

## Land Carrying Capacity Assessment for Harmonizing Environmental and Anthropogenic Pressures in the Tiworo Watershed

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### Abstract

The Tiworo Watershed on Muna Island, Southeast Sulawesi, is experiencing increasing ecological and anthropogenic pressure threatening ecosystem sustainability. Land cover change has intensified surface runoff and affected downstream and coastal ecosystems. This study assesses land carrying capacity in the Tiworo Watershed based on biophysical characteristics to support management. The assessment applies three key indicators—Percentage of Critical Land (PCL), Percentage of Vegetation Cover (PVC), and Erosion Index (EI) in accordance with Minister of Forestry Regulation No. P.61/Menhut-II/2014. A spatial analysis approach using Geographic Information Systems (GIS) was employed. Secondary data was obtained from satellite imagery and relevant agencies, including watershed boundaries, land use and land cover, critical land maps, rainfall, soil type, and slope. Soil erosion was estimated to be using the Universal Soil Loss Equation (USLE), with tolerable erosion (ETOL) values from previous studies. Land carrying capacity was calculated using a regulation-based weighted scoring method, in which PCL, PVC, and EI were weighted at 50%, 25%, and 25%, respectively, to generate a composite score. The results show that 65.4% of the watershed is classified as potentially critical land, with 8.14% categorized as critical to very critical. Vegetation cover remains high at 89.57%, while the erosion index reached 13.65, exceeding tolerable limits across more than half the watershed. The composite land carrying capacity score of 87.5 places the watershed in a good sustainability category despite localized degradation. These findings highlight the need to control land conversion, strengthen soil and water conservation, rehabilitate degraded land, and integrate land carrying capacity into spatial planning.

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## 1. Introduction

The Tiworo Watershed on Muna Island, Southeast Sulawesi, represents a clear example of the tension between the ideal conditions of ecological equilibrium and the realities of land use driven by anthropogenic activities in island watersheds. Ideally, watershed ecosystems function as integrated biophysical systems capable of regulating hydrological processes, maintaining soil stability, and supporting ecological services within their natural tolerance limits. However, empirical evidence indicates that this balance has been increasingly disrupted in the Tiworo Watershed. Based on research by Imran et al. (2021), the landscape of the Tiworo Watershed has undergone drastic changes in recent years, with natural areas being converted into agricultural and residential land, resulting in a decline in ecological conditions. Similarly, Tunda et al. (2025) demonstrated that land cover change in the Tiworo Watershed increased surface runoff by up to 15% and sediment accumulation by 25%, reflecting a growing mismatch between land use practices and the watershed's natural regulation capacity. These patterns are consistent with the findings of Borrelli et al. (2020), who identified land-use change as a dominant driver of degradation in approximately 65% of tropical watersheds. Gandri et al. (2023) further emphasized that land conversion in watershed areas poses serious risks to land quality, water quantity, and water quality, while simultaneously increasing the extent of critical land and erosion potential.

Empirical studies also indicate that anthropogenic pressures in the Tiworo Watershed have exceeded its ecological carrying capacity, leading to significant environmental impacts. More than 55–80% of the watershed area is classified as unsuitable (class N) for major food crops due to limited water and nutrient availability and high erosion risk, while climate data show the occurrence of 2–3 dry months annually with minimum rainfall as low as 34.17 mm, indicating disrupted hydrological functions and increased seasonal drought (Taufik et al., 2021; Zulfikar et al., 2020). Degradation processes in the upper watershed have implications that extend beyond terrestrial systems, as sedimentation alters downstream and coastal ecosystems that depend on stable water and material fluxes. Therefore, the coastal areas in the Tiworo region are particularly vulnerable, given their strong dependence on upstream watershed conditions to maintain the marine ecological balance (Ketjulan et al., 2019). In island environments such as Muna Island, where biophysical resources are inherently limited, these pressures further highlight the urgency of applying land carrying capacity principles in watershed management.

