Detection of water seepage in lake body using ground penetrating radar method

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Abstract. Ground Penetrating Radar (GPR) is a geophysical method used to identification subsurface condition at a certain depth, using a source of electromagnetic waves in the form of radar. Geoscanners Akula A9000C and Antenna Gecko 60 with 60 MHz antenna frequency were used for data acquisition for this study. Survey data was conducted as many four lines, located on the south and east sides of the lake, with the distance range from 0 to 145 m. This paper reports basic signal processing GPR data using matGPR for the analysis and modelling. The results show that there is anomaly which is suspected as water seepage appear on depth of 2 m. On the lengthwise line, anomalies show on a distance of 20 m and 35 m (line A) and 125 m and 135 m (line B), while on the crosswise line anomalies show on a distance of 35 m and 50 m (line C), 25 m and 95 m (line D). Water seepage can be found in this area as it is formed by alluvial depositional environment, remembering that the characteristics and rocks lithology in this area can stimulate water infiltration process. Water seepage will cause erosion of the lake and can collapse the lake’s structure.

1. Introduction

Jakarta is an area with active land development as well as a risk of disasters such as landslides and floods. The geological conditions of Jakarta, which are generally alluvial deposits and young geological formations, are the highest causes of land subsidence. Geologically, the entire plain consists of Pleistocene deposits which are located ± 50 m below the ground surface. The southern part consists of an alluvial layer, while the coastal lowlands stretch inland for about 10 km. Underneath there is a layer of older sediment that is not visible on the soil surface because it is completely covered by alluvium deposits. At the Late Miocene, clay-sand deposits were deposited in the study area which had become a transitional and coastal area. At the Pliocene, the magmatic arc moved towards the middle of Java, and then the West Java lifted [7]. In this study location, the sediments in the southern part consist of alluvial deposits, which are covered by floodplain clay. And in the north, the sediments consist mainly of marine clay and organic clay from mangrove swamp deposits and contain shell residues of coastal deposits [9].

Jakarta is an urban area which has experienced rapid urbanization. Therefore, it is necessary to pay attention to the need for clean water by finding several aquifers as water supply. In Shaad's research (2018), it is said that in Jakarta the water sources are mostly shallow groundwater aquifer. With the coupling method which has clay to silt lithology. The increased urban development also can introduce
several environmental problems, one of them is land subsidence. It caused by the lithology, alluvial deposits, that can be supported the ground water infiltration [8]. Budiono, et al. (2012) did the research of investigating subsidence at North coast Jakarta using the GPR. In this study, it was found that the research area has alluvium geology with the majority of clay lithology with different levels of plasticity. One of the reasons why the settlement occurred in the north of Jakarta coast is the lithology that has very soft marine clay sediments which have shallow ground water table. The decrease in soil surface in Jakarta was caused by the decreased pore pressure in the sediment layer. The disturbance in the sand sediment layer due to reduced pore pressure in the sand can trigger a more dynamic sea floor subsidence and cause the waters of Jakarta Bay much deeper [2] and In Waspodo's research (2011), lithological estimates obtained by the resistivity method of the East Jakarta area (to be precise, Cimanggis Depok) include clay, sand, and a mixture of sand and clay which has the potential to have groundwater sources.

Because of Jakarta's geographical setting, this area has been flooding for hundreds of years [5]. So that existence of the lake or reservoir is needed for area infiltration of rainfall and the risk of flooding will decrease [16]. The research location in this paper is one of the lake or reservoir in Jakarta and used as a recreation area for the people. Water seepage in the lake or reservoir which its lithology is poor soil cannot be avoided, but uncontrolled water seepage will excess pore pressure and weaken the soil mass as a foundation. So that it causes internal erosion of the lake or reservoir [4], which is dangerous for the people. Nondestructive geophysical method that uses electromagnetic waves radiation, Ground Penetrating Radar method [3], can be conducted for identify water seepage and erosion [12] which is most effective in electrically resistive materials (sediments) after the research which has been carried out in hundreds of sites [6], so that GPR method is suitable for this paper which is the site located at alluvial deposits.

