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Erosion Analysis With Geographic Information System On Watershed Area of Tapin Dam, South Kalimantan

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Abstract

Population growth in the Tapin Dam watershed area causes increasing land needs and changes in land function. Changes in land use and high rainfall can cause erosion, which causes sedimentation in rivers and shallowing of the Tapin Reservoir so that the service life of the reservoir is reduced. The importance of good land conversion management and the existence of national strategic infrastructure in the form of dams that need to be maintained for sustainability. A study was conducted to determine the value of the critical level of land and the amount of erosion in the Tapin Dam watershed. Based on the USLE formula using GIS analysis, four USLE method parameters are required, namely rainfall erosivity, soil erodibility map, land use map, and slope map. The overlay process is carried out to obtain the value of the amount of erosion to calculate the sediment transport ratio that occurs. The results of this study are the value of the erosion rate in the Tapin Dam watershed of 15,424.28 tons/ha/year and the amount of sedimentation released is 8,892,228.83 tons/year or 637.35 tons/ha/year.

Keywords

Tapin dam watershed, Erosion rate, Geographic Information System (GIS)

INTRODUCTION

As the population increases, the level of human need for land also increases [1]. The population in the Tapin Dam watershed area was recorded at 6,264 people in 2022, with a growth rate of 2 percent per year from 2021 to 2022 [2]. The high rate of population growth and uneven distribution causes dense activity to be concentrated in a region, which requires increased exploitation of land resources, but on the other hand, land availability is limited.

Encouragement of population density causes land conversion can affect environmental conditions in the watershed area. If land use often does not pay attention to its sustainability, especially on lands that have limitations, both physical and chemical limitations, which take place continuously, it is feared that critical land will occur and result in decreased soil fertility and soil productivity [3]. In addition, land use change and high rainfall are associated with erosion.

Erosion can cause sedimentation in the river that flows into the Tapin Reservoir, leading to siltation and decreasing the service life of the reservoir. If this occurs in conjunction with high rainfall, it is feared that it will cause flooding. As in February 2023, the Tapin River overflowed, causing flooding in Kupang village and there were also several other settlements in the Tapin Dam watershed that were affected by flooding, namely Malingkung Village and its surroundings where this flooding was due to increased water discharge in the upstream Tapin River [4].

Land conversion can lead to a negative direction if the change exceeds the land capability and carrying capacity of the available land, and vice versa if land conversion is based on appropriate regional governance planning by taking into account the ability and carrying capacity of the land, then land change will lead to a positive direction [5]. A well-organized watershed can help reduce flood risk by controlling water entering the dam [6].

The Tapin Dam watershed has potential agricultural land to be developed but has annual flooding problems in the Tapin River flow caused by land use changes in the area [7]. Given the importance of good land use change management and the existence of national strategic infrastructure in the form of dams that need to be maintained for the sustainability of the surrounding community, this study conducted an Erosion Analysis with Geographic Information Systems in the Tapin Dam Watershed in South Kalimantan.

RESEARCH SIGNIFICANCE

This study aims to analyze the amount of erosion rate in the Tapin Dam watershed in Tapin Regency, South Kalimantan. The goal is to be able to plan appropriate actions for stakeholders to maintain the service life of the reservoir as planned.

METHODOLOGY

The main objective of this research is to analyze the amount of erosion value that occurs in the Tapin Dam watershed in Tapin Regency, South Kalimantan. The method used is the USLE method with rain erosivity parameters, soil erodibility maps, land use maps, and slope maps. The maps are then overlaid to find out the value of the amount of erosion, which is then carried out the calculation of the Sediment Delivery Ratio (SDR) so that the amount of surface sediment that is chipped can be known.

A. RESEARCH LOCATION

The location of this research is at Tapin Dam, Pipitakjaya Village, Piani District, Tapin Regency, South Kalimantan Province which is located at coordinates 020 56' 31“ LS and 1150 20' 14.6” East. The position of Tapin Dam is 42 km from the capital of Tapin Regency, namely Rantau City and 130 km from Banjarmasin City, South Kalimantan. The research location can be seen in Figure 1.

Figure 1 Research location

Data collection of coordinate points was carried out along the road that became the object of observation where the coordinate points were all within the Tapin Dam watershed.

