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EROSION HAZARDS IN THE TAYAN SUB-WATERSHED, WEST BORNEO PROVINCE

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Abstract:
This research focuses on predicting erosion in the Tayan Sub Watershed, a part of the Kapuas Watershed in the Tayan Hilir District, Sanggau Regency, West Kalimantan Province. Watersheds play a crucial role in providing quality water, and land changes can lead to watershed damage, particularly concerning erosion. This research utilizes the Universal Soil Loss Equation (USLE) model combined with Geographic Information System (GIS) to predict the distribution of erosion hazard in Sub DAS Tayan. Parameters analyzed in this research include rainfall factors, soil erodibility, slope steepness, and land cover. The results indicate that erosion hazard classes in Sub-DAS Tayan range from low to high. Although most soils have low erodibility, the presence of areas with high erodibility suggests potential erosion risks that need attention. The majority of slopes fall into the flat to moderately steep categories, coupled with the dominance of secondary forest land cover, indicating an environmentally risky condition for future erosion occurrence. This research is expected to assist decision-making regarding soil and water conservation actions in the Tayan Sub Watershed.

Keywords: Environmental risk, Erosion hazard, Erosion prediction, Geographic Information System (GIS)

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INTRODUCTION

Watersheds are crucial for supplying water with both quality and quantity essential for life (Asdak, 2023; Triatmodjo, 2006). The significance of their function makes them highly susceptible to damage, particularly erosion-induced, which can significantly impact life, especially the watershed function. The primary causes of watershed damage often stem from inappropriate land use changes, marked by a decline in the watershed's water retention capacity.

Land use changes within watersheds can significantly impact the potential for land erosion. Diminished land function can affect hydrological processes and the amount of water present on the soil surface. Hardjowigeno (1987) states that if rainfall intensity surpasses infiltration rates, surface runoff occurs, leading to erosion.

Erosion is a leading cause of soil degradation (Arsyad, 2009). It occurs when raindrops hit the soil, dispersing it into small particles transported elsewhere by surface runoff (Arsyad, 2009). According to Morgan (2009), soil transportation results in the loss of the top layer, rich in organic matter and nutrients, thereby reducing soil productivity and its ability to regulate water balance.

This problem can be addressed by calculating the potential for erosion, enabling the determination of appropriate conservation techniques. Direct field measurement of erosion values incurs high costs, indicating the need for accurate models. The Universal Soil Loss Equation (USLE) model, frequently used for erosion calculation and prediction, forecasts long-term soil erosion averages over a specific land area with certain planting and management systems (Arsyad, 2009).

The application of the USLE model has been widespread in various watersheds in Indonesia, yielding differing results. For instance, a study by Purba et al (2020) the Garang Watershed received moderate to high erosion values, mainly due to slope steepness, while Surono et al (2013) found low to high erosion values in the Dumoga sub-watershed, influenced by vegetation cover.

Estimating erosion rates using the USLE model is commonly combined with Geographic Information System (GIS) (Devatha et al., 2015). GIS facilitates spatial distribution determination as each factor in the USLE model can be computed using GIS facilities (Dabral et al., 2008). According to Prayitno et al (2015), the USLE model combined with GIS is highly efficient in calculating erosion hazard

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levels over large areas. The accuracy of the USLE model depends on rainfall erosivity index (R), soil erodibility (K), slope length and steepness (LS), vegetative type (land cover), and conservation techniques (CP).

Tayan sub-watershed is a part of the Kapuas watershed located in the Tayan Hilir District, Sanggau Regency, West Kalimantan (no research has been conducted on erosion prediction using the USLE model). Therefore, this research aims to predict the magnitude of erosion in Sub DAS Tayan, with the objective of aiding decision-making regarding soil and water conservation measures in the Sub DAS Tayan watershed. Based on the stated problem description, the objective of this research is to determine the distribution of erosion hazard classes in the Tayan sub-watershed using a Geographic Information System (GIS) approach.

