The effect of coal stockpile on shallow groundwater aquifer: Study case Tarahan

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Abstract. This paper aims to determine the existence of groundwater contamination due to coal stockpile activity in shallow groundwater. The research area is located in a stockpile that has been operating since 1986. We conducted chemical content analysis at several points around the coal stockpile and outside the stockpile area to see the impact of pollution on the surrounding residents’ areas. This study also uses geoelectric methods and direct observations to identify shallow groundwater levels (water table). The research area has a groundwater depth of about 2 m from the surface, and groundwater flows from northeast to southwest (sea). The chemical content analysis results show that each sample taken around the stockpile is below the water quality standard threshold, so it can be concluded that coal stockpile activity does not contaminate the shallow groundwater. However, there is nitrate contamination from shallow groundwater located outside the stockpile area taken from dug wells and drilling wells with a depth of 8 m shows a value of 14.08-23.67 ppm (>10 ppm threshold). We suspect that this pollution is caused by the large number of mining activities carried out in the north of the study area.

1. Introduction

It cannot be denied that coal is still the preferred energy source in Indonesia because coal can be classified as a relatively cheap energy source. According to the national energy plan, coal is projected to contribute around 30% of the national energy mix in 2025 and 25% in 2050 [1]. PT. Bukit Asam is a state-owned company (BUMN) engaged in mining, especially coal. The influence of PT Bukit Asam is very large in the coal industry activities, where PT Bukit Asam supplies around 10.15% of Indonesia's total coal reserves of 32.3 billion tonnes. PT. Bukit Asam Tarahan Port Unit (PTBA PELTAR) is a part of PT. Bukit Asam is located in Lampung Province, precisely in Panjang District, Bandar Lampung City. The operational activities carried out by PTBA PELTAR in the form of loading, unloading, and distribution of coal have started since 1986.

Coal loading and unloading activities can harm environmental aspects if there is no intensive maintenance. The infiltration of rainwater flowing through the coal deposits can bring harmful elements such as high coal pyrite (FeS) concentrations below the surface, affecting the quality and quantity of
hydrogeological aspects in this area. The acid content due to the dissolving of the elements contained in the coal pile can potentially form sulfuric acid (H$_2$SO$_4$) which decrease the pH of water and form acid mine water (AWM) [2]. Research on coal stockpiles in Muara Telang shows a change in the pH value of water and soil becomes more acidic [3]. In addition, several studies have shown the effect of coal mining on local hydrogeological conditions [4–8].

Geologically, the research area (coal stockpile) is located in Tarahan Formation based on Mangga et al. [9]. The Tarahan Formation consists of welded tuff and breccias with chert intercalation that formed in the Early Paleocene-Oligocene [9]. The coal stockpile is located on a flat seafront with a hilly area in the east to facilitate loading and unloading activities using barges.

According to Al-Amin et al. [8], leachate from coal stockpiles has a negative impact on the quality of soil, surface water, and groundwater. This study aims to determine the existence of shallow groundwater contamination caused by coal stockpiles. Groundwater condition observation is based on observing the physical condition of surface water, chemical analysis of groundwater, and geoelectric modelling. Groundwater flow patterns will be displayed based on the results of groundwater level mapping to support the analysis of the potential for groundwater pollution around the study area.

2. Materials and methods
In this study, the chemical content of groundwater, both shallow and deep aquifers was analyzed to perceive the impact of coal stockpiles on the groundwater. Observation of the groundwater level was also carried out at several points to understand the distribution pattern of the groundwater level in the study area. In addition, the geoelectric method was used to obtain the depth of groundwater level data more accurately and can be elaborated with field data.

Water geochemical analysis was carried out to determine the quality and quantity of groundwater in the study area. Groundwater quality is carried out by analyzing samples at several observation points using physical and chemical parameters (Figure 1).
Physical parameters analysis including colour, total dissolved solids, temperature, taste, smell, pH was carried out by direct measurement and observation. As for pH, it was measured using Hanna HI 8424 intelligent meter. Then, a chemical analysis of water was carried out to determine the dissolved elements in the water and analysed in the laboratory of PT. Sucofindo, Lampung. The contents analysed were: Fe, Mn, Zn, Pb, Cd, Nitrate (NO\textsubscript{3}^-), SO\textsubscript{4}, F, Nitrite (NO\textsubscript{2}^-), As, Se, Cr according to the standard regulation. It is essential to see the effect of coal stockpile activities on groundwater content. Therefore, the chemical content in water should not exceed the threshold value for clean water quality for sanitation purposes, as stated in the regulation of the Minister of Health of the Republic of Indonesia number 32 of 2017.