B. DATA COLLECTION METHOD

Data collection was conducted to obtain relevant information to analyze the level of land criticality. The data used in this study consisted of primary and secondary data. The primary data are Tapin Dam watershed map and coordinate point of erosion location. The secondary data are soil type map, topographic map, land use map, rainfall data, and land cover type. The research aims to determine the amount of erosion rate in the Tapin Dam watershed under study.

C. DATA PROCESSING AND ANALYSIS

Data analysis used a Geographic Information System (GIS) approach with ArcGIS software. Data processing and analysis were conducted on four types of maps to obtain the factor value of each parameter required in calculating the level of land criticality. The four types of maps, namely rainfall erosivity map, slope map, land cover map, and soil type map are expressed as layers in shapefile (shp) form and created with the same scale in ArcMap. These types of maps are used in this analysis with the interaction between the USLE method and GIS applications that can predict erosion rates spatially on each land unit. The land criticality map can be obtained by overlaying the four types of maps from the USLE parameters on each land unit. The final result of the GIS analysis is obtained land units in spatial form with all attribute data resulting from the overlay process. Each land unit obtained is numbered to facilitate further analysis.

RESULTS AND DISCUSSIONS

The results of the amount of erosion rate is obtained from the following four parameters whose values are sought first. after that, the value of the amount of erosion can be known from overlaying the four maps with the usle method.

A. ANALYSIS OF RAINFALL CALCULATION

In this study there are 2 rain posts that affect the Tapin Dam watershed, namely post 1 (115.376, -2.8814) and post 4 (115.4634, -2.9431). Calculation of the number of days of rain is used for erosivity parameters. The erosivity parameter requires the calculation of the number of rainy days. A rainy day is a day with rainfall of at least 1 mm/day (one millimeter per day).

B. RAIN EROSIVITY FACTORS (R)

Large amounts of rain with low intensity do not always cause large erosion, and conversely heavy rain in a short period of time can cause small erosion. If the amount and intensity of rain is high, soil erosion tends to be high.

Dams as water structures require information about flow speed, which is an important consideration from various points of view to obtain flow parameters [8]. Determination of the erosivity value (R) in the Tapin Dam Watershed uses rainfall data for 11 years from 2013 - 2023 at post 1 and post 4. Rainfall data is obtained from satellite rainfall data which then from the data obtained average rainfall, maximum rainfall, and number of rainy days. This research applies the Bols method to analyze rainfall characteristics and their impact on surface flow and erosion. Furthermore, the erosivity value is processed into an erosivity map using ArcMap 10.8 software. The rain erosivity map is shown in the Figure 2.

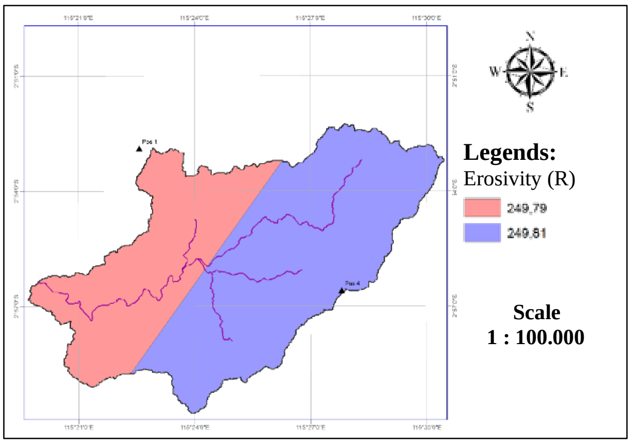

Figure 2 Rainfall erosivity map

C. SOIL ERODIBILITY FACTORS (K)

Soil erodibility or soil erosion sensitivity factor, is the resistance of soil to both detachment and transport, depending mainly on soil properties, such as texture, shear strength, infiltration capacity, and so on. Soil erodibility is the average of soil characteristics and soil response to long-

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term rainfall energy. Erodibility is used to predict long-term or annual average soil erosion.

Soil erodibility in the Tapin Dam watershed was determined based on existing soil types by referring to data criteria by Dudal-Soepraptohardjo (1957, 1961) in the book Soil Morphology and Classification by Joni, et al. The soil data obtained from the soil map contains information on the different soil types in the Tapin Dam watershed area. The soil erodibility map was created by re-digitizing the soil type map issued by Geospatial or FAO (Food and Agriculture Organization) using ArcMap 10.8 software.

