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Evaluation of the Level of Physical Damage Due to Erosion in Post-Sand Mining Land Using the Universal Soil Loss Equation (USLE) Method

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ABSTRACT

Sand mining activities at Km. 29 in Bukit Batu District, Palangka Raya City, have caused significant physical land damage. This study quantifies erosion rates in former sand mining areas using the Universal Soil Loss Equation (USLE) through field surveys and laboratory analysis. Soil samples were collected purposively from four locations (Kolong 1 TL, Kolong 2 TL, Kolong 1 BD, Kolong 2 BD) at 0-20 cm depth with three replications. Results showed erosion rates ranging from 0.54 to 2.52 tons/ha/year, classified as "very low" according to standard erosion hazard categories. However, in post-mining contexts with initial degradation, these rates indicate serious land vulnerability. The dominant factors influencing erosion were high rainfall erosivity (R=998.45 MJ.mm/ha/hr/year), minimal vegetation cover (C=0.8), and the absence of conservation practices (P=1), whereas soil erodibility was inherently very low (K=0.005-0.014). Although numerically classified as very low, the former sand mining land requires immediate conservation intervention. Practical implications emphasize integrated conservation through vegetative approaches (fast-growing cover crops) and mechanical methods (gulud terraces and rorak), focusing on modifying the conservation practice factor (P) as the most easily intervenable variable to prevent increased erosion and restore land conditions.

INTRODUCTION

Sand mining has become one of the most significant natural resource exploitation activities in supporting infrastructure development and economic growth. However, this activity often leaves serious environmental impacts that require deep attention from various stakeholders. The physical degradation of former mining sites is a primary concern, characterized by the loss of topsoil, the formation of voids, and unstable ground surfaces (Smith et al., 2020). This condition accelerates the erosion process, which not only leads to land degradation but also pollutes surrounding water bodies. According to Dewi et al. (2019), the implementation of weak environmental management policies for illegal sand mining has resulted in severe ecosystem damage, including increased erosion and sedimentation in receiving water bodies. Natural topographic changes and the removal of vegetation cover during the mining process expose subsoil material to erosive forces, thereby increasing surface runoff and sediment transport to downstream environments (Sukri et al., 2023).

Furthermore, the environmental impact of sand mining also encompasses a decline in biodiversity. Natural habitats disrupted by mining activities can lead to the loss of local flora and fauna species. This is exacerbated by changes in water flow, which can result in flooding during the rainy season and droughts during the dry season. The Global Sand Observatory (2021) reported that global sand consumption has tripled in the last two decades, making it one of the most exploited resources after water. This trend raises concerns about the sustainability of sand resources and their long-term environmental implications. Open-pit mining methods, commonly used in sand extraction, are highly susceptible to high erosion rates due to the disturbance of soil aggregation and increased interaction with rainwater (Zulkarnain et al., 2023). According to FAO (2015), approximately 33% of the world's land is experiencing moderate to severe degradation, largely caused by erosion, underscoring the urgency of addressing degraded ex-mining land.

Identifying land's physical damage, particularly through the calculation of erosion rates, is a crucial step in reclamation and rehabilitation planning. The Universal Soil Loss Equation (USLE) is a widely used tool for predicting soil erosion and has proven effective across various geographical and climatic contexts (Renard et al., 1997). Although the USLE model has been widely applied to predict erosion in various land types, including post-mining land, most previous studies have focused more on large-scale coal mining areas with steep topography (Sarminah et al., 2017; Revara & Nugroho 2025). Research that specifically examines the interaction of USLE factors on post-sand mining land with very coarse texture characteristics (dominated by sand), relatively flat topography, and humid tropical climate such as in Central Kalimantan is still very limited. Therefore, this study aims to analyze in depth how the very low soil erodibility factor (K) interacts with poor management factors (C and P) and high rainfall erosivity (R) in determining the level of land damage. By employing the USLE model, this study aims not only to calculate erosion rates but also to identify the key factors most contributing to land vulnerability, thereby providing more targeted conservation recommendations. Therefore, this research not only contributes to a local understanding of soil erosion in ex-sand mining areas but also offers insights applicable in broader contexts. The primary objective of this study is to quantify erosion rates in ex-sand mining areas and analyze the dominant causal factors using the USLE model.

