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Erosion Modeling in Overburden Excavation in Mining Areas with the Approach of Rain Intensity and Duration

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Abstract: This study investigates erosion modeling in overburden excavation in mining areas with the approach of rain intensity and duration. The main variables considered included rainfall erosion as well as slope length and slope, which were identified as key factors in predicting soil management. The linear regression method evaluated the relationship between independent variables (rainfall erosion, length, and slope) and dependent variables (soil management). The analysis showed that in Model 1, not all independent variables significantly influenced soil management. However, Model 2 revealed that precipitation erosion and slope length and slope significantly affected the dependent variables. These results provide an in-depth understanding of how weather and topographic factors affect soil management practices in mining environments. These findings can be used as a basis for environmental conservation and mitigation decision-making, especially in minimizing soil erosion due to mining activities. By paying attention to these factors, it is hoped that soil management practices can be improved to achieve better environmental sustainability. Further research is recommended to expand this understanding in various geographical conditions and mining environments.

Keywords: Soil erosion; Excavation overburden; Mining area; Rain intensity; Rain duration.

Introduction

The mining industry plays an important role in the global economy, providing important raw materials for various industrial sectors (Yu et al., 2024; Q. Zhang, Wang, Wang, Luo, & Zhang, 2024). However, mining activities often have significant environmental impacts, including soil erosion. This problem becomes especially critical in excavation overburden, which is the layers of soil and rock that must be removed to expose the ore or precious minerals underneath (Gao et al., 2024). Inadequate overburden management can result in severe erosion, leading to sedimentation in rivers and lakes, degradation of soil quality, and disruption to local ecosystems (Majewski & Szpikowski, 2024).

Soil erosion that occurs in mining areas is influenced not only by the physical characteristics of the soil and topography but also by meteorological factors, especially the intensity and duration of rainfall (Pan, Shi, Jiang, & Xu, 2024; Vergamini, Olivieri, Andreoli, & Bartolini, 2024). Rainfall with high intensity and long duration can increase the surface flow rate, accelerating erosion. Therefore, understanding how rainfall patterns affect soil erosion in overburden excavation is essential to develop effective mitigation strategies.

The main problem faced in this study is the lack of an accurate and practical model to predict soil erosion based on the intensity and duration of rainfall in the mining area (de Souza Batista et al., 2024; Duressa et al., 2024). Existing models often do not adequately consider the variability of rain conditions and the specific characteristics of each excavation site. As a result, the mitigation measures implemented may not be effective,

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leading to continued environmental damage (B. Zhang et al., 2024; Zhou, Yi, Liu, Tang, & Zhang, 2024).

The study of soil erosion has long been the focus of environmental science research, especially in agriculture and forestry (Cao et al., 2024; Qi et al., 2024). However, in recent decades, attention to erosion in mining areas has increased in line with awareness of the environmental impact of mining activities. Previous research has shown that the intensity and duration of rain are the main factors affecting erosion, i.e., the ability of rain to cause erosion (Lu, Gu, Shi, & Zhou, 2024). In addition, topographic characteristics such as the slope's length and slope also play an essential role in determining the erosion rate. However, research specifically examining the combined influence of these factors in the context of excavating overburden is still limited.

Recently, more sophisticated erosion modeling approaches have begun to be implemented, using statistical techniques and computer simulations to predict erosion in various environmental conditions. One widely used method is linear regression, which allows the analysis of relationships between multiple independent and dependent variables (Tsegaye, Degu, Mekonnen, & Gashaw, 2024; H. Zhang & Renschler, 2024). This study adopts the method to evaluate the effect of rain intensity and duration, slope length, and slope on erosion in mining areas. As such, this research contributes to a scientific understanding of erosion mechanisms and provides mine managers with practical tools to improve their soil management practices (Fentaw & Abegaz, 2024; Wei, Ding, Li, Zhang, & Duan, 2024).

This study introduces an innovative approach to erosion modeling in overburden excavation by integrating rain intensity and duration as the main variables (Chen et al., 2024; Wu et al., 2024). The uniqueness of this study lies in the application of linear regression methods to examine the combined influence of these factors along with the length and slope of slopes, which have not been explored in depth in the context of mining (Xiong, Wu, Wang, Ma, & Lin, 2024; Y. Zhang et al., 2024). In addition, this research focuses on identifying the factors that affect erosion and developing models that can predict erosion more accurately and applicatively in the field. This provides a new foundation for further research that could lead to more effective and sustainable soil management strategies in the mining industry.

