Integrating Ground Penetrating Radar, Induced Polarization and Aerial Photograph to Analyze Land Subsidence in Borehole Mining Operation Area: A Case Study from South Bangka Island

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Abstract. The remaining alluvial tin reserves around large ex-mining area can be an opportunity to optimize the potential reserves using a small-scale mining system. One of the latest breakthroughs in the mining system for the remaining alluvial tin reserves on land is the borehole mining (BHM) method. However, mining operations using BHM have several environmental impacts especially related to its former holes. This study aims to identify the changes in geometry of the former holes both on the surface and below the surface through direct field observations and measurements using geophysical methods. The study is in the large ex-mining area of Air Nudur Block in South Bangka Regency, Bangka Belitung Islands Province. The geophysical methods used to identify the changes in the geometry of the BHM holes are GPR (ground penetrating radar) and IP (induced polarization). The GPR method has high resolution subsurface visual capabilities at shallow depths and this method can distinguish between stable and unstable layers. The IP method is used to determine the overburden layer and the condition of the alluvial layer where some of it has become a hole. These two methods will mutually reinforce in interpreting the change in the geometry of the BHM holes. Changes in hole diameter and depth were measured directly in the field within 2 (two) months from the completion of mining operations using the BHM method followed by the periodic topographic measurements using UAV (unmanned aerial vehicle).

1. Introduction

Air Nudur large mine is no longer operated but there is a plan to remining alluvial tin reserves large ex mining area and optimization. Re-mining is carried out with the aim of optimizing the remaining reserves that have not been mined optimally[1]. One of the latest breakthroughs in the mining system for the remaining alluvial tin reserves on land is the borehole mining (BHM) method. Mining operations using BHM have several environmental impacts especially related to its former holes of BHM[2]. This study is to identify the land subsidence around in BHM area and the changes former of geometry holes both on the surface and below the surface through direct field observation and measurement using geophysical methods is needed to avoid this environmental impact on both surface and subsurface. Meanwhile, subsurface visualization can be measured using the Ground-Penetrating Radar (GPR) method and the Induced Polarization (IP) method[3]. The actual method and the geophysical method are expected to be able to identify and monitor the occurrence of land subsidence in the mine environment[4]. Geophysical methods can be used to identify subsurface and can visualize subsurface conditions. The purpose of the GPR method is to detect objects that are under the ground with a certain level of depth using radio waves that have a frequency 100 MHz[6]. The GPR method has high resolution subsurface visual capabilities at shallow depths and this method can distinguish between stable and unstable layers[4]. The IP method is used to determine the overburden and alluvial layer[4].

Keywords: BHM, GPR, IP, topographical change, former holes
2. Research Method
The GPR and IP acquisition survey was conducted after the presence of aerial photographs to illustrate the target area of the hole that will be targeted for monitoring. Aerial photographs are also used as non-renewable location update data from satellites. In addition, it is used to model the topographic surface that will be validated by the GPS RTK to see the alluvial upper limit. IP measurement was conducted on GPR lines so that the data can be correlated and can connect the two models for interpretation.

a. Ground Penetrating Radar (GPR)
Some cases in geological environmental problems can be solved by GPR with a 100MHz antenna and good resolution can be delivered to provide a shallow layer image[4]. GPR acquisition using MALA X3M system with 100 MHz frequency was carried out for shallow or medium resolution targets [3] Figure 1. Measurements with a trigger as a provider of instructions to the radar system to collect recorded data with an interval of 0.1 m[6]. GPR acquisition was carried out on 5 BHM holes, namely BHM 11 to BHM 15. Trajectories were made of 4 trajectories each hole directed in all directions and clockwise. Data processing is done using Reflexw 6.0.7 software through a process of static correction, subtract-mean, gain, bandpass and topographic correction to interpret the radargram data. Interpretation is doing by finding in research area and look the processing section which will be linked with theories so we can get the accurate and correct information

Figure 1. GPR acquisition line map (PT.Timah Tbk)
b. **Induced Polarization (IP)**

IP acquisition data at 1.5 m electrode spacings was collected. The measurement of IP has a trajectory from northwest to southeast. IP measurement uses a set of 4point light hp 10w of Lipmann tool and switchboxes were mounted on a cable and connected directly to the electrodes Figure 2. This acquisition uses a multichannel dipole-dipole configuration and fast data acquisition measurement. Data processing is done using RES2DINV to determine the resistivity and chargeability distribution to get a 2-dimensional cross section of the inversion model[1].