RESEARCH METHODS

This research was conducted in October 2025 at the site of a former sand mining area, Km. 29, Bukit Batu District, Palangka Raya City. The study was carried out at four former sand mining locations divided into two directional sectors, namely Northeast (NE) and Southwest (SW), with specific locations of Pit 1 and Pit 2 within each sector (Figure 1).

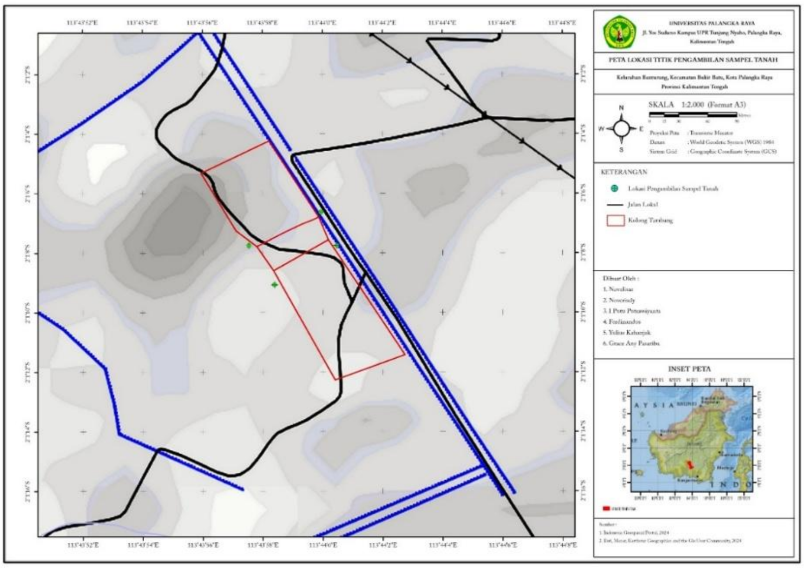

Figure 1. Soil Sampling Locations

Data Collection

Rainfall Data. Secondary daily rainfall data for 2024 were utilized to calculate the rainfall erosivity factor (R) using the Fournier method modified by Renard & Freimund (R=0.548 x (MFI)1.287). This method was chosen due to its ability to integrate monthly rainfall variability into a single, easily interpretable index, the Modified Fournier Index (MFI) (Neuman, 2011).

Soil Sampling was carried out using purposive sampling at four post-mining locations representing different conditions (Kolong 1 TL, Kolong 2 TL, Kolong 1 BD, Kolong 2 BD). At each location, one representative sampling point was determined. At each point, soil samples were taken at a depth of 0-20 cm (topsoil layer) with three replications (composite) to obtain accurate data. Sampling was conducted using ring samples (for bulk density analysis) and plastic bags (for texture, pH, and moisture content analysis). These parameters are crucial as they directly influence soil erodibility (K).

Topography. Topographic measurements, specifically slope gradient (degrees) and slope length (m), were conducted using a clinometer and measuring tape. This data was employed to compute the topographic factor (LS).

Land Cover. Field observations determined the land cover types, which were then converted into a land cover management factor (C). In this study, all locations were assumed to be "Open Land" (C=0.8) based on field observations showing no significant vegetation cover.

Conservation Practices. Observations were made regarding the presence or absence of soil conservation practices. As no conservation practices were identified, the conservation practice support factor (P) was set at 1, following the standard reference where P=1 indicates no conservation measures (Arsyad, 2010).

Data Analysis

To calculate the erosion rate, the Universal Soil Loss Equation (USLE) was used, formulated as follows:

A = R x K x LS x C x P

where:

A = Soil erosion rate (tons/hectare/year)
R = Rainfall erosivity factor (MJ.mm/ha/hr/year)
K = Soil erodibility factor (tons.ha.hr/ha.MJ.mm)
LS = Slope length and gradient factor (dimensionless)
C = Land cover management factor (dimensionless)
P = Support practice factor (dimensionless)

To clarify the research flow, Figure 2 presents a flowchart illustrating the stages from data collection to analysis and interpretation of results.

