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Erosion Mapping Based on Erosion Evidence Features in the Micro Watershed of Parangtritis

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ABSTRACT

This study involves detailed observations of erosion indicators within the watershed to produce a comprehensive mapping of erosion patterns. The detailed mapping of erosion patterns and spatial distribution, along with the factors influencing erosion, is essential. Mapping erosion spatially often yields data that may differ from the actual erosion conditions observed in the field, there is a need for a more accurate yet efficient mapping of erosion hazard levels by combining spatial analysis methods and field surveys. The primary focus of the research is to develop an efficient erosion mapping survey procedure at the Micro Watershed Scale, considering diverse erosion typologies and land-use dynamics. The Micro Watershed of Parangtritis, chosen for its unique erosion characteristics, was used as the main research area. This mapping method involves a combination of field surveys and geospatial analysis to capture various erosion features. Important data to collect are various erosion and landform features based on their geomorphology and anthropogenic features. The mapping results demonstrate complex erosion patterns. Topography, vegetation cover, anthropogenic, and soil types play key roles in erosion distribution. Steep slopes and insufficient ground cover vegetation significantly contribute to the soil erosion. In the upstream area of the watershed, characterized by steep topography and a predominantly natural anthropogenic, there is a tendency for severe erosion, including 8.87 ha (6.38%) classified as 'very severe', 16.81 ha (12.08%) as Severe, 23.46 ha (16.87%) as Catastrophic, and 11.81 ha (6%) as 'high'. Meanwhile, in the downstream area with relatively flat topography and an urbanogenic and agrogenic, erosion tends to be light, with 23.34 ha (16.78%) classified as Light, 7.08 ha (5.09%) as 'moderate', and 28.63 ha (30.98%) as 'very light'. These findings reveal diverse evidence of erosion, including splash erosion, sheet erosion, rill erosion, gully erosion, and landslides, and influenced by variations of topography, vegetation cover, anthropogenic, and soil types that significantly contribute to the erosion patterns within the watershed. Special attention is given to micro-sized erosion features that may not be visible through broader mapping methods. This detailed mapping approach provides valuable insights into the spatial distribution of erosion, facilitating more targeted conservation efforts. These findings contribute to a deep understanding of erosion patterns in the karst environment and provide fundamental information for soil and water conservation planning. In the context of environmental sustainability, detailed-scale erosion mapping in the Micro Watershed Area needs to further explore the anthropogenic influences on erosion occurrence..

Keywords: Anthropogenic, Erosion, Soil, Water Conservation

PENDAHULUAN

Soil erosion management at the micro watershed scale presents a complex challenge within the context of environmental sustainability. The erosion process plays a crucial role in shaping topography and land, significantly impacting the availability of natural resources. While direct erosion measurements provide accurate information, their implementation in micro watersheds covering less than 5000 ha is often difficult and inefficient.

The research was conducted in Parangtritis Village, the micro watershed, which is administratively located, Kretek Subdistrict, Bantul Regency, Yogyakarta. It is situated at coordinates 110°18'55" E-7°59'43" S, with a total area of 139.07 ha, downstream of the Opak

Watershed. The micro watershed in Parangtritis ranges in elevation from 6 to 290 meters above sea level (m.asl) .

The upstream part of the micro watershed in Parangtritis is situated in the Gunung Sewu Region with karst characteristics, making it susceptible to soil erosion. Karst terrain refers to landscapes formed on soluble rocks, including carbonates like limestone, dolomite, and marble, evaporite rocks such as anhydrite, gypsum, and halite, as well as some partially soluble non-carbonates like quartzite and siliceous sandstones (Ford and Williams, 2007; Lewin and Woodward, 2009; Goldscheider et al., 2020). The upstream area has relatively steep slopes with dense vegetation cover. The downstream area flows directly into the main river, the Opak River. The downstream area has relatively gentle and flat slopes with diverse land cover, including mixed plantations, settlements, and rice fields.

Soil erosion modeling serves as a viable alternative. Modeling requires extensive input data, and not all regions have complete datasets. Additionally, modeling weakness emerges in the inability to encompass all erosion typologies. For instance, some models only consider surface erosion, overlooking aspects such as gully and rill erosion. The lack of prediction of sediment delivery ratios by USLE and its failure to predict gully erosion (Trimble and Crosson, 2000). USLE modeling does not measure erosion of larger rills or gullies (linier structures with a depth >30 cm) but is limited to sheet/interrill erosion and erosion of small sreeks only (Alewall et al, 2019). Despite advancements like the Soil and Water Assessment Tool (SWAT), Modify Universal Soil Loss Equation (MUSLE) and Revised Universal Soil Loss Equation (RUSLE), they also have limitations and require lengthy calibration processes.

The dynamic nature of changing land use is often challenging to adopt into modeling coefficients, resulting in inaccuracies in the outcomes. As the shift from field-based to GIS-based modeling takes place, the absence of spatial information for calculating the land cover factor becomes evident. This means that in the majority of catchment-to regional-scale GIS-based models, the significant impact on soil erosion has been overlooked (Alewell, 2019).

This survey can be conducted by leveraging field evidence of erosion as the basis for determining the erosion hazard level. Through an inventory of land units used, we can categorize erosion levels based on the erosion processes occurring in each land unit. Morgan's classification is employed as a guide to determine the erosion levels. The geomorphological mapping system, according to Williams and Morgan (1976), illustrates information related to the distribution and types of erosion, erosivity, runoff, slope length, slope steepness, slope curvature in profile and plan, relief, soil types, and land use.

Splash erosion is the main erosion type during early rainfall, characterized by the movement of soil particles, the formation of surface crust, a decline in infiltration capacity, and a degradation in productivity, can have adverse effects on the sustainable development of agriculture and the ecological environment (Cook, 1937, Le Bissonnais, 1996, Meyer and Harmon, 1989, Prats et al., 2019, Zhang et al., 2017). In the process of splash erosion, soil particles experience dispersion and movement as a result of the impact of rain (Beczek et al., 2019, Fu et al., 2019, Sun et al., 2021).

Sheet erosion and splash erosion indicate lighter erosion hazards. As splash erosion stage evolved into sheet erosion stage, the erosion rates and hydrodynamic characteristics during these two stages are obviously different, which certainly leads to the differences in the processes of soil detachment, sediment transport, and sediment deposition. The impacts of erosion caused by sheet and splash erosion are not as severe as those caused by channel and gully erosion. Sheet and splash erosion can be observed after rain, as they are easily washed away without significant human activity.

Splash erosion marks the initial stage of soil erosion, where raindrop impact causes the dispersal and movement of soil particles. Following this, sheet erosion occurs as a thin layer of soil is removed uniformly across a broad area. Rill erosion then ensues as the sheet flow concentrates into small channels or rivulets, further exacerbating soil loss. These sequential stages highlight the progression and intensification of soil erosion processes on the landscape. Sheet and rill erosion, considered as the primary contributors to soil loss on hillslopes, represent significant phases in the progression of soil erosion (Li, 2024).