The main contribution of this study is to provide in-depth insights into the complex interaction between weather and topographic factors in influencing soil erosion in mining areas. These findings can be a critical decision-making tool in environmental conservation and mitigation efforts. The developed model can help mine managers design more effective drainage systems, reducing erosion rates and minimizing negative impacts on the surrounding environment. The evaluation shows that by comprehensively considering the erosion of rainfall, length, and slope, soil management can be significantly improved to achieve better environmental sustainability.

This study aims to develop an erosion model that integrates the intensity and duration of rainfall as the main factors. By utilizing meteorology, topography, and soil physical property data, this model is expected to provide more accurate predictions regarding the level of erosion in overburden excavations. This approach will help in the identification of areas prone to erosion as well as in the planning of better preventive measures.

Through this approach, it is hoped that a more effective solution to the problem of soil erosion in mining areas can be obtained, which will ultimately support more sustainable and responsible environmental management. This research will contribute to the scientific literature on soil erosion and provide practical benefits for the mining industry in efforts to mitigate environmental impacts.

Method

The research was carried out at PT. Bukit Asam Tbk is in the MTBU Pit of the Muara Tiga Besar IUP Mining Operation area, Lahat Regency, South Sumatra, with a research location area of 538 ha. The research time will be carried out from December 2023 to February 2024. The analysis of soil samples was carried out at the PT. Bukit Asam Tbk.

This study uses quantitative methods and field sampling to explore the relationship between rainfall and soil erosion in the overburden excavation area. The quantitative approach involves statistical data analysis to measure the relationship between the variable intensity and duration of rain and soil erosion at the mining site. Meanwhile, field sampling was carried out to collect soil erosion data through direct observation, which was then used to validate the model and support further analysis. This study aims to understand the impact of rain intensity and duration on soil erosion rates in the overburdened excavation area. In addition, this study analyzes how meteorological factors, such as rainfall, intensity, and duration, play a role in influencing soil erosion in the mining area.

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Result and Discussion

Data Description

The data description aims to describe the characteristics of each of the research variables, consisting of: Eroticism (X1), Erodiability (X2), LS Factor (X3), and CP Factor (X4), as well as Soil Tillage (Y) in excavation overburden in mining areas. The data of all these variables are processed based on descriptive statistics.

Table 1. Data Frequency Distribution

Year	Eroticism	Erodibility	LS	CP	A
2019	2,682.8	0.35	5.62	0.46	4,287.32
2020	2,866.6	0.35	8.05	0.56	7,689.42
2021	3,102.1	0.35	10.83	0.72	13,901.57
2022	3,303.2	0.35	14.97	0.80	22,427.10
2023	1,553.9	0.35	17.50	0.90	19,743.82
Average	2,701.2	0.35	11.39	0.69	68,049.22

From the available data, we can see some important patterns and trends LS and CP factor increase: There is an increase in LS and CP factors from 2019 to 2023. This indicates that the length of slopes and slopes of slopes is increasing, and crop management and conservation practices are also increasing Fluctuations in Erosivity: The erosivity values show some variation with the lowest values in 2023 and the highest in 2022. Significant Tillage: Tillage has seen a significant increase each year, especially in 2022, although there has been a slight decline in 2023. This analysis is important to understand the factors affecting soil erosion in mining areas and to develop effective mitigation strategies. Additional data and advanced statistical analysis are needed to deepen this understanding and to make more specific recommendations.

Test Requirements Analysis

The analysis requirements test is carried out as a basis for consideration to determine the data analysis technique used in hypothesis testing. The testing of the analysis requirements includes, normality testing and regression linearity testing.

Normality Test

If the normality used is a normality test of the estimation error. The normality of estimation error testing was carried out with the help of the SPSS program on the basis of the following decision-making:
If the value of Sig. > α = 0.05, then the data is normally distributed
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Table 2. Data Normality

Variable	Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)	Conclusion
Rainfall Eroticism	0.643	0.802	Normally distributed data
Erobility	0.418	0.807	Normally distributed data
Length and Slope of Slope	0.377	0.999	Normally distributed data
Land Conservation	0.383	0.999	Normally distributed data
Soil Management	0.418	0.995	Normally distributed data

The results of this test show that all variables have Asymp values. Sig. (2-tailed) is greater than 0.05, which means there is no strong evidence to reject the null hypothesis that the data is normally distributed. Thus, it can be concluded that the distribution of data from all five variables follows the normal distribution.

The results of normality analysis using the Kolmogorov-Smirnov Test One Sample showed that all research variables were normally distributed. This is important because many of the statistical methods used in this study assume the normality of the data.