Ground Penetrating Radar (GPR) is a geophysical method used to identification subsurface condition at a certain depth, using a source of electromagnetic waves in the form of radar, usually with a frequency range of 1 to 1000 MHz. This method is generally used to map structures and objects that are buried or are under the surface. The parameters of the GPR method are frequency and wavelength [15]. The basic principle of the GPR method is to emit high-frequency radio waves below the surface through a transmitter. When electromagnetic waves propagate, the energy generated from these waves penetrates into the earth's surface. The deeper the energy penetration of the wave gets, the energy attenuates and converts into heat energy. In addition, the greater the distance, the energy will decrease, and eventually disappear at a certain depth. Thus, at the lower boundary of the layer surface there can be no positive exponential. The penetration ability of GPR depends on the signal frequency, the radiation efficiency of the antenna and the dielectric properties of the material. Radar signal with high frequency will produce high resolution with limited penetration depth, whereas low frequency will result in greater depth penetration but low resolution. The choice of the frequency used depends on the target size, target depth, and the maximum depth that can be reached [10].

2. Methodology
This paper aims to maintain the structure of the lake body by identifying the potential of water seepage in subsurface conditions that used Ground Penetrating Radar method. The location of measurement is located in Penggilingan, East Jakarta, Indonesia. The measurements were using Geoscanners Akula A9000C and Antenna Gecko 60 with an antenna frequency of 60 MHz. Survey data was conducted in 4 (four) lines, located on the south and east sides of the lake with each distance is 0-145 m. The measurement track is shown in the Figure. 1(a) and the steps can be seen in Figure. 1(b).
The data obtained is data recorded on a computer screen that describes the subsurface vertical section called the georadar recording profile. After obtaining the data, the GPR data processing is carried out using matGPR software which is run using MATLAB. There are several steps in processing data, including: Input Data; Adjust signal position, is used to delete the signal so that the signal can be in the time zero position; DEWOW, used to remove DC components and low frequency noise; Mean Filter, is a filter that is used to refine the b-scan cross-sectional appearance. The greater the time axis and scan axis values, the smoother the display will be and can eliminate ringing. However, if the display is too subtle it can eliminate the target anomaly. So that in determining the value of the time axis and scan axis, it is necessary to pay attention and be adjusted properly; Inverse Amplitude Decay, is a function that can amplify the signal; Remove Global Background, is a function to eliminate any horizontal banding (noise that has the same amplitude from the beginning to the end of the same path); Karhunen-Loeve Filter, is a filter to remove noise and increase the lateral level by reconstructing the signal based on the number of eigenvectors. This filter will produce reconstructed data or residuals. In reconstructed data, there was a very large increase in lateral coherence so that the b-scan display that was initially unique turned lateral, on the other hand, there was an increase in lateral coherence but not too large so that the b-scan shape remained unique; FIR (Finite Impulse Response) Frequency Bandpass, is a filter to remove signals and frequencies that do not match the GPR signal range used in the survey; Create 1D velocity model, is a step to import or export 1D velocity models; and Time to depth conversion, is a section used for convert the travel time vs. distance to depth vs. distance, with assumption that the result has uniform or layered structure [14].

3. Result

The data processing generated images of GPR survey, which are known as radargram. Radargram is a picture of propagation’s electromagnetic waves at different velocity, depending on the material in the subsurface. Radargram of several steps in processing data shown in Figure 2. First, we have to input the raw data of line A (see Figure 2.a), travel time of this data starts from 0 until 1000 ns and the distance range from 0 to 145 m. The second step of basic data processing is to adjust signal position (see Figure 2.b), as we can see that the signal is on time zero position. The third step is dewowing to remove DC components and low frequency noise, but there are no significant changes on the B-scan (see Figure 2.c). The fourth step is mean filtering, the display of radargram is smoother and there is a reduction of the “ringing” effect, but the target anomaly still can be seen (see Figure 2.d). The fifth
step is inverse amplitude decay (see Figure 2.e), the processing generated a greater signal power because this function caused amplitude gain. Based on Figure 2.f, which is a result from the sixth step, removing global background, the horizontal banding is not found. From Figure 2.g, we can see that there are some significant changes. This is a result from the seventh step, which is Karhunen-Loeve filtering. This filtering process generated reconstructed and residual results, but we chose to use residual result because it increased not too large lateral coherence so that it obtained a unique display, while the reconstructed result turned out to be a lateral display. The eighth step is FIR (Finite Impulse Response) Frequency Bandpass filtering, which its result can be seen in Figure 2.h. The data result processed with FIR Frequency Bandpass filtering became clearer than the previous steps that presented amplitude gain. The last step is 1-D time to depth conversion. Data acquisition process used a relatively low antenna frequency 60 MHz. It conducted the GPR data has a better depth penetration than its resolution, so that the radargram showed depths of up to 30 m (see Figure 3).
Figure 2. Result of processing data GPR in line A: (a) raw data, (b) adjust signal position, (c) dewow, (d) mean filter, (e) inverse amplitude decay, (f) remove global background, (g) karhunen-loeve filter, (h) FIR (Finite Impulse Response) bandpass filter, and (i) 1-D time depth correction.