Effective and sustainable watershed management requires a comprehensive understanding of the relationship between biophysical characteristics and land use intensity, as this relationship determines whether human activities remain within the ecological tolerance limits. Key factors such as land use type, slope gradient, soil properties, rainfall, and vegetation cover collectively define a watershed's capacity to support anthropogenic activities without triggering degradation (Xie et al., 2018; Bai et al., 2021). Liu et al. (2020) showed that incompatibility between land use and regional biophysical

conditions is a primary cause of environmental degradation at the watershed scale. In Indonesia, the importance of evaluating land conditions is explicitly recognized in Government Regulation No. 37 of 2012 on Watershed Management and the Regulation of the Minister of Forestry No. P.61/Menhut-II/2014 on Monitoring and Evaluation of Watershed Management, which emphasizes indicators such as the percentage of critical land, vegetation cover, and erosion index. As part of a rapidly developing area in West Muna Regency, the Tiworo Watershed exhibits pronounced spatial variability in biophysical conditions, with certain areas experiencing high ecological pressure owing to extensive land conversion and declining vegetation quality. In this context, evaluating land carrying capacity based on biophysical parameters has become a strategic tool for identifying conservation priorities and guiding land use to remain within the ecological limits of the watershed (Zhang et al., 2022).

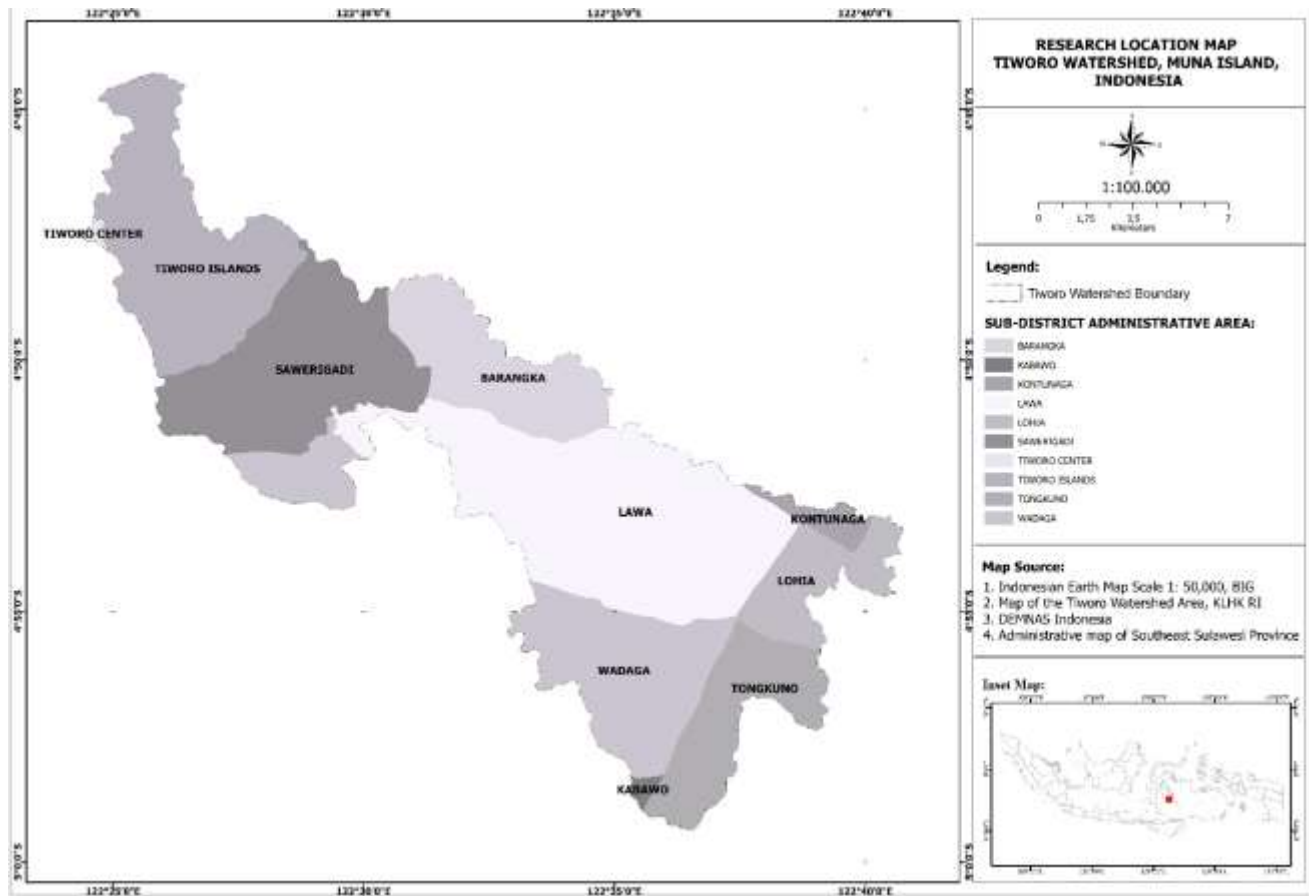
Given the widening gap between the theoretical ideal of ecological equilibrium and the observed impacts of anthropogenic land use in the Tiworo Watershed, a comprehensive spatially based evaluation of land carrying capacity is essential. Such an assessment not only provides an objective representation of the current biophysical conditions but also offers a scientific basis for adaptive and sustainable spatial planning. By integrating geospatial analysis with land carrying capacity assessment, this study aimed to identify priority areas for protection and formulate land use directions that align with the natural capacity of ecosystems to sustain human activities. This study contributes to strengthening evidence-based decision-making in spatial planning and natural resource management, particularly in ecologically vulnerable archipelagic regions.