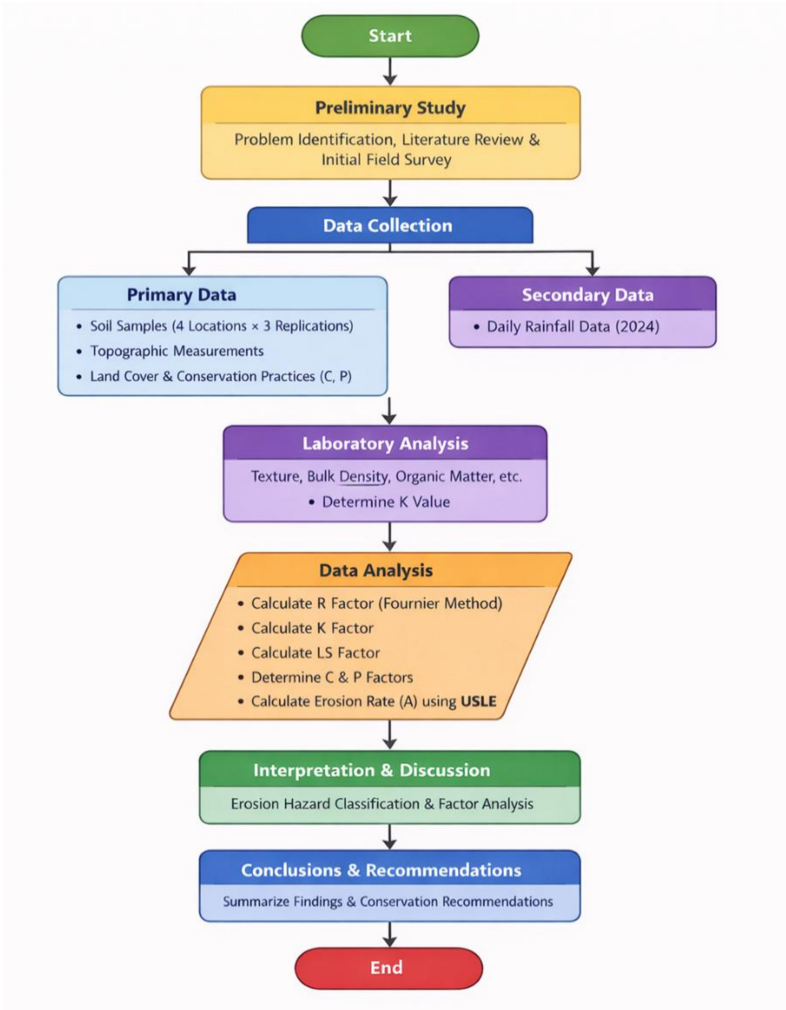

Figure 2. Research Flowchart

The resulting erosion rate (A) is then classified based on erosion hazard level categories according to Arsyad (2010) to assess the degree of land damage, as presented in Table 1.

Table 1. Erosion Rate Categories

Erosion Rate (ton/ha/year)	Category	Damage Level
<15	Light	Insignificant, still tolerable
15 – 60	Moderate	Requires attention and monitoring
61 – 180	Severe	Quite severe damage, requires conservation
> 180	Severe High damage	High damage, requires immediate intervention

Source : Arsyad (2010)

RESULTS AND DISCUSSION

Rainfall Erosivity (R)

Based on calculations using 2024 rainfall data, the R-factor value (rainfall erosivity) at the research site was obtained as 998.45 MJ.mm/ha/hr/year. This value is classified as very high and indicates that the rainfall energy with the potential to cause erosion is substantial, primarily driven by extreme monthly rainfall, such as in November, which reached 566.56 mm. The Modified

Fournier Index (MFI) calculation yielded a value that reflects the high rainfall variability throughout the year, characteristic of tropical climates with distinct wet and dry seasons.

This finding aligns with various studies that confirm the role of rainfall erosivity as a primary driving factor in the Universal Soil Loss Equation (USLE). Research by Ambarwati (2019) in the Sampean Watershed, East Java, for instance, demonstrated that an increase in rainfall directly elevates the R-value, ultimately increasing the erosion rate. This study affirmed that even if the overall erosion hazard level is considered low due to gentle topography, rainfall erosivity remains the principal determinant of the potential erosion magnitude.