Water sampling was carried out on several types of water, including inlet water in settling ponds, shallow groundwater, deep groundwater, and river water using 200 ml HDPE bottles. The water samples was acidified to prevent deposition. Water sampling is carried out by referring to standards [10]. The settling pond is a pool made to accommodate water that comes out of the stockpile before dumping into a public ditch. In the pool, treatment will be carried out to reduce toxic and unwanted substances. The term inlet is a sampling point in the place before the water enters the settling pond. In this study, water sampling at the outlet was not conducted, considering that the water was just treated and is relatively clean. Assuming it would not contaminate groundwater. Alternatively, the sample is taken in September when the rainfall is still not dominating. The sampling points can be seen in Figure 2, while the details of the sampling locations are presented in Table 1. Water samples of Air-1 to Air-6 were taken from the surrounding of coal stockpiles, while Air-7 to 11 were taken outside the working area located in residential areas. We conducted this to compare the condition of the water in the stockpile area with the surrounding.

To support groundwater level observation data in the field, we identified the groundwater level using the geoelectric method. Two-dimensional geoelectric measurements were carried out using a resistivity meter on two lines with a path length of 100 meters and an electrode spacing of 5 meters (Figure 2). Furthermore, the processing and inversion of the geoelectric data were carried out using Res2Dinv software.

| No. | Sampling code | Sampling date | Sample type   | X (m E)  | Y (m S)  |
|-----|---------------|---------------|---------------|----------|----------|
| 1   | Air-1         | 02/09/2020    | Settling pond inlet | 538,435  | 9,390,290 |
| 2   | Air-2         | 02/09/2020    | Settling pond inlet | 538,497  | 9,390,257 |
| 3   | Air-3         | 02/09/2020    | Monitoring well   | 538,187  | 9,390,778 |
| 4   | Air-4         | 02/09/2020    | Monitoring well   | 538,233  | 9,390,700 |
| 5   | Air-5         | 02/09/2020    | Drilling well     | 538,357  | 9,390,597 |
| 6   | Air-6         | 03/09/2020    | Stockpile trench  | 538,065  | 9,390,526 |
| 7   | Air-7         | 06/09/2020    | Dug well          | 538,720  | 9,390,248 |
| 8   | Air-8         | 06/09/2020    | Drilling well     | 538,499  | 9,390,585 |
| 9   | Air-9         | 06/09/2020    | Dug well          | 538,387  | 9,390,715 |
| 10  | Air-10        | 06/09/2020    | River             | 538,101  | 9,391,127 |
| 11  | Air-11        | 06/09/2020    | Dug well          | 538,208  | 9,390,937 |
3. Result and discussion

3.1. Physico-chemical properties

The groundwater quality can be inspected from a physical, chemical, and biological perspective, with the specific standard stated in the Minister of Health Regulation No. 32 of 2017. This research is limited to physical and chemical parameters because biological parameters cannot be carried out due to laboratory limitations. The physico-chemical parameters of water samples observed in the field are presented in Table 2, including water and air temperature, pH, eH, and TDS, while the pictures of several sampling locations are presented in Figure 2. Based on the regulation of the Minister of Health No. 32 of 2017, the maximum water temperature level is ± 3°C from air temperature, pH 6.5-8.5, and TDS <1000 ppm. Field observations show that the content of water samples from inlets, wells, and rivers do not exceed the threshold value, so it can be concluded that the above parameters are still classified as safe. The eH value in each sample shows a negative number which indicates that the water sample is in a reduction condition, while the Air-1 sample shows a positive value caused by the presence of a chemical treatment/mixture before the water is released into the public ditch to prevent contamination.

