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MORPHO-CONSERVATION ANALYSIS IN CRITICAL HILLS OF BINUANG MICRO-WATERSHED, SOUTH KALIMANTAN

ANALISIS MORFOKONSERVASI PERBUKITAN KRITIS DAS MIKRO BINUANG, KALIMANTAN SELATAN

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ABSTRACT

Geomorphology is crucial in analyzing erosion potential and selecting conservation measures to improve land resources. Morphometric analysis reveals that the Binuang Micro Watershed, with its upper part being a critical hilly area, has a high erosion potential due to the occurrence of splash erosion, sheet erosion, and rill erosion in all existing landforms. The analysis of watershed morphometry, such as shape, area, drainage density, bifurcation ratio, and drainage density, using DEM data at the research site, reveals a strong correlation between the morphometric conditions of the Binuang Micro Watershed and the incidence of erosion and flood inundation. These conditions are also influenced by the dominant soil texture, namely clay. This research has developed recommendations for conservation actions based on morphometry and the level of erosion occurrence for each landform condition. These recommendations are intended for policymakers to prioritize natural resource management for the sustainability of watershed development.

Keywords*:* Morphometry; Morpho-conservation; Watershed; Critical Hills; Geomorphology.

ABSTRAK

Geomorfologi memegang peranan penting dalam menganalisis potensi erosi dan pemilihan tindakan konservasi untuk perbaikan sumberdaya lahan. Melalui analisis morfometri dapat diketahui bahwa DAS Mikro Binuang yang bagian hulunya merupakan kawasan perbukitan kritis, memiliki potensi erosi yang besar ditandai oleh adanya kejadian erosi percik, erosi lembar, dan erosi alur di semua bentuklahan yang ada. Penggunaan data DEM untuk analisis morfometri DAS seperti bentuk dan luas DAS, kerapatan drainase, bifurcation ratio, dan drainage density di lokasi penelitian menunjukkan bahwa terdapat relasi kuat antara kondisi morfometri DAS Mikro Binuang dengan kejadian erosi dan genangan banjir, selain dipengaruhi oleh tekstur tanah dominan yaitu lempung. Melalui analisis deskriptif kuantitatif penelitian ini telah menyusun arahan rekomendasi tindakan konservasi berbasis morfometri yang didasarkan pada setiap kondisi bentuklahan dan level kejadian erosi. Rekomendasi ini ditujukan untuk pemangku kebijakan agar dapat lebih memperhatikan pengelolaan sumberdaya alam untuk keberlanjutan pengembangan DAS.

Kata kunci*: Morfometri; Konservasi Morfo; DAS; Perbukitan Kritis; Geomorfologi.*

INTRODUCTION

Geomorphology is the study of landforms on the Earth's surface, including the geological processes that shape them and their spatial relationships (Verstappen, 1983). According to (Thornbury, 1989), these processes are known as geomorphological processes, which physically and chemically alter the Earth's surface. Various types of terrain configurations or appearances are formed as a result of this process. Geomorphology studies the evolution and genesis of landforms in detail (Thornbury, 1989). Therefore, the focus of geomorphology is the origin of landform formation, the forces and processes at work, the types of rocks and materials that make up the landform, and their relationship with the environment.

The natural landforms on the Earth's surface change due to the geomorphological processes. These processes include two types, namely endogenous and exogenous. Endogenous forces originate from within the Earth through volcanic and tectonic activities. The geomorphological processes of endogenous forces tend to form (aggrade) landforms on the Earth's surface, such as the formation of volcanoes or mountain ranges. Exogenous energy comes from outside the earth's crust and tends to damage existing landforms (degradation). For example, the energy carried by wind and water can erode and transport material on the earth's surface, causing landforms that were previously higher to gradually decrease towards equilibrium with the surrounding lower areas. The geomorphological process resulting from exogenous forces is influenced by topography, climate, geology, land cover or vegetation, and soil.

Various types of exogenous processes have been observed in the field, such as marine abrasion, landslides, and erosion features. This study focuses on erosion as one of the exogenous processes. Essentially, erosion occurs naturally on the Earth's surface and is proportional to the rate of soil formation and rock weathering. However, the rate of erosion will increase or accelerate due to the complexity of human activities as the trigger, such as land clearing and changes in land use to non-vegetated land. This will have significant consequences for ecology and the economy due to decreased land productivity and increased sedimentation.

