Analysis of Groundwater Contamination Level in Residential Areas Around Cipayung Landfill Using Ground Penetrating Radar

Maryadi Maryadi¹, Supriyanto¹, Fira Mariah Sausan Champai¹, I Nyoman Triananda¹, and Desi Nur Fitriana²

¹Program Studi Geoﬁsika, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Indonesia, Depok City, West Java Province, 16424
²Program Studi Geologi, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Indonesia, Depok City, West Java Province, 16424

*maryadi@sci.ui.ac.id

Abstract. Cipayung Landﬁll is the last disposal location of waste processing in Depok City, West Java. In a day, approximately 800 tons of garbage is dumped, which is then processed by being burned and left to decompose for inorganic and organic waste, respectively. However, poor waste management has resulted in an accumulation that continues to this day. This creates a variety of problems, especially leachate contamination that inﬁltrates to the groundwater, ﬂows along and threaten the health of residents who live in the vicinity. This liquid contains toxins and hazardous materials. Therefore, it is essential for residents to know the level of contamination occurred and its dispersion, along with actions that must be taken to reduce the impact of pollution. In this study, we map the distribution of contaminated groundwater using the geophysical ground penetrating radar method, together with the chemical analysis of water samples. Ground penetrating radar has been useful to detect the change of permittivity and conductivity of layers below the surface. It is possible to mark off the contaminated groundwater to the fresh one indicated from an extensive amount of electromagnetic signal attenuation. This study suggests that there is contamination occurred in radius up to hundreds of meters from the landﬁll site. The result of this community-based research gives an advisable policy regarding waste management and groundwater usage in this area.

1. Introduction

Landﬁll is a land that is built for the disposal of solid waste originating from cities both households and industries [1] which has reached the ﬁnal stage in waste management starting from the ﬁrst time the waste is produced, collected, transported, managed and disposed of. According to Government Regulation of the Republic of Indonesia, a landﬁll must have a location that is well isolated so as not to cause a negative inﬂuence on the environment around the landﬁll, especially residential areas (more than 1 km from the settlement).

Cipayung Landﬁll is the ﬁnal disposal site in the waste management stage in Depok City, West Java. The total waste sent to this location reaches approximately 900 - 1000 tons each day [2]. The rubbish is then burned (for inorganic waste) or left to rot (for organic waste). As a result of poor waste management
system, the accumulation of waste continues to occur until now reaching 23 m, even though the height limit of the garbage pile is 20 m [3]. This raises a variety of problems, especially those related to cleanliness and health of residents who live around the landfill site. Leachate from the garbage pile is mixed with Pesanggrahan river water which is located on the east side of the landfill, which then pollutes the river water [4]. Groundwater used by residents around the landfill might be contaminated by harmful substances from the leachate. The situation could get worse both in terms of the level of contamination and in terms of distribution. This problem leads to a decline in the health of residents due to the low level of water cleanliness in their area.

One of the causes of pollution around landfills is leachate. Leachate, or wastewater, is a liquid that results from mixing surface water with substances produced from decomposed waste [5]. Leachate can seep into the surface of the soil, then contaminate the ground water underneath. Underground water flow allows the spread of contaminants to other areas around the landfill. Therefore, it is feared that people consciously or unconsciously have used contaminated water for their daily needs. Previously in 2012 a geophysical investigation was carried out using DC resistivity and induced polarization methods in this area, to map the depths of aquifers that were indicated to have been polluted by leachate [6]. In the study it was found that leachate seepage reached 80 to 120 m from the outer side of the Cipayung landfill with a depth of about 30 m.

Therefore, it is important for residents to know the level of pollution of water resources in their area, know the level of safety or danger, along with the actions that must be taken to reduce the negative impact of the situation. In this study, we are attempting to map the distribution of contaminated groundwater through direct surveys through groundwater content testing using a water test kit and indirect estimation based on geophysical surveys using the ground-penetrating radar method. Ground-penetrating radar method was chosen because it has been proven and can be used to detect contamination of groundwater thanks to its sensitivity to any conductive material below the surface in which related to the contaminants [7-11].