| No. | Sampling code | T water (°C) | T air (°C) | pH     | eH (mV) | TDS (ppm) | Description                          |
|-----|---------------|--------------|------------|--------|---------|-----------|--------------------------------------|
| 1   | Air-1         | 31.4         | 30         | 6.66   | 21.2    | -         | Settling pond inlet, very murky, smell of iron, itchy. |
| No. | Sampling code | T water (°C) | T air (°C) | pH  | eH (mV) | TDS (ppm) | Description |
|-----|---------------|--------------|------------|-----|---------|-----------|-------------|
| 2   | Air-2         | -            | -          | 7.67 | -35.5   | 570       | Settling pond inlet, very murky, smell of iron, itchy. |
| 3   | Air-3         | 29           | 29.9       | 7.61 | -27.4   | 345       | Monitoring well, clear, odourless, tasteless. |
| 4   | Air-4         | 29.9         | 30.8       | 8.03 | -51.1   | 253       | Monitoring well, clear, odourless, tasteless. |
| 5   | Air-5         | -            | -          | 7.76 | -38.5   | 646       | Drilling well, 100 m depth, clear, a little bit smell of iron, tasteless. |
| 6   | Air-6         | 32.7         | 33.7       | 7.29 | -8.8    | 112       | Water on the stockpile trench, very murky, strong iron smell, itchy. |
| 7   | Air-7         | 31.7         | 32.7       | -    | -       | -         | Dug well, 2 m depth, a little bit murky, a little bit smell of iron, weak acidity. |
| 8   | Air-8         | 30.4         | 31.4       | -    | -       | 272       | Drilling well with 8 m depth, clear, odourless, a little bit acid. |
| 9   | Air-9         | 30.1         | 31.2       | -    | -       | 203       | Dug well, a little bit itchy. |
| 10  | Air-10        | 29.9         | 30         | -    | -       | -         | River water, clear, odourless. |
| 11  | Air-11        | 30.3         | 32.1       | -    | -       | -         | Dug well, little bit murky. |

Note: (-) not measured

Mapping the movement of groundwater is very important to determine the presence of groundwater contamination. The observation was performed on several water table depths in unconfined/shallow aquifers at locations Air-3, 4, 7, and 11, with water table levels measured from the surface of 2, 2, 1.47, 1.15 m, respectively. In addition, the observed depth data of the water table will be elaborated with the results of the inversion modelling of the geoelectric data to support the interpretation.

Based on the results of subsurface modelling from the geoelectric data in line-4 and 5 (Figure 3), it can be seen that there are shallow aquifer layers with varying depths from 1-4 m indicated by low resistivity values (dark blue). In line-4, the seam with a high resistivity value is a coal pile because the acquisition of geoelectric data on line-4 is carried out on the coal stockpile. The resistivity value of clean water ranges from 2-100 ohm-m, while coal has a value of 10-800 ohm-m [11–13]. Meanwhile, the high resistivity value at line-5 is the pile of rock used for the road base.
From the results of direct observation and subsurface inversion modelling using geoelectric data, it can be concluded that there is groundwater with a depth of about 2 m from the surface in the study area. The map of groundwater level is shown in Figure 4 below. As shown in that map, the samples of Air-7, 8, 9, 10 have excess nitrate content.

Figure 3. Inversion modelling of the geoelectric data on line-4 and 5.

Figure 4. Groundwater depth with flow relative to the southwest.
This map shows that groundwater moves relatively from the northeast to the southwest of the study area towards the sea. This is because the eastern part of the study area, which is located outside the PTBA PELTAR area, is a mountainous area with an altitude of up to 125 meters above sea level so that groundwater will flow from higher to lower regions. The area outside the study area is a residential area with residents using shallow groundwater for sanitation. This indicates that if contamination occurs on the shallow groundwater, the water will not flow outside the coal stockpile or residential area. Therefore, we carried out a chemical analysis of groundwater to determine whether the contamination was in shallow groundwater or not. The strategy to place the stockpile near the sea is an excellent strategy to arrange. In addition to facilitating loading and unloading activities and mobilization, it also minimizes contamination with groundwater in residential areas because the area near the sea is the lowest area, and groundwater will move relatively toward the sea.

3.2. Chemical analysis

The results of chemical analysis on water samples compared with water quality standard of the Minister of Health regulation No. 32 of 2017, presented in Table 3. Values that exceed the threshold value set in the regulation are the contaminated areas. Based on the water sample analysis, it can be seen that almost all chemical parameters are below the threshold value, except for nitrate content in samples Air-7, 8, 9, and 10, which the samples obtained from outside the coal stockpile area. This result indicates that all samples located around the stockpile or in the working area show values below the threshold and are categorized as uncontaminated areas. It can be concluded that the coal stockpile activity in the study area does not cause shallow or deep groundwater pollution.