This study area includes rough topography in the upstream area, flat terrain and wetland areas in the downstream area, high rainfall, and small areas of standing vegetation, resulting in many open areas in this region (Figure 1). Floods and erosion that frequently occur in the Binuang Micro Watershed are influenced by several factors. Floods during the rainy season are caused by shallow drainage channels due to increased sedimentation in the Binuang Micro Watershed. This is a fragment of a text discussing the high erosion rate in the upstream area of a watershed. The eroded soil is carried downstream by the river flow and deposited in the flat terrain of the lower area, such as drainage channels, agricultural irrigation canals, lakes, or swamps. This concept is consistent with the explanation that erosion in the upstream area causes riverbed shallowing or sedimentation downstream, leading to increased frequency of flooding during the rainy season and droughts during the dry season (Arsyad, 2010).

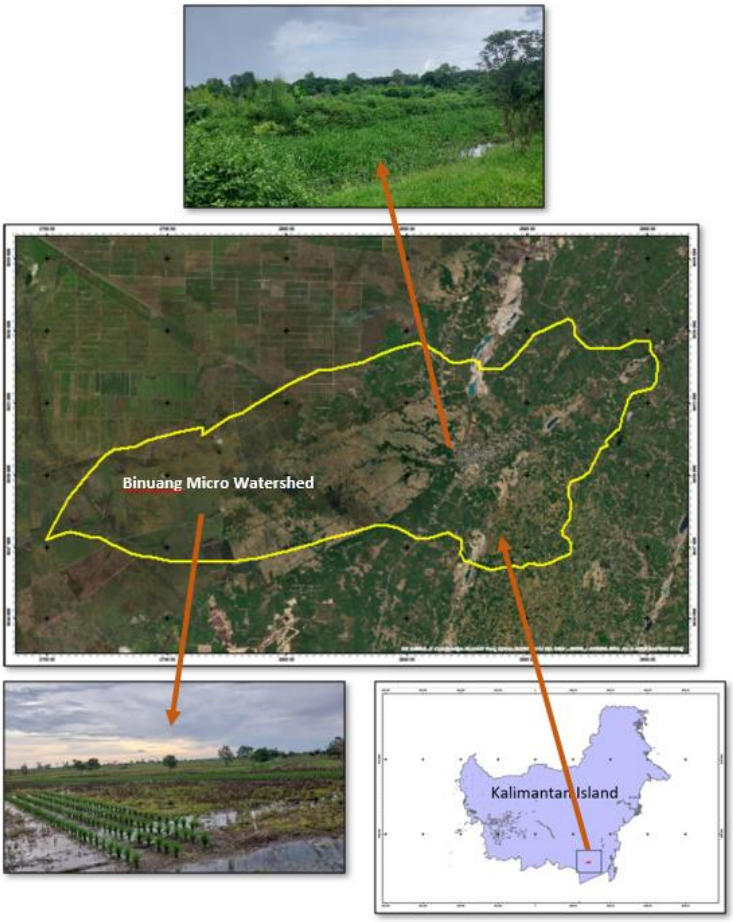

Figure 1. Location of Research Study

Binuang Micro Watershed is located at the foot of the Meratus Mountains in South Kalimantan, where many joints have been found (Yusuf, dkk, 2014). The discovery of many rock outcrops in the upstream area of the Binuang Micro Watershed indicates a high potential for erosion. Additionally, these exposed rocks are susceptible to both chemical and physical weathering. Previous research described that physical weathering on rock outcrops is indicated by the presence of cracks that are highly susceptible to erosion, which is the process of rock erosion and breaking into smaller particles such as gravel and sand (beer and Lamb, 2010). This illustrates the presence of geotechnical control on soil erodibility, both of which significantly impact the level of erosion in an area.

The environmental problems in the Binuang Micro Watershed are not only caused by natural factors, but also by social and cultural factors, especially the community's sensitivity to environmental preservation, such as dumping waste into rivers, deforestation, opening land for illegal mining, and land use change, particularly increasing the number of settlements and other built-up areas. These factors have led to land degradation and decreased land productivity. The most significant impact is felt by farmers in downstream areas who often experience crop failure due to flooding of agricultural land. Meanwhile, farmers in upstream areas will also feel the impact in the form of decreased soil fertility due to increasing soil erosion.

Land use in the Binuang Micro Watershed varies, ranging from open lands such as coal mines and former mines (261 ha), settlements (918.2 ha), tidal swamp rice fields (6720.6 ha), mixed gardens (5177.8 ha), oil palm plantations (1701.3 ha), and the remaining 482.4 ha are marshes. In the upstream area, which theoretically should be densely vegetated, open land and mixed gardens are prevalent in the Binuang Micro Watershed. Land and water conservation is the most important step towards preventing land degradation in the Micro Binuang watershed.

Watershed morphometry is a quantitative measure of watershed characteristics associated with the geomorphological aspects of an area. These characteristics are related to the process of drainage of rainwater that falls within the watershed. This action must be taken to ensure the preservation of the biogeophysical environment in the area. Based on the explanation of the geomorphological conditions of the Binuang Micro Watershed, a thorough analysis of the watershed's morphometry, erosion rates, and conservation methods is necessary to determine the distribution of erosion events.