When compared regionally, the R-value of 998.45 MJ.mm/ha/hr/year at this research site falls within the typical range for wet tropical regions. Research by Dash et al. (2019) in the Eastern Ghats Highland, India, reported higher annual R-values, ranging from 3,040 to 10,127 MJ.mm/ha/hr/year. Meanwhile, research by Das et al. (2022) in Tripura, India, obtained varied results between 533.17 and 2,452.27 MJ.mm/ha/hr/year for the period 2008–2017. This comparison places the R-value at the research site in a medium to high range within the regional context, while also confirming that areas with high rainfall possess significant erosion potential.

In the specific context of former mine sites, this high R-value becomes critically important. Research by Sarminah et al. (2017) in a coal mine reclamation area in East Kalimantan noted that the combination of a high R-value with minimal vegetation cover (C approaching 1) and no conservation measures (P=1) resulted in very high erosion rates, reaching 499 to 2,822 tons/ha/year. This is relevant to the conditions at the research site, which exhibits similar characteristics, where significant erosion potential requires primary attention in land rehabilitation efforts.

Soil Erodibility (K)

The results of laboratory analysis of soil samples and the calculation of the K-factor are presented in Table 2.

Table 2. Soil Erodibility (K) Analysis Results

Sample Code	Location	Sand (%)	Silt (%)	Clay (%)	K Value	Category
A1	Kolong 2 TL	87.06	7.23	5.71	0.014	Very Low
A2	Kolong 1 TL	96.98	0.33	2.69	0.006	Very Low
A3	Kolong 1 BD	95.25	0.31	4.44	0.005	Very Low
A4	Kolong 2 BD	95.42	1.41	3.17	0.009	Very Low

A "Very Low" K-value (0.005 - 0.014) inherently indicates that the soil is difficult to erode. This is attributed to the dominance of the sand fraction (>87%), which possesses low cohesion and high permeability, allowing rainwater to infiltrate more easily and resulting in less surface runoff. However, in the context of post-mining land, the disturbed soil structure makes these loose sand particles to be transported easily by water flow.

This finding aligns with the concept of soil erodibility as explained by Michigan State University (NRCS-USDA), where coarse-textured soils (sandy soils) have low K-values, ranging from 0.05 to 0.2, due to low surface runoff, even though these soils are easily detached. A similar point is emphasized by Zhang & Yu (2023) in their study on soil erodibility factors, stating that low K-values are assigned to soils with very high sand content because the dominant sand fraction results in low cohesion and high permeability.

The research by Suprapti & Arsyad (1992) in the Saguling Sub-watershed, Bandung, also confirms that low K-values are found in soils with high sand content, low silt, and low clay. This finding reinforces the analysis that the dominance of the sand fraction with its coarse texture is the primary cause of the low K-values at the research site. Conversely, soils with high silt and clay content result in higher K-values because they are easily detached and form surface crusts that increase surface runoff.

The study by Djuwansah & Mulyono (2017) on Lombok Island further confirms that a lower clay content in the soil leads to higher soil erodibility. However, in the case of sandy soils with a dominance of coarse fractions, the K-value becomes low due to high infiltration. This highlights the complexity of erodibility factors, which are not solely determined by a single parameter but by the interaction of all soil physical properties.

Nevertheless, the research by Seo (2018) in a mine disposal area in South Kalimantan found that despite a high sand content (30.03% – 69.43%) and relatively low K-values, erosion still occurred due to the disturbance of the soil structure post-mining. This finding is highly relevant to the research conditions, where sandy soils with low K-values remain susceptible to erosion due to the loss of soil aggregation and vegetation cover. This is consistent with the statement that even though a soil may have a low natural K-value, anthropogenic disturbances such as mining can increase its actual erodibility due to the loss of soil structure and organic matter.

Topography (LS) and Cover-Practice Factors (C & P)

Based on calculations, all four locations exhibit LS values of 0.23 and 0.13, derived from slope lengths of 30-50 meters and gradients of 1-2°. Positive LS values indicate that topography contributes to the erosion processes, even on gentle slopes. The consistency of this finding is further strengthened by the research of Zulkarnain et al. (2023) in East Kalimantan, which revealed that under identical R, C, and P conditions, the topographic factor (LS) was the primary differentiator of erosion rates. Meanwhile, Revara & Nugroho (2025) found erosion rates ranging from 2,474 to 8,709 tons/ha/year across various slope gradients. This significant difference is attributed to the predominantly gentle topography (LS 0.13-0.23) in this study compared to the steeper slopes in those aforementioned studies. This corroborates the theory proposed by Renard et al. (1997), stating that slope length and gradient (LS) factors play a significant role in surface runoff accumulation and its transport energy.