This study differs from previous watershed research by implementing a regulation-based land carrying capacity assessment in an archipelagic watershed, specifically the Tiworo Watershed on Muna Island, where a comprehensive and integrated evaluation has not been previously undertaken. In contrast to earlier studies that focused mainly on land cover dynamics or hydrological responses in isolation, this study systematically integrated the percentage of critical land, vegetation cover, and erosion index as key biophysical indicators for quantifying land carrying capacity. Through this integrated approach, this study narrows the gap between the theoretical concept of ecological equilibrium and the practical realities of land use management in small island environments. Accordingly, this study aimed to assess the carrying capacity of land conditions in the Tiworo Watershed based on regional biophysical characteristics as a foundation for formulating sustainable watershed management strategies.

## 2. Material and Methods

This study was conducted in the Tiworo Watershed on Muna Island, Indonesia. This watershed is located within two administrative areas, namely Muna Regency and West Muna Regency. The Tiworo River Basin covers an area of 25,445.84 hectares. In Muna Regency, the Tiworo watershed covers four subdistricts, namely Kabawo, Kontunaga, Lohia, and Tongkuno, with a total area of approximately

3,893.34 hectares, representing approximately 15.30% of the total area of the Tiworo watershed. The administrative area of the Tiworo watershed in West Muna Regency covers six subdistricts, namely Barangka, Lawa, Sawerigadi, Tiworo Kepulauan, Tiworo Tengah, and Wadaga, which have a total area that reflects a significant proportion of the total watershed coverage. A location map of the study is shown in Figure 1.



**Figure 1.** Map of the Tiworo Watershed Research Location

The materials used in this study were the Tiworo watershed data map, Tiworo watershed land use map, and erosion hazard index map (Data Source: BPDAS). The tools used in this study were GPS, computers and GIS software.

The analysis of land carrying capacity in this study refers to the Regulation of the Minister of Forestry of the Republic of Indonesia Number P.61/Menhut-II/2014 concerning Monitoring and Evaluation of Watershed Management (KLHK RI, 2014). The evaluation was carried out by considering three main parameters, namely the Percentage of Critical Land (PCL), Percentage of Vegetation Cover (PVC), and Erosion Index 9EI), which integrally reflect the level of land degradation and the ecological capacity of watersheds in supporting hydrological and land conservation functions.