High-density rill erosion can lead to the loss of fertile soil layers. This can reduce the soil's ability to support plant growth and increase the risk of downstream flooding. Additionally, continuous erosion can alter soil texture, impact water infiltration capacity, and lead to land degradation.

In karst regions, the thin and discontinuous soil layer, coupled with a dual hydrogeological structure, results in distinct runoff generation and soil erosion processes compared to non-karst regions (Fang et al., 2022, Fu et al., 2016). Severe rill erosion is frequently observed on slopes in studies focusing on soil erosion in non-karst regions (Lou et al., 2022, Niu et al., 2020). In karst areas, the infiltration of surface flow into the rock enhances soil moisture around rock outcrops, stimulates surface runoff, and consistently erodes the soil surrounding these geological formations (Zang et al., 2023). This condition favors the development of rills on the slope.

Gully erosion is similar to rill erosion but with bigger dimensions. The density and depth of rill erosion and gully erosion indicate different levels of erosion hazards, the denser and deeper, the greater the erosion hazard.

In the upstream area, extensive rock outcrops with porous rock conditions are also found. Large rock outcrops can be found with minimal soil in rock basins, indicating very thin soil conditions. This suggests severe erosion conditions, where erosion can carry away a significant amount of soil particles, almost depleting the soil.

According to the residents, tree roots play a role in preventing landslides by stabilizing the soil during heavy rainfall, preventing it from sliding. However, due to persistent high erosion, the soil surface is continually eroded, exposing tree roots and diminishing their ability to hold the soil. Alterations in wood anatomy in roots exposed within a gully not only provides insights into the duration of root exposure but also offers information about the processes leading to it, whether they be surface or subsurface erosion (Jakiel and Walach, 2018). This unauthorized activity exacerbates soil conditions, contributing to increased erosion and landslides.

Landslides are an indication of high erosion in an area, leading to massive soil loss. The research location, especially in the upstream areas, is prone to erosion (Wibowo, 2001). Landslides occurred at several points in the research area, all in the upstream part of the watershed with steep and very steep topography. Slope steepness is one of the main factors causing landslides.

Damage or changes to infrastructure also occur in roadways, bridges, or buildings due to soil erosion. Cracks or shifts in the foundation of infrastructure can be evidence of significant erosion. Erosion results in significant damage to critical infrastructure like bridges, roadways, flood protection systems, and dams (Deng and Wang, 2016, Li et al., 2019, Fluixá-Sanmartín et al., 2018)

Erosion is the process of soil particle movement from one place to another caused by rainfall. Continuous and prolonged erosion with a significant volume of transported soil can result in substantial soil loss. This leads to the thinning of the soil, causing tree roots to become visible on the surface over time. Under extreme erosion conditions, there can be significant soil loss, causing tree roots to be exposed to a height almost equal to that of an adult. Tree roots serve as the foundation for the tree, and continuous erosion can lead to tree collapse as the roots are unable to support the tree's weight.

Exposed tree roots can serve as an indicator of the severity of erosion hazards in the area. When plant roots remain within the soil, it indicates that the area has a very low erosion hazard. However, as more exposed plant roots become visible, it reflects a higher risk of erosion in that area. In some erosion-prone areas, soil erosion has eroded the ground to the extent that plant roots are exposed to a significant depth.

The primary focus of the research is to develop an efficient erosion mapping survey procedure at the Micro Watershed Scale, considering diverse erosion typologies and land-use dynamics. Agrogenic influences encompass changes resulting from both agricultural practices and forestry activities (Szabó et al, 2010). Thus, the expectation is to contribute to better soil erosion management, supporting environmental sustainability.

.MATERIAL AND METHODS

The condition of the Micro Watershed in Parangtritis is quite vulnerable to potential natural disasters, including landslides, floods, fires, storms, and droughts. This situation is exacerbated by the presence of many houses situated below cliffs and hills without retaining walls, relying solely on plant roots and existing rocks for support.

Land Unit

The land unit is used as the mapping unit for erosion mapping at a 1:10,000 scale. The land unit is determined by anthropogenic landforms and slope gradients. Landforms spatially depict the distribution of geological formations as the constituent of landforms, topography as the process of landform formation, and geological processes that act on specific geological and topographical conditions resulting in distinctive and diverse formations. Meanwhile, anthropogenic elements depict human activities that have altered existing landforms. Slope gradient is one of the determining factors in causing erosion, crucial to consider in soil erosion mapping. The results from the land unit are utilized to determine the locations for survey sample points. The selection of survey locations uses purposive sampling, considering the land units and their respective areas.

Soil Erosion Survey

The data collection was conducted in several stages, including surface erosion observation, vegetation cover analysis, anthropogenic analysis, and slope measurement. The survey locations were determined by selecting sample points based on the land unit map that had been prepared. The chosen survey locations represent the mapping units, and the selection of survey points must be dispersed and representative to the entire Micro Watershed of Parangtritis area.

Surface erosion observation was carried out to identify the types of erosion that occurred in each land unit. This was done to identify the types of soil erosion found in the research area. The types of soil erosion are related to the erosion process and can serve as an indication of the potential magnitude of erosion in each land unit.\

Soil erosion surveys, as outlined by Morgan (2005), are categorized into static, sequential, and dynamic surveys. Static surveys involve mapping through aerial photographs related to the types of soil erosion, including sheet erosion, gully erosion, and furrow erosion in a specific area (Jones & Keech, 1966, as cited in Morgan, 2005). Sequential surveys involve mapping erosion features and influencing factors while seeking relationships between them.

The features of erosion, as one of the indications of erosion hazard, include clear patterns or forms on the soil surface caused by the movement of soil by rainfall or river flow. Watermarks, especially during rainy periods, create small or large channels on the soil surface. This is most easily observed immediately after rainfall. Asdak (2010) classifies erosion into seven types based on appearance and severity: splash erosion, sheet erosion, rill erosion, gully erosion, riverbank erosion, internal river erosion, and landslides.

The classification of erosion levels is conducted through direct field surveys using a method of land unit generated from anthropogenic landforms and slope gradients. Landforms visually represent the spatial distribution of geological formations, comprising the foundation of land configurations, while topography illustrates the process of landform creation and the geological activities shaping them into unique and varied structures. Additionally, anthropogenic elements signify human interventions that have modified the original landforms. The slope gradient plays a pivotal role as one of the primary factors contributing to erosion, making it essential to account for soil erosion mapping.

Soil erosion assessment is carried out in detail to obtain information about the severity of erosion. The severity level is determined through a simple assessment by considering visible features in the field. These features include exposed tree roots, surface hardening, splash marks, size of rills and furrows, and the type and structure of the vegetation cover. The severity of erosion is determined based on the observed conditions of these criteria in the field. This direct field assessment allows for a detailed evaluation of the erosion severity levels in the study area. The Table 1 represent the severity of erosion which is rated by a simple scoring system which is features that are easily visible, such as the exposure of tree roots, crusting of the soil surface, formation of splash pedestals, the size of rills and gullies and the type and structure of the vegetation cover.