![Map of Induced Polarization Line Acquisition](image)

Figure 3. IP acquisition line map
Topography

Topography is used for monitoring changes in elevation data. Retrieval of data using drones, GPS. The monitoring was carried out for 4 weeks starting from mid-April 2019 to mid-May 2019. Topographic monitoring was used to see the surface deformation in the BHM hole area and around the BHM hole, which then made a topographic cross section for each week. Topographic section A-A' represents holes BHM 15 and BHM 14, topographic sections B-B' represent holes BHM 13 and BHM 12, topographic section C-C' represents holes BHM 11 in Figure 4.

![Topography Cross-section Map Nudur](image)

**Figure 4. Topography cross-section map**

### 3. Result and Discussion

The results of the three methods of GPR, IP and topography show that there is land subsidence based on table measuring the diameter and depth of BHM holes. The table 1 shows the changes of borehole geometry and land subsidence in BHM holes. The change in diameter from the first week to the 4th week shows that there is material on the surface that has collapsed into the hole, result that subsidence shows around borehole.

| NO | BHM Hole ID | Diameter (m) | Depth (m) |
|----|-------------|--------------|-----------|
|    |             | Week I | II | III | Week I | II | III |
| 1  | BHM 11      | 0.16   | 0.2 | 0.3 | 7.5    | 7.5 | 7.5 |
| 2  | BHM 12      | 2.9    | 3.28| 3.42| 1.7    | 1.7 | 1.5 |
| 3  | BHM 13      | 3.2    | 3.24| 3.52| 1.29   | 0.98| 0.89|
| 4  | BHM 14      | 0.85   | 1.38| 1.52| 1.54   | 1.36| 1.09|
| 5  | BHM 15      | 2.4    | 2.54| 3.1 | 3.3    | 0.78| 1   |

Table 1. Table measuring the diameter and depth of BHM holes
a. Cross section topography

Figure 5. Cross Section Topography BHM All Week
Topography cross-section shows that all topography cross-section shows that BHM Holes experienced land subsidence of 1 m for 4 weeks. In the GPR interpretation, the Radargram used is BHM12 and the line used to interpret is BHM 12_1 – BHM 12_1’ to represent another BHM hole. The subsidence in subsurface conditions are explained through GPR interpretation. GPR interpretation shows a change in the radargram pattern in Figure 6A to Figure 6B, a change in the radargram pattern from hummocky to chaotic shows a decrease in the subsurface layer: subsidence below the surface occurs to a depth of 1.7 m. subsurface decline occurred during 3 weeks is 0.3 m.

Figure 6A. Result of GPR Monitoring BHM Cross section 12_1-12_1’ April 2019 and (B) BHM Cross section 12_1-12_1’ May 2019

Figure 6B. Result of GPR Monitoring BHM Cross section 12_1-12_1’ May 2019 and (B) BHM Cross section 12_1-12_1’ May 2019

Figure 7. Result of IP Inversion and Topography effect

GPR interpretation shows that the layer subsidence indication occurs in the depth range of 1.7 – 2.0 m at BHM 12 and at a depth of 4- 5 m there is a change in layer shape. Then the GPR interpretation is linked to IP to show subsidence area. IP indicates the presence of holes and alluvial layers with a value range of 2-4 ms which is indicated in yellow and orange color.
4. Conclusion

Based on interpretation, the topography shows a decrease in elevation values and land subsidence around the BHM operating area of 1.2 m and the BHM hole of 1 m. Subsurface subsidence is indicated by GPR interpretation where the hummocky radargram pattern changes to chaotic and the layer decreases by 0.3 m below the surface. IP shows the alluvial layer which is still dominated by tin minerals under the surface with ranges chargeability value 2-4 ms.

Acknowledgment

We sincerely thank PT Timah Tbk. For their contribution and support in the field investigation and mapping in Bangka Island and also for this paper.

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