The potential for land erosion due to primary tin mining in Bangka Island

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Abstract. In the context of primary tin mining by PT. Timah on the Bangka Island, an analysis of environmental impacts is needed concerning various related aspects. One of the potential impacts that need to be considered is erosion due to open land for mining activities. Rain and mining water triggers the process of erosion on open land with particular soil and topographic characteristics. This paper presents an analysis of the potential for erosion due to primary tin mining at five mining locations in Bangka Island. The soil erosion rate can be analyzed using the Universal Soil Loss Equation (USLE) and GIS. The environmental data used to predict the erosion rate include soil type, soil texture and structure, land cover, rainfall, slope, and soil management techniques. In this study, rainfall erosivity is taking into account based on average monthly rainfall from 2010-2019. The results showed that the erosion rate at the primary mining sites are relatively low, ranging from 4.72 to 683.47 tons/ha/year. The results showed that the erosion rate is more influenced by the topography (slope factor). Besides, the considerable land-use change will also contribute significantly to the amount of soil erosion.

1. Introduction
Tin Mining Activities by PT. Timah Tbk in the Province of the Bangka Belitung Islands has encouraged various job and business opportunities for the local community, regional accessibility, education, and public health. However, onshore and offshore tin mining activities, including processing and supporting facilities, can negatively impact the environment. In 2019, PT. Timah Tbk plans to change the onshore tin mining system, especially in Bangka Island, using the Carbon Dioxide (CO₂) Cracker and Static Expansion methods. This method is used to break the rock soil by the cracking technique. After the rock is cracked, the mining process is carried out using conventional methods. In general, the conventional mining process is carried out by excavating/dredging a layer of soil to a certain depth and then washing the soil layer to obtain tin ore.

Tin mining with an open-pit system (conventional method) causes damage to the biophysical aspects of land resources that need serious attention. Open-pit mining activities generally damage the topsoil. Furthermore, pit side erosion, landslides, hazardous materials, or mining waste affect downstream areas and even reach the sea [1]. Excavation at the mining site causes the opening of land cover and causes differences in the contour lines of the mining site to the surrounding area. The overburden and topsoil from the excavation are piled up to the area around the mining site, which can be eroded by rainfall runoff. The eroded soil can cause sedimentation in the water body around the mining site, reduce water quality and cause an increase in surface runoff. A study on the potential for soil erosion at the mining site needs to be carried out after a change in the plan for the primary tin mining system in five locations.
on Bangka Island. The results of this study can be used by PT. Timah Tbk as the basis for managing hydrological impacts due to mining activities at the location.

This study analyzes the potential for erosion at the primary mining site on Bangka Island based on the existing land use conditions and conditions after turning into mining land.

2. Literature Review

Studies on soil erosion have received progressive attention from many researchers. Erodibility is an essential parameter of erosion analysis for estimating soil loss and assessing and predicting environmental impacts on surface water bodies. Many factors affect soil erodibility. Due to the complexity of erosion processes, the inherently complex nature of soil erodibility, and inadequate or incomplete data sets from many previous studies, there is a large gap between available and required factors in current soil loss prediction and soil conservation technologies [2]. Various methodologies and models have been developed to observe the disintegration of soils by water and anticipate the hazards and forces of soil erosion. Several models in previous studies have proven effective in estimating soil erosion at different scales. One of the most commonly used models is the universal soil loss equation (USLE) [3]–[11].

The USLE method is still widely used because of its simplicity, high level of data flexibility and accessibility, and extensive scientific literature. Nowadays, the use of the USLE method is integrated with geographic information systems (GIS) [2], [6], [7], [10], [11], because it can overcome the problems where input model data is difficult to obtain. According to [3], the USLE model can be successfully used to estimate soil erosion because it considers climatic factors, topography, soil types, and land management practices. However, the USLE model cannot assess the impact of a single factor on soil erosion, such as changes in land use alone or changes in rainfall erosivity. The USLE model parameters are written as follows:

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \]  

(1)

where \( A \) is the average annual soil loss (ton/ha/year); \( R \) is rainfall erosivity factor (MJ mm/ha/year); \( K \) is soil erodibility factor (ton/ha/R unit); \( L \) is slope length factor (dimensionless); \( S \) is slope steepness factor (dimensionless); \( C \) is crop management factor (dimensionless); and \( P \) is the erosion control practice factor (dimensionless).

2.1. Rainfall erosivity factor (\( R \))

Rainfall erosivity is an impact factor for the quantitative assessment of soil erosion. This factor reflects the ability of soil erosion caused by rainfall, which is closely related to rain depth, rainfall energy, and rainfall duration. Many approaches can be used to estimate the magnitude of the rain erosivity index, including the developed Equation by Abdurachman (1989), Bols (1978), Lenvain (1989), Soemarwoto (1991), dan Utomo dan Mahmud (1984) [12]. However, a more straightforward approach that gives reasonably good approximate results is the Lenvain equation. The equation is written as follows:

\[ R = 2.21(R_m)^{1.36} \]  

(2)

where \( R_m \) is the average monthly rainfall (mm).