Table 1. Classification System for Assessing Soil Erosion in The Field

No	Class	Erosion Rate (ton/ha)	Indicators
1	Very slight	< 2	The soil surface shows no signs of compaction or crusting; no indications of wash marks or scour feature; no splash pedestals or exposed tree roots; the area boasts a plant cover of over 70%, encompassing both ground and canopy vegetation
2	Slight	2 - 5	The soil surface exhibits some crusting; instances of localized wash, although scouring is either absent or minimal; rills are observed at intervals of approximately 50-100 meters; small splash pedestals with depths ranging from 1 to 5 mm are present in areas where stones or exposed trees shield the underlying soil, covering no more than 10% of the total area; soil level slightly elevated on the upslope or windward sides of plants and boulders; plant cover ranges from 30% to 70%.
3	Moderate	5 - 10	Wash marks; discontinuous rills spaced every 20-50m; splash pedestals and exposed tree roots mark the level of the former surface, soil mounds protected by vegetation, all to depths of 5-10mm and occupying not more than 10% of the area; slight to moderate surface crusting; from 30% to 70% plant cover; slight risk of pollution problems downstream if slopes discharge straight into water courses.
4	High	10 - 50	A network of rills or gullies forms a connected and continuous pattern, with rills occurring every 5-10m or gullies spaced approximately every 50-100m; tree roots are exposed, accompanied by splash pedestals and soil mounds reaching depths of 10-50mm, covering no more than 10% of the area; surface crusting is evident over extensive areas; less than 30% plant cover; there is a risk of downstream pollution and sedimentation issues.
5	Severe	50 - 100	There is an uninterrupted network of rills every 2-5m or gullies spaced every 20m; tree roots are exposed, accompanied by splash pedestals and soil mounds reaching depths of 50-100mm, covering more than 10% of the area; splays of coarse material; bare soil; siltation of water bodies; erosion and sedimentation causing harm to roads and infrastructures.
6	Very severe	100 - 500	An unbroken system of channels with gullies occurring every 5-10 meters; the soil in the surrounding area is extensively crusted; significant issues of siltation, pollution, and eutrophication; bare soil.
7	Catastrophic	> 500	Extensive network of both rills and gullies; large gullies (>100m^2) every 20m; the majority of the original soil surface has been eroded or removed; severe on-site and downstream damage caused by erosion and sedimentation.

Source: Morgan (2004)

The loss of soil and the severity class of soil erosion are closely related. Gully erosion is one of the primary forms of soil erosion, accelerating the rate of soil loss (Vanmaercke et al., 2021) and posing a threat to valuable land resources (Xu et al., 2016). Figure 1 below illustrates the relationship between soil loss and the severity class of soil erosion with the cross-sectional area of the gully/channel, assuming a bulk density of 1.4 Mg m^{-3} for the soil material.

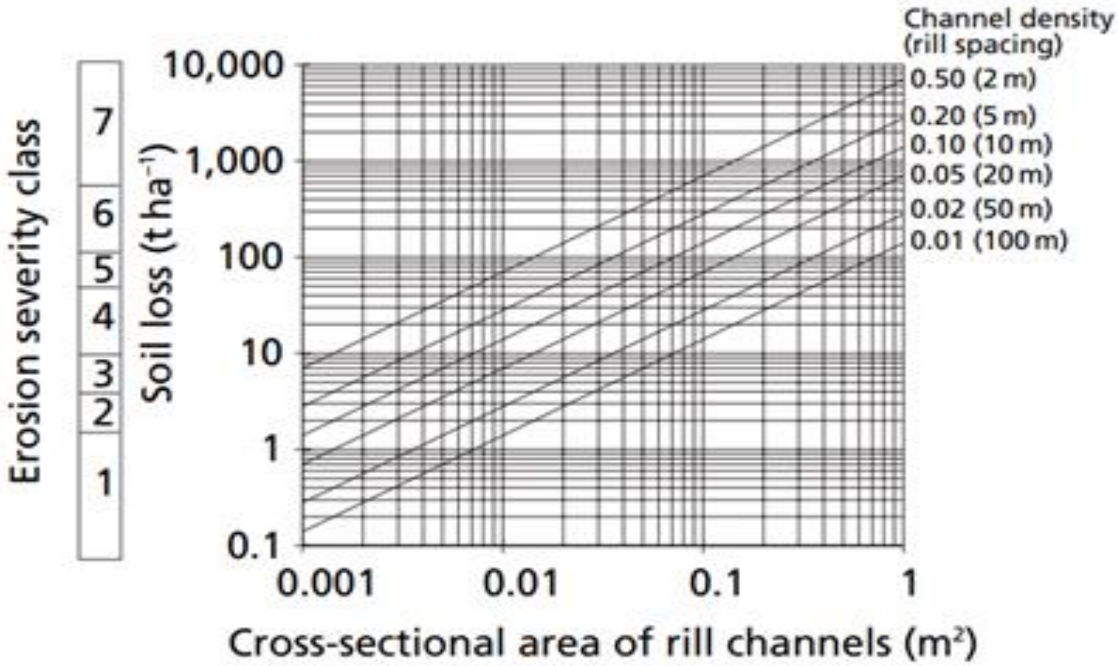


Figure 1. Relationship between soil loss, soil erosion severity class and cross-sectional area of rill channels, assuming a bulk density of 1.4 Mg m-3 for the soil material. Source Morgan (2005)

The field assessment of soil erosion to determine the classification of erosion levels is based on the mapping unit. Observations needed to determine the classification of erosion levels include the condition of the soil surface such as rills and furrows, the condition of exposes tree roots due to erosion, the presence of coarse rock fragments, vegetation cover, and damage to roads and infrastructures caused by erosion and sedimentation.

Data Analysis and Validation

The data processing stage involves various techniques for data analysis and validation, including satellite image processing (pre-processing), digital image processing, spatial data processing analysis, land cover analysis, accuracy assessment, ground checks, and reclassification. The Figure 2 below shows the flowchart of the research.