2. Study Area

Cipayung District, located in the southern part of Depok City, West Java Province, has an area of 11.63 km which stretches in low-lying and slightly hilly areas with an elevation of 70 to 100 m above sea level (Badan Pusat Statistik (BPS), 2017). Cipayung Landfill itself is located on the western edge of Cipayung Subdistrict as shown in Figure 1. The subdistrict itself has an area of almost 269 hectares, of which 183.3 hectares are settlements for 9482 households divided into 11 neighborhoods (BPS, 2017).

Figure 1. Location of Cipayung Landfill on Cipayung Subdistrict map (modified from BPS, 2017)
The area of the Cipayung landfill is widening from around 4 hectares in the initial year of operation to 20 hectares in 2018 [13] with a height reaching 20 meters. Various problems began to arise due to the prolonged accumulation of waste and management systems that have not been maximized. In reports in various media, residents complained of the increasingly bad odors that flow with the air, an increasingly dirty and polluted environment, lack of clean water for daily necessities, to health problems such as skin diseases and respiratory infections [14]. In order to understand the water contamination level and its distribution, both direct and indirect assessment were performed. The former was done using an instrument for groundwater quality tests while the latter was carried out using ground penetration radar.

3. Methodology

A. Ground Penetrating Radar Method

Ground Penetrating Radar (GPR) is a tool that can be used to detect objects that are in the soil at a certain depth. The term GPR refers to a non-destructive geophysical method that uses electromagnetic techniques to record subsurface characteristics. GPR uses electromagnetic wave vectors in the range of radio frequencies that are transmitted into the ground. The level of depth that can be achieved depends on the frequency used. For surveys at far depths, lower frequency GPR is preferred as used in this research. This frequency has the possibility to detect the presence of underground water sources, as well as study the soil layers or geological basement.

In the process, the GPR signal will be fired by the transmitter which is then reflected by the surface layer of soil or rock in the ground before the signal is finally received by the receiver embedded in GPR system. The signals are transmitted into the ground in a very short duration (in the order of 10 seconds) and are propagating until it meets the boundary between two different layers. Some of the waves are reflected, while the remaining energy is transmitted into the next layer. The amplitude of the reflected waveform recorded in the receiver is associated with the wave energy itself. The percentage of the reflected wave (R) depends on the relative dielectric permittivity difference between the host (RDP$_1$) and the reflector material (RDP$_2$) as follows,

\[ R = \frac{\text{RDP}_1 - \text{RDP}_2}{\text{RDP}_2} \]
so that when the wave progressed from soil (RDP = 9) to water table or water-saturated soil (RDP > 23), strong reflected signal could be recorded.

The transmitted wave, to some extent, will not be able to penetrate any deeper as it runs out of energy due to signal attenuation \[15\]. Electromagnetic signal attenuation \((\alpha)\) is highly affected by electrical conductivity of the invaded material as formulated as follows,

\[
\alpha = \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{\sigma}{2\sqrt{RDP}}
\]  

(2)

where \(\sigma\) represents electrical conductivity of material, while \(\mu_0\) and \(\varepsilon_0\) are magnetic permeability and permittivity of vacuum, respectively. Ground water that has been polluted by waste is generally characterized by an increase in conductivity caused by the presence of Fe and Pb contaminants in the water, this can be a useful parameter for detecting areas that experience water pollution using the GPR method. It is expected that surveys will be able illustrates the contrast between polluted water and water that is still in good condition by means of their reflection amplitudes and signal attenuation level.

In this GPR survey process we used electromagnetic waves with a frequency of 50 Mhz with a maximum penetration of 40 m, because the location of the water table is estimated to be located at a depth of 10-30 m. Then the data collection was carried out in 9 lines measuring 100 - 250 m spread over three zone based on its relative distance to the landfill, to find out the extent of the distribution of water contamination. The GPR profiles in the study area are shown in Figure 3. After GPR data is obtained, the data is then processed in 2-D to get a picture related to the distribution of ground water pollution that occurs.