Rainfall Rosivity: Has a normal distribution with a Kolmogorov-Smirnov Z value of 0.643 and a significance of 0.802. This shows that the rainfall data in this study are quite uniform and can be used for further analysis without additional transformation. Erobility: Shows results similar to the Kolmogorov-Smirnov Z value of 0.418 and significance of 0.807. This indicates that the factors affecting the soil erosion in this sample are normally distributed.

Length and Slope of Slope: With a Kolmogorov-Smirnov Z value of 0.377 and a significance of 0.999, this distribution of data is very close to the normal distribution, facilitating further analysis that requires assumptions of normality. Land Conservation: The test results with a Kolmogorov-Smirnov Z value of 0.383 and a significance of 0.999 also show a normal distribution, which is important for conservation analysis and implementation of mitigation strategies. Soil Management: This variable has a Kolmogorov-Smirnov Z value of 0.418 and a significance of 0.995, indicating that the soil management in this sample is also normally distributed.

From the results of the Kolmogorov-Smirnov Test One Sample, it can be concluded that the data for all research variables are normally distributed. This allows the use of parametric statistical methods that require assumptions of data normality. This finding also strengthens the validity of the results of the analysis that will be carried out next.

Linear Regression Test

Linear regression is a statistical method used to analyze the relationship between one dependent variable (bound) and one or more independent (independent) variables. The linear regression test aims to determine whether there is a significant relationship between dependent and independent variables, as well as how strong the relationship is.

Table 3. Multiple Regression Model 1.

Model	Independent Variables	Coefficients are not standardized (B)	Std.Error	Standardized coefficients (Beta)	T	Sig	Correlation
	Constant	-22185,419	6029,552		-3,679	0,169	
1	Rainfall Eroticism	3,904	0,865	0,346	4,512	0,139	-0,113
	Slope Length and Slope Data	2028,483	675,033	1,283	3,005	0,205	0,949
	Land Conservation Data	-8366,447	18079,824	-0,193	-0,463	0,724	0,944

Table 4. Model 2 Multiple Regression.

Model	Independent Variables	Coefficients are not standardized (B)	Std.Error	Standardized coefficients (Beta)	t	Sig	Correlation
2	(Constant)	-23943,973	3647,354		-6,565	0,022	
	Rainfall Eroticism	3,800	0,651	0,337	5,837	0,028	-0,113
	Slope Length and Slope Data	1720,845	91,216	1,088	18,866	0,003	0,949

Model 1:

Constant: A coefficient value of -22185.419 with a value of t -3.679 and Sig. 0.169 indicates that this constant is not significant at a 95% confidence level. Rainfall Erosivity: A coefficient of 3.904 with a t-value of 4.512 and Sig. 0.139 shows an insignificant relationship. Slope Length and Slope Data: Coefficient 2028.483 with t-value 3.005 and Sig. 0.205 shows an insignificant relationship. Land Conservation Data: Coefficient -8366.447 with t-0.463 and Sig. 0.724 shows an insignificant relationship. Model 2: Constant: A coefficient value of -23943.973 with a value of t -6.565 and Sig. 0.022 indicates that this constant is significant at a confidence level of 95%. Rainfall Erosivity: A coefficient of 3.800 with a t-value of 5.837 and Sig. 0.028 shows a significant relationship at a 95% confidence level. Slope Length and Slope Data: Coefficient 1720.845 with t-value 18.866 and Sig. 0.003 shows a very significant relationship at a 95% confidence level.

Interpretation Model 1: There were no significant variables at the 95% confidence level, which means that Rainfall Erosivity, Slope Length and Slope Data, and Land Conservation Data had no significant influence on the Soil Management Data in this model.

Model 2: Significant constant with a Sig. value of 0.022. The erosivity of Rainfall was significant with a value of Sig. 0.028, indicating that this variable had a significant influence on Soil Management Data. The Length and Slope Data were very significant with a value of Sig. 0.003, indicating that this variable had a very significant influence on the Soil Management Data.Based on the results of Model 2, it can be concluded that the Erosivity of Rainfall and the Length and Slope Data are important predictors for the Soil Management Data.

The results showed that not all independent variables had a significant influence on soil management in Model 1, indicating the presence of other factors that may play a role in influencing erosion. The erosity of rainfall, although an important factor, does not always make a large contribution in the absence of interaction with other variables such as the length and slope of the slope. This suggests that a more holistic approach is needed to understand soil erosion dynamics more comprehensively. In addition, the variability of rainfall data and the heterogeneity of topographic characteristics at the study site can also affect the regression results, so the initial model is not sufficient to accurately predict erosion (Yifei Wang et al., 2024; Yong Wang et al., 2024).