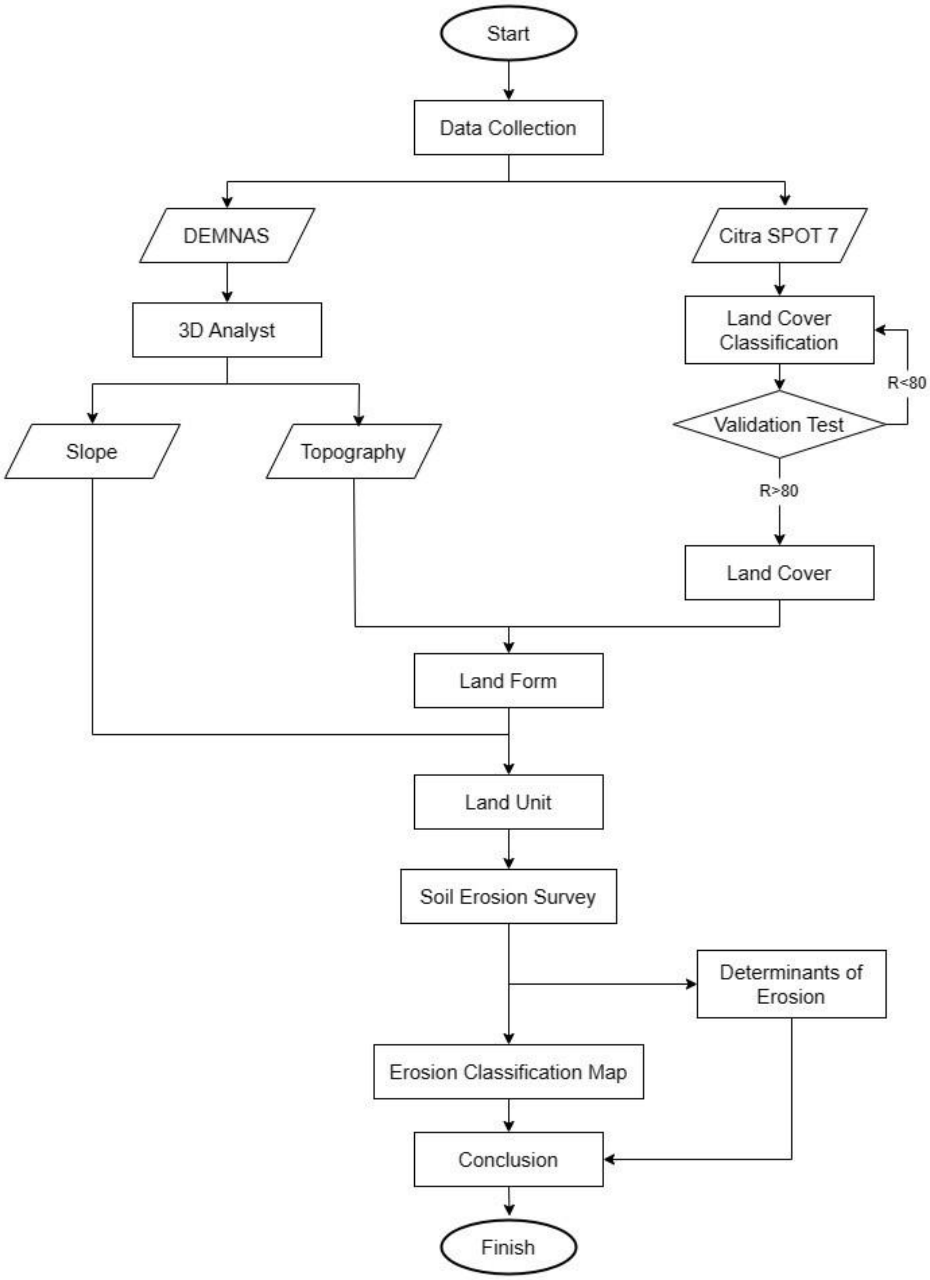


Figure 2. Research Flow Diagram

HASIL DAN PEMBAHASAN

Land Cover

The land cover in the micro watershed of Parangtritis consists of forests, mixed plantation, fields, village settlements, and rice fields. The sustainable development of land plays a crucial role in fostering economic and societal prosperity in rural areas (Zang et al., 2019). Forest land is the most dominant land cover, covering an area of 60.65 ha, equivalent to 43.62% of the watershed area. Forest land cover is primarily found in the upstream to middle parts of the watershed. The types of plants prevalent in the forest land cover are dominated by hardwood species such as teak, mahogany, acacia, calabash, and rosewood. Figure 3 below is the land cover map of the micro watershed of Parangtritis.

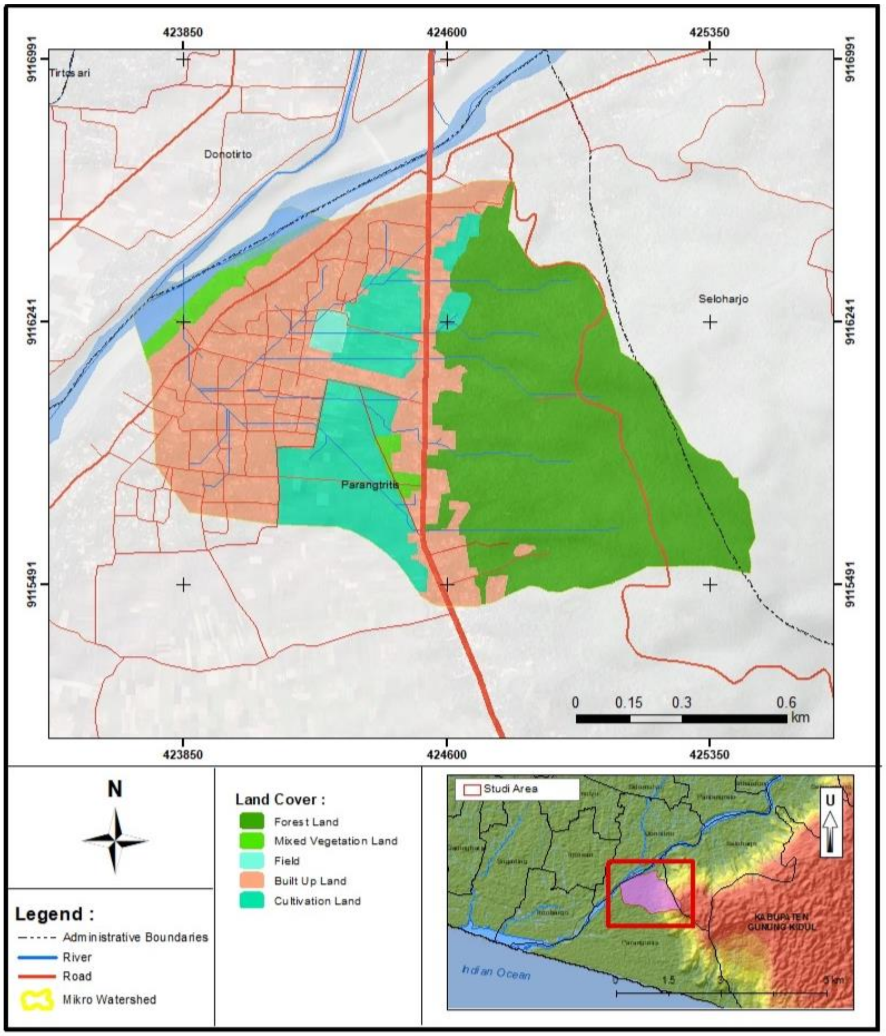


Figure 3. Land Cover

Settlements as build up land are also a prevalent land cover in the central and downstream parts of the watershed. High-density rural settlements are located on both sides of the main road, namely Parangtritis Road, situated in the central part of the watershed. In contrast, other areas consist of low-density settlements characterized by spacious yards and mixed vegetation plants. The total area of buildup land is 50.08 ha, equivalent to 36.02% of the entire watershed area.

Table 2. Land Cover Percentage of Total Area

No	Land Cover	Area (ha)	Area (%)
1	Forest land	60.65	43.62
2	Mixed vegetation land	3.85	2.77
3	Built up land	50.08	36.02
4	Cultivation land	20.07	14.43
5	Field	1.14	0.82
6	River	3.26	2.34
Total		**139.07**	**100.00**

Source: SPOT 7 2021 Image and 2024 Analysis Result.