METHODS

This research was conducted from January 31st to February 21st, 2024. The data obtained ranged from the past 20 years (2003-2023) for rainfall, soil types in 2018, and satellite imagery in the same year with soil types (2018). The location discussed in this paper is located in the Sub Watershed Tayan, Tayan Hilir District, Sanggau Regency.

The tools we are using are Quantum GIS software. The materials used in this research were Digital Elevation Model (DEM) raster data, Landsat 8 raster data, Soil Types of West Kalimantan Province 1:50,000 Scale in 2018, Watershed data of Sanggau Regency, Shapefile data of Rivers in West Kalimantan, 20-Year Daily Rainfall Data from BMKG Meteorological Station Class III Sintang Regency, and soil physical property data through literature studies.

Parameters and Assessment. Based on erosion modeling, erosion values tend to emphasize certain parameters such as rainfall, slope steepness, land cover vegetation, and land conservation practices rather than soil characteristics (Belasri et al., 2017). The erosion process is closely related to the soil properties because soil, as the eroded object, will undergo this process even though it may have different intensities. If only viewed from the aspect of soil characteristics without considering non-soil factors, it will result in different characteristics as well.

The main focus of this research is to calculate the magnitude of erosion (tons/hectare/year) and determine the Erosion Hazard Class of the Tayan sub-watershed. The magnitude of erosion is determined using the Universal Soil Loss Equation (USLE) method. USLE is a parametric model commonly used to predict erosion on a land surface. The prediction of erosion with USLE can be obtained with the following equation:

$$\mathbf{A = R * K * LS * CP}$$

Where:
A = Amount of soil eroded (tons/hectare/year)
R = Rainfall and surface runoff factor (erosivity) (cm/hectare/year) K = Soil erodibility factor (tons/hectare/year)
LS = Slope length and steepness factor (Dimensionless)
CP = Factor of ground cover, vegetation, crop management, and conservation practices

After obtaining the erosion values, the next step is to determine the Erosion Hazard Index (EHI), which is calculated with the following equation:

$$\mathbf{EHI = A / TSL}$$

Where:
EHI = Erosion Hazard Index
A = Amount of soil eroded (tons/hectare/year) TSL = Tolerance Soil Losses (tons/hectare/year)

The value of TSL (Tolerance Soil Losses) is obtained based on soil characteristics, particularly soil depth and drainage conditions. The TSL value used is as follows.

Table 1. Determination of TSL Values for Soils in Indonesia

No	Soil Properties and Substratum	TSL Value (tons/hectare/year)
1	Very shallow soil (<25 cm) over bedrock	0
2	Very shallow soil (<25 cm) over weathered material (unconsolidated)	4.8
3	Shallow soil (25-50 cm) over weathered material	9.6
4	Moderately shallow soil (50-90 cm) over weathered material	14.4
5	Deep soil (>90 cm) with impermeable subsoil over weathered substrate	16.8
6	Deep soil (>90 cm) with slowly permeable subsoil over weathered substrate	19.2
7	Deep soil (>90 cm) with moderately permeable subsoil over weathered substrate	24.0
8	Deep soil (>90 cm) with a permeable subsoil over weathered substrate	30.0

Source : Thompson, (1952); Yuningsih et al., (2012)

The ability of rainfall to cause erosion can be indicated by rainfall erosivity (R). Rainfall erosivity also affects the rain's power to detach soil particles. High-intensity rainfall can cause soil particles to break apart into grains, which are then carried away by water, leading to soil erosion. Rainfall erosivity is expressed in the form of maximum rainfall intensity over 30 minutes (EI30) with the following equation (Bols, 1978).