Table 1 Soil Type in the Tapin Dam Watershed

Soil Type	K Values	Area (ha)	Area (%)
Humic acrisols	0.32	1735.01	12.44
Humic ferrasols	0.31	12216.91	87.56
Total		13951.9	100.00

The higher the K value, the easier it is to erode [9]. In the Tapin Dam watershed, the soil that has the greatest soil erodibility value is humic acrisols with a value of K = 0.32 and an area of 173.01 ha or 12.44%, then the K value on humic ferrasols is 0.31 with an area of 12216.91 ha or 87.56% of the entire Tapin Dam watershed area. Based on the map of soil types, Tapin Dam watershed is dominated by humic ferrasols.

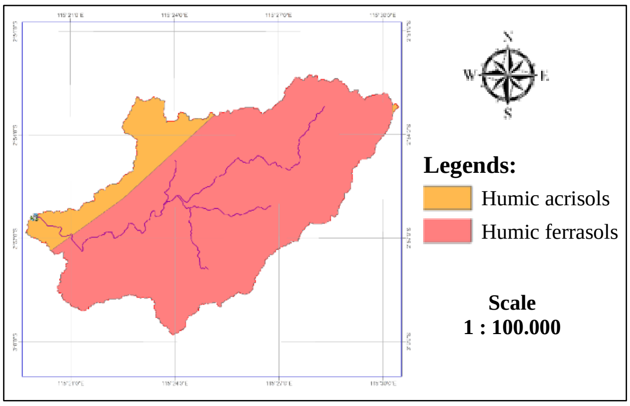

Figure 3 Soil Type Map

Latosol (humic ferrasols) is a type of soil that is widely distributed in Indonesia with an area of 84.6 million ha. Latosol soils are generally located in areas with a wet climate and have a crumbly soil structure [10]. Latosol soils are also advanced weathering soils characterized by acid pH, low organic matter and nutrient content [11]. While red yellow podzolik soil (humic acrisols) is a type of soil with low productivity due to intensive leaching and advanced weathering. This causes the soil to have low nutrient content and poor soil physical and chemical properties [12]. According to [13], this soil is spread throughout Kalimantan, which is estimated to be around 30.15 million hectares. In the character of soil texture, yellow red podzolic (humic acrisols) soil formed from quartz mineral granite will be dominated by sandy clay texture while yellow red podzolic (humic acrisols) soil from limestone, andesite rock, and tuff tends to have a fine texture such as clay and fine clay. The structure of yellow red podzolic (humic acrisols) soil generally has a medium to strong character, with an angular clumpy shape and a fairly high soil volume content weight ranging from 1.3 g.cm-3 - 1.5 g.cm-3 with low water absorption [14].

D. LAND USE AND SOIL MANAGEMENT FACTORS (CP)

In this study, there are several land uses that have different abilities to affect erosion rates. To determine the CP factor is entirely done by digitizing the location map obtained from indo geospatial data using ArcMap 10.8 software.

Table 2 CP Values in the Tapin Dam Watershed

Land Cover	Area (ha)	Area (%)	CP Values
Open land	120.38	0.86	0.20
Dryland farming mixed with shrubs	7796.62	55.88	0.10
Mining	257.53	1.85	1.00
Secondary dryland forest	1523.59	10.92	0.03
Shrubs	4253.80	30.49	0.07
Total	13951.92	100.00	

From the analysis of the land cover map, it is known that the Tapin Dam watershed area is dominated by dry land farming mixed with shrubs which has a value of CP = 0.1 with an area reaching 7796.62 ha in percentage is 55.88% of the total watershed area. While the lowest area is on open land with an area of 120.38 ha (0.86%) and a value of CP = 0.2; then followed by mining with an area of 257.53 ha (1.85%) and a value of CP = 0.1; secondary dryland forest with an area of 1523.59 ha (10.92%) and a value of CP = 0.03; and shrubs with an area of 4253.80 ha (30.49%) of the entire Tapin Dam watershed area and has a value of CP = 0.07. The CP value at the watershed location will affect the magnitude of erosion, where the greater the CP value will increase the erosion that occurs, and vice versa. The map of land use and land management shown in this figure.