Table 2 above presents the results of data processing, providing the area for each land cover type. Other land covers found in the study area include fields and rivers. Fields cover an area of 1.14 hectares, while rivers cover an area of 3.26 hectares. The overall total land cover in the Micro Watershed of Parangtritis is 139.05 hectares. Soil erosion has a more detrimental impact on open and unprotected areas, contrasting with terrains that are fortified and shielded against erosion (Chakrabortty et al., 2020).

Landform

Landforms are surface features resulting from the alterations of the Earth's surface by geomorphological processes that operate on the Earth's surface. Geomorphological processes encompass all physical and chemical changes occurring on the Earth's surface due to forces generated by natural elements present on the Earth's surface, including the atmosphere (Widyanto, 2013). Figure 4 below is the landform map of the micro watershed of Parangtritis, representing the distribution of landforms in the study area.

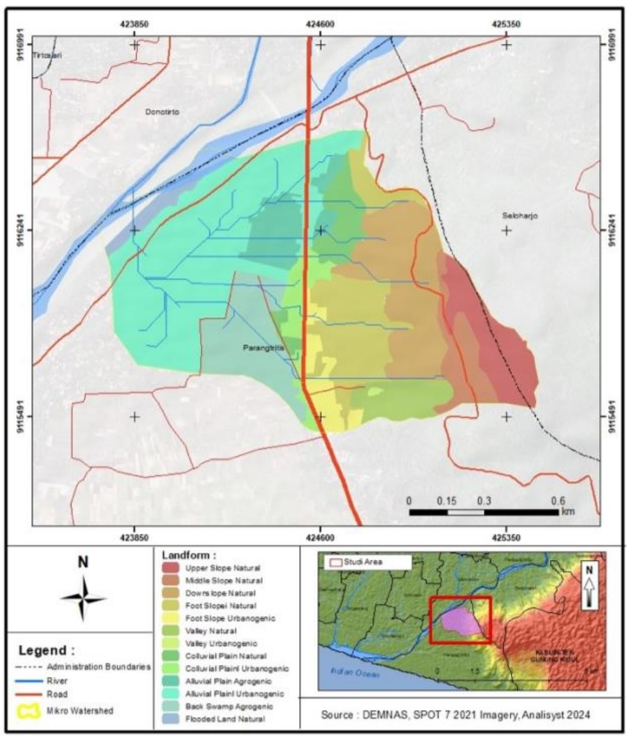


Figure 4. Landform

Landforms are classified based on their geomorphology and anthropogenic features. The landforms identified in the study area include upper slopes, middle slopes, lower slopes, foot slopes, valleys, colluvial plains, alluvial plains, backswamps, and floodplains. Anthropogenic features encountered include urban, natural, and agricultural influences. The area of each landform is presented in Table 3 below.

Table 3. Landform Percentage of Total Area

No	Landform	Area (ha)	Area (%)
1	Upper slope-natural	9.53	6.85
2	Middle slope-natural	6.18	4.44
3	Downslope-Natural	18.3	13.16
4	Foot Slope-Natural	16.17	11.63
5	Foot Slope-Urbanogenic	4.71	3.39
6	Valley-Natural	5.43	3.91

No	Landform	Area (ha)	Area (%)
7	Valley-Urbanogenic	0.15	0.11
8	Colluvial Plain-Natural	6.05	4.35
9	Colluvial Plain-Urbanogenic	4.8	3.45
10	Alluvial Plain-Agrogenic	1.67	1.21
11	Alluvial Plain-Urbanogenic	41.56	29.89
12	Flood Land-Natural	2.85	2.05
13	Back Swamp-Agrogenic	18.41	13.24
14	River	3.26	2.34
Total		**139.07**	**100.00**

Source: SPOT 7 2021 imagery, DEMNAS, 2024 Analysis

The urbanogenic alluvial plain is the dominant landform in the micro watershed of Parangtritis, covering an area of 41.56 hectares or approximately 29.89% of the total watershed area. This landform features a relatively flat to gently sloping topography and is predominantly found in the downstream part of the watershed. The characteristics of this landform include rural settlements with low population density.

The slope landform is divided into upper slope, middle slope, lower slope, and foot slope based on their locations. This landform is found in the upstream part of the watershed with a relatively steep topography. The majority of this landform is still in its natural state, predominantly covered by forests with teak, mahogany, acacia, and rosewood. The natural foot slope has an area of 16.17 ha, equivalent to 11.63% of the total watershed area.

There is a valley landform, which is a large basin in the central part of the watershed. The majority of the valley landform is still natural, covered by forests, although some parts consist of rural settlements with very low population density.

The agrogenic backswamp landform is also found in the downstream part of the watershed. This landform is characterized by lower elevation compared to its surrounding areas, featuring relatively flat topography and serving as agricultural areas. The agrogenic backswamp landform covers an area of 12.87 ha, equivalent to 9.26% of the total watershed area.

Topography

The topography map illustrates the distribution of slope conditions in the micro parangtritis watershed. The downstream part of the watershed tends to have a relatively flat to gently topography, the middle part has a relatively gentle to moderately steep topography, while the upstream part exhibits a relatively steep to very steep topography. Figure 5 below is the slope inclination map of the Micro Watershed of Parangtritis.

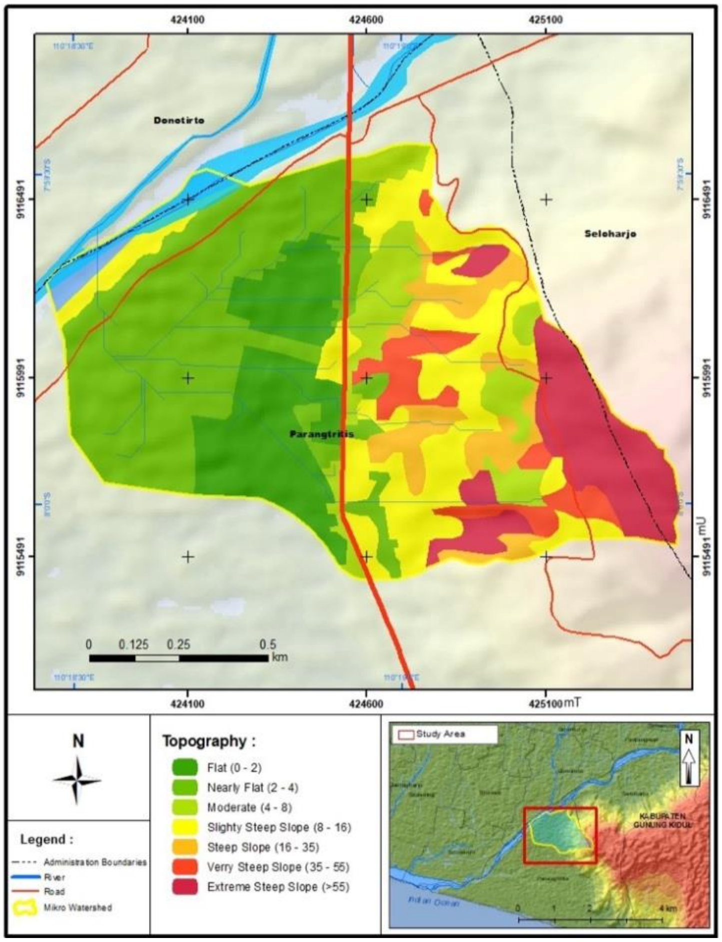


Figure 5. Topography

The research area is predominantly characterized by the nearly flat topography, with slopes ranging from 2° to 4°, covering an area of 42.23 ha or approximately 30.37% of the total watershed area. The flat and nearly flat slope class is found in the downstream part of the watershed, which includes agricultural and residential areas. Table 4 below illustrates the slope inclination classes and their respective areas.