$$\mathbf{EI30 = 6.199\ (RAIN)^{1.21}\ (DAYS)^{-0.47}\ (MAXP)^{0.53}}$$

Where:
EI30 = monthly rainfall erosion index (cm/ha/year) RAIN = average monthly rainfall (cm)
DAYS = average number of rainfall days per month (days)
MAXP = maximum 24-hour rainfall in the respective month (cm)
Soil erodibility, in general, can be controlled by soil texture, soil structure, organic matter, and permeability, which are the main factors. Erodibility calculations using this equation (Wischmeier & Meyer, 1973).

$$\mathbf{100\ K = 1.292\ [2.1\ M^{1.14}\ (10^{-4})\ (12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3)]}$$

Where:
M = grain size parameter (%silt+%very fine sand) * (100 - % clay)
a = % organic matter
b = structure class
c = Soil profile permeability
M = (% silt + % very fine sand) x (100 - % clay)

The topography or elevation of the Earth's surface can trigger soil erosion. The change in slope occurs due to different topographies. The length and steepness of slopes can affect surface runoff and soil erosion. The factor of slope length is the ratio between the erosion amount of soil over a certain slope length to the erosion amount of soil over a slope length of 77.6 feet (22.1 meters) under identical conditions. Meanwhile, the slope steepness factor is the ratio between the erosion amount occurring on a soil with a certain slope steepness to the erosion amount of soil with a 9% slope under identical conditions. The topographic factor can be calculated using the following equation (Wischmeier & Meyer, 1973).

$$\mathbf{LS = (x/22)^{m}\ (0{,}43 + 0{,}30\ s + 0{,}043\ s^{2})/6.613}$$

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Where:
x = slope length
s = slope steepness percentage

m = 0.5 if slope ≥ 5%; 0.4 if slope is between 3.5 -4.5%; = 0.3 if slope is between 1 - 3%;0.2 if slope < 1% The land cover factor (C) is the ratio between the erosion magnitude of a certain area with specific vegetation cover and crop management to the erosion magnitude of identical soil without vegetation (Arsyad, 2009) In this research, the land cover factor is spatially based, employing the NDVI (Normalized Difference Vegetation Index) approach using Landsat 8 imagery with the following equation (Erencin, 2000; Lillesand et al., 2015).

$$\mathbf{NDVI = ((NIR - RED) / (NIR + RED) * 127) + 127}$$

Where:
NDVI Normalized Difference Vegetation Index NIR Near Infra Red Band
RED= Red Band

The next step is determining the C factor value prior to classification. The C value can be obtained using an alternative estimation method (regression) by Erencin (2000). This can be done because NDVI values have a strong relationship (97% coefficient of determination) with the C factor in the valleys of the Lom Sak/Lom Kao region, Thailand (Erencin, 2000).

$$\mathbf{C = (210.19 - NDVI) / 87.25}$$

Where:
NDVI = Normalized Difference Vegetation Index C = Land cover factor (C-factor)

After calculating the C factor, classification is performed according to the rule that if the pixel value is <0, it will be set to 0, and if the pixel value is >1, it will be set to 1. Then, the values are divided into 10 classes (Erencin, 2000; Kooiman, 1987). The factor of specific conservation actions such as soil conservation (management and planting according to contour, strip planting, ridges, terraces) is the ratio between the erosion magnitude of soil subjected to specific conservation actions, such as contour cultivation, strip planting, or terracing, to the erosion magnitude of soil cultivated along the slope, under identical conditions (Arsyad, 2009). In this research, conservation management is considered absent; thus, the value of P = 1 (Arsyad, 2009).

Data Analysis. Data analysis was conducted through literature review and spatial data collection. The spatial data was then processed using the QGIS 3.26 application through various calculations and equations as described in the method for each factor considered.

RESULT AND DISCUSSION

Climate and Rainfall Factor (R). Based on data obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) Tebelian Station, the average annual rainfall over 20 years (2003-2023) in the Tayan sub-watershed is 3188.76 mm/year. The calculation of the rainfall factor (R) using the Bols (1978) equation indicates that the influence of rainfall on erosion is 2732.76 cm/ha/year. This indicates that the energy generated from the rainfall intensity is quite high. This result is supported by the classification of the Schmidt Ferguson climate, which states that the Tayan sub-watershed belongs to type A, which is very wet.

