Determination of Soil Erodibility Factor (K) In A Nickel Mining Site In Tubay, Agusan Del Norte

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ABSTRACT

Soil erodibility indicates the soil's innate susceptibility or resistance to erosive activity. It is one of the most crucial variables in estimating soil loss. The distribution of the soil's grain size, structural stability, permeability, and organic matter are all related to how easily the soil erodes. In an open-pit mining operation, soil erosion could lead to more severe problems resulting in land degradation and sediment transport affecting the nearby environment if left unmanaged. This study aims to estimate the soil erodibility, K, in Tubay, Agusan del Norte, Philippines, using the Universal Soil Loss Equation (USLE) model with the application of QGIS for spatial erodibility visualization. The K estimations ranged from 0.016 to 0.066, were generally influenced by the soil particle distribution in the area. The region with the most silt concentration contributed to the highest K factor estimate.

Keywords: nickel mine, open-pit mining, soil erodibility, USLE

1. INTRODUCTION

Surface mining techniques are applied to clear overburden from Ni laterites approximately 1-3 meters below the surface. As a result, the slope weakens, resulting in surface collapse, ground fissure, debris flow, water supply pollution, and landslide. Mining operations have resulted in severe geological and environmental issues, such as the degradation of land and water supplies, geologic hazards, and ecological landscape destruction, potentially contributing to the desertification of mining areas [1], [2]. The extraction of nickel often substantially influences water and sediment quality [3], which may escalate significantly during rainfall events.

Soil erosion is one of the leading causes of land degradation [4]. At the same time, streambed sediment runoff can also pollute surface water [5], which may be present in streams, paddy fields, and fish near mines, posing a risk to agricultural resources and human health [6], [7]. Surface mine soil erosion can be severe without proper management and sediment control, especially in stockpiled topsoil [8], [9].

Soil erodibility, K, as a measure of soil sensitivity to erosion, shows the intrinsic susceptibility or resistance of the soil to erosive action and is the most critical component in predicting soil loss [10]–[12]. The K factor in Universal Soil Loss Equation or USLE [13], developed by Wischmeier and Smith in 1978, is most adopted in soil erosion models [14], [15], represented by equation (1):

$$A = R * K * L * S * C * P \quad (1)$$

Where average annual soil loss (A), rainfall factor (R), soil erodibility factor (K), topography factor (LS), crop factor (C), and control practice factor (P).

USLE is a conservation tool generally accepted and widely used in various kinds of research regarding soil management. It includes the estimation of erosion for land use [16], upland erosion [17], [18], specific sediment yield [19], erosion patterns [20], as well as estimating soil erosion in mining [8]. This model and subsequent Revised (RUSLE) and Modified (MUSLE) variants are commonly used worldwide, with many developed models.

It is essential to thoroughly understand the patterns and intensity of soil erosion in the region and its effects on the surrounding environment. This study explores the soil erodibility at an open-pit mining site in Tubay, Agusan del Norte, using the USLE-K factor. QGIS software also allows for a comprehensive view of erodibility. The computation and display of the soil erosion factor K can significantly assist in formulating conservation measures and management plans in the mining zone and determining the danger and severity of risks.

2. METHODOLOGY

2.1 Study Site Background

The research area is a mining facility primarily using open-pit mining to extract nickel laterite ore. It is at a maximum altitude of 301 meters above sea level within a 4,995-hectare Mineral Production Sharing Agreement (MPSA) contract area in the neighboring towns of Tubay, Jabonga, and Santiago, Agusan del Sur, Philippines. It lies between 9°17'- 9°16' N and 125°31'- 125°32'E, near the proximity of Butuan Bay and Lake Mainit, about 21.7 kilometers distant. Agriculture, including rice farming, is practiced in the neighboring areas of the mine site.

This analysis considers seven of the mining facility's exploration sites—including its discharge area, designated as 1,2,3,4,5,7,9 and 10 (discharge area), illustrated in Figure 1.