Figure 3. The GPR acquisition profiles (solid lines with arrow) are divided into 3 zones (separated by dashed lines) in respect to each relative distance to the landfill. Arrow represents measurement direction.
B. Water Quality Analysis

Groundwater quality test was carried out against 25 water samples collected from the residents’ homes that were selected based on their zones. The collected samples were tested using an AMTAST water test kit to measure the water quality parameter test and obtain the value of TDS (Total Dissolve Solid) to determine the chemical mass of solids dissolved in the water. The higher value of TDS in water means it requires more processing for the water to be drinkable. The next process was determining pH of the water. pH is a measure of how acidic or basic water is. The range goes from 0 to 14, with 7 being neutral, less than 7 indicate acidity and greater than 7 is basic.

The most important parameter in this water quality assessment is conductivity, which can be directly compared to the result of GPR survey. The higher value of conductivity might indicate that the water had been contaminated. Another parameter that was measured is ORP (Oxidation-Reduction Potential) measurement which was done to indicate the level of hygiene in water and to isolate materials that could potentially contaminate the water. These parameters were then taken to determine the quality of groundwater that had been contaminated by waste. By combining the results of all the parameters and methods, an attempt to map the groundwater contamination was accomplished.

4. Results And Discussions

Several physical and chemical parameters from water samples were presented in the distribution maps. Kriging method was used for lateral interpolation of each of the value, since the sample locations are sparsely distributed. The map of conductivity, pH, ORP and TDS are shown in Figure 4.

![Figure 4. Distribution map of groundwater conductivity (cond), pH, ORP, and TDS around Cipayung Landfill, overlying the aerial image of the study area. The dots are the sampling locations.](image-url)
Upper left image in Figure 4 shows that there is an area with high conductivity levels in the south and northeast direction from the landfill, where the conductivity levels can reach up to 300-500 µS/cm. Water that is safe to drink has a level of conductivity around 150 to 500 µS/cm [16]. Despite the value is being under 500 µS/cm, does not necessarily mean that the water is safe to drink. Further studies and supervision are still needed, by measuring other parameters to finally signify whether the groundwater of the area is safe for everyday use or not. The other areas are, however, not having the same condition, where the conductivity values are considerably low.

The pH level of drinkable water should be neutral between 6.5 to 8.5, as water with acidic properties would dissolve metallic materials in the water and therefore contaminating it. Upper left image in Figure 4 shows that the distribution of groundwater pH near the Cipayung landfill is varying from 8 to 9, which indicates that the water is considered basic and, therefore, unsafe to drink. Whereas in the western areas, the groundwater is considered neutral as the pH is differing around 7. There are also several anomalies in the middle of the area where high pH zones are encountered. This is probably occurred because this area was presumably a swamp that could isolate the contaminated water.

In the lower left area of Figure 4, the ORP distribution map is presented. The ORP of drinking water should be around 250 mV. The lower the value of ORP in an area indicates that the water is contaminated and therefore unsafe to use [17]. Fig. 4 clearly shows that some areas near the Cipayung landfill have low ORP values, no higher than 250 mV. This result suggests that that the groundwater in these areas need to be supervised as they are most likely contaminated.

Total Dissolve Solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as follows: excellent, less than 300 mg/litre; good, between 300 and 600 mg/litre; fair, between 600 and 900 mg/litre; poor, between 900 and 1200 mg/litre; and unacceptable, greater than 1200 mg/litre [18]. The TDS values in Fig. 4 are various, in between 60 to 320 mg/L (60 to 320 ppm). The result indicates that there was no indication of water contamination due to hazardous solids in most of the area, which, however, contradicts the other results.