Erodibility Factor (K). In this research, erodibility (along with the TSL value) is determined by soil type. The physical and chemical properties are obtained from literature studies and calculated using the Wischmeier & Smith equation (1978). In the Tayan sub-watershed, soils are divided into 3 orders: ultisols with 5 sub-groups, oxisols with 2 sub-groups, and inceptisols with 3 sub-groups (Figure 1). The calculated erodibility based on the soil's physical and chemical properties in the Tayan sub-watershed

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is relatively low (0.001- 0.151). Out of the 10 tested soil sub-groups, 9 have erodibility values < 0.1, while 1 sub-group (Typic Endoaquepts) has an erodibility value > 0.1 (Table 2).

Table 2. The K factor values based on the physical and chemical properties of the soil type in the Tayan sub-watershed

Soil Type* (Sub-Group)	Texture**	Organic C (%)**	Structure **	Permeability rate**	Erodibility (K)***	Criteria ****	TSL*** (tons/ha/year)
Typic Kanhaplududults	Sandy Clay Loam	1,70 %	Granular (F)	Moderate	0,001	Very Low	24.00
Aquic Kanhapludults	Silty Clay	1,18 %	Granular (M)	Slow	0,076	Very Low	24.00
Typic Hapludults	Clay	3,30 %	Granular (M)	Slow	0,075	Very Low	19.20
Typic Kandiudults	Clay Loam	2,19 %	Granular (M)	Moderate	0,044	Very Low	30.00
Acrudoxis Kandiudults	Sandy Loam	4,60 %	Granular (VF)	Moderate	0,085	Very Low	30.00
Typic Hapludox	Clay	2,58 %	Granular (M)	Moderate	0,042	Very Low	24.00
Typic Kandiudox	Clay	3,05 %	Granular (M)	Moderate	0,043	Very Low	24.00
Typic Endoaquepts	Sandy Loam	3,96 %	Massive	Slow	0,150	Low	24.00
Typic Dystrudepts	Loam	3,35 %	Granular (M)	Moderate	0,044	Very Low	24.00
Fluventic Dystrudepts	Silt Loam	1,42 %	Granular (F)	Moderate	0,004	Very Low	16.80

Source: Peta Jenis Tanah 1:50.000 Kalimantan Barat, 2018)*
Modificatiob based on Belasri et al.,(2017); Dariah et al., (2015); Siregar et al., (2014); Yatno & Prasetyo, (2010)** Data Analysis, (2024)***
Wischmeier & Meyer, (1973)****

Soil texture affects the soil's ability to retain and pass water. More coarser the soil texture, More weaker the soil's ability to retain water. Soils with medium texture have better resistance than soils with coarse or fine texture (Table 2).

The organic matter content (as value a) contributes negatively to erodibility. The higher the organic matter content, the lower the contribution of value a to erodibility, and vice versa (Table 2).

Soil structure affects the soil's ability to absorb and pass water. The lower the soil's ability, the higher the risk of surface waterlogging and runoff. Soil structure is classified with the symbol "b", with values ranging from 1-4. The b values are based on soil structure classification in the Tayan sub-watershed (Table 2), referring to soil structure classification (Arsyad, 2009).

The value of c is determined based on soil permeability in cm/hour. The scale of c values ranges from 1-6, with higher values indicating lower permeability. Permeability affects erodibility levels. In the case of c values in the Tayan sub-watershed, soils in the Typic Endoaquepts sub-group have the lowest permeability value (c = 5), indicating a higher potential for erodibility. However, this indication should be considered in conjunction with other factors such as texture, structure, and organic matter.

Topography Factor (LS). The analysis of DEM SRTM (30m) raster data indicates that the study area has slopes ranging from 0% to 15%, although there are some areas with slopes between 15% and 30% (Table 3). Based on the slope classification (Arsyad, 2009), the Tayan Sub Watershed is divided into four classes (Flat, Gently Sloping, Moderately Sloping, and Steep), with the flat areas dominating, covering an area of 16,3541.71 hectares or approximately 78.37% of the total sub Watershed area. The data indicates that the erosion threat arising from runoff on sloping terrain in the sub-watershed area tends to be low if other factors are not considered. However, erosion estimation should take other factors besides the topography factor (Lillesand et al., 2015).

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Table 3. The distribution of slope in the Tayan Sub Watershed

Slope (%)**	Slope Classes**	Area (Hectare)*
0-3	Flat	16,3541.71
3-8	Gently sloping	4,4437.69
8-15	Moderately sloping	689.89
15-30	Steep	3.84
Total		**208.673,13**

Source: Data Analysis, (2024)*
Arsyad, (2009)*

Land Cover Factor (C). The results of the land cover analysis based on NDVI (Figure 2) indicate that the majority of land in the Tayan Sub-Watershed has C factor values of 0.2 - 0.3 and 0.3 - 0.4. From this data, it can be concluded that the majority of land cover in the Tayan Sub-Watershed is classified as secondary forest areas with high to moderate density (Table 4).

Table 4. Land cover area on Tayan Sub Watershed

Classes**	Land Cover **	Area (Hectare)*
1	High-Density Primary Forest	5.22
2	Medium Density Primary Forest	4228.47
3	High-Density Secondary Forest	112,102.50
4	Medium Density Secondary Forest	72,606.06
5	Shrubland and Grassland	13,293.81
6	Fallows/Cultivated land (low cover vegetation)	4,178.43
7	Residential Area with Green Spaces	1,424.25
8	Residential Area without Green Spaces	497.16
9	Slightly Vegetated Open Land	225.90
10	Very Bare Soil	111.33
	Total	**208.673,13**

Source: Data Analysis, (2024)*
Erencin, (2000); Kooiman, (1987)

a) b)

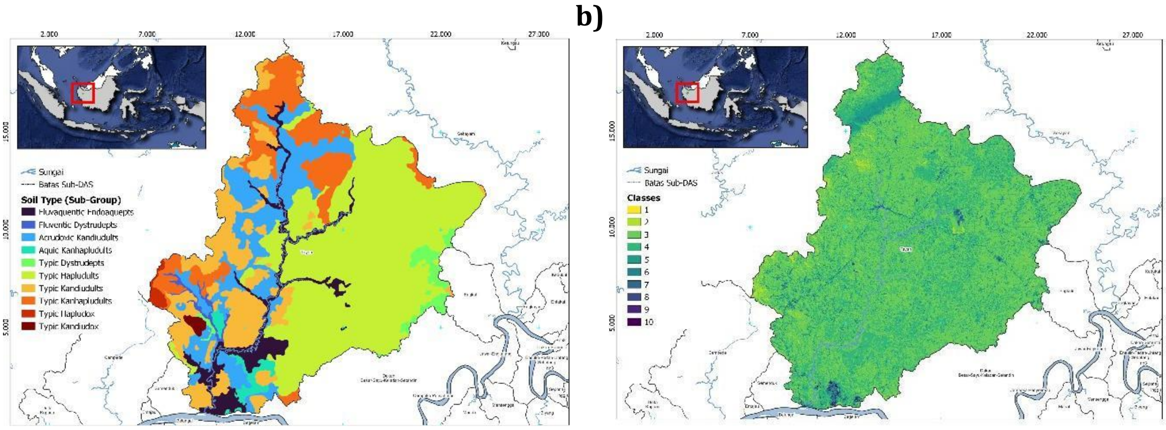

Figure 1. Soil Type (a) and Land Cover (b) on Tayan Sub Watershed

Erosion Hazards. The Tayan sub-watershed is predominantly characterized by categories with a very high erosion hazard class covering an area of 63,232.70 hectares, down to low, covering an area of

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50,727.03 hectares (Table 5; Figure 2). Based on this data, it can be concluded that the Tayan Sub-Watershed has a varied and proportional erosion hazard class for all categories.