## 2.1 Monthly Rainfall in Tiworo Watershed (2015-2022)

The rainfall pattern in West Muna Regency from 2015 to 2022 showed strong seasonality and high interannual variability, reflecting a monsoonal climate regime that directly influences land and water processes within the Tiworo Watershed. Rainfall is generally concentrated in the early and late months of the year, whereas prolonged dry conditions frequently occur between July and October.

This variability has direct implications for land carrying capacity. Periods of high rainfall increase surface runoff, erosion risk, and pressure on land systems, particularly in areas with intensive agriculture and reduced vegetation cover. Conversely, extended dry months reduce soil moisture availability and water supply, constraining land productivity and increasing competition between ecological needs and human activities.

Therefore, rainfall dynamics play a critical role in shaping the balance between ecological functions and anthropogenic demands in the Tiworo Watershed. Incorporating rainfall variability into land carrying capacity assessments is essential for ensuring sustainable land use planning, minimizing environmental degradation, and supporting long-term watershed resilience.

**Table 1.** Monthly Rainfall in the Tiworo Watershed.

Month	2015	2016	2017	2018	2019	2020	2021	2022
January	194.9	65.1	173.0	173.0	156.0	324.4	352.1	164.4
February	350.0	432.5	319.5	319.5	104.0	289.9	171.1	380.0
March	180.6	204.2	189.5	189.5	357.0	282.7	210.6	291.0
April	336.0	260.2	153.5	153.5	176.0	183.0	83.1	99.0
May	149.8	149.8	366.5	366.5	105.0	194.8	156.2	177.0
June	47.1	120.3	477.0	477.0	38.0	221.1	140.7	495.0
July	4.9	249.8	271.5	271.5	68.0	80.1	100.1	18.0
August	0.0	17.1	106.0	106.0	0.0	1.9	148.6	119.0
September	0.0	57.3	97.0	97.0	0.0	96.8	201.9	63.0
October	0.0	185.0	157.0	157.0	5.0	40.3	62.1	211.0
November	26.6	46.1	199.5	199.5	9.0	100.9	289.5	274.0
December	178.8	280.8	67.9	67.9	170.0	266.9	437.3	350.0

(Statistics Indonesia of West Muna Regency, 2016-2023)

## 2.2 Percentage of Critical Land

Information regarding critical land conditions was obtained from secondary data sourced from mapping and classification conducted by official institutions in charge of forestry, particularly those responsible for managing watersheds. Critical land can be divided into two levels, namely critical and highly critical, which indicate severe land degradation that requires immediate restoration measures to ensure the sustainability of its function. The proportion of critical land area was calculated based on the classification categories presented in Table 2.

**Table 2.** Calculation of the Proportion of the Critical Land Area.

Subcriteria	Weight	Parameters	Value	Class	Score
Percentage of Critical Land	20	PCL = (Critical Land Area/Watershed Area) x 100 %	PCL ≤ 5	Very Low	0,5
			5 ≤ PCL ≤ 10	Low	0,75
			10 ≤ PCL ≤ 15	Moderate	1
			15 ≤ PCL ≤ 20	High	1,25
			PCL ≥ 20	Very High	1,50

## 2.3 Percentage of Vegetation Cover

The evaluation of vegetation cover aims to determine the proportion of watershed area covered by permanent vegetation by comparing the area of annual vegetation with the total watershed area. Information on vegetation cover was obtained through secondary data from the interpretation of high-resolution satellite imagery or land cover maps produced by the Ministry of Forestry. The types of permanent vegetation include annual plants, such as forest areas, shrubs, and plantation land. The calculation of the proportion of vegetation cover was based on the classification categories presented in Table 3.

