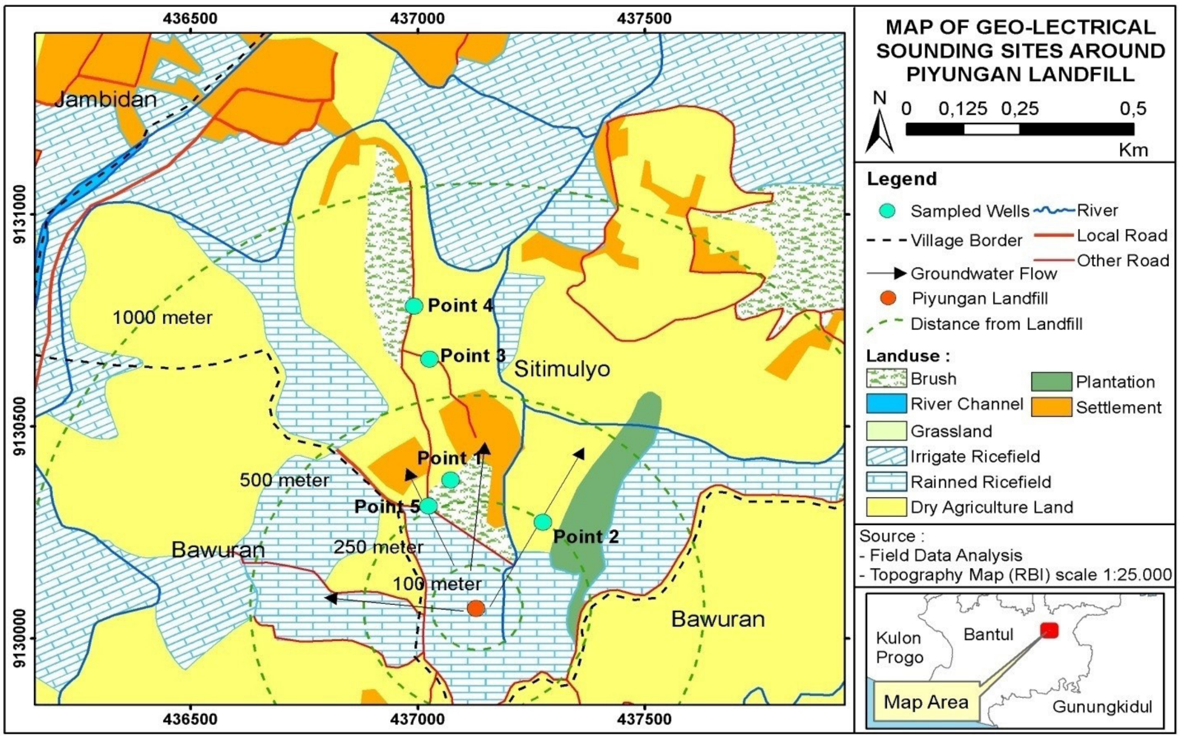

Figure 1. The location of geo-electrical sounding

measuring points throughout Piyungan Landfill. The reasons location reasons are the location should be open and not close to the power line,the length and width of the location should be sufficient for the span of the cable geoelectric survey,the ground surface is not covered by cement or asphalt as it will complicate when electrode insertion, there are no puddles as they may endanger safety,location does not endanger the survey, e.g. areas prone to landslides or very cliffs and the location is not a funeral area. These points are distributed evenly in all under lying geological Formations in the research area is a Semilir Formation composed of rocks consisting of breccias between breccia, breccia tuff, tuff, tuff andesite and tuff dacite and tuff in clay [Rahardjo, et al, 1995 in Sismanto, 2004].

Data Processing

Data acquisition process results in electrical current (I) and electrical potential difference (V) [Lowrie,W, 2014; Eugeniusz Koda et.al, 2017]. However, data processing requires pseudo-electrical resistivity instead of these two data. Pseudo-electrical resistivity (ρa) is calculated based on electrical current and electrical potential difference using the following equations:

R = , (1.1)

ρa = , (1.2)

ρa = . (1.3)

In inverse modeling technique, the inversion process of pseudo-electrical resistivity is conducted using Res2DINV in computer program. This process aims to convert pseudo-electrical resistivity into the actual electrical resistivity of the materials.[Walid Al-Fares,2014; George Vargemezis et.al, 2015]