Figure 3. Result of the last processing data, time to depth correction, in: (a) Line A, (b) Line B, (c) Line C, and (d) Line D.
4. Discussion

Result of processing data GPR in the lake body can be interpreted as a four different stratigraphic units, by qualitative interpretation based on its reflection configuration in GPR data. The interpretation is validated with previous research using geoelectrical method [13]. In the previous research that used geoelectrical method, the resistivity value range that divide three different of rock lithology can be known. The structure of lake body formed of sediment deposits and covered on the top layer with top soil. Qualitative interpretation of four stratigraphic units and its thickness can be marked with brown line, blue line, and yellow line.

(a)

(b)
Based on Figure 4., it shows four stratigraphic units. The boundary between the first and second unit marked by the brown line, the boundary between the second and third unit marked by blue line, while the boundary between the third and fourth units marked by the yellow line. According to the figure, the first stratigraphic unit with 0-2 m depth is interpreted as top soil. The second stratigraphic unit with 2-6 m depth is categorized as a continuous parallel reflection configuration and the lithology is interpreted as clay. The third stratigraphic unit with 6-15 m depth is categorized as a continuous hummocky reflection configuration and the lithology is interpreted as sand. And the fourth stratigraphic unit is categorized as a wavy reflection configuration (depth cannot be determined because the lower boundary is not recorded) and the lithology is interpreted as sandy clay. This is supported by previous research that used geoelectrical method with dipole-dipole configuration in line A:

| Stratigraphic Units | Depth (m)   | Resistivity Value (ohm meter) |
|---------------------|-------------|-------------------------------|
| 1                   | 0-1.84      | 20.5-64.1                     |
| 2                   | 1.84-5.89   | 6.54                          |
| 3                   | 5.89-6.82   | 64.1-201                      |
According to Figure 5, anomalies show at a depth of 2-16 m. At a depth of 2-6 m (the second stratigraphic unit) known from the wave response that is less clear because it is influenced by the presence of tree’s roots in this area, and because of roots can absorb water from the soil. Then at a depth of 6-16 m is marked with a darker image. On the crosswise line, anomalies show on a distance of 20 m and 35 m (line A) and 125 m and 135 m (line B), while on the lengthwise line anomalies show on a distance of 35 m and 50 m (line C), 25 m and 95 m (line D). In the previous research that used geoelectrical method with dipole-dipole configuration in line A, anomaly showed in the distance of 7-21 m, 24-30 m, 32-35 m, and 36-38 m. and its depth is 1.84-5.89 m. From the previous research that used geoelectrical method in this area, resistivity value of the anomaly is 0.213-2.89 ohm meter [13]. The detection of anomaly suspected as a water seepage indicates that the rock lithology in the research location has a lower resistivity and water seepage can be found in this area as it is formed by alluvial depositional environment, remembering that the characteristics and rocks lithology in this area can stimulate water infiltration process.
Figure 5. Anomaly in: (a) crosswise line A, (b) crosswise line B, (c) lengthwise line C, (d) lengthwise line D

5. Conclusion
In this study, we used Ground Penetrating Radar (GPR) Method for early mitigation of the potential for water seepage in the body of the lake. The GPR method of this study that used 60 MHz antenna frequency can identify a maximum depth of 30 meters and the interpretation of subsurface condition at research location shows four stratigraphic units, it assumed as a top soil with depth of 0-2 m in first stratigraphic unit, clay with depth of 2-6 in second stratigraphic unit, sand with depth of 6-15 in third stratigraphic unit, and sandy clay with depth that cannot be determine in fourth stratigraphic unit. From the result of Ground Penetrating Radar (GPR) survey with 2 crosswise lines and 2 lengthwise lines, we found that anomaly which is suspected as water seepage appear on depth of 2 meters. On the crosswise line, anomalies show on a distance of 20 m and 35 m (line A) and 125 m and 135 m (line B), while on the lengthwise line anomalies show on a distance of 35 m and 50 m (line C), 25 m and 95 m (line D). To determine the types of rock lithology of subsurface conditions in this area, we need further research using drilling method, and the further research using geotechnical methods will be carried out for identify the existence of water seepage in this area.
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