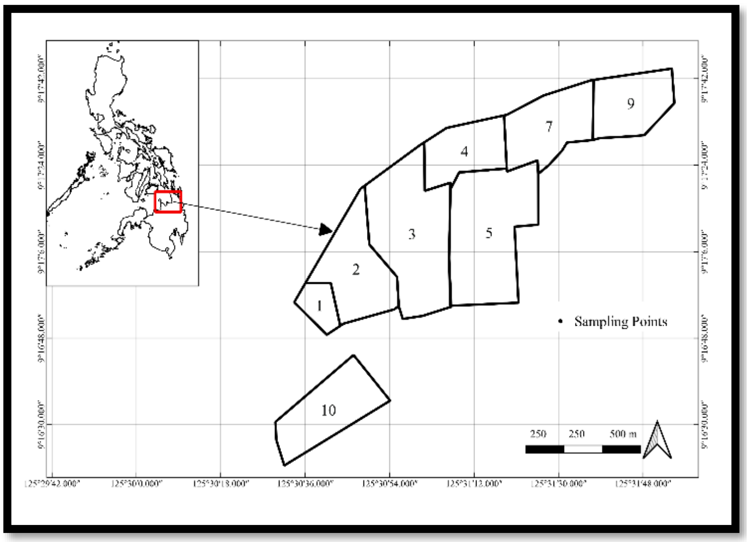

Figure 1. Study Area for K factor Estimation

2.2 Soil Sampling and Analysis

The top 15 centimeters of the soil's surface were used to obtain soil samples. Each sample was air-dried before being sieved through a 2mm screen to be analyzed for soil texture, pH, organic matter content, and the distribution of sand, silt, and clay particle sizes. The composite soil sampling technique used eight mining locations, including the discharge area, as sampling areas. For this investigation, 24 composite samples were examined from 72 subsamples. Large boulders and other objects were removed before mixing and blending each subsample to obtain three homogeneous samples in each sampling site.

The soil's relative proportions of sand, silt, and clay are determined using particle size analysis (PSA). When combined, these size fractions make up the soil's mineral composition. Sieve analysis and hydrometer method [21] were used to determine the particle distribution of sand (0.05 - 2 mm), silt (0.05 - 2 mm), clay (2 mm), and clay while the United States Department of Agriculture (USDA) triangle [22] determine the soil texture in the site.

Organic matter (OM) content was determined using the Loss of Ignition or LOI method, illustrated in various studies [23], [24] using equation 2:

$$OM = (W_{105} - W_{450})/W_{105} \quad (2)$$

W_{105} and W_{450} are the weights after subjecting the samples in a furnace to 105°C and 450°C, respectively.

2.3 Soil Erodibility Factor, K

The USLE-K factor estimate has become the most prevalent and well-accepted soil erodibility estimation method [16], [18]–[20]. In this study, the USLE -K was used with a mathematical formula [13] in equation (2):

$$K = 2.1\ M^{\wedge}1.14 \times 10^{-4}\ (12 - OM) + 3.25(S - 2) + 2.5(P - 3) \quad (3)$$

Where M, equation 4, is the texture of the first 15 cm of the soil surface as presented in equation 3 relating to soil particles, OM is the organic matter content determined in the laboratory, S for soil structure code, and P for soil permeability. The calculated K equations are in t-ha-h-ha^{-1} MJ^{-1} mm^{-1}.

$$M = (100\text{-}\%clay)\ (\%very\ fine\ sand + \%silt) \quad (4)$$

Pearson correlation was employed for analysis.

3. RESULT AND DISCUSSION

3.1 Soil Properties, Erodibility, and Analysis

Soil particle distribution (% sand, %silt, %clay) and organic matter content within the research area's 0-15 cm topsoil are presented in Table 1. Based on the USDA triangle [22], the mining site is sandy soil with a mean value of 90.61% sand, 7.76% silt, 1.63% clay, and 4.33% organic matter. Mine site 7 has the most silt (13.54%) and the least sand content (84.78%), USDA-classified as loamy sand. Clay content ranges between 1.21 and 2.72 percent, which is generally low. The clay content appears to be influenced by the geology [25] and the existing nickel mine activities in the research area.

Table 1. Soil Characteristics in nickel mine site and their estimated K factor value

Site	Elev., m	% Sand	% Silt	% Clay	% OM	USLE- K
Mine 1	209	92.99	5.80	1.21	2.38	0.027
Mine 2	245	94.46	4.07	1.47	3.45	0.017
Mine 3	265	93.23	5.15	1.62	2.29	0.016
Mine 4	262	90.27	8.43	1.30	6.52	0.025
Mine 5	277	91.86	6.90	1.24	7.42	0.016
Mine 7	130	84.78	13.54	1.68	3.38	0.066
Mine 9	238	89.49	8.72	1.79	5.91	0.033
Discharge	17	87.83	9.45	2.72	3.28	0.045
Mean		*90.61*	*7.76*	*1.63*	*4.33*	*0.031*

3.2 Relationship between K factor and soil properties

A significantly strong negative correlation exists between %sand (r = -0.80, p<.001) by correlation analysis in table 2. The soil erodibility parameters and susceptibility to erosion are influenced significantly by soil aggregates [26]–[28]. Given that sandy soils have a low runoff rate, this study's negative correlation with the erodibility factor suggests that decreased erodibility is achievable for soils high in sand, whereby sand content decreases soil erodibility [26], [27], [29].

Soil erodibility factor, K, also shows a significant strong positive correlation between %silt (r = 0.78, p<.001) and %clay (r = 0.78, p<.05). According to [30] and [29], soils with a high silt content are more likely to erode due to their ease of detachment and high runoff rate, while clay particles cause clumping in soil. Clay is vital for determining the K factor because it acts as a binder for the aggregates required for soil structure analysis. However, clay particles may not combine in water, resulting in increased soil loss.

In other studies, clay-rich *soils* appear to have strong resilience to erosion [11], [26], [27]. A concurrent drop in sand content is likely the only direct cause of a positive association between clay content and K factor value [29]. It is likely that in the examined soil samples, the clay content is insufficient to produce an erosion-resistant soil aggregate but is sufficient to reduce the permeability of the soil and increase the risk of surface runoff. [29].