Table 4. Topography of Total Area

No	Topography	Slope	Area (ha)	Area (%)
1	Flat	0° - 2°	24,19	17,39
2	Nearly Flat	2° - 4°	42,23	30,37
3	Moderate	4° - 8°	12,40	8,92
4	Slighty Steep Slope	8° - 16°	26,60	19,13
5	Steep Slope	16° - 35°	9,77	7,03
6	Verry Steep Slope	35° - 55°	7,61	5,47
7	Extreme Steep Slope	>55°	16,27	11,70
Total			**139.07**	**100.00**

Source : DEMNAS, 2024 Analysis

Topography influences the formation and accumulation of runoff, affecting the development of gully erosion (Li et al., 2022). The hazard of erosion is estimated based on simple indicators such as the density of gully erosion that can be observed in the field (Morgan, 2005). Some visual evidence that can be identified and used for erosion mapping includes surface erosion scars, sedimentation and deposits, movement of soil and rocks, affected vegetation growth, features in slope structures, water pollution, and changes to infrastructure.

Land Unit

Erosion mapping at a scale of 1:10,000 utilizes the land unit as its mapping framework, determined by anthropogenic landforms and slope gradients. Landforms represent geological formations and topographical features, shaped by geological processes, while anthropogenic elements signify human-induced alterations. The inclusion of slope gradients is essential in erosion mapping due to their significant influence on erosion processes and soil stability.

Findings obtained from the land unit analysis are employed to identify suitable survey sample locations. Purposive sampling is employed to select survey points, considering the characteristics of the land units and their respective areas.

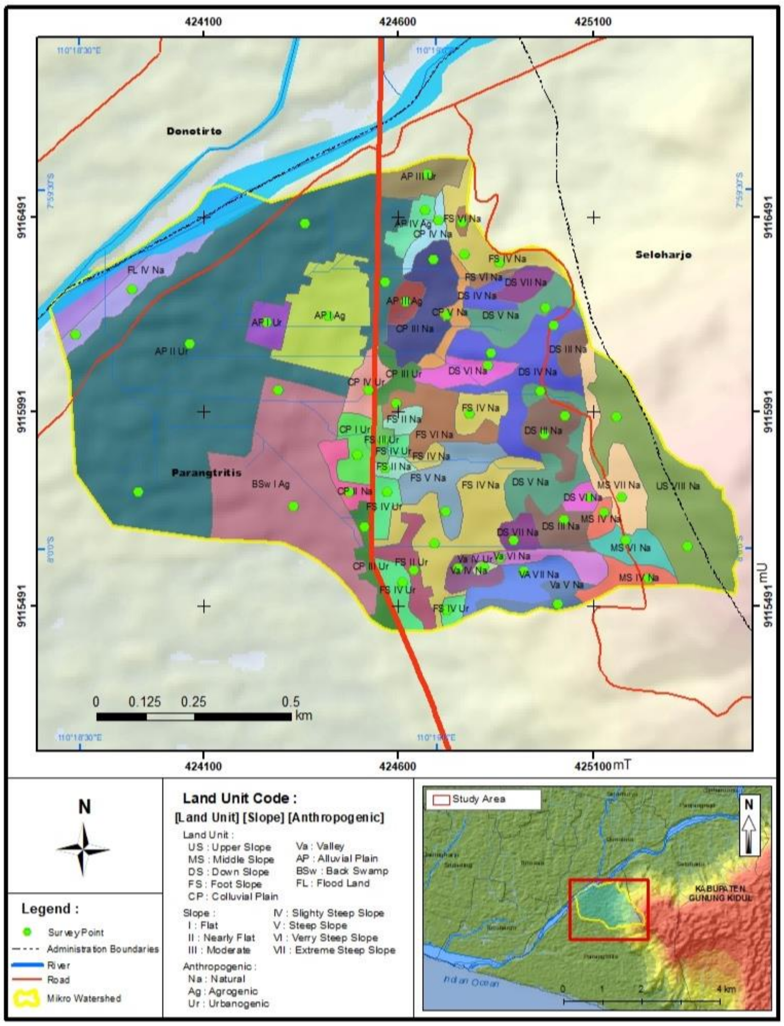


Figure 6. Land Unit and Survey Point Map

Figure 6 above shows the survey observation points for erosion in each land unit. There are 54 survey points distributed, covering all land units. At each survey point, erosion observations are conducted, documenting every erosion finding in that area. From these erosion findings, according to Morgan (2005), the erosion class can be determined.

Features of Erosion

Erosion is a critical natural process that significantly impacts landscapes and ecosystems worldwide. Understanding and mapping erosion patterns are essential for effective land management and conservation efforts. In this report, we present the results of our analysis of erosion features, focusing on the identification and classification of erosion levels in a specific geographical area. Through field surveys and data analysis, we aimed to assess the extent and severity of erosion, considering various factors such as landforms, topography, anthropogenic influences, and slope gradients. The findings of this study provide valuable insights into erosion dynamics.

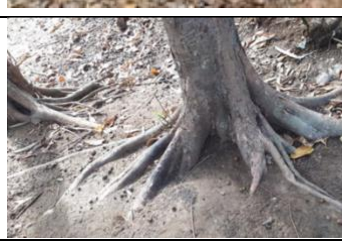
Table 5 below displays erosion features identified within the research area, these erosion features were observed and documented during field surveys conducted as part of the research study. The erosion features found in the micro watershed of Parangtritis encompass various types, including splash, sheet, rill, gully erosion, and soil loss from landslides. These indicate the watershed's susceptibility to soil erosion, emphasizing the urgency for effective erosion management strategies to safeguard its ecological health.

Splash erosion, occurring during initial rainfall, disrupts soil particles, forms surface crusts, and hinders infiltration, posing risks to agriculture and the environment. It precedes sheet and rill erosion, escalating soil loss. Rill erosion, particularly high-density instances, can deplete fertile soil layers, disrupt plant growth, and heighten downstream flood hazards.
Unique runoff and erosion dynamics characterize karst regions due to their thin soil layers and complex hydrogeological structures. Gully erosion, akin to rill erosion but on a larger scale, signifies heightened erosion risks. Landslides, prevalent in steep upstream areas, underscore erosion's impact.