**Table 3.** Calculation of Vegetation Cover Proportion.

Subcriteria	Weight	Parameters	Value	Class	Score
Percentage of Vegetation Cover	10	PVC = (Vegetation Cover Area/Watershed Area) x 100 %	PVC > 80	Very Good	0,5
			60 < PVC ≤ 80	Good	0,75
			40 < PVC ≤ 60	Moderately	1
			20 < PVC ≤ 40	Bad	1,25
			PVC ≤ 20	Very Bad	1,50

## 2.4 Erosion Index

Observations of land conditions prone to erosion were conducted using an erosion index approach in the watershed area, obtained by comparing the actual amount of erosion that occurred with the erosion threshold value that was considered acceptable. The actual erosion value was obtained through a calculation approach using the Universal Soil Loss Equation (USLE) method, while the

permissible erosion threshold value was determined based on soil damage standards for dry land. The erosion index calculation was based on the classification categories presented in Table 4.

**Table 4.** Calculation of the Proportion of the Erosion Index Area.

Subcriteria	Weight	Parameters	Value	Class	Score	
Erosion Index (EI)	10	$EI = (A/ETOL)$ Where: A = Average weighted erosion ETOL = Tolerable erosion values	$EI > 0,5$	Very Low	0,5	
			0,5	Low	0,75	
			$<EI \leq 1,0$			
			1,0	Moderate	1	
			$<EI \leq 1,5$			
			1,5	High	1,25	
		$<EI \leq 2,0$				
			$EI > 2,0$	Very High	1,50	

### 2.5 Assessment of Land Carrying Capacity Watershed Areas

The assessment of watershed land carrying capacity was conducted by comprehensively evaluating three main indicators, namely the proportion of critical land, the level of vegetation cover, and the erosion index. Each indicator was classified, scored and weighed according to predetermined criteria. The overall land carrying capacity value was obtained by summing the weighted scores of all indicators, after which the results were further interpreted using sustainability categories (sustainable, moderately sustainable, and unsustainable) to indicate the extent to which the current land conditions can support long-term ecosystem functions and sustainable watershed management. The weights and values of the watershed land condition carrying capacity criteria are shown in Table 5.

**Table 5.** Weight and Value of Land Condition Carrying Capacity Criteria in Watersheds.

Variables/Parameters	Weight		Lowest Value	Highest Value
	%	%		
Land Conditions	100			
Percentage of Critical Land	50		25	75
Percentage of Vegetation Cover	25		12,5	37,5
Erosion Index	25		12,5	37,5

## 3. Results and Discussion

### 3.1 Rainfall of Tiworo Waterhed

The rainfall variability observed in West Muna Regency during 2015–2022 can be meaningfully interpreted in the context of climate anomalies, which exert a strong influence on the hydrological conditions within the Tiworo Watershed. Several years in the dataset showed pronounced deviations

from typical seasonal patterns, which were reflected in the extreme monthly rainfall and extended dry periods.

Periods of exceptionally high rainfall, such as those recorded in 2016, 2017–2018, 2021, and 2022, were consistent with the influence of La Niña–related conditions, which are known to enhance rainfall across much of Indonesia. These wet anomalies increase runoff and flood potential, intensify soil erosion, and accelerate land degradation in vulnerable areas, thereby reducing effective land carrying capacity, despite higher water availability.