Based on the description provided, the problem formulation in this study can be simplified as follows:

The upstream part of the Binuang Micro-Watershed is a hilly area with a rough topography where many erosional features are found, indicating the onset of land degradation.

Flooding in the middle and lower reaches of the Binuang Micro-Watershed is caused by eroded sediments, which is further evidence of land degradation.

Analyzing the morphometric condition of the watershed is crucial as it is closely linked to geomorphological processes.

The goal is to provide recommendations for the most effective conservation measures to improve the current conditions in the study area.

RESEARCH METHOD

The method used in this study was a survey method with a quantitative descriptive approach, and the sampling technique was based on the slope class to obtain the results of morphoconservation analysis.

Data Processing

Several quantitative descriptive analysis parameters used in this study, along with their data processing, are as follows:

Watershed Morphometry

The morphometric analysis of the watershed in this study focuses on the area and shape of the watershed, the density of river channels, and the river branching index.

Watershed Area

A watershed area is a physiographic unit of the ecosystem that is bounded by ridges or mountain edges as topographic boundaries that function as receivers, collectors, and distributors of water that falls on the surface of the watershed from rainwater and through various hydrological processes that occur within it. The area of a watershed can be calculated by topographic map by using ArcGIS 10.8. The calculated watershed area is then classified as follows Table 1:

Table 1. Watershed Area Classification

No.	Watershed Area (ha)	Classification
1	>1.500.000	Very large
2	500.000 – 1.500.000	Large
3	100.000 - <500.000	Medium
4	10.000 - <100.000	Small
5	<10.000	Very small

Modified from Peraturan Direktur Jenderal Bina Pengelolaan Daerah Aliran Sungai dan Perhutanan Sosial, 2013

The shape of the watershed

The calculation of the shape of a watershed refers to (Gregary and Walling, 1973) circularity ratio (Rc) as shown in equation (1):

$$Rc = \frac{4nA}{P2} \quad \text{.............................. (1)}$$

where Rc represents the basin circularity, A is the area of the watershed in square kilometers, P is the perimeter of the watershed in kilometers, and π is the mathematical constant pi (3.14).

Flood occurrences in each watershed are influenced by the shape of the watershed itself. Circular-shaped watersheds generally have a larger flood discharge and peak flow throughout all tributaries. Elongated watersheds also tend to have a large flood discharge, but the peak flow is located at the river mouth. Meanwhile, watershed forms resembling bird feathers tend to have low flood discharge and a relatively long time Yendri, dkk. (2022).

Drainage Density

Drainage density is an index that describes the number of river branches within a watershed.

$$Dd = \sum L_n / A \quad \text{........................ (2)}$$

Dd represents the drainage density index (km2/km), ∑Ln represents the total length of rivers
and their branches (km), and A represents the area of the watershed (km^2).

Drainage density is an index that describes the level of the number of tributaries or branches of a river in a river basin in its capacity to store surface water in bodies of water such as rivers, lakes, and swamps (Peraturan Direktur Jenderal NOMOR: P.3/VSET/2013 dalam Pedoman Identifikasi Karakteristik Daerah Aliran Sungai). The drainage density area is also important in determining the speed of overland flow. The higher the flow density, the greater the speed of the overland water flow.

Stream density is closely related to drainage control in a watershed (Horton, 1945). The following is the classification of stream density in this study: A watershed with a density of less than 0.7 km/km^2 tends to have poor drainage, characterized by frequent flooding, while a density between 0.73 - 2.74 km/km^2 tends to improve drainage conditions in the watershed. However, when the stream density exceeds 2.74 km/km^2, the watershed often experiences drought. Table 2 presents the drainage density descriptions for each classification (Soewarno, 1991).

Table 2. Drainage Density Index

No.	Dd (km/km^2)	Density Class	Description
1	<0,25	Low	Streams able to pass through hard resistance rock are characterized by less sediment transport compared to streams passing through soft rock.
2	0,25 – 10	Medium	The river flow passes through rocks with softer resistance than class 1, so that more sediment is transported.
3	10 – 25	High	The river flows through rocks with soft resistance, so more sediment is transported.
4	>25	Very high	The river flows through impermeable rocks. This condition illustrates that rainwater that turns into surface flow will be greater when compared to a smaller Dd.

Modified from Soewarno (1991)

Bifurcation Ratio (Rb)
This value is a quantitative step to assess the condition of a drainage density in a watershed. This value can be calculated using the following formula:

$$Rb = Nu/Nu+1 \quad \text{........................(3)}$$

Nu represents the number of channels in the u-order stream.
Nu+1 represents the number of channels in the (u+1) order stream.
The results were classified in Table 3 below according to Rahayu (2009).