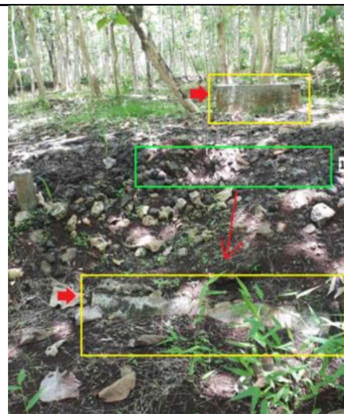
Infrastructure damage, like cracks and shifts in roads and bridges, exemplifies erosion's consequences. Continuous erosion diminishes soil depth, exposes tree roots, and jeopardizes tree stability. Exposed roots serve as indicators of erosion severity, with deeper exposure indicating heightened risk. In essence, erosion poses a significant threat to soil and environmental stability, necessitating prompt and effective erosion control interventions. Classification of erosion on each land unit, and erosion features that are found in the field during a survey. Each erosion feature found will determine the erosion class in the study area.

Table 5. Features of Erosion

No	**Features of Erosion**	**Image**	**Description**
1	Splash Erosion		Splash erosion indicates very light erosion hazards. Splash erosion can be observed after rain as they are easily washed away without significant human activity. Sheet erosion in residential areas is more challenging to identify, even a day after heavy rain, due to human activities that may trample or be compressed by vehicles. Meanwhile, splash erosion can still be found in some home gardens.
2	Sheet Erosion		As splash erosion stage evolved into sheet erosion stage, the erosion rates and hydrodynamic characteristics during these two stages are obviously different, which certainly leads to the differences in the processes of soil detachment, sediment transport, and sediment deposition. The impacts of erosion caused by sheet erosion are not as severe as those caused by rill and gully erosion. Sheet erosion can be observed after rain, and was found in the middle part of watershed, specifically in agricultural areas.
3	Rill Erosion		In upstream areas, rill erosion is prevalent and serves as an indicator of soil erosion intensity by water. Rill density, influenced by factors like rainfall, soil structure, slope, and land management, correlates with erosion impact on soil layers. High-density rill erosion can lead to loss of fertile soil, hampering plant growth and increasing downstream flooding risk. Continuous erosion alters soil texture, reduces water infiltration, and contributes to land degradation. In karst regions, unique runoff and erosion processes occur due to the thin soil layer and dual hydrogeological structure, differing from non-karst areas (Fang et al., 2022, Fu et al., 2016).

No	Features of Erosion	Image	Description
4	Gully Erosion	 	Gully erosion is commonly found in the upstream part of the watershed. The depth of the gullies, reaching up to an adult, indicates high erosion hazard in that area. The thin soil on the surface of the channel network is the result of erosion transport during rainfall.
5	Rock Fragment		The condition of the gully appears more extreme shortly after rainfall. The large size of the channels reflects the volume of water carried along with surface runoff during rainfall, and how much sediment is capable of being transported. In some other areas, evidence of larger and deeper gully erosion is also found but is located in hard-to-reach ravines. The transported sediment consists mainly of soil, but there are also large rock fragments
6	Rock Exposure		The upstream area is influenced by karst processes, resulting in soil with high clay content. Laboratory test results indicate that the upstream area has a clay content of 78.6% and relatively slow permeability. This region has relatively thin soil depth, less than 30cm, and is characterized by many coarse rocks. The picture shows areas with numerous exposures of coarse rocks due to high erosion hazard, leading to the almost complete loss of soil through erosion.
7	Root Exposure		Exposed tree roots are found in the downstream area of the Parangtritis Micro Watershed, which is a residential area. The presence of slightly exposed tree roots indicates mild erosion, influenced by the relatively flat topography.

No	Features of Erosion	Image	Description
			The research location in the central part of the watershed with very steep slopes, wide and deep gully erosion, exhibits a condition where tree roots are entirely exposed to a considerable depth. It is evident that these tree roots are still attempting to stabilize the soil and prevent landslides.
8	Sediment Deposit	 	Sedimentation and deposits in certain areas, especially those receiving runoff from slopes, are indicators of high erosion hazards in the upstream region.
9	Erosion and Infrastucture	 	This indicates that erosion also affects infrastructure, particularly in water channels. The erosion transports soil particles from higher areas to lower ones. Water channels function as drainage to convey rainwater from the surface, indicating the presence of runoff from the surrounding area. High erosion occurs in this area, capable of transporting sediments and depositing them in the water channel until it becomes full. In locations with lower erosion risk, it is observed that the water channels are not covered with sediment.

No	Features of Erosion	Image	Description
			The riverbank infrastructure is also affected, considering that rivers are the main paths traversed by rainwater carrying sediment. Some riverbanks are visibly cracked, and in some cases, even eroded significantly from their original positions
			The road infrastructure with cracked and eroded asphalt indicates that erosion affects the condition of the road infrastructure, eroding it, causing the asphalt to crack, and even break, and being eroded. Some areas have severely damaged asphalt, and in other areas, there is no asphalt, only rocks.
10	Landslide		Landslides can block road access, posing a danger to humans in the backyard as they are very close to residential buildings.
			Many teak trees have been cut down at the top of the cliffs, but their roots remain in the soil. These remaining roots have aesthetic value, and many people attempt to collect them for bonsai or decorative purposes. Local residents have prohibited such activities, but illegal harvesting still occurs frequently.

Source: 2024 Analysis.