Data Analysis Technique

In order to identify the location of leachate accumulation, this research uses quantitative descriptive analysis, i.e. an analysis technique for understanding the distribution of electrical resistivity in polluted areas. Every material has its own range of electrical resistivity. A lower electrical resistivity than the inherent range of related materials indicates the presence of leachate [Umar Hamzah, Mark Jeeva and Nur Atikah Mohd Ali, 2014]. For example, a groundwater aquifer (freshwater) with electrical resistivity between 10-100 Ω m will present a reading of lower than 10 Ω m if it is polluted [Loke,2000]. Identifying the spread direction of leachate is based on the electrical resistivity pseudo-section and three-dimensional model that are correlated with hydrologic and geologic data. The pseudo-section provides information on both lateral and vertical distribution of electrical resistivity. The distribution is presented in a log data model in order to create a three-dimensional model for either electrical resistivity or material/lithology. The three-dimensional model that has been correlated with hydrologic and geologic data shows the spread direction of the leachate. Laboratory analysis on groundwater quality aims to validate the ERT survey result, which is a quantitative descriptive analysis, with the Regulation of the Ministry of Health No. 492/MenKes/Per/IV/2010 on the Requisite of Drinking Water Quality as reference.

3.Results and Discussion

The ERT measurement results show that the distribution of electrical resistivity along the sounding line is between 0.5-800 Ωm. The analysis results of geo-electrical sounding data in the research area show an indication of pollution because leachate in Piyungan Landfill seeps through intermittent river system. The intermittent river makes leachate-contaminated water absorbable by the underlying soil through infiltration process, the measurements of leachate in this place show the value 22,565 (μS/cm). This process, then, slowly triggers percolation, i.e., the vertical flow of fluids or liquid materials into groundwater system. The contamination is indicated by very low electrical resistivity in aquifer zone, i.e., 3-9 Ωm. According to Loke [2000], the value of groundwater resistivity does not experience pollution that is 10-100 Ω meters, so it is suspected that this groundwater has been polluted due to the movement of leachate water. Results of similar research conducted by Chambers et al., [2006] successfully identified groundwater pollution in the

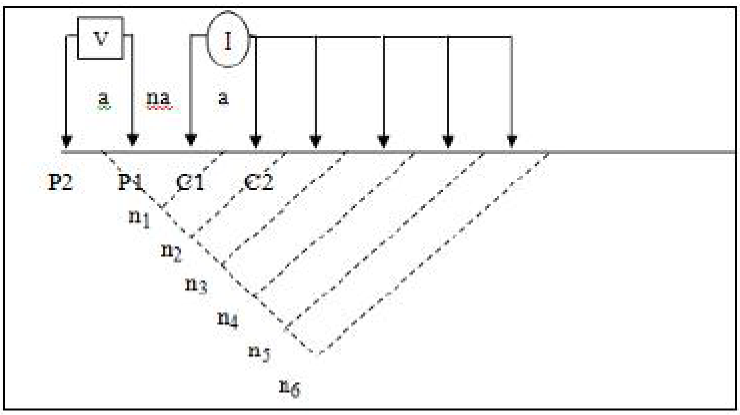

Figure 2. The arrangement of electrodes in Dipol-Dipole configuration forms an electrical circuit [Loke,2000]

Scottish Midland Valley region with a groundwater resistivity value of 2.2-9 Ώ meters.Such low electrical resistivity is caused by increased ions in groundwater as the results of leachate migrating downward into groundwater. The increased ions will trigger an increase in electrical conductivity (EC), i.e. up to 1,284 μmhos/cm, and a decline in electrical resistivity level.

Groundwater pollution in the area is found at a depth of 6-17 m with a thickness of 4-11 m. The distribution and interpretation of electrical resistivity in this zone are presented in Figure 3.

The shape and plume of leachate distribution depend on the concentration of pollutant and the type of groundwater flow. Contaminants with high concentration and fast groundwater flow result in a big and extensive plume. The model shows the three-dimensional topography of the research area, which describes groundwater flow. Based on the three-dimensional model of the distribution of electrical conductivity, the obtained shape and plume are presented in Figure 4. According to the three-dimensional model (Fance model) resulted from ERT survey at G1 and G2 with intersecting lines, the spread direction of leachate is indicated by low electrical resistivity, as presented in Figure 4.