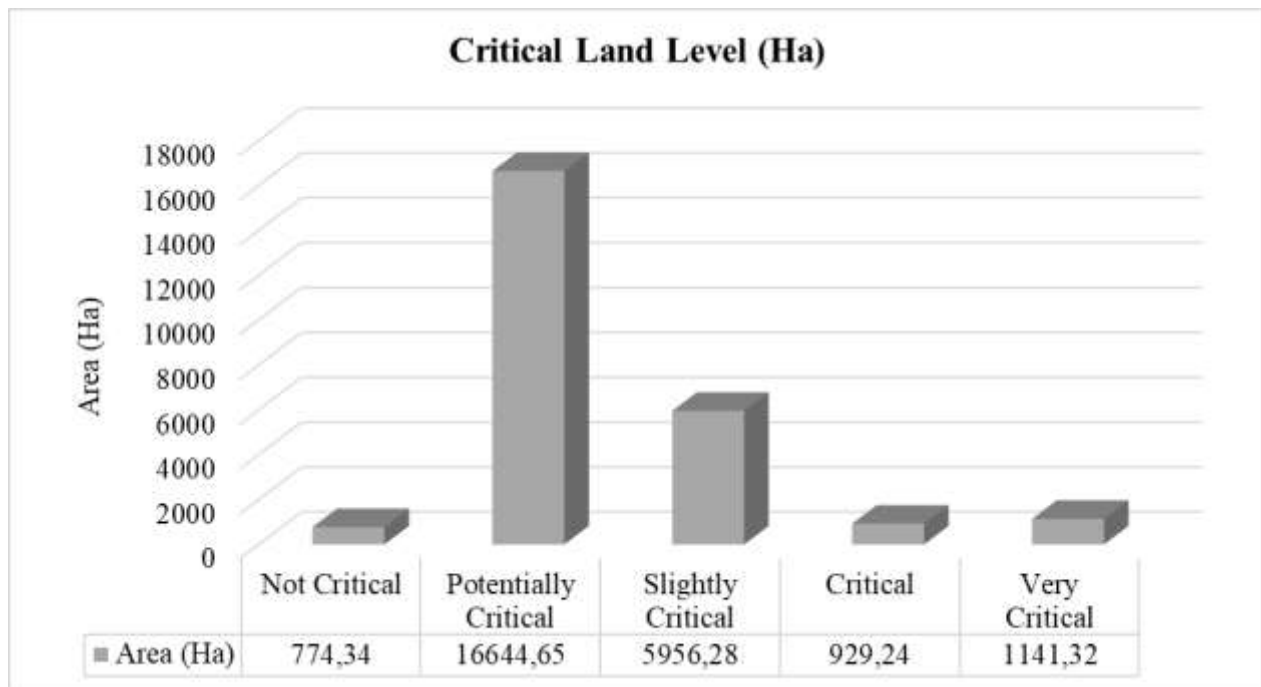
Conversely, months with near-zero rainfall, particularly in 2015 and 2019, aligned with documented El Niño–related drought anomalies that affected eastern Indonesia. These dry anomalies constrain water availability, suppress vegetation growth, and reduce agricultural yields, leading to heightened pressure on land resources as anthropogenic demands persist, despite declining ecological support capacity.

The alternating occurrence of wet and dry anomalies highlights that climate variability amplifies the tension between ecological functions and human land use in the Tiworo Watershed. Under wet anomalies, ecological thresholds may be exceeded through physical land degradation, whereas under dry anomalies, the carrying capacity is exceeded through water scarcity and ecosystem stress. Therefore, the rainfall data underscore the importance of embedding climate anomaly considerations, particularly ENSO-related variability, into land carrying capacity assessments. Integrating these dynamics allows for a more realistic evaluation of watershed resilience and supports adaptive land-use strategies capable of maintaining a balance between ecological integrity and anthropogenic needs under a changing climate.

### 3.2 Percentage of Critical Land in the Tiworo Watershed

The Tiworo watershed is one of the areas in West Muna Regency that faces land pressure due to human activities and vulnerable biophysical conditions. An evaluation of the critical land categories in this watershed provides an overview of the level of land degradation and serves as the basis for determining the overall carrying capacity of the land. The level of critical land in the Tiworo watershed is shown in Figure 2.