Table 3. Rb Classification

Index	Description
Rb < 3	A condition where the water level rises quickly during a flood, but the rate of receding is slow.
Rb 3-5	A condition where the rise and fall of the water level during a flood is neither too fast nor too slow.
Rb > 5	A condition where the rise and fall of the water level during a flood is equally rapid

Modified from Rahayu (2009)

Erosion Level
The erosion level classification used is based on observations and measurements in the field, including the types of erosion that occur in the field, such as splash erosion, sheet erosion, rill erosion, and gully erosion. Data collection and field observations were carried out in each slope class and then classified in Table 4 based on the depth and width of erosion (van Zuidam, 1979).

Table 4. Erosion Level Classification

No.	Depth of erosion (cm)	Width of erosion (cm)				
		<20	20-50	50-150	150-300	>300
1	<50	Medium	Minor	-	-	-
2	50-150	Major	Medium	Minor	-	-
3	150-300	Extremely major	Major	Medium	Minor	-
4	>300	Extremely major	Extremely major	Major	Medium	Minor

Modified from van Zuidam (1979)

The data analysis in this study focuses on the objectives and goals of land and water conservation in the Binuang Micro Watershed through the selection of effective and efficient conservation measures. Land capability is related to soil conservation practices through the provision of alternative planting that is appropriate to the characteristics and capabilities of the land. This study still considers land capability and suitability, slope, technical culture, and environmentally friendly conservation principles (Pedoman Pola Pembangunan di DAS," Departemen Pertanian, 1987). The aim is to maintain the optimal functioning of the land without compromising its sustainability. Table 5 explains the relationship between land capability, existing land use, and recommended conservation actions, all of which are linked to land criticality.

Table 5. Alternative Conservation Based on Critical Land

Land Capability	Land condition	Critical Land	Alternative Conservation
I	It can be cultivated	Non-critical land	Very intensive to limited management
II		Light critical land	Intensive to limited management
III		Light-medium critical land	limited management
IV		Medium critical land	Grazing (intensive to limited), forest farming, production forest, protected forest
V		Medium-severe critical land	Grass crops, pasture, production forests and protected forests

VI	It cannot be cultivated	Severe critical land	Grazing (intensive to limited), forest production forest, protected forest
VII		Highly critical land	Limited grazing, production forest, protected forest protected forest
VIII		Highly critical land	Protected forest/nature reserve, recreation area

Modified from Arsyad (2010)

The research is limited by the lack of data on erosion appearance, which is currently limited to splash erosion, sheet erosion, and rill erosion. Future research should consider adding advanced erosion types, such as gully erosion, to better describe land criticality by taking into account the amount of soil loss. This will make the relationship between watershed morphometric analysis and land critical more visible.

RESULT AND DISCUSSIONS

Landform Characteristics of Binuang Micro Watershed

Binuang Micro Watershed has unique geomorphological characteristics and varied topography, ranging from swampy plains to hills (Figure 2). The hilly morphology is located in the northeast, which is the lower foothills of the Meratus Mountains that stretch from north to south on the western side of the island of Kalimantan. The differences in characteristics within the study area, indicated by variations in morphology, describe the differences in geomorphological processes that occur and have implications for the various land uses and anthropogenic activities. In general, there are two main types of morphogenesis found in this area: fluvial (F) and structural denudation (S).

The classification of minor landforms is based on morphological and morphographic criteria. Examples of landforms resulting from structural morphogenesis include middle slopes, upper slopes, hill ridges, and hilltops. Minor landforms resulting from fluvial genesis are mainly composed of alluvial plains. The geomorphological processes that cause damage or denudation lead to land degradation, such as erosion, which is commonly found in the genesis of denuded structural areas, especially in the ridges and hilltops. The slope inclination in this area ranges from 16^{0}-55^{0}, with the dominant slope shape being convex. The land use pattern in this area is dominated by terraced agricultural land with a mixed cropping system of various types of plants.

The upper slope is characterized by a slope inclination of 8^{0}–16^{0}, resulting in erosion processes that are still in the developmental stage, such as sheet erosion and rill erosion. The same is true for the lower slope, with a slope class of 4^{0}–8^{0}, where splash erosion is more commonly found as the initial stage of erosion.

The largest unit of the alluvial plain in the Binuang Micro Watershed is dominated by flat morphology and the use of paddy fields and swampy land [Figure 2]. Depositional processes are dominant and characterized by frequent floods that occur every year during the rainy season. Rainwater puddles are difficult to recede, resulting in settlements and paddy fields being submerged for a relatively long time. The transitional zone between fluvial and denudational processes occurs in the depression area of this region. Accumulation of flood discharge and erosion materials occurs in alluvial plains due to their flat topography and the fact that the downstream of the river is located in this area.