Figure 4 shows that the lithology of Piyungan Landfill consists of either dry or saturated clay, a mix of clay and sand/sandy, and hard rocks at the base. The materials are vertically distributed from soil surface down to 1.5 m in depth. Meanwhile, soil surface with dry clay has an electrical resistivity of 8-20 Ωm with vertical distribution from soil surface to 4 m deep. Beneath this material, there is a mix of clay and sand with electrical resistivity between 20-200 Ωm. It is the primary material and the major composing material of aquifer in the research area. Its thickness is more than 20 m. Meanwhile, the aquifer layers in the area contain sandy clay, which is found at a depth of 6 m from soil surface. The thickness of aquifer along the sounding line is between 14 m and more than 17 m. The last layer at the bottom of the resistivity section has an electrical resistivity of 1,000-8,000 Ωm, which indicates the presence of breccia as the underlying impermeable layer because the study area is located on sediments of young Merapi that lies on Semilir Formation. Semilir Formation is made up from tuff, pumice breccias, tufaceous sandstone, and shale.

Figure 5 shows that the movement of leachate

Table 1. The Electrical Conductivity (EC) in around location

Sample	EC (μmhos/cm)
Point 1	1164
Point 2	1160
Point 3	1284
Point 4	1068
Point 5	982

Source: Direct measurement, 2016

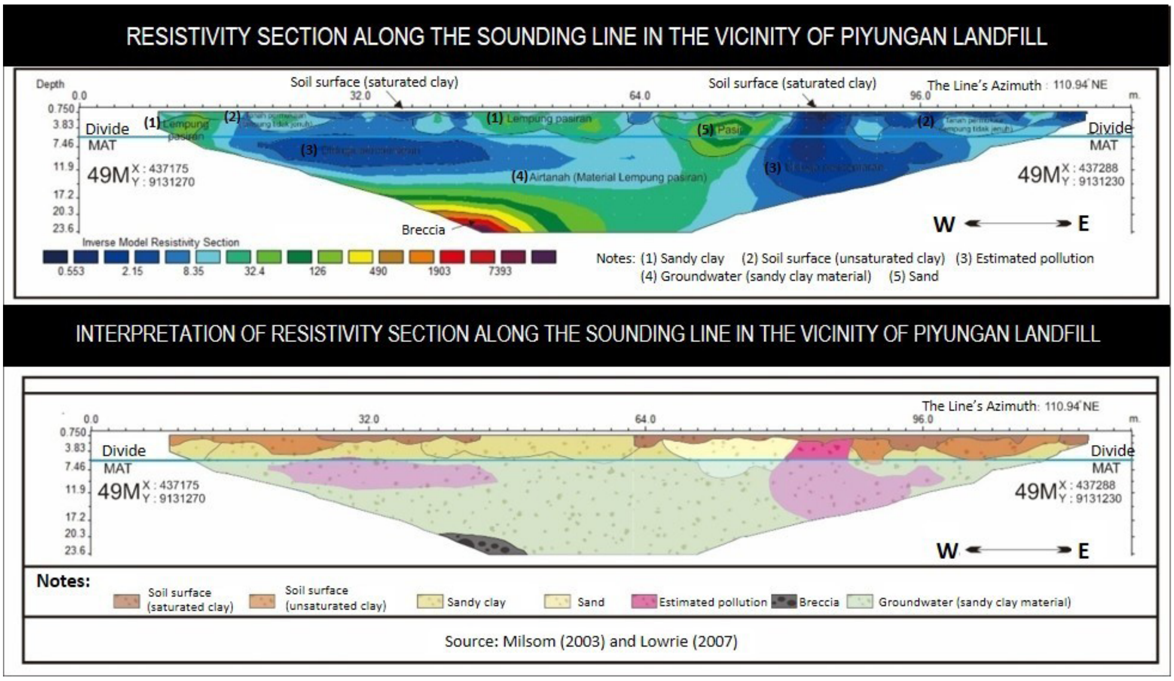

Figure 3. Resistivity section and interpretation result along the sounding line around Piyungan Landfill