Across all locations, a C value of 0.8 was determined, indicating minimal vegetation cover (bare land). Arsyad (2010) defines the C factor as the ratio of erosion from land with specific vegetation to the erosion from bare land. C values range from 0 to 1, where 1 represents bare land conditions without vegetation. Wischmeier & Smith (1978) stated that vegetation reduces erosion through three mechanisms: (1) intercepting the kinetic energy of rainfall, (2) slowing down surface runoff, and (3) increasing infiltration via root systems. The C value of 0.8 in this study is close to the maximum value of 1, signifying very minimal vegetation cover and bare land conditions. This situation leads to soil particles, predominantly sandy, being highly susceptible to detachment by the impact energy of raindrops, particularly at locations with steeper slopes. This aligns with the statement by Asdak (2014) asserting that vegetation cover is the most effective factor in controlling erosion. The research by Sarminah et al. (2017) demonstrated that revegetated areas had the lowest erosion rates (499.12 tons/ha/year) compared to active disposal areas (2,822.40 tons/ha/year) and soil stock areas (884.40 tons/ha/year). These findings confirm the effectiveness of vegetation cover in reducing erosion rates, consistent with the mechanisms elucidated by Wischmeier & Smith (1978).

A P value of 1 was assigned, signifying the absence of implemented soil conservation practices. The P factor, according to Renard et al. (1997), reflects the influence of conservation measures. A P value of 1 indicates no conservation measures, which, according to Morgan (2005), represents the worst-case scenario. The combination of C = 0.8 and P = 1 represents the worst-case conditions that maximize erosion potential. Kusumandari et al. (2012), in their research in the Ngrancah Kulonprogo Sub-watershed, found that the P factor (soil and water conservation practices) was one of the most dominant factors differentiating erosion levels between land units. This finding underscores the importance of the P factor as a modifiable key variable for the rehabilitation of ex-mining land. This is further reinforced by the findings of Irawan (2016) in a clay mine in Bogor, where erosion rates before conservation measures reached 156.12 tons/ha/year but drastically decreased to 6.245 tons/ha/year after the implementation of conservation (P<1). This strengthens the assertion by Sukartaatmadja et al. (2002) that C and P factors are modifiable variables for mitigating erosion.

Erosion Rate (A)

The results of the erosion rate (A) calculation are presented in Table 3.

Table 3. Erosion Rate Calculation on Former Sand Mining Land

Location	R (MJ.mm/ha/hr/yr)	K	LS	C	P	A (tons/ha/yr)
Kolong 2 TL	998.45	0.014	0.23	0.8	1	2.52
Kolong 1 TL	998.45	0.006	0.23	0.8	1	1.61
Kolong 1 BD	998.45	0.005	0.13	0.8	1	0.54
Kolong 2 BD	998.45	0.009	0.13	0.8	1	0.87

Based on Table 3, the erosion rates across all former sand mining sites ranged from 0.54 to 2.52 tons/hectare/year. According to Arsyad's (2010) classification of erosion hazard levels, values below 15 tons/ha/year are numerically categorized as very low. However, this interpretation requires extreme caution within the specific context of critical post-mining land.

This analysis is strengthened by observing the direct interaction of USLE factors in the field. The high rainfall erosivity value (R) of 998.45 MJ.mm/ha/hr/year, when in direct contact with bare land surface (C=0.8) and without conservation practices (P=1), creates a highly risky scenario. Field observations show that although sandy soils have low K values (0.005-0.014) meaning high infiltration, the kinetic energy of rainfall is still capable of detaching loose and unaggregated sand particles. This is evident from the presence of small channels (rill erosion) at several research locations, especially at Kolong 2 TL which has a higher LS value (0.23). At these locations, the combination of slightly longer and steeper slopes increases the volume and velocity of surface runoff, enabling it to transport more sediment, which is reflected in the highest erosion rate (2.52 tons/ha/year).