2.2. Soil erodibility factor (\( K \))

The soil erodibility factor (\( K \)) indicates the resistance of soil particles to peeling and transport of soil particles by the kinetic energy of rainfall. Soil erodibility is affected by many soil properties. In principle, soil properties that affect soil erodibility are soil properties that affect infiltration rate, soil permeability, and soil properties that affect the resistance of the soil structure to dispersion and erosion by rainwater droplets and surface runoff [13]. Estimating the erodibility index of several types of soil in Indonesia can refer to [13] and [14].
2.3. Slope length factor (L) and slope steepness factor (S)
Slope length and slope steepness factors were used to estimate the effect of topography on soil erosion using the ULSE model. \( L \) and \( S \) respectively represent the effect of slope length and slope steepness on erosion. The calculated soil erosion rate is more sensitive to the steepness of the slope than the length of the slope. In other words, the steeper and longer the slope, the higher the risk of erosion [3]. The composite value of the slope length and slope steepness factor (\( LS \)) can be determined based on the value issued by Forest Minister, Government of Indonesia [15].

2.4. Cover-management and the support-practice factors (CP)
The \( C \) factor measures the combined effect of all interrelated land use and management variables that can easily change to reduce erosion. Changes in land use will not bring serious problems as long as it follows soil and water conservation and land capability grade rules [6]. The \( P \) factor plays an essential role in the form of land conservation practices. The \( P \) factor is the ratio of soil loss from land with a particular conservation practice to land plowed in a direction parallel to the slope if all other conditions remain unchanged. The value of crop management factor and erosion control practice factor (\( CP \)) based on land use can be seen in Table 1.

| Land use           | CP Factor |
|--------------------|-----------|
| Uncultivated land  | 1         |
| Rice field         | 0.05      |
| Forestry           | 0.03      |
| Plantation         | 0.4       |
| Mixed Plantation   | 0.2       |
| Water body         | 0         |
| Shrubs             | 0.3       |
| Settlements        | 0         |
| Swamp              | 0         |

3. Data set and Methodology
There are five locations of PT Timah Tbk’s primary tin mining that are the focus of this research, namely the Mayang (DU-1494) and Tempilang (DU-1509) in West Bangka Regency, Pemali (DU-1517) and Sambung Giri (DU-1522) in Bangka Regency, and Paku (DU-1536) in South Bangka Regency. The map of the study location is presented in Figure 1. The area of each tin mining site and its topographic characteristics are shown in Table 2.

| Mining site          | Area (ha) | Slope gradient |
|----------------------|-----------|----------------|
| Mayang (DU-1494)     | 146.88    | 8-40%          |
| Tempilang (DU-1509)  | 408.15    | 8-15%          |
| Pemali (DU-1517)     | 207.39    | 0-8%           |
| Sambung Giri (DU-1522)| 118.35  | 0-8%           |
| Paku (DU-1536)       | 13.83     | 0-15%          |
In this study, the potential for erosion that occurs at the primary tin mining location is predicted by using the USLE model (Equation 1), where the review is carried out on two conditions, namely the existing condition (before tin mining) and the condition of land conversion to mining (uncultivated area). Erosivity indexes (R) are calculated using Equation (2) based on the average monthly rainfall on Bangka Island from 2010 to 2019 (Figure 2).

Soil erodibility indexes (K) are determined based on references from [13] and [14]. To determine the type of soil and land cover at each primary tin mining location, Imagery maps of the Province of Bangka Belitung in 2018 are used. Land use data along with conservation practices are used to determine the CP value according to Table 1. The amount of soil loss in ton/ha/year is calculated using Equation (1).

Overall, the determination of the value of the USLE model variables related to the spatial index was carried out using geographic information system software.

4. Result and Discussion

Monthly rainfall in Bangka Island is relatively high, with the highest average occurring in December and the lowest average in September. Only 17% of rainfall values <100 mm/month, while rainfall between 100-200 mm/month occurs as much as 33%, the remaining 50% is rainfall with a depth of >200 mm/month. The monthly rainfall erosivity indexes in Bangka Island that were calculated using Equation (2) are presented in Table 3.

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Rainfall depth (cm) | 21.85 | 25.91 | 27.83 | 23.66 | 19.33 | 13.59 | 12.73 | 9.78 | 8.25 | 13.54 | 22.85 | 29.58 |
| Erosivity | 146.52 | 184.81 | 203.63 | 163.28 | 124.07 | 76.85 | 76.85 | 49.13 | 38.95 | 76.41 | 155.75 | 221.23 |

In most study locations, the soil type is Hapludox (rather fast) with erodibility value (K) = 0.43. Only at Mayang site is dominated (48%) by Dystrudepts soil type (a bit slow) with K value = 0.2, followed by Hapludox soil type as much as 38%, and the rest (14%) is Endoaquepts soil type (slow) with a value of K = 0.1.