On the other hand, each GPR raw data was processed through filtering, noise removal, and gain control to get a clearer image of the subsurface condition. The results are presented in two-dimensional vertical cross-section up to 40 m depth with varying horizontal distance. Both water quality and GPR data were combined to explain about water contamination level and its distribution. To ease the understanding, the interpretation of the results is divided for each zone.
A. Zone 1

There are 3 GPR profiles in this zone: Profile 4, 5, and 10. Vertical cross-sectional view of GPR results from these profiles and their respective locations are shown in Figure 5. Profile 4 is located in about 320 m from the Cipayung Landfill. Based on the GPR image, a reflection contrast was found at a depth of 7.5 m which is most probably occurred due to the difference in electrical permittivity between the soil and water table. Another important finding is that there are occurrences of signal attenuation zones at a depth of 12.5 to 25 m which are suspected to be caused by the presence of conductive substances in the area. Similar situation is also found in profile 5 which is situated in about 215 m to the southeast from the garbage dump. Line 10, the closest profile to the landfill, is in about 150 m from the main entrance of the city waste dumping site. In this profile, the sign of signal attenuation is very distinct and massive. The conductive anomaly each profile is detected in the deeper part of water table since the density of contaminated water is higher than the unaffected ones.

It is obvious that these results is, to some extent, in agreement with the water quality assessment which conclude that in Zone 1, the conductivity is relatively high. This finding is also consistent with other chemical parameters mapped in Fig. 4. It can thus be suggested that there is some level of groundwater contamination occurred in this zone and further action must be taken.

B. Zone 2

In Zone 2, three GPR profiles are exist (Profile 1, 2, and 9) and the results of GPR survey in this zone are shown in Figure 6. The results of GPR survey in these profiles indicate that there are chances of water impurity in this area. However, this outcome is contrary to the water quality studies (Fig. 4) which have suggested that there is no evidence of water contamination in the same spots. One unanticipated finding is that the signal attenuation is uneven and detected in the relatively shallow depth. A possible explanation for this might be that these conductive sections have no relation with the leachate from the landfill but, instead, the anomaly is found after the existence of an archaic swamp in this area. This interpretation is, however, need to be evaluated further.
FIGURE 6. GPR cross-sectional results from Profile 1, 2, and 9 located in Zone 2. Red circles show the electromagnetic signal attenuation due to the conductive bodies in the subsurface which is probably related to the presence of water contaminants.

C. Zone 3

FIGURE 7. GPR cross-sectional results from Profile 1, 2, and 9 located in Zone 2. Red circles show the electromagnetic signal attenuation due to the conductive bodies in the subsurface which is probably related to the presence of water contaminants.

There are four GPR Profiles measured in Zone 3 (Profile 3, 6, 7, and 8). However, Profile 6 is neglected due to high level of noise which could distort the result and interpretation. The results of GPR survey in this zone are shown in Figure 7. The GPR investigation in this area generally did not detect any evidence for water contamination as this area is quite far away from the garbage dump. These results support the findings from water quality assessment in the same zone. One inconsistency is found
in the result of Profile 3, where the EM signal attenuations are detected in some spot of the cross-section. This rather contradictory result may be due to the presence of past drainage swamps which probably holds conductive substance.

All the results may help us to understand that there are groundwater contaminations occurred in radius up to hundreds of meters from the landfill site as the GPR survey and water analysis conducted in Zone 1 suggest the same conclusion. However, further work is required to confirm the findings in Zone 2 and 3. To develop a clearer picture of water contamination level, more water sample analysis from denser sample location is needed. It would be better if the data is measured in the rainy season. It is also highly suggested that the water sample location should be adjacent to the GPR profiles so that the data comparison and interpretation would be more explicitly explained.

5. Conclusions

This study is set to understand the groundwater contamination level around landfill using GPR and direct water quality assessment. Both methods have found that the occurrence of contamination is happened within a radius of 400 m from the dump, which could affect the civilians living in that area regarding their water consumption. Overall, this study strengthens the idea that ground penetrating radar could be useful for detecting the groundwater table and contamination in terms of its conductivity. Although small number of GPR profiles and water samples did not allow a comprehensive interpretation, this study gives the idea about groundwater assessment using geophysical method, especially GPR. A limitation of this study is that the data was taken in dry season and therefore leachate contamination is minimal. Comparison study carried out rainy season is highly suggested.