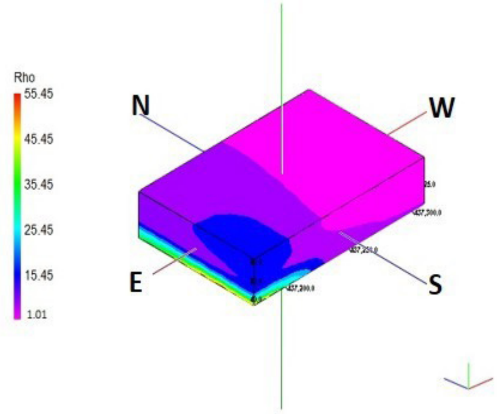

Figure 4.The three-dimensional pattern of leachate

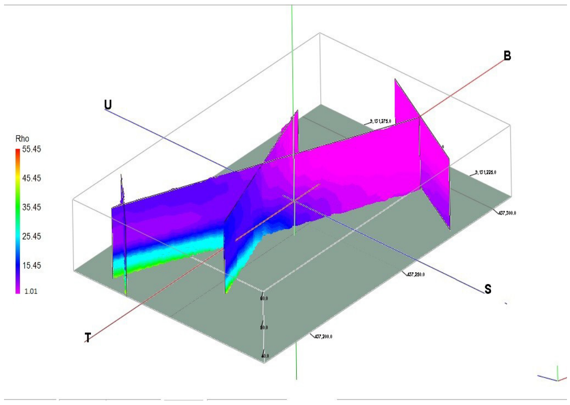

Figure 5.The three-dimensional spread direction of leachate

follows the direction of groundwater movement, which is controlled or influenced by the direction of rock layers. The rock layers around Piyungan Landfill have a strike of 900-1050 and a dip of 50-100. The direction of the rock layers show that groundwater in the area tends to flow westward and northward. Therefore, the leachate in the area flows westward and northward as well, following the direction of groundwater flow. The depth of groundwater level in the stratigraphic level is 5.4 m at the east end and 6 m at the west end. The westward and northward groundwater flows tend to cause leachate that seeps into the groundwater system to flow westward and northward. The cause of groundwater pollution in the research area is poor leachate treatment. Leachate that comes from a pile of wastes stored in landfill requires a proper treatment that can reduce its harmful contents. Ithas to go through a proper treatment process before its disposal. A properly treated leachate will not introduce any pollutants when it seeps into groundwater. Immediate improvement of leachate treatment becomes necessary in order to prevent a wider groundwater pollution.

The landfill management model, basing on leachate movement and groundwater system vulnerability,is designed as follows:

Base Lining (Liner)

Infilling requires a base lining system that aims to reduce the mobility of leachate into groundwater. An effective liner prevents pollutants from migrating to the environment, especially groundwater. However, there is empirically no 100% efficient liner system. The discharge of leachate is inevitable, implying the need of leachate collection channel aside from liner system. Therefore, the bottom of landfill has to be sealed with layers of liner materials to prevent leachate from migrating to outside of the landfill and equipped with leachate collection channel. The liner is made of natural materials (e.g., clay, bentonite) or synthetic materials. It may comprise one material (single) or a combination between natural and synthetic materials, commonly referred to as geocomposite, depending on the necessary functions.

The layer formations and the types of liner materials vary according to the characteristics of solid waste piled on to the landfill. R.Kerry Rowe, F.ASCE et al.,2010 recommends that applying single liner system with clay as its material is sufficient for city waste. The recommended base lining is geosynthetic or known as flexible membrane liner (FML) [R.Kerry Rowe, F.ASCE et al., 2010]. The commonly used geosyntheticfor base lining is Geotextile as filter, Geonet as drainage channel, and Geomembrane and geocomposite as buffer layer. Geomembrane, as an impermeable layer, is a geosynthetic made of impermeable polymer. The best polymer is high-density polyethylene (HDPE) that is resistant to chemical reactions occurring in B3 waste. The scheme of double liner system between FML and compacted soil is presented in Figure 6.

Leachate Collection Channel

Leachate collection system is recommended to have holed pipes located inside the rock-coated channels. In addition, it requires coated channels that contain hollow river stones (N.I. Thusyanthan, S.P.G. Madabhushi, S. Singh,2007). The facilities required for pipe-equipped leachate collection channels are as follows:

Terraced Slope

In order to prevent leachate from accumulating at the bottom of landfill, the base of landfill is transformed into terraces with certain slope (1-5%) that allows leachate to flow into collection channels (0.5-1%). In order to make leachate flow into collection or re-circulation unit, every collection channel is equipped with holed pipes. The maximum slope and length of collection channels are designed based on the capacity of collection channel facility. In order to assess this capacity, the research uses Manning's equation.

