Spread of liquid waste in un-licited gold mining by geoelectrical method in Krueng Sabee sub-district Aceh

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Abstract. Illegal gold mining has increased significantly in Keude village of Krueng Sabee Aceh Jaya subdistrict. This causes environmental damage in the form of waste mercury pollution in the area. Environmental pollution caused by waste needs to be addressed. However, it needs to determine the appropriate method to overcome it by knowing the depth and the spread of mercury waste. This study aims to visualize subsurface conditions in the area of Krueng Sabee to provide information and data on the spread of mercury wastes. By using the method of geoelectrical resistivity Schlumberger array, the contamination can be seen below the surface by the resistivity value of the sites. Results from these measurements after inverted using Earth Imager software of Res2Dinv can get a picture and visualize the location of subsurface conditions of the study. The results show that the resistivity value of waste mercury-contaminated soil at the study site ranged from 2–5 Ωm, and waste mercury contamination occurs vertically to a depth of 3 meters.

1. Introduction

The amount of illegally gold mining in Indonesia is increasing [1]. In early 2008, there are about 480 illegal gold mining in all over Indonesia, particularly in areas with potential gold deposits. Personal or a bunch of people, even by a private company, on private or public land without concession or the necessary paperwork, is doing [2] these illegal mining activities. In general, illegal gold miners use mercury for extracting precious metals [3]. Mercury is a hazardous metal that can harm organs [4] and the immune system. U.S. Food and Administration (FDA) determines 0.005 ppm as the threshold limit value for mercury in the environment.

In Aceh itself, one of the illegal gold mining takes place in Krueng Sabee area, Aceh Jaya district [5]. This area is located in southwest Aceh. It has tremendous gold deposits exploited illegally by the local communities. Because of their lack of knowledge about mining principles, such illegal activities have some bad impacts [6] on the nearby environment.

One of the impacts of the illegal mining activity in Krueng Sabee is the contamination of mercury in residential areas [7]. This happened because the machines used to extract the gold, called Gelendung, operates within the settlement. Right after using the mercury to amalgamate gold particles, the miners dump the mercury waste straight away [8].

The wasted mercury flows through the subsurface. It is hard to predict how far the waste will spread. An initial study needs to conduct to monitor the mercury proliferation since it may contaminate the groundwater, and the groundwater is the main water source for the communities.
living in that area. The use of polyurethane foam adsorbents to adsorb mercury can reduce mercury pollution [9]. This study uses the geoelectrical method to observe how far the mercury has contaminated the land (Figure 1). The geoelectrical method can distinguish between the contaminated area and the non-contaminated area based on the resistivity value [10]. The mercury waste has a higher resistivity value compared to the groundwater.

![Figure 1. Research location](image)

Keude Krueng Village, located in Krueng Sabee sub-district, Aceh Jaya district, has the potential for gold mining [11]. The local people extract the gold found with a machine called “gelundung”. Gelundung uses mercury to separate gold from its gangue [12]. Mercury, also called quicksilver, is a chemical substance with the symbol of Hg. Hg stands for Hydrargyrum with liquid silver meaning. According to Rustagi and Singh [13], mercury is a heavy metal liquid at standard temperature and pressure conditions.

Mercury has silvery-white color and belongs to a fair conductor of electricity. However, it is a poor heat conductor with a freezing temperature of -38.9°C and a boiling temperature of 357°C. Another property of mercury is its tendency to dissolve other metals to form a metal alloy mixture, such as gold, known as amalgam [14]. The gold is dissolvable into the mercury. Therefore, mercury is useful to extract the gold [15] in the extraction process or amalgamation process.

Amalgamation is a process to bring free gold particles into contact with mercury to mix both substances to form a compound called amalgam [16]. In the final process, the collecting of mercury and gold amalgam takes place after separating the two substances. Taking the gold goes on, yet the mercury waste dumping occurs by just letting it flow out into the environment. If this disposal is not controlled, it can devastate the nearby environment such as the river, residential areas, and so on.

2. Methodology
The survey was conducted in a gold extraction area with the amalgamation process in Krueng Sabee [17]. Three sets of measurements along three different lines with each 55-meter length and 2.5 m electrode spacing were carried out to gather the data. These measurements used the geoelectrical method with Wenner-Schlumberger configuration in order to get more data points [18]. The more datum points measured horizontally, even vertically, the more accurate the model generated by Res2Dinv software [19]. The data acquisition process was done by using SuperSting resistivitimeter R8/IP [20] as indicated in Figures 2 to 4.
Figure 2. Flow chart

Figure 3. Multi-channel superstring
3. Results and Discussions
The direct observation and the resistivity models from Res2Dinv software shows a clay layer of the measurement area (Figure 5). Its resistivity indicates it in the value range of 1–100 Ωm. Higher resistivity values between 100–250 Ωm (loose clay) were also obtained in three lines. At line KS1, the higher resistivity is in the range of 0–16 meters, while in KS3, it is in the range of 42–55 meters. At line KS2, it is also along the ditch in the range of 48–49 meters, and 49–55 meters along the dirt road.

![Figure 4. Survey line](image)

![Figure 5. Cross-section resistivity, Line KS1, KS2 dan KS3](image)
3.1. Line KS1
KS1 line was measured along the water disposal ponds contaminated by mercury. The ponds are sealed with concrete walls on all sides. They have a different size with 2 meter depth. There are five ponds along the KS1 line. The first pond distance is from 24–28 meters from the starting point of measurement. The others are from 36–39 meters, 42–45 meters, 40–43 meters, and 53–55 meters for the second, third, fourth, and fifth ponds, respectively.

At the line KS1, the lower resistivity (conductive) value is in the range of 2–5 Ωm. It was found at 22–28 meters, 31–38 meters, and 41–55 meters, with 2–3 m depth (showed by the dashed line in Figure 6). The blue colors inside the dashed line indicate the mercury-contaminated soil. The soil becomes contaminated as the mercury in the waste ponds comes through the concrete walls.

![Figure 6. Cross-section resistivity, Line KS1](Image)

3.2. Line KS2
At line KS2, the lower resistivity values were in the range of 2–5 Ωm (Figure 7). It was found in the range of 0–21 meter distance from the starting point with 2–3 meter depth. However, the soil is not contaminated with mercury as there is no horizontal continuity with the contaminated soil detected at line KS1. Moreover, the lower resistivity zone is about 5 meter depth, whereas the mercury infiltrates the soil only up to 3 meters in KS1.

![Figure 7. Cross-section resistivity, Line KS2](Image)

3.3. Line KS3
Line KS3 crosses line KS1 at 39 meter distance, while for line KS1, the cross point is at 46 meters from its starting point (Figure 8). The measurement at 41–45 meter distance in line KS3 shows almost the same depth in the conductive zone with a lower resistivity value (2–5 Ωm) as that in line KS1 with 34–39 m distance. The cross-section model clearly shows that there is no correlation between the contaminated zone (lower resistivity value) in KS1 and the lower resistivity zone in KS2.
4. Conclusion
Mercury waste has contaminated Keudeu village, sub-district of Krueng Sabee, up to 3 meter depth. The contamination does not spread horizontally. The resistivity value of the contaminated soil below the mercury waste ponds is in the range of 2–5 Ωm.

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