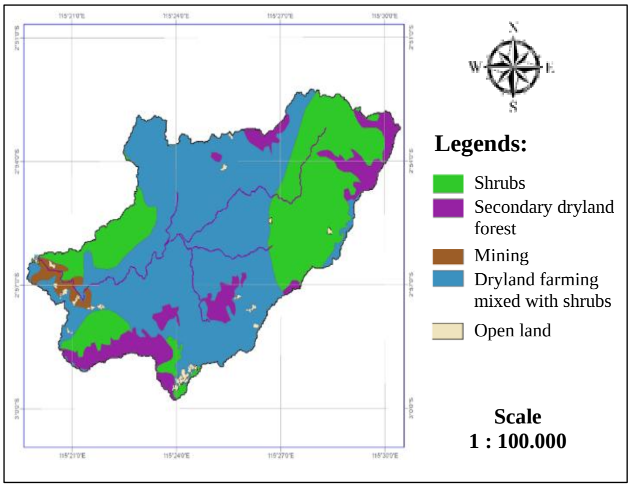

Figure 4 Land Use and Land Management Map

E. SLOPE FACTORS (LS)

The slope map is obtained from the processing of Digital Elevation Model (DEM) data using ArcMap 10.8 software. The following are the results of the slope classification.

Table 3 Slope Classifications

Class	Slope (%)	Classification	LS	Area (ha)	Area (%)
I	0 – 8	Flat	0.4	1024.83	7.35
II	8 – 15	Ramps	1.4	2085.02	14.94
III	15 – 25	Somewhat steep	3.1	4096.95	29.36
IV	25 – 40	Steep	6.8	5040.19	36.13
V	> 40	Very steep	9.5	1704.93	12.22
Total				13951.90	100.00

The dominant slope class is a steep slope that has a LS factor value of 6.8 with a percentage of 36.13% or an area of 5040.19 ha. In general, a slope that tends to be low in the downstream part of a watershed can cause the accumulation of eroded sediment from the slope part that has a greater slope. The slope gradient map shown in Figure 5.

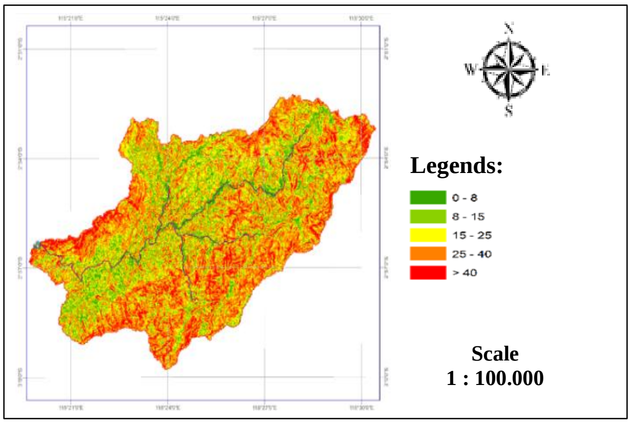

Figure 5 Slope Gradient Map

F. ANALYSIS OF EROSION MAGNITUDE

The results of erosion forecasts in this study are obtained based on the calculation of the USLE (Universal Soil Loss Equation) method where several factors will be calculated including, rainfall erosivity factor (R), soil type or soil erodibility (K), length and slope (LS), and land use and soil management (CP). All of these factors will be applied to the Tapin Dam watershed by combining or overlaying several maps that represent factors that affect erosion in the area. This is done to obtain an estimate of the erosion rate that occurs at the study site.

In this sedimentation analysis, the calculation of erosion rates in the Tapin Dam watershed will be carried out through the application of geographic information system analysis, namely by using polygon overlay techniques on rainfall erosivity (R), soil erodibility (K). length and slope (LS), and land use and soil management (CP) based on equations referring to the USLE method. The result of the overlay process involving the four variables will provide a land erosion rate (A) measured in units of tons/ha/year. Furthermore, the calculation of the USLE formula ($A = R \times K \times LS \times CP$) will be done using ArcMap software. The classification results and erosion maps can be seen below.

Table 4 Classification of Erosion Hazard Classes

Class	Soil loss (tons/ha/year)	Description	Area (ha)	Area (%)
I	< 15	Very light	3362.43	24.10
II	15 – 60	Light	9593.20	68.76
III	60 – 180	Medium	807.90	5.79
IV	180 – 480	Heavy	85.70	0.61
V	> 480	Very heavy	102.69	0.74
Total			13951.90	100.00

The level of erosion hazard in the Tapin Dam watershed is mostly in the light category with an area of 9593.20 ha (68.76%), but there are also heavy and very heavy erosion categories with an area of 85.70 ha and 102.69 ha respectively. The following map shows the level of erosion hazard.