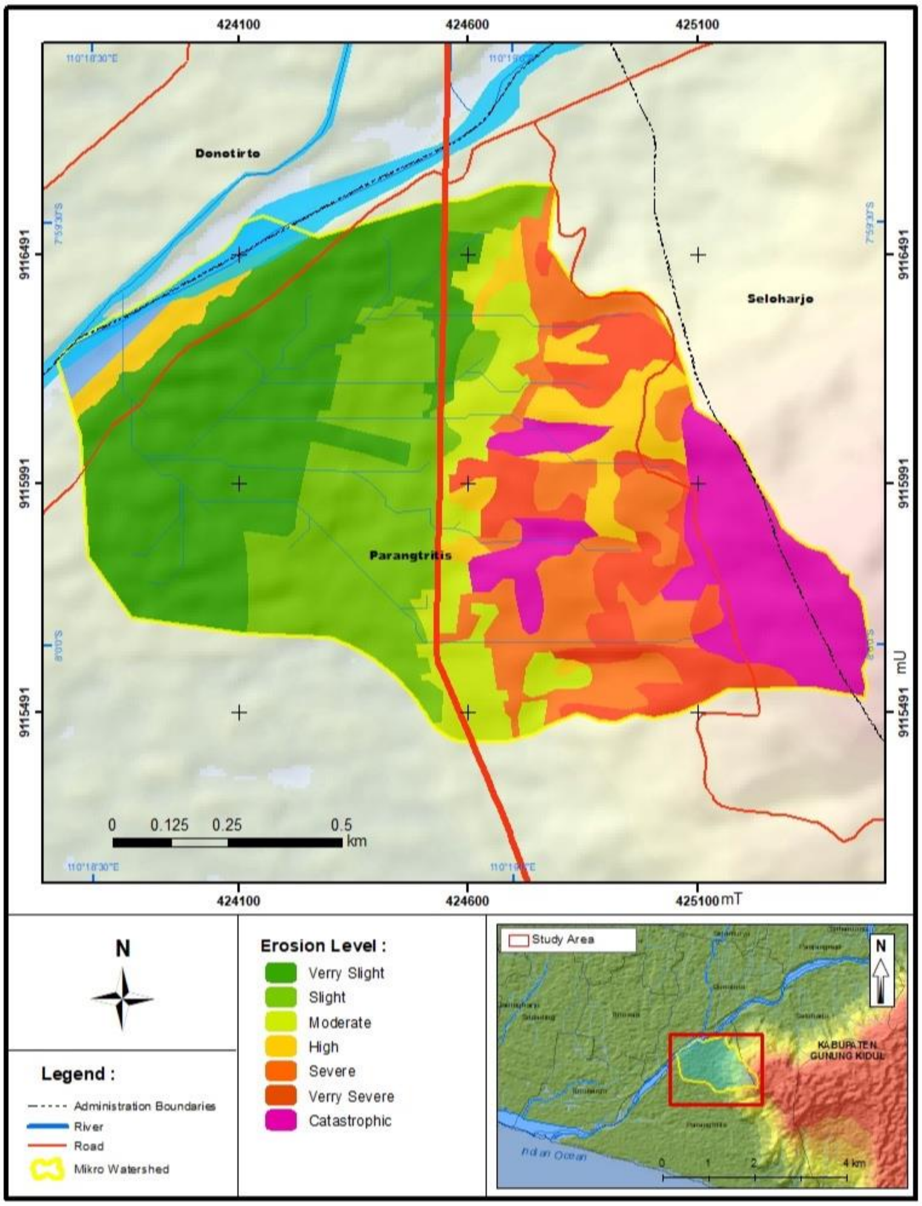


Figure 7. Erosion Level

Figure 7 above is a map illustrating the level of erosion hazard in the micro watershed of Parangtritis, based on field surveys of erosion features. The map depicts the distribution of erosion classes in the micro watershed of Parangtritis. The very light erosion class dominates the downstream areas, while the upstream areas exhibit a range of erosion classes, from moderately severe to catastrophic. This variation is attributed to the steep topography in the upstream regions.

Determining the erosion class based on field evidence, especially in the very light erosion class, is quite challenging in the Micro Watershed of Parangtritis due to extensive human activities as anthropogenic factors. Human activities play an active role in soil formation (Sartohadi, 2014). The field conditions in the Micro Watershed of Parangtritis have a flat topography, with well-maintained grass. There is no visible evidence of erosion on the soil surface, which leads to the field being assessed as having a very light erosion class.

The identification of erosion classes in built up land as urbanogenic and agricultural as agrogenic areas is challenging, as the formation of channels during rainfall is prevented by land conservation practices and buildings that block the fall of rainwater. However, upon closer examination at specific locations such as house yards, evidence of splash erosion can still be identified. The condition of vegetation cover and land cover is also considered in determining the class of light erosion. The slightly exposed tree roots indicate the occurrence of erosion in the area, providing evidence that the area has a light erosion class.

The low density of settlements and the presence of many yards with vegetation cover ranging from 30-70%. Rainfall interception by plants slows down the fall of rainwater to the ground surface, providing more time for the infiltration process, thus reducing surface runoff (Sarminah et al., 2018). The identification of moderate erosion classes in agriculture and builtup land is challenging due to extensive human activities in these areas. Evidence of gully erosion is easily lost due to agricultural practices. However, other signs of erosion can still be identified.

The severe and very severe erosion classes are more easily identified as they are located in the upstream part of the watershed, which is still relatively natural anthropogenically. Rills and gullies are easily observed and measured, and shortly after rainfall, the gully features are severe, indicating very severe erosion in that area. Shallow soil overlying rocks is a result of soil transport during rainfall. The size of the gullies reflects the large volume of water carried by surface runoff during rain, along with a significant amount of sediment. The transported sediment consists mainly of soil, but there are also large rock fragments.

The kinetic energy of rainfall and the easily transportable soil condition indicate that erosion has reached the catastrophic stage. Infrastructure damage is severe, including severe road damage, destroyed riverbanks, sedimentation in water channels, and landslides on the slopes. Landslides can block road access, posing a danger to humans in the backyard as they are very close to residential buildings.

Nugraha (2023) conducted a hazard-level erosion analysis through spatial analysis using the USLE method in Seloharjo Village, part of the upstream area of the Micro Watershed of Parangtritis. It was found that the upstream area of Micro Watershed in Seloharjo Village exhibited a very severe erosion level. This corresponds with the erosion level results based on field surveys. However, spatial erosion mapping using the USLE method yielded uniform results and lacked clear boundaries in the field. Therefore, for more accurate results, it is preferable to conduct erosion surveys based on the characteristics of erosion observed in the field.

CONCLUSIONS

In the Micro Watershed of Parangtritis, erosion classes are divided into 7 categories: very light, light, moderate, somewhat heavy, heavy, very heavy, and catastrophic. Each erosion class has different characteristics of field evidence. The verry light erosion class is the most dominant, covering an area of 43.08 ha or equivalent to 30.98% of the total watershed area. Next is the catastrophic erosion class, covering an area of 23.46 ha or equivalent to 16.87% of the total watershed area. The downstream area with a relatively flat topography has lighter erosion compared to the upstream area with a steep topography. This proves that topography influences erosion in the micro watershed of Parangtritis.

The settlements in the area indicate significant human activity. The discovery of a gully feature on the cliff, which then serves as a water channel descending into the residential area and functions as a road, suggests environmental modification by humans. Additionally, it's worth noting that such conditions may be challenging to identify during clear weather or without rain, as the gully feature serving as a channel may not be clearly visible without surface runoff. This magnify the importance of observing the environment under different weather conditions to comprehensively understand the impact of erosion and human-induced modifications.

Agriculture represents another human activity that leads to alterations on the Earth's surface. The vegetation cover conditions in agrogenic areas undergo rapid changes. The brief farming cycles in Indonesia, coupled with different types of crops each season, contribute to varying degrees of erosion. Additionally, the conservation efforts employed by farmers in agricultural areas mitigate the impact of erosion. Farming activities conducted by farmers influence the visible signs of erosion. Different types of land conservation practices, combined with varying slope conditions, result in diverse erosion classes. Erosion surveys conducted during the dry and rainy seasons yield different data. During the dry season, crops such as chili, corn, watermelon, melon, and beans are cultivated in the study area. In contrast, rice is planted in agricultural fields during the rainy season.

In the areas with anthropogenic conditions that are still natural, evidence of erosion is easily found and classified. The classification of erosion according to Morgan (2005) has undergone many adjustments in the study area due to the high anthropogenic influence in urbanogenic and agrogenic areas. It would be better to make adjustments for the erosion class to determine the indicators in areas with a high anthropogenic influence, specifically in urbanogenic and agrogenic areas. This is important when mapping erosion at a 1:10,000 scale, especially in micro-watersheds with diverse urbanogenic and agrogenic conditions

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