Piped Bottom

The bottom of landfill is divided into several

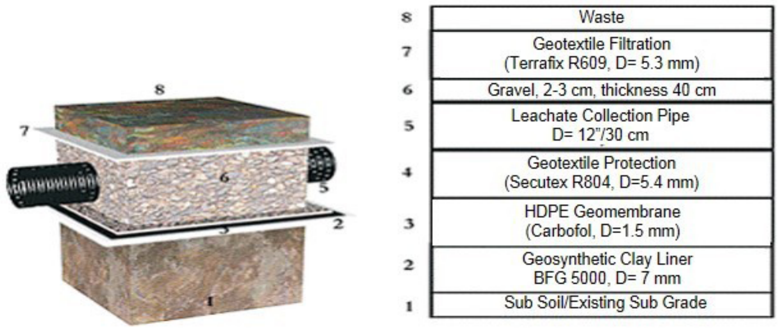

Figure 6.The structure of base lining (liner) system [R.Kerry Rowe, F.ASCE et al.,2010]

rectangles with clay divides. The width of the divide depends on the width of the cells. Leachate collection pipes are placed parallel to the length of cells and directly on geomembrane.

Final Cap

The final cap of landfill consists of several parts. The upper part is soil that functions as protection and plant-growing medium (top soil). When soil in the area does not accord to the requisites, it needs an improvement, i.e. by mixing or replacing it with soils from other areas. The thickness of top soil is 60 cm. The layer beneath it functions as drainage system, which drains as much precipitation as possible so that rainwater does not seep into the layer beneath it. The materials used for composing this layer are porous, e.g., sand, gravels, and synthetic materials like geonet. The thickness of this layer is around 30 cm. The second part is leachate-retaining layer, which is commonly composed of geocomposite (geomembrane and compacted clay). The thickness of geomembrane is recommended to be more than 2.5 mm, while the thickness of clay is more than 50 cm. Beneath this layer is the gas ventilation system, which is a requisite for city waste treatment because most of city waste is organic matters that decompose biologically. In aerobic condition, the resultant gas is mainly carbon dioxide and methane. Therefore, this biogas can be utilized as an alternative source of energy. The layer of gas ventilation system consists of porous medium like sand/gravel or pipe system. The lowest part of the final cap is subgrade layer that functions to increase the stability of the surface of landfill. Furthermore, it helps to form a necessary slope for accelerating lateral drainage and reducing hydraulic level. Its thickness is 30 cm. Aside from this final cap, reducing the amount of overland flow that enters landfill involves slope arrangement, equipped with surface drainage and sowing.

Leachate Treatment

Leachate contains the same composition of liquid domestic waste, but the concentration of its organic matters is higher than a pile of domestic waste, as indicated by the high BOD5 level of leachate, i.e. around 2,000-30,000. Leachate treatment system is divided into two steps, namely secondary treatment and tertiary treatment. The secondary treatment consists of stabilization pond (facultative and anaerobic) and aeration pond.

4.Conclusion

According to the aforementioned results, the research conclusion is as follows data analysis of geo-electrical sounding in the research area results in indications of pollution. The indications are potentially caused by the presence of leachate originating in Piyungan landill that seeps into intermittent river system, the measurements of leachate in this place show the value 22,565 (μS/cm). The intermittent river makes leachate-contaminated water absorbable by the underlying soil through infiltration process. This process, then, slowly triggers percolation, i.e. the vertical flow of fluids or liquid materials into groundwater system. Such pollution is indicated by very low electrical resistivity (3-9 Ωm) in aquifer zone.

The leachate spreads westwardat a depth of 6-17 m with a thickness between 4-11 m. The spread direction of leachate in this area is westward, following the direction of groundwater flow. The westward and northward groundwater flows tend to cause leachate that seeps into groundwater system to flow westward and northward as well.

The landfill management model, basing on leachate movement against groundwater system vulnerability, consists of base lining (liner), leachate collection channel, final cap composed of geomembrane, and leachate treatment.

5.Acknowledgments

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