The data in Figure 2 show that 65.4% of the land area in the Tiworo watershed (16,644.65 ha) was classified as Potentially Critical, indicating a high level of vulnerability to degradation. This indicates that most of the watershed is vulnerable to further degradation if adequate conservation measures are not implemented immediately. Land with a Moderately Critical level of criticality is the second largest category, covering 5,956.28 ha, or approximately 23.4% of the total area. Meanwhile, the land area classified as Very Critical and Critical was recorded at 1,141.32 ha and 929.24 ha, respectively. The Very Critical and Critical categories covered areas of 1,141.32 and 929.24 ha, respectively, which reflected a small but significant portion of the total watershed area.

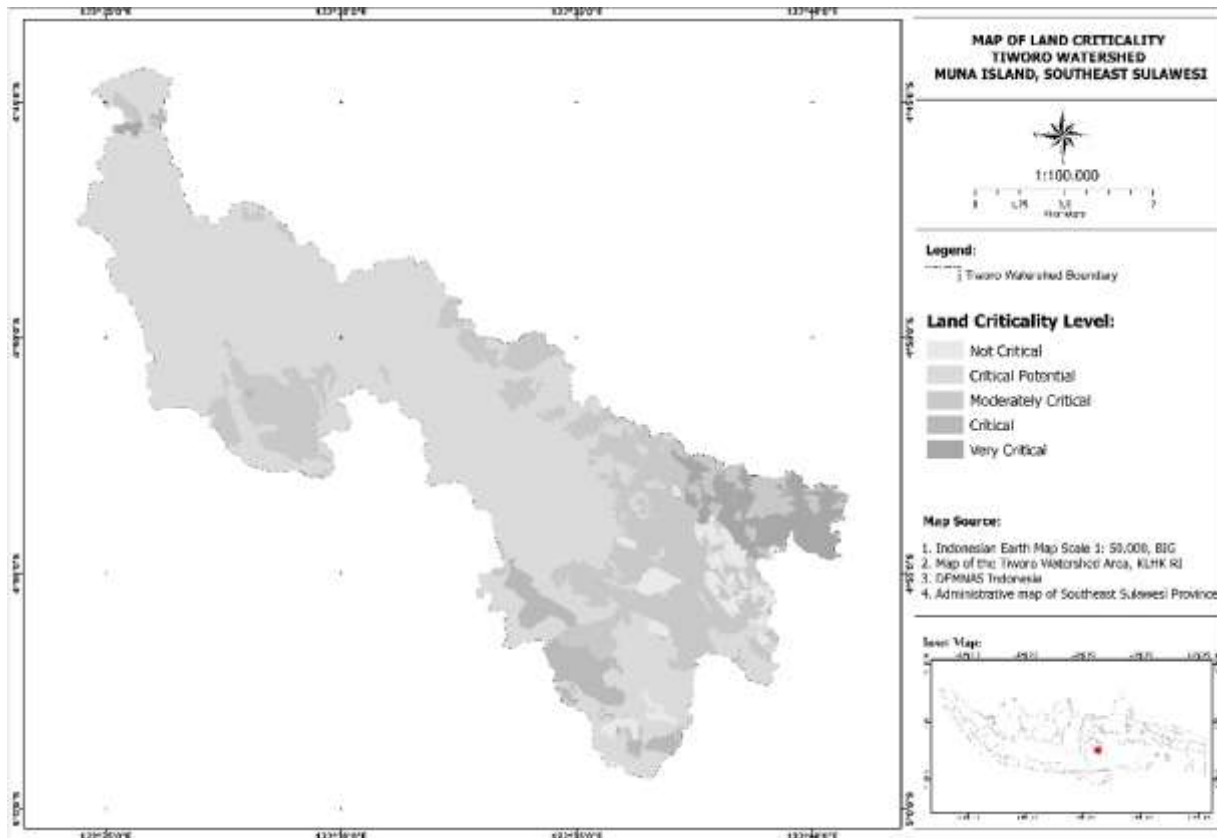


**Figure 2.** Criticality Level of Tiworo Watershed Land in 2022.

This distribution illustrates an alarming situation, as most of the watershed area has experienced mild-to-severe degradation. This situation is consistent with the findings of Torabi et al. (2021), who showed that land with low vegetation cover and high slopes tends to have higher criticality levels. The phenomenon of Critical Potential class dominance is not only found in the Tiworo watershed but also in several large river basins, such as the Citarum and Ciliwung. This condition is closely correlated with massive land-use changes, particularly the conversion of natural vegetation cover into intensive agricultural land and settlements.