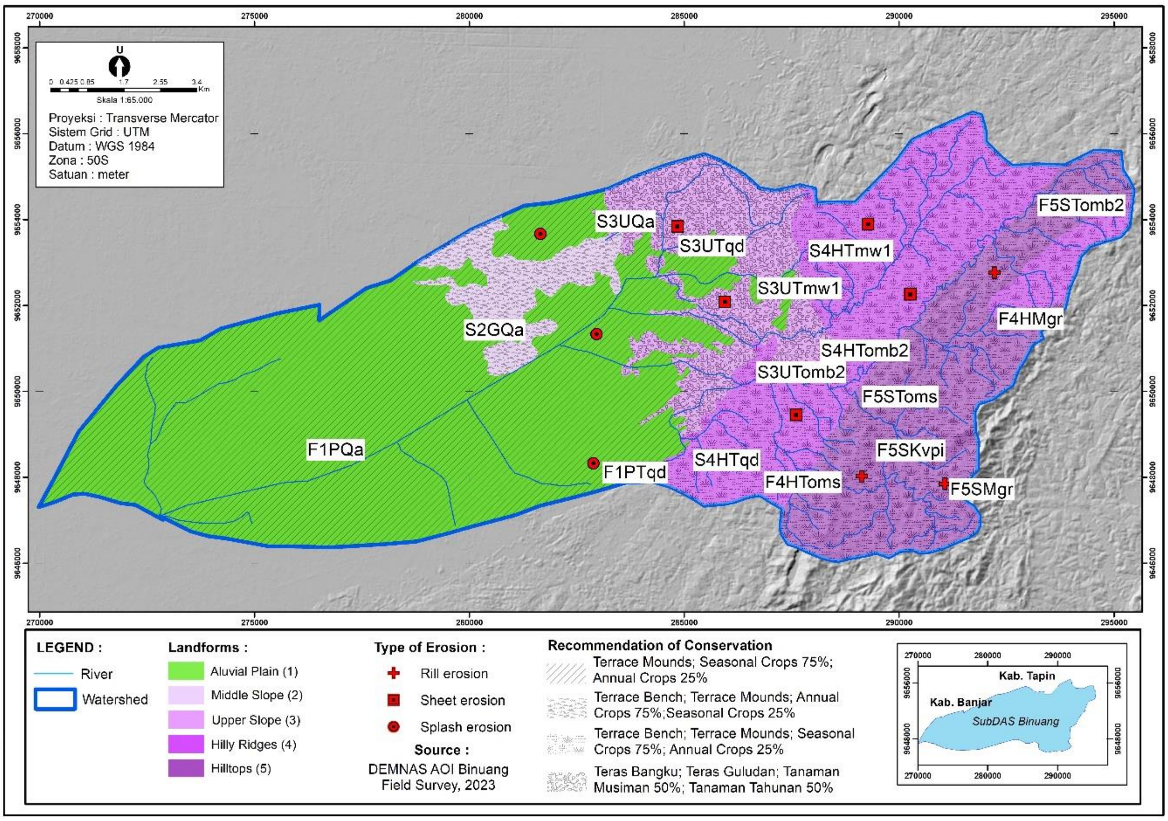

Figure 2. Geomorphological Map of the Study Area

Shape and Area of The Watershed

The Binuang Micro watershed covers an area of 15261.25 hectares and is classified as a small watershed. Despite its size, the watershed exhibits diverse characteristics of the ecosystem, including both morphological and existing anthropogenic features such as land use patterns. The quantitative value of the circularity ratio calculation shows an Rc value of 0.45, indicating that the Binuang Micro Watershed belongs to the elongated-shaped watershed category. The shape observed at the study site suggests an increase in surface flow, as demonstrated by flooding in the settlement area and middle surface during the rainy season. This finding contradicts previous research that suggested a positive correlation between Rc value, watershed shape length, infiltration capacity, and reduced surface runoff (Yadaf et.al., 2014). This may be influenced by the physical properties of the dominant soil at the research site, which is clay, especially in the downstream area, which is included in the alluvial plain landform and the marsh area (Ayuningtyas, 2023).

The flow pattern in this area is sub-dendritic, resembling a dendritic pattern but less perfect due to local geological controls such as fault structures and topography (Howard, 1967). These dendritic flow patterns were formed as a result of the erosion process, and many were found in the front that depicted the homogeneity of the stone and the minimalism of structural control (Umrikar, 2017). Another flow pattern that has been found in this area is sub-trellis which condition affects the time it takes for floods to reach their peak and the concentration of rainwater towards the outlet or downstream. A stretched watershed shape indicates relatively smaller flood fluctuations (Soewarno, 1991). Furthermore, previous research (Gregari and Walling, 1973) also explained that a stretched watershed shape characterizes the increasing concentration required, resulting in a lower flood frequency.

Drainage Density

Drainage density indicates the resistance of a certain type of soil to erosion. A lower Dd value indicates that the soil is more permeable and the relief is flatter. A lower Dd value indicates that the soil is more permeable and the relief is flatter. A lower Dd value indicates that the soil is more permeable and the relief is flatter. Higher Dd values are generally found in areas that are easily eroded, have rough topography, are impermeable, and have sparse vegetation. The calculation results show that the Dd value in the Binuang Micro Watershed is 1.11, indicating a moderate density class. The meaning is that the ruggedness and cracks on the surface of the ground's rocks begin to weather and soften, allowing sheet erosion and channels to occur, carrying sedimentary material downstream. This value also describes the resistance of surface materials to erosion and the capacity of infiltration in the soil (Farhan et.al., 2017).

Bifurcation Ratio

Determining river order in the Binuang Micro Watershed is done using the Strahler method (Strahler, 1964). If two streams of order 1 meet, they form a stream of order 2. Similarly, if two streams of order 2 meet, they form a stream of order 3, and so on (Sukiyah, 2017). The technical segmentation method is chosen for river order determination as it is more in line with the geological conditions. The higher the segmentation, the higher the tectonic intensity (Prabowo, 2022). The conditions in this study are similar to those of the Binuang Micro Watershed, which has joints associated with surface and subsurface cracks that can become the origin of new cracks and river channels. The identification results show that the Binuang Micro Watershed has the highest order, which is 5. The Rb value is 2.89, which illustrates that the river channel has a rapid rise in flood water level, while the decline is slow because Rb < 3. With an Rb value of 2.89, the Binuang Micro Watershed may be tectonically controlled as indicated by the Rb < 3 value and there appears to be a sub-trellis pattern in the west. If traced on the geological map, this section contains intrusive rocks from the Sintang Intrusive Formation. This situation aligns with the recent earthquake that occurred at the Meratus Joints at the top of the Binuang Micro Watershed [Figure 3].

Figure 3. Position of Binuang Micro Watershed against the source of tectonic debris in February 2024

The bifurcation ratio (Rb) is closely related to geomorphological analysis and has a significant role in area erosion assessment (Aher et.al., 2014). The Rb value in the Binuang Micro Watershed describes that there are indications of soil degradation, i.e., the occurrence of surface erosion events. This is in line with the previous study's explanation that Rb values describe the presence of high surface runoff and erosion events (Pandey and Das, 2016).

Erosion Level

The distribution of erosion occurrences in the Binuang Micro Watershed is dominated by splash erosion, sheet erosion, and rill erosion (Figure 4). Splash erosion is a type of erosion caused by the kinetic energy of raindrops detaching soil particles. This definition is further explained by Rose (1960) and Hairsine and Rose (1991) in Zambon et al. (2021), who note that splash erosion affects soil aggregates more than surface flow and is the initial stage before the formation of rill and gully erosion. Furthermore, a dense canopy can better block rainwater droplets that cause splash erosion (Apriani, dkk., 2021). Sheet erosion and minor rill erosion were found in the Binuang Micro Watershed. The average dimensions of the observed sheet erosions are less than 50 cm deep and 20 to 50 cm wide. These conditions fall under the category of mild erosion. However, the rivers in the Binuang Micro Watershed often experience floods and high sedimentation, as indicated by the very turbid river watercolor and sediment rich in clay content.

Figure 4. Splash Erosion on the Lower Slopes of the Binuang Micro Watershed

Erosion is prevalent in the slope morphology, with splash erosion found on the lower slopes, sheet erosion on the upper slopes, and gully erosion on the ridges. Splash and sheet erosion are common in residential areas, palm oil plantations, and open land. Gully erosion is found in the deforested areas upstream of the Binuang Micro Watershed. This type of erosion is a natural response to land-clearing activities carried out by the local coal mining company during the early pre-mining stage. Although rare, channel erosion is the initial indication of the vulnerability of rock mass movement such as landslides and soil creep, which can potentially occur due to the presence of many tilted trees and power poles.

Conservation Recommendations

The most crucial step that can be taken immediately is land reclamation, given the high potential for critical land to occur in the research area. This is one of the efforts to reclaim land so that land conservation continues to run. The main goal is to reduce the dominant erosion rate that occurs in open land and non-vegetated land. Post-mining land reclamation is mandatory to restore their suitability. Therefore, land reclamation planning must consider comprehensive techniques to achieve effectiveness and meet the expected targets. This requires further research and analysis.