Land use at the primary mining location on Bangka Island is a mixed plantation, shrub, mining area (uncultivated land), forestry, plantation, and water body. The percentage of each land use at each
primary mining site on Bangka Island is presented in Table 4. From Table 4, it can be seen that only at the Mayang mining site is there an area of forestry, and only at the Pemali mining site is there an area of the water body. In general, almost all mining sites have land cover in the form of plantations and mixed plantations. CP values are estimated from 0.03 - 1 at the Mayang site, 0.2 - 1 at the Tempilang site, 0 - 1 at the Pemali site, 0.2 - 0.4 at the Sambung Giri site, and 0.2 - 0.3 at the Paku site.

| Land use          | Mayang | Tempilang | Pemali | Sambung Giri | Paku |
|-------------------|--------|-----------|--------|--------------|------|
| Uncultivated land | 19.7   | 68.8      | 74.9   | -            | -    |
| Forestry          | 10.2   | -         | -      | -            | -    |
| Plantation        | 3.9    | 0.5       | 3.5    | 95.6         | -    |
| Mixed Plantation  | 54.6   | 30.7      | 4.8    | 4.4          | 61.2 |
| Water body        | -      | -         | 16.8   | -            | -    |
| Shrubs            | 11.6   | -         | -      | 38.8         |      |
| Total             | 100    | 100       | 100    | 100          | 100  |

LS values are determined based on the slope gradient in Table 2 and the guidance from [15]. At the Mayang site, the LS values are 1.4 and 6.8, where the land area with a slope of 8-15% is almost the same as the land area with a slope gradient of 25-40%. For the Tempilang site, the LS value is 1.4. LS values at Pemali and Sambung Giri sites are 0.4, while the LS values at Paku site are 0.4 and 1.4. 65% of the area at the Paku site has a slope of 8-15%.

By entering the values of existing variables into the USLE model (Equation 1) for each land use, soil type, and slope, the magnitude of the potential for erosion at the primary mine site on Bangka Island can be computed (Table 5). The values in Table 5 indicate that the potential for erosion in the existing conditions at the primary mining site is relatively low, ranging from 2.60 to 37.97 tons/ha/year. Interestingly, the slope factor indicates the higher erosion rates at the Mayang, Tempilang, and Paku sites than the Pemali and Sambung Giri sites. An area dominated by a steep slope will provide a significant contribution to the LS variable.

By converting all land use into mining areas, there was a significant increase in erosion at the Mayang, Sambung Giri, and Paku sites (>150%). This is indicated due to a considerable change from the plantation and mixed plantations area to the mining area (uncultivated land). There was no significant increase at the Tempilang and Pemali sites because mining areas dominated the existing land use conditions at these locations. Based on this fact, it can be concluded that the considerable land-use change will also contribute significantly to the amount of soil erosion.

Even though there was an increase in soil loss at the three primary mining sites, the erosion hazard class with changes in land use was still relatively low, except for the Mayang mine site, which changed to a moderate erosion hazard class. The increase in potential erosion from existing conditions to mining conditions is presented in Figure 3.

| Mining site       | Soil loss (ton/ha/year) – erosion hazard class | Increase (%) |
|-------------------|-----------------------------------------------|--------------|
| Mayang (DU-1494)  | 28.39 – low                                   | 247.66       |
| Tempilang (DU-1509)| 37.97 – low                                   | 33.08        |
| Pemali (DU-1517)  | 2.60 – very low                               | 29.23        |
| Sambung Giri (DU-1522)| 3.80 – very low                             | 158.16       |
| Paku (DU-1536)    | 9.53 – very low                               | 297.17       |
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As presented in Table 5 and Figure 3, the increase in soil loss only considers land-use change conditions without considering the mining activities themselves. Since open pit mining has several processes that can trigger erosion, such as excavation and soil piling, as well as material washing/separation of tin ore, the actual potential for erosion during the active tin mining process at the mine site can be much greater than the currently estimated. A closed-circuit drainage system and settling pond can be applied at the mining site to minimize the impact of erosion triggered by the mining process in the surrounding area.

5. Conclusion
The primary tin mining site on Bangka Island has a low level of erosion under existing conditions. The study showed the slope factor has a significant contribution to soil erosion. When the existing land-use converted to a mining area, there has been a considerable increase in erosion at three mining sites: Mayang, Sambung Giri, and Paku. However, the increase in erosion does not necessarily increase the erosion hazard at the mining site. Further research needs to be done to evaluate the actual erosion caused by the tin mining process applied at the primary tin mining location.

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Figure 3. Potential for erosion from existing conditions to mining conditions
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