Acknowledgments

We acknowledge the Universitas Indonesia as this study is funded through Universitas Indonesia Community Engagement Grant Program number NKB-1372/UN2.R3.1/HKP.05.00/2019. We also thank the government of Cipayung District and Subdistrict for the cooperation during data acquisition processes.

References

1. A. C. Tse and C. I. Adamu, “Assessment of Anthropogenic Influence on Quality Of Groundwater In Hand-Dug Wells In Parts Of Makurdi Metropolis, North Central Nigeria”, Ife Journal of Science 14, pp. 123 - 135 (2012).
2. Windarto, “Kondisi TPA Cipayung Di Depok Kritis” (Suara Karya, June 11, 2019), Accessed on August 23, 2019
3. R. Kisar, “Depok Akui Pengolahan Sampah di TPA Cipayung Buruk” (Media Indonesia, March 4, 2019), Accessed on August 23, 2019.
4. J. Armanto, “Kali Pesanggrahan Diduga Tercemar TPA Cipayung, Pemkot Depok Terancam Dilaporkan” (Indopos, June 11, 2018), Accessed on August 23, 2019.
5. J. Soemirat, Kesehatan Lingkungan (Cetakan Keempat) (Gadjah Mada University Press, Yogyakarta, 2000).
6. Y. S. Arbi, Pemetaan Sebaran Air Lindi di Daerah TPA Depok dengan Menggunakan Metode Resistivity dan IP, Thesis, Universitas Indonesia, 2012.
7. N. S. Wijewardana, L. W. Galagedara and M. I. M. Mowjood, “Assessment of groundwater contamination by landfill leachate with ground penetrating radar” (14th International Conference on Ground Penetrating Radar (GPR), Shanghai, 2012), pp. 728-732.
8. J. J. Daniels, R. Roberts and M. Vendl, “Ground penetrating radar for the detection of liquid contaminants ” (1994) (Journal of Applied Geophysics 33 1995), pp. 195-207.
9. L. Capozzoli, V. Giampaolo, E. Rizzo, M. Votta, P. L. Cucci, M. D. Biase and S. Straface, “Ground Penetrating Radar as A Powerful Tool for The Study and The Monitoring Of Lnapl-Contamination In The Subsoil” (GNGTS, 2012), pp. 60-67.

10. J. L. Porsani, W. M. Filho, V. R. Elis, F. Shimeles, J. C. Dourado and H. P Moura, “The use of GPR and VES in delineating a contamination plume in a landfill site: a case study in SE Brazil”, Journal of Applied Geophysics 55, pp. 199-209 (2004).

11. K. K. Singh, “Application of Ground Penetrating Radar for Hydro-Geological Study”, Journal of Scientific & Industrial Research 65, pp. 160-164 (2006).

12. Badan Pusat Statistik, “Kecamatan Cipayung Dalam Angka, Badan Pusat Statistik (BPS) Kota Depok” (2017) ISBN: 978-602-0925-56-1.

13. B. Arifianto, “Pengelolaan TPA Cipayung Buruk, Warga Gugat Pemkot Depok”. (Kompas, 2018), Accessed on February 20, 2019.

14. I. Sarwindaningrum, “Sampah Tak Terkelola Baik, Warga TPA Cipayung Mengeluh Kian Sengsara”. (Kompas, 2018), Accessed on February 21, 2019.

15. J. J. Daniels, “Ground Penetrating Radar Fundamentals”, Appendix to U.S.EPA, Region V, Ohio, 2000.

16. S. Behar, “Testing the Waters: Chemical and Physical Vital Signs of a River”, VT: River Watch Network, Montpelier, 1997, ISBN 0787234923.

17. T. Bastian and J. Brondum, “Do Traditional Measures of Water Quality in Swimming Pools and Spas Correspond with Beneficial Oxidation Reduction Potential?”, Public Health Rep., 124, pp. 255–261 (2009).

18. W. H. Bruvold and H. J. Ongerth, “Taste quality of mineralized water”, Journal of the American Water Works Association, pp. 61:170 (1969).