The existence of Critical and Very Critical land, although not dominant, is an important indicator that the degradation process is already underway and needs to be immediately addressed through land rehabilitation programs. Recommended interventions include vegetative conservation, such as agroforestry, reforestation, and mechanical conservation measures, such as terracing and control dams. Conversely, areas classified as non-critical should be maintained as ecological protection zones to ensure the sustainability of the natural functions of the ecosystem within them. In general, the distribution pattern of land criticality levels in the Tiworo watershed reflects the declining biophysical capacity of this area to support important ecological functions, such as hydrological regulation, carbon storage, and protection against soil degradation. This emphasizes the urgency of implementing a spatial and participatory integrated management approach to prevent further degradation and

increase watershed resilience to climate change and anthropogenic pressures. The spatial distribution of critical land in the Tiworo watershed is shown in Figure 3.



**Figure 3.** Spatial distribution of critical land in the Tiworo watershed in 2022.

The percentage of critical land in the Tiworo watershed was 8.14, which is within the range of 5 to 10. Based on this classification, the area received a score of 0.75 and was categorized as having a moderate level of criticality.

### 3.3 Percentage of Vegetation Cover in the Tiworo Watershed

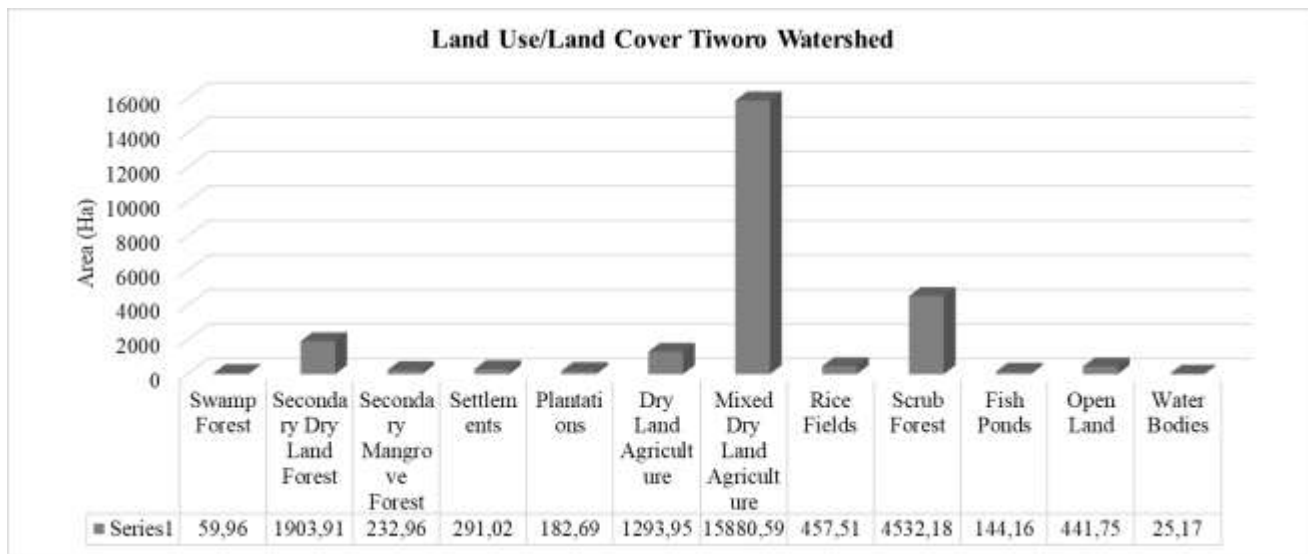
Vegetation plays a vital role in maