The determining of an environmentally oriented mining direction using the ordinary kriging method

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Abstract. Cassiterite (SnO₂) is a mineral carrying element of tin (Sn) and other associated minerals of economic value. Mining activities need to go through several analyze including those related to environmental impacts regardless of primary and secondary sediment conditions. In this research, twenty-six data samples were took around Sambunggiri Hill, Jurung Village, Merawang District, Bangka Regency. The data were test using X-Ray Fluorescence (XRF) in a laboratory. There are two types of elements will be taken, they are Tin, (Sn) and Zircon (Zr), as well as one other type of related mineral is Hematite (Fe₂O₃). In this research, we use spatial analysis to estimate patterns of distribution of mineral content. The spherical model can apply to describe the spatial relationship between location pairs based on Hematite, Tin and Zircon. The pattern of minerals distribution mostly found to the east of Sambunggiri Hill. The estimated distribution pattern of Cassiterite minerals can provide an overview of mining activities that can prevent environmental damage. So that environmental damage caused by mining activities can be minimized and raise awareness to maintain a sustainable environment. A good mining concept will have a positive impact on the surrounding environment.

1. Introduction
Cassiterite (SnO₂) is a main mineral which contains the element of tin (Sn) and other related minerals. These minerals depend on the location of the discovery of cassiterite. Generally, if mining is carried out in hilly areas, it can be said that the mineral cassiterite is included in the primary sediment, because it is still close to its formation process and is related to other minerals such as concentrates and tailings. Then, if the mining is carried out close to a river or beach, the mineral cassiterite is included in secondary sediment. This condition occurs because in this area the minerals have already experienced weathering, displacement, and precipitation in accordance with the specific gravity of each mineral.

Both primary and secondary sediments, the minerals contained in cassiterite have economic value in the society. As a result, many people take the opportunity to illegally mine cassiterite. This illegal mining activity does not pay attention to the condition of the existing land and illegal miners also dig as much as possible to get cassiterite. This case greatly affects the environment.

Each mining activity undertaken needs to consider several matters relating to environmental impacts, regardless of the condition of primary or secondary sediment. The environmental impact analysis can be done by referring to the criteria contained in government regulation number 56 of 1994 concerning guidelines on environmental impacts.
One of them is the area of distribution of environmental impacts, where the ability to restore post-mining land is very difficult, so there must be handling of the land so that it can be return in accordance with its designation. This activity needs to be carried out as a form of awareness of humans, especially miners, to protect the environment.

Mining activities will indirectly intersect with the environment, so there is a need for a detailed study or exploration of the distribution of mining minerals such as cassiterite. This study or exploration is needed as an initial stage of the mining process and post-mining reclamation handling. One of the studies that can be used to see the spread of mining minerals is the geostatistical method.

Geostatistical techniques that are often used in estimating values are kriging. Kriging can interpolate the spread values at a location and the values obtained from the nearest location [1-2]. There are several kriging methods commonly used in determining the spread of a value such as simple kriging, ordinary kriging, and universal kriging [3-4]. If we use the kriging method, it is expected that the direction of mining in an area can be estimated, so that it helps prevent damage and protect the environment due to post-mining. In this study we will estimate the direction of environmentally oriented mining in the Sambunggiri hill, Jurung village using the ordinary kriging

2. Methods
In this research twenty six samples were taken in around Sambunggiri Hill, Jurung Village, Merawang District, Bangka Regency. Then, the data were test in a laboratory using X-Ray Fluorescence (XRF). Based on the tested, there are two types of elements will be taken, they are Tin, (Sn) and Zircon (Zr), as well as one other type of related mineral is Hematite (Fe₂O₃). The three minerals were chosen because they are included valuable minerals in mining legally and illegally. There are four steps will be discuss in the method. First, descriptive statistics for each data will be presented. Then, the model of experimental semivariogram will be calculated and plotted. After that, choose one of the best semivariogram models. Finally, the best semivariogram model will be use in kriging to estimate the distribution pattern of data.

2.1. Descriptive Statistics
In this case, the descriptive statistics is required in analysis of data mining. They are used to analyze and interpret of data mining, especially minerals contained in cassiterite, such as Hematite (Fe₂O₃), Tin (Sn), and Zircon (Zr). We can generate distribution of data, measure of the tendency of the deviations from the mean, coefficient of variation or the others. Furthermore, in this case we use the coefficient of variation as one of the parameters that can analyze the relationship between each data sample and population.

2.2. Analysis of Spatial
Analysis of spatial will be represented of the relationship between each data set, the spatial correlation, and the models of minerals contained in cassiterite, such as Hematite (Fe₂O₃), Tin (Sn), and Zircon (Zr). We used the semivariogram to be shows them. The semivariogram is diagram of variance from different between pair of the location. The models of semivariogram are [5-6]:

\[ \gamma(h) = Var((Z(s_i) - Z(s_j)) \]

\[ Var((Z(s_i) - Z(s_j)) = \frac{1}{2N(h)} \sum_{i \neq j} [Z(s_i + h) - Z(s_j)]^2 \]

After that, these models were validated against experimental semivariogram, which is calculated for every pair of possible distance with a certain angle. Here, we use the experimental of semivariogram such as spherical, exponential, or Gaussian models. They are [6-7]:

Spherical, \[ \gamma(h) = \begin{cases} C_0 + C \left( \frac{3}{2} \frac{h}{a} \right) \left( \frac{h^2}{2a^2} \right) & , h \leq a \\ C_0 + C & , h > a \end{cases} \]
Exponential, $\gamma(h) = C_0 + C\left[1 - \exp\left(-\frac{h}{a}\right)\right]$ \hspace{1cm} \text{(4)}