Organic matter content shows no significant correlation to the K factor. A negative correlation, however, may suggest that increasing OM in the soil properties potentially decreases the soil erodibility [27] in the mine site. Higher amounts of OM theoretically decrease soil's vulnerability to detachment and reduce the amount of erosion [26], [31].

Table 2. The correlation coefficient of soil properties and erodibility factor, K

Parameters	%Sand	% Silt	% Clay	OM	K
%Sand	--				
% Silt	-0.98	--			
% Clay	-0.81	0.68	--		
OM	0.09	-0.07	-0.13	--	
USLE	-0.80	0.78	0.65	-0.29	--

3.3 Soil Erodibility K factor

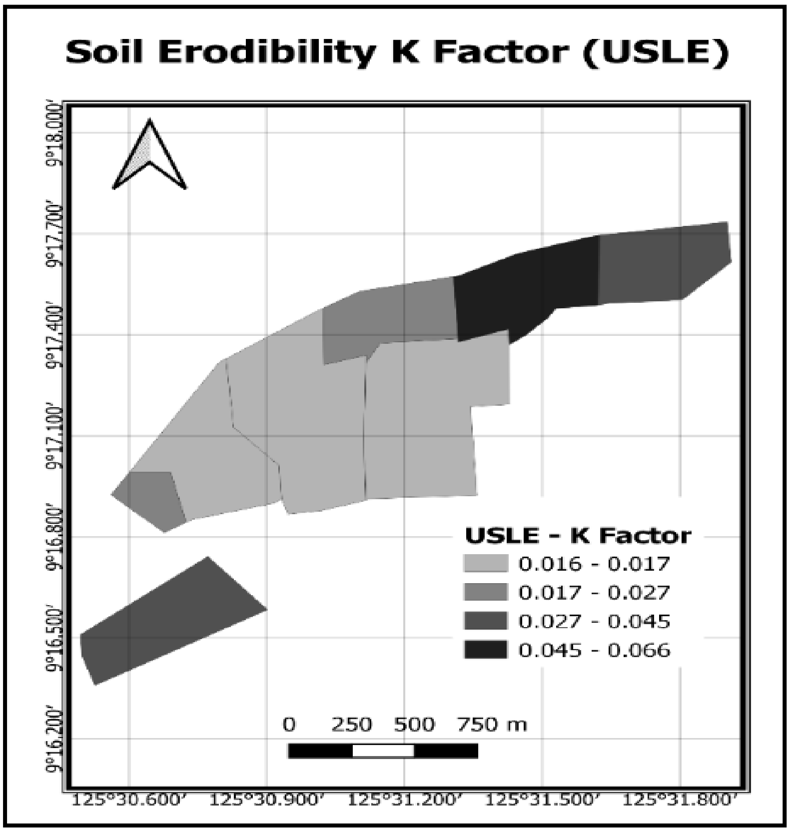

Figure 2. Soil Erodibility factor, K, using USLE

Soil erodibility factor varies from 0.016 to 0.066, as shown in Figure 2. QGIS illustrates the soil erodibility at each sampling site. These results depend on the calculated soil particle distribution in the area. K is highest at mine site 7, with the least %sand (84.78%) and the most silt (13.54%). USLE-K estimates the soil erodibility lowest for mines 3 and 5.

3.4 Implications and future work

The results found in this study reveal areas needing more attention in terms of soil management. The available information is most important in applying soil management in open-pit mining to reduce soil loss, thereby minimizing the effects on its neighboring environments, especially in extreme rainfall events.

Soil erosion and sediment transport go hand in hand. Sediment transport negatively impacts land and water quality through runoff and is a major pollutant to the aquatic environment [5], [32]. Heavy metals like Ni and Fe are present in high amounts when there is anthropogenic activity [33], [34], such as in the Tubay mining site. Due to pollution of the surface or groundwater, offsite contamination through water erosion, and plant absorption, these heavy metals may endanger agricultural resources [33], [34]. Generated soil erodibility map in the area may help model and predict erosion and determine soil conservation techniques.

A precise assessment of the K factor is the most effective managerial tool. In addition, a web-based map may provide a more unified framework for displaying and presenting map-based data using mobile technology [38].

4. CONCLUSION

Using the USLE K factor, this study calculated the erodibility factor for a nickel mining location in Tubay, Agusan del Norte. The K estimations range from 0.016 to 0.066 t-ha-h-ha^{-1} MJ^{-1} mm^{-1}., which is influenced by the soil particle distribution in the area. The data suggests soil erodibility is high at locations with that high silt concentration. It confirms that silt is more sensitive to soil erodibility because silt particles are easily detached and generate a high flow rate [29], [31]. High sand percentage minimizes soil erosion's effects [39], [40]. Organic matter in soil is crucial to soil quality and erodibility because it impacts how soil particles combine into a stable structure [28]. However, in this study, the minimal amount of organic matter content shows no significant effect on the estimated K. The most significant value for K was found in the area with the most silt content, thus needing more attention for soil conservation management.

5. ACKNOWLEDGEMENT

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