Based on field observations that include identification and measurement of erosion, flood characteristics, and quantitative data processing of watershed morphometry, it is evident that the Binuang Micro Watershed requires conservation guidance to improve its existing condition through post-coal mining land control and overall land conservation. Geomorphological analysis in this study aided researchers in prioritizing strata for conservation action. Table 7 below provides details of conservation guidelines that can be recommended for the sustainability of the Binuang Micro Watershed.

The land management practices and patterns that have been implemented in the Binuang Micro Watershed can be categorized as conservation measures. However, based on the analysis of the morphology and morphometry of the watershed, as well as observations of erosion, there is a need for conservation recommendations. The alluvial plain landform is a flat area dominated by marshes that have been flooded for a long time, making terracing the most feasible conservation recommendation. Despite this, maintaining the terrace of the rice field becomes an additional task for farmers as land inundation tends to make conservation difficult. The most feasible action is to regulate the circulation of water supply in and out of the agricultural area to ensure that the plants remain in a state of adequate water supply, without excess or deficiency.

The upper part of the area is shaped like a hilly ridge, and the critical area is the peak. As a result, farmers will experience decreased productivity due to the deposition of soil fertility elements along the river flow downstream. Therefore, the land conservation direction is different. The dominant land use is vegetable gardens, shrubs, and production crops. If this pattern is maintained, soil erosion is feared to continue to erode the surface soil. Therefore, the most suitable recommendation for the upstream area of the Binuang Micro Watershed is to have a much larger proportion of perennial plants than seasonal plants. The strong roots of woody trees are capable of keeping soil aggregates stable, and their canopies also function to reduce the kinetic energy of rainfall, preventing it from directly hitting the ground surface and thus reducing the potential for erosion. The major challenge for the Binuang Micro Watershed is to address the issue of land clearing by coal mine owners, which requires extraordinary efforts to maintain the sustainability of land resources.

Conservation practices that can be implemented in the Binuang Micro Watershed include forest preservation and protection, particularly in the upper watershed. The best approach to land conservation is to maintain agricultural productivity to ensure the stability of the ecosystem. Agroforestry is the most effective form of conservation as it involves the community in protecting the forest while maintaining agricultural activities. According to Supriyadi (2014), the agroforestry system can provide a source of livelihood and income for farmers while also preserving the environment and biodiversity. Sobola et al. (2015) share a similar understanding that agroforestry is a land-use system that aims to increase agricultural productivity, leading to sustainable economic benefits.

Figure 5 shows the distribution of erosion occurrences and recommended conservation methods based on a literature review and quantitative analysis. The central part of the watershed requires different treatment compared to other landforms due to the high amount of open land resulting from mining and oil palm plantations, both in preparation and post-mining land. The conversion of land use into non-agricultural and non-vegetated land is the most prominent environmental issue in the research area.

In determining the type of soil conservation in the critical hills of the Binuang Micro Watershed, it is important to consider the type of terrace applied, specifically terrace mounds (teras guludan). Terrace mounds are soil mounds equipped with water channels at the back, serving the same function as bench terraces by reducing surface flow rates and increasing soil infiltration rates. Terrace mounds are more appropriate on land with a slope of 10-40%, more than that will be less effective due to the influence of gravity and soil solum thickness. Water channels are constructed to drain surface water to the sewer after rainfall. The creation of gulud terraces involves soil removal, which is compensated for by planting economic crops on the terrace. Recommended crops include coffee, cacao, moringa, katuk, pepper, basil, and Japanese papaya.

The agroforestry system may be the optimal solution for addressing erosion issues in the critical hills of the Binuang Micro Watershed. This system incorporates ecological aspects, such as physiographic conditions, and biological aspects, such as the selection of production crops. Additionally, economic interactions are controlled by farmers as the primary actors. For instance, the selection of crop types, as mentioned above, has been successfully implemented in the research location. This statement aligns with previous research, which suggests that traditional agroforestry practices in tropical regions involve planting sturdy trees in a dispersed pattern within agricultural areas, such as coffee plantations (Madalcho and Tefera, 2016).