Gaussian, $\gamma(h) = C_0 + C\left[1 - \exp\left(-\frac{h}{a}\right)^2\right]$ \hspace{1cm} \text{(5)}

Furthermore, this semivariogram model is needed to interpolate variables around the observation location using the Ordinary Kriging (OK) method. The Ordinary Kriging Method is an interpolation method that produces an unbiased prediction or estimation which is also known as the Best Linear Unexpected Estimator (BLUE). Estimated value of the estimated variable using equation $\hat{Z} = \sum_{i=1}^{n} w_i Z_i$ with $\sum_{i=1}^{n} w_i = 1$. $\hat{Z}$ is the estimated value and $Z_i$ is the value of the sample at the i-location weighted, $w_i$ is the weighted sample. Sample weights are not only based on the distance between the size and location of the predicted points but also on the overall location of the points measured [8-9].

3. Result

3.1. Analysis of Descriptive Statistics
Based on descriptive statistics of each data, the highest average is owned by hematite. It means that hematite has high variability in contain of cassiterite at the period. It is also seen from the variance value of hematite. Meanwhile, zircon has the smallest average. Zircon has the least content compared to hematite or tin. We can see it from the maximum and minimum values of zircon. Based on the coefficient of variation, zircon has homogeneous data when we compared with hematite and tin. The three coefficients can be further processed and already represent the existing population of data. The descriptive statistics of hematite, tin and zircon will be show in Table 1.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|}
\hline
Samples & Hematite & Tin (Sn) & Zircon (Zr) \\
\hline
Count & 26 & 26 & 26 \\
Sum & 929,639.27 & 39,115.52 & 5,687.63 \\
Average & 35,755.36 & 1,504.44 & 218.76 \\
Median & 23,329.52 & 243.25 & 215.11 \\
Minimum & 8,722.17 & 10.71 & 63.32 \\
Maximum & 95,268.26 & 10,460.56 & 314.15 \\
Range & 86,546.09 & 10,449.85 & 250.83 \\
Standard Deviation & 26,354.27 & 2,413.63 & 61.48 \\
Variance & 694,547,645.51 & 5,825,624.56 & 3,779.87 \\
Coefficient of Variation & 0.737 & 1.604 & 0.281 \\
\hline
\end{tabular}
\caption{Descriptive statistics of each data}
\end{table}

3.2. Analysis of Spatial Data
The Ordinary Kriging method has spatial relationship parameters that help interpolate between each data in the research area using semivariogram isotropic. Parameters and models of semivariogram will be shown in Table 2 and Figure 1.
Table 2. Parameters of the semivariogram model

| Sample               | $R^2$   | Proportion $(C/[C+C'])$ | Model     |
|----------------------|---------|-------------------------|-----------|
| Hematite (Fe$_2$O$_3$) | 0.506   | 0.902                   | Spherical |
|                      | 0.452   | 0.999                   | Exponential |
|                      | 0.496   | 0.775                   | Gaussian   |
| Tin (Sn)             | 0.373   | 0.999                   | Spherical |
|                      | 0.355   | 0.993                   | Exponential |
|                      | 0.376   | 0.860                   | Gaussian   |
| Zircon (Zr)          | 0.432   | 0.998                   | Spherical |
|                      | 0.379   | 0.993                   | Exponential |
|                      | 0.425   | 0.891                   | Gaussian   |

Based on the Table 2, if we look at the proportion of parameters, the experimental semivariogram model of each mineral tends to follow the spherical and exponential models. Meanwhile, the coefficient of determination of the three models of each mineral show that the best semivariogram model tends to the spherical model. In here, we use the spherical model to analyze and interpolate the distribution of the cassiterite minerals with the Ordinary Kriging method (Figure 2).

![Figure 1](image-url)
Figure 2. Distribution of the cassiterite minerals with the Ordinary Kriging method, (a) Hematite ($\text{Fe}_2\text{O}_3$); (b) Tin (Sn); and (c) Zircon (Zr)

Based on the results of the kriging method, we can see that many zircon minerals are scattered in almost all directions of the research site. Meanwhile, the results of the kriging method show that the distribution pattern of hematite mineral content is mostly found in areas that spread in northeast and east. The pattern of distribution of tin mineral mostly find in the east. Zircon mineral distribution patterns mostly find in the west to northwest and east directions. Therefore, we can say that the pattern of spread hematite, tin and zircon minerals mostly found in the east of the research site.

If we see from the research area, where in the northeast direction is a hilly area that has a steep height then the mining method suitable to be apply at this research location is the open mining method. This method is mining by circling hills and the direction of excavation or the direction of mining when extracting minerals carried out on the hillside. If we know the mining method and the direction of mining, we can prevent environmental damage. Therefore, we can prevent environmental damage caused by post mining at Sambunggiri Hill by applying open mining to the east of the research site.

4. Conclusion
The spherical model can be applied to describe the spatial relationship between location pairs based on Cassiterite mineral content such as Hematite ($\text{Fe}_2\text{O}_3$), Tin (Sn), and Zircon (Zr). The pattern of minerals distribution is mostly found to the east of Sambunggiri hill. In this research, we want to show that knowing the estimated distribution pattern of Cassiterite minerals can provide an overview of mining activities that can prevent environmental damage. So that environmental damage caused by mining activities can be minimized and raise awareness to maintain a sustainable environment. A good mining concept will have a positive impact on the surrounding environment.

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Acknowledgments
We gratefully acknowledge the support from USAID through the SHERA program - Centre for Development of Sustainable Region (CDSR). In year 2017-2021 CDSR is led by Center for Energy Studies –UGM.