In Model 2, after considering the interaction between rainfall erosion and slope length and slope, it was found that all of these variables significantly affected soil management. This suggests that the effect of rain on soil erosion is amplified by the length and slope of the slope, where longer and steeper slopes tend to accelerate the flow of surface water and increase the potential for erosion. These findings are consistent with the theory that topography plays an important role in directing and accelerating the flow of water, which in turn increases the ability of rain to erode the soil. Therefore, the integration of topographic variables with weather parameters in erosion models provides more accurate and reliable predictions (Al-hasn, Alghamaz, Dikkeh, & Idriss, 2024; He, Miao, Wang, Yang, & Zhang, 2024).

In addition, the practical implications of this study are the importance of management strategies that consider weather and topographic factors simultaneously. For example, the design of drainage systems and terraces on steep slopes can be optimized based on rainfall intensity and duration data, as well as local topographic characteristics. This can reduce the rate of erosion and minimize the negative impact on the surrounding environment (Dong, Fu, Liu, & Yin, 2023; Pal, Hembram, & Jana, 2024; Shi, Zheng, Zhao, Xu, & Liu, 2024). Thus, this research not only provides theoretical insights but also offers practical solutions for land management in mining areas. These findings can serve as a reference for the development of more effective soil conservation policies and practices, as well as provide a basis for further research to broaden understanding in a variety of different geographical conditions and mining environments (Cea, García-Feal, Nord, Piton, & Legoût, 2024; Gholami et al., 2024; K. Wang et al., 2024).

The results of the regression analysis show that factors such as rainfall intensity (Rainfall Erosivity) and topography (Length and Slope of Slope) play an important role in influencing the level of erosion in the mining area. These results are consistent with the existing literature, which states that rainfall and topography are key determinants in the erosion process. Land conservation variables, although expected to have a significant effect, do not show significance in this model. There are several reasons that may explain why land conservation does not show a significant influence:

1. Effectiveness of Land Conservation Implementation: Perhaps the land conservation methods used are not effective enough to significantly reduce erosion. This can be due to improper technique or inconsistent application.
2. Data Variability: The data used may not be varied enough to show significant differences. Larger samples or data from different locations with different conservation conditions may be required.
3. Interactions with Other Factors: Land conservation may have complex interactions with other variables such as rainfall erosion and topography that cannot be captured well in simple regression models.

An in-depth interpretation of the findings of this study shows that the interaction between rainfall erosion with slope length and slope significantly increases the risk of soil erosion in mining areas (Ma, Tian, Zhao, Wu, & Liang, 2024; Zeng, Peng, Liu, Dai, & Chen, 2024). High-intensity rainfall tends to accelerate the flow of surface water on steep, long slopes, resulting in faster and more severe erosion of the topsoil layer (Asempah, Shisanya, & Schütt, 2024; Bai et al., 2024). This shows that weather and topography factors not only work independently, but reinforce each other in influencing erosion rates. Therefore, erosion prediction models that integrate these two variables offer higher accuracy and greater practical relevance in designing mitigation strategies.

For example, this approach can be used to determine strategic locations for the construction of terraces or drainage systems designed to reduce the speed of water flow and prevent erosion (Shojaeezadeh et al., 2024; Xie et al., 2024; Zi et al., 2024). Additionally, this model can aid in more thoughtful land-use planning by identifying areas most vulnerable to erosion and prioritizing conservation interventions in those areas. Thus, this study not only improves the theoretical understanding of erosion dynamics but also provides practical tools for more effective and sustainable environmental management in mining areas.

Conclusion

This study concluded that the interaction between the intensity and duration of rainfall with the length and slope of the slope significantly affects the level of soil erosion in the mining area. Using the linear regression method, this study successfully identified that weather and topographic factors not only impact individually but also synergistically strengthen erosion risk. These findings underscore the importance of an integrated approach in erosion modeling, which combines weather data and topographic analysis to provide more accurate and relevant predictions in the context of soil management. These results provide a strong foundation for the development of more effective conservation and mitigation strategies, which aim to reduce soil erosion and support environmental sustainability in mining areas. Thus, this research makes a significant contribution in improving land management practices and supporting better decision-making in the mining industry.

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Author Contributions
Each author contributes in some way to the completion of this research activity. The main author provides basic ideas and provides research materials and the second, third, fourth authors design research methods and furthermore, all authors share responsibility for data collection, data tabulation and analysis, review process, and article writing.

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Conflicts of Interest
Regarding this study, the author declares that there is no conflict of interest.

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