| No. | Sampling code | Fe  | Mn   | Zn   | Pb   | Cd  | Nitrate (NO₃⁻) | SO₄²⁻ | F   | Nitrite (NO₂⁻) | As  | Se  | Cr  |
|-----|---------------|-----|------|------|------|-----|----------------|-------|-----|----------------|-----|-----|-----|
|     |               | ppm |      |      |      |     |                |       |     |                |     |     |     |
| 1   | Air-1         | <0.02 | <0.02 | 0.1  | <0.05 | <0.002 | 6.24 | 241.1 | 1.1 | <0.007 | <0.001 | <0.005 | -   |
| 2   | Air-2         | <0.02 | <0.02 | 0    | <0.05 | <0.002 | 3.02 | 144.7 | 0.8 | <0.007 | <0.001 | <0.005 | <0.02 |
| 3   | Air-3         | <0.02 | <0.02 | 0.1  | <0.05 | <0.002 | 0.79 | 23.11 | 0.2 | <0.002 | <0.001 | <0.005 | <0.02 |
| 4   | Air-4         | <0.02 | <0.02 | 0    | <0.05 | <0.002 | 2.55 | 24.98 | 0.9 | <0.007 | <0.001 | <0.005 | <0.02 |
| 5   | Air-5         | <0.02 | <0.02 | 0.6  | <0.05 | <0.002 | 2.67 | 48.3  | 1   | <0.007 | <0.001 | <0.005 | <0.02 |
| 6   | Air-6         | <0.02 | 0.02  | 0    | <0.05 | <0.002 | 8.19 | 149.2 | 1   | 0.124  | <0.001 | <0.005 | <0.02 |
| 7   | Air-7         | <0.02 | <0.02 | 0.1  | <0.05 | <0.002 | 14.37 | 13.03 | 0.5 | 0.001  | <0.001 | <0.005 | <0.02 |
| 8   | Air-8         | <0.02 | <0.02 | 0    | <0.05 | <0.002 | 23.67 | 17.53 | 0.5 | 0.002  | <0.001 | <0.005 | <0.02 |
| 9   | Air-9         | <0.02 | <0.02 | 0.1  | <0.05 | <0.002 | 52.99* | 16.08 | 0.5 | 0.12   | <0.001 | <0.005 | <0.02 |
| 10  | Air-10        | <0.02 | 0.23  | 0.1  | <0.05 | <0.002 | 14.08 | 19.6  | 0.9 | <0.007 | <0.001 | <0.005 | <0.02 |
| 11  | Air-11        | <0.02 | <0.02 | 0    | <0.05 | <0.002 | 1.85  | 10.77 | 0.5 | 0.124  | <0.001 | <0.005 | <0.02 |

Samples with a nitrate content above the threshold (>10 ppm) were Air-7, 8, 9, and 10 samples with ranging from 14.08-23.67 ppm. In the Air-9 sample, the nitrate content reached 52.99 ppm because the sample was acidified using nitric acid to preserve the sample. However, we suspect that the sample will also have a value that exceeds the threshold if no acidification is applied.

Unexpectedly, the contaminated samples found in the study area are actually located outside the stockpile area and around residential areas. As for the water samples around the stockpile, the water in the inlet, monitoring wells, and drilling well were not contaminated and showed chemical content below the threshold. Because of the direction of groundwater flowing from northeast to southwest (Figure 4),

\[ \text{Nitrate (NO}_3^-) \]
\[ \text{SO}_4^{2-} \]
\[ \text{F} \]
\[ \text{Nitrite (NO}_2^-) \]
\[ \text{As} \]
\[ \text{Se} \]
\[ \text{Cr} \]
it is suspected that the contamination in residential areas does not come from PTBA PELTAR's coal stockpile activity.

Water Samples 7, 8, 9, and 10 are water taken from dug wells, drilling well with 8 m depth, and rivers. This fact indicates that there has been contamination of shallow groundwater around the residential area. The contamination is probably caused by a large number of mining activities in the northern part of the study area, causing the nitrate content in the groundwater to increase. A study in China shows that the nitrate content in surface water is increased caused by a large number of mining activities [14]. Several studies shows that using of oxygen, nitrogen isotope, and understanding the hydrogeological pattern can be very helpful to trace the nitrate source [15,16]. Otherwise, it is necessary to conduct further research to determine the source of the excessive nitrate content in the groundwater to prevent health fatality for the local people. The nitrate content consumed by the body can be harmful and cause health risks such as methemoglobinemia, cancer, diabetes, etc., in both humans and animals [17]. Therefore, groundwater in the contaminated residential area is not suitable for consumption.

4. Conclusion
Based on direct observations and geoelectric inversion modelling, the research area has a groundwater depth of about two meters, with groundwater moving relatively from northeast to southwest of the study area. So that if contamination occurs in the groundwater, the groundwater will not move to the residential area because the stockpile location is at a low elevation and is close to the sea. The results of chemical analysis on several samples taken in the coal stockpile area of PTBA PELTAR show that there is no contamination of shallow or deep groundwater due to stockpile activity. The presence of nitrate content that exceeds the threshold level (>10 ppm) in shallow groundwater outside the stockpile area is thought to be due to mining activities at the northern of the study area. This condition makes the shallow groundwater in the area is not suitable for consumption concerning the increase of health risks.

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