This indicates a complex and mutually influencing relationship between factors. The low K factor does not automatically make the land safe from erosion. Conversely, the very high R factor and unsupportive C and P factors become "levers" that trigger erosion, albeit on a small scale. On critical post-mining land that has lost its topsoil layer and has disturbed soil structure, even minor erosion rates can have significant impact on land recovery potential. These eroded sand particles are often not only lost from the land but also deposited in water bodies (ponds) around the mining site, potentially causing siltation and water quality degradation. These findings directly confirm the USLE theory stating that erosion is a multiplicative product of all factors (Wischmeier & Smith, 1978), and the variation in A values between locations is largely determined by topographic factors (LS) and soil erodibility (K). In other words, the erosion potential at the research sites is very high despite currently low actual rates, indicating that the land is in a vulnerable condition and requires immediate intervention.

Further analysis indicates that the variation in erosion rates among sites is significantly influenced by the slope length and steepness factor (LS) and soil erodibility (K). Kolong 2 TL, with LS 0.23 and K 0.014, exhibited the highest erosion rate, while Kolong 1 BD, with LS 0.13 and K 0.005, recorded the lowest. These findings directly corroborate the Universal Soil Loss Equation (USLE) theory by Wischmeier & Smith (1978), which posits that erosion is a multiplicative product of all factors, meaning a change in one factor will affect the final output. The consistency of these findings is further reinforced by the research of Zulkarnain et al. (2023) in East Kalimantan, who found that under identical R, C, and P conditions, the topographic factor (LS) became the primary differentiator of erosion rates.

A deeper connection with previous research is strengthened by Kusumandari et al. (2012) in their study in the Ngrancah Kulonprogo Sub-watershed. Through cluster analysis and discriminant testing, they identified K (erodibility) and P (soil and water conservation practices) as the most dominant factors in distinguishing erosion levels between land units. This finding not only reinforces the analysis that variations in erosion rates among sites are influenced by the interaction of K and LS factors but also confirms the relevance of the theory within the post-mining land context, while highlighting P as a key modifiable variable for rehabilitation.

The implications of these findings are further clarified by Asdak's (2014) assertion that vegetation cover is the most effective factor in controlling erosion. Consistent with Asdak's concept, on critical land, indicators of damage are not solely assessed by the magnitude of erosion but also by the erosion potential and land sensitivity to disturbance. This is highly relevant to the research conditions, where a combination of high R, poor C, and P=1 indicates very high erosion potential despite currently low actual rates.

Overall, the findings of this research confirm the erosion hazard theory proposed by Renard et al. (1997) in the USLE revision, which states that erosion hazard is determined by the interaction of all factors, not just the final A value. The high erosion potential at the research sites, despite their low actual rates, demonstrates that post-mining land is in a state of genuine erosion hazard and requires immediate intervention.

CONCLUSION

Based on the evaluation of physical damage due to erosion using the USLE method at Km. 29, Bukit Batu Sub-district, Palangka Raya City, it can be concluded that the former sand mining land at all research locations experiences serious physical vulnerability, with erosion rates ranging from 0.54 to 2.52 tons/ha/year numerically classified as "very low" according to Arsyad's (2010) classification, yet this condition remains concerning in the context of post-mining land that has lost its topsoil and has disturbed soil structure, as the USLE method analysis revealed that high rainfall erosivity (R=998.45 MJ.mm/ha/hr/year), minimal vegetation cover (C=0.8), and the absence of conservation practices (P=1) render the land highly susceptible to erosion, despite its inherently very low soil erodibility (K=0.005-0.014). Therefore, immediate conservation interventions are recommended based on the USLE method findings, including : (1) immediate vegetative reclamation with fast-growing cover crops to modify the C factor; (2) simple mechanical conservation through construction of gulud terraces and rorak at locations with higher LS values (Kolong 2 TL and Kolong 1 TL) to modify the P and LS factors; (3) focusing on modifying the P factor as the most easily intervenable variable in the USLE equation; (4) integrated management of ex-mining ponds with vegetative buffer zones to filter sediment; and (5) regular monitoring of changes in USLE factors to evaluate conservation effectiveness, all of which are expected to mitigate the high erosion potential, minimize actual erosion rates, and restore the condition of post-sand mining land for its function as productive land or protected areas.

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