Table 5. The distribution of Erosion Hazard Classes (EHC) in the Tayan Sub-Watershed

Erosion Hazard Index**	Erosion Hazard Classes**	Area (hectare)*
<1.0	Low	50,727.03
1.01-4.0	Moderate	48,325.22
4.01-10.0	High	46,388.18
>10.0	Very High	63,232.70
Total		**208,673.13**

Source: Data Analysis, (2024)*
Hammer, (1981)**

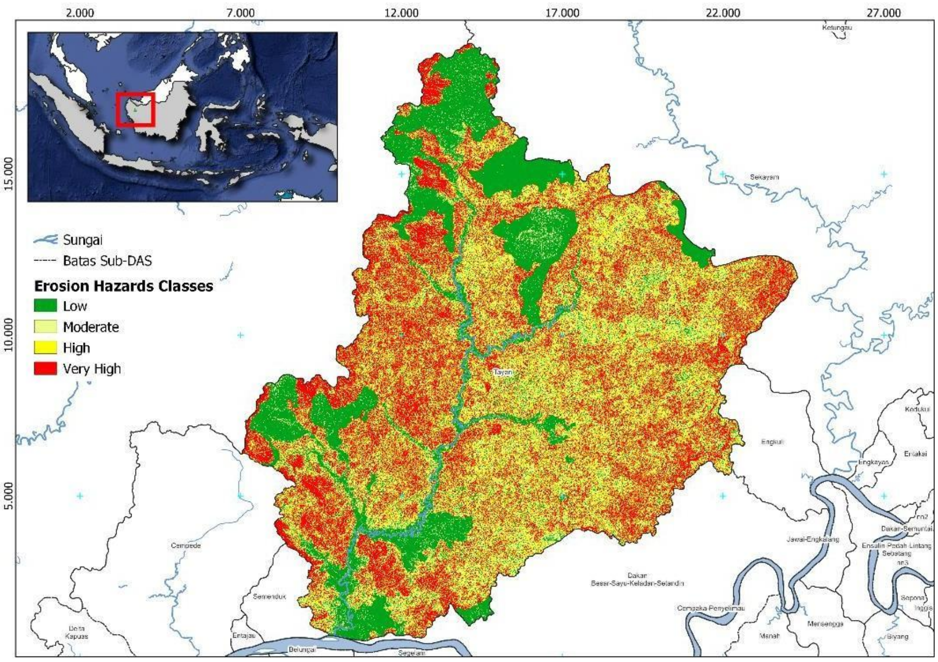

Figure 2. Erosion Hazards Map in the Tayan Sub Watershed

The main factor for the high erosion hazard in Tayan Sub-Watershed is heavy rainfall, which matches the tropical climate of West Kalimantan, especially Sanggau District. This area gets much rain, even classified as very wet by the Schmidt Ferguson climate system. To address the different levels of erosion risk in Tayan Sub-Watershed, it is suggested to use conservation methods tailored to local conditions. This could involve things like building terraces, planting crops to protect the soil, restoring vegetation, and managing water sustainably.

CONCLUSION

Based on the analysis of soil erodibility, slope steepness, land cover, and Erosion Hazard Classes (EHC) in the Tayan Sub-Watershed, Sanggau District, West Kalimantan Province, it can be concluded that the soil erosion conditions in that area range from low to high. Although most of the soil has low erodibility, the presence of areas (based on soil types) with higher erodibility values indicates a potential erosion risk that needs attention. High rainfall, predominantly gentle to moderately sloping terrain, along with the dominance of secondary forest land cover, indicates an environmentally risky condition for increased erosion in the future.

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