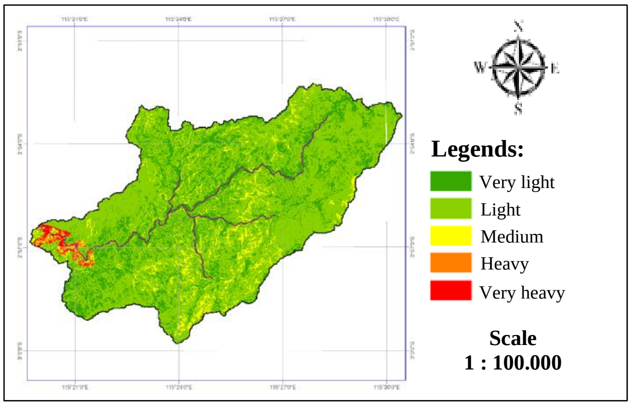

Figure 6 Map of Erosion Hazard Level

Based on the erosion magnitude value map shown in Figure 6 and the land cover map in Figure 4, it can be seen that the areas with greater erosion rates are areas with mining type land cover. this is in line with research [15] that sand mining activities have a high influence on increasing erosion and sedimentation rates in rivers. [16] also mentioned that mining activities are one of the causes of critical land due to loss of vegetation cover, changes in topographic shape, and disruption of soil layer structure. In line with research [17], the state of vegetation is also the most dominant factor in determining the level of land criticality in protected areas. In this case, critical land also affects the amount of erosion rate, where land degradation in Indonesia generally occurs due to increasingly severe erosion due to human activities, which ultimately causes a decrease in the quality of physical, chemical, and biological properties of the soil [18].

The magnitude of the erosion value is also influenced by the slope of the slope, this is in line with [19] that the slope of the slope plays the most role in increasing soil erosion compared to rain intensity where with the influence of slope slope, the magnitude of erosion measurements increases by 2-3 times from each level of intensity.

however, in addition to the slope of the slope there are also other factors that affect the rate of erosion, namely vegetation [20] that in his research, steep and sloping slopes have a higher coverage value than the coverage value on a flat slope so as to cause erosion on a flat slope greater.

According to [21], land protected by trees is an effective way of preventing land erosion. Erosion control by covering the soil with trees is a cheap and easy way to do. Common land erosion control efforts are vegetative methods and the use of additional construction using stone or concrete or a combination of both. Vegetative methods have many limitations, especially for land with large slopes, which require protection against erosion and landslides with special buildings.

G. SEDIMENT DELIVERY RATIO (SDR) ANALYSIS

Sediment Delivery Ratio (SDR) is the ratio between the volume of sediment entering the water body or river and the total erosion that occurs on the land. The amount of SDR is obtained using the Boyce (1975) formula:

$$SDR = 0.41 \times A^{-0.3}$$
$$= 0.41 \times 13{,}951.92^{-0,3}$$
$$= 0.023$$
$$= 2.34\%$$

Description:
SDR = Sediment Delivery Ratio
A = Area of watershed (ha)

After that, the amount of surface sediment released can be calculated:

$$D = \frac{Sy}{T}$$
$$= \frac{0.023}{27{,}225.94}$$
$$= 637.35 \text{ tons/ha/year}$$
$$= 8{,}892{,}228.83 \text{ tons/year}$$

Description:
D = Sediment Delivery Ratio (SDR)
Sy = Sediment results obtained at the outlet of the watershed (tons/ha/year)

The amount of sediment delivery ratio (SDR) is 2.34%. Meanwhile, the amount of surface sediment released in the Tapin Dam watershed is 637.348 tons / ha / year or 8,892,228.83 tons / year.

With these conditions, the appropriate action for the Government is the need for land and environmental conservation efforts which are carried out to maintain the service life of the reservoir. In addition, it is necessary to carry out conservation planning both vegetation conservation and conservation with physical buildings in the form of Sediment Control Buildings in the Tapin Dam Watershed, to inhibit sedimentation rates in order to maintain the service life of the reservoir as planned. For the community, there needs to be awareness of the importance of sustainable land use and management in the Tapin Dam watershed area.

CONCLUSIONS

This study has provided the value of the erosion rate in the Tapin dam watershed. Based on the results obtained from a series of analyses, the following conclusions can be drawn:

1. The value of the erosion rate that occurs in the Tapin Dam watershed is 27,225.94 tons/ha/year.
2. The amount of sedimentation released in the Tapin Dam watershed is 8,892,228.83 tons / year or 637.35 tons / ha / year

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