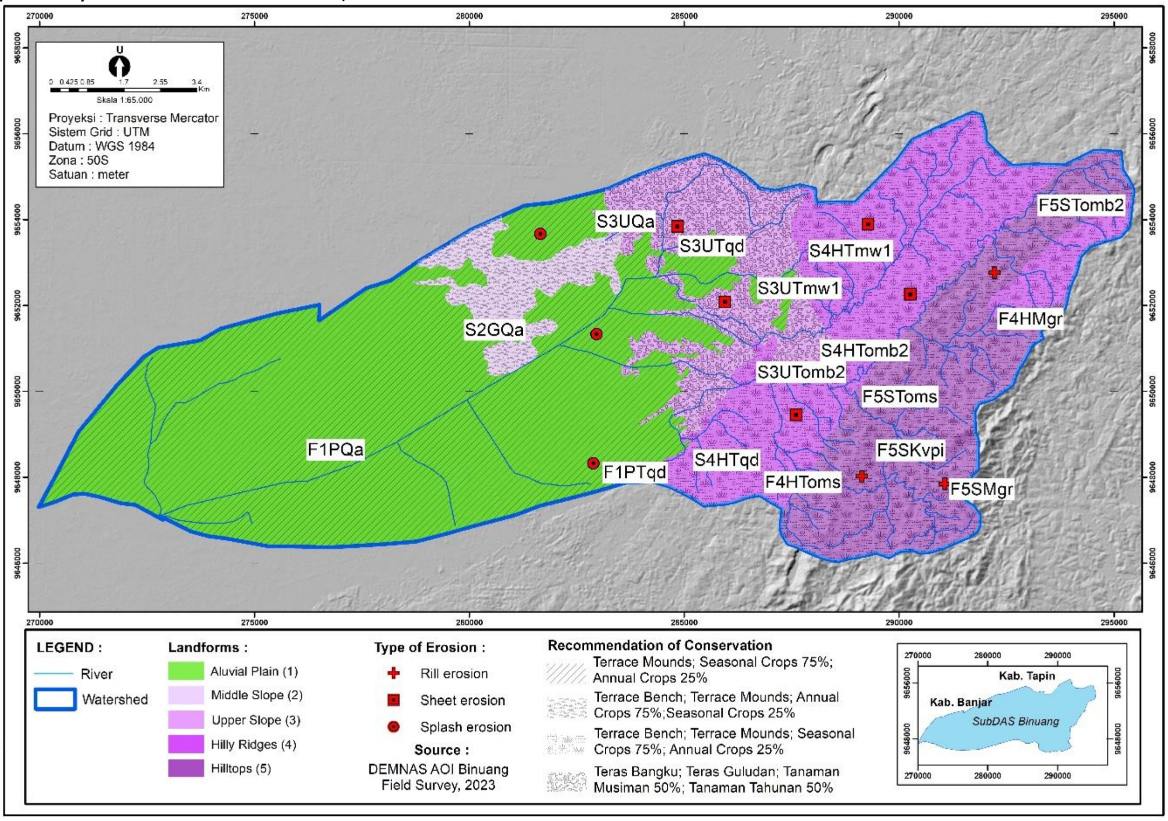

Figure 5. Morpho-conservation Maps of Binuang Micro Watershed

CONCLUSION

The Binuang Micro Watershed has a unique and distinctive geomorphological character, which is characterized by differences among minor landforms. The results of watershed morphometry calculations show that the Binuang Micro Watershed is naturally prone to flooding with a longer flood receding time. This natural potential is worsened by the presence of open land in the form of former coal mines and oil palm plantations. The rising occurrence of flooding, erosion, and sedimentation, particularly during the rainy season, highlights the pressing need for land conservation to protect the environment. It is important to consider each landform's characteristics when determining the appropriate conservation measures, as land management practices cannot be uniformly applied across all watersheds. The percentage of land cover in the form of perennial plants is higher in upstream watersheds than in downstream areas. Revegetation is the most urgent conservation action in the middle slopes where there are many open lands and former mining lands.

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Table 7. Land Conservation Recommendation

	Erosion		Existing Conervation		Conservation Recommendation		
Morphography	Depth (cm)	Width (cm)	Mechanical	Vegetative	Mechanical	Vegetative	Type of plant
Plain	4	17	-	Seasonal Crops	Terrace mounds	Seasonal Crops 75% Annual Crops 25%	Paddy, mixed garden, pepper
Undulating	22	30	-	Seasonal Crops	Terrace Bench Terrace mounds	Annual Crops 25% Seasonal Crops 75%	Paddy, mixed garden, pepper
Wavy	32	35	Terrace mounds	Seasonal Crops Crops Annual Crops	Reforestation	Seasonal Crops 50% Annual Crops 50%	Peanut, pepper, jackfruit, papaya, jati, cacao
Hilly	55	45	Terrace mounds; Garden Terrace	Seasonal Crops Crops Annual Crops	Terrace Bench Terrace mounds	Seasonal Crops 25% Annual Crops 75%	Acacia, sengon, papaya, coffee, cacao, jackfruit
Mountainous	158	78	Terrace mounds ;Garden terrace	Seasonal Crops Crops Annual Crops	Terrace Bench Terrace mounds	Seasonal Crops 25% Annual Crops 75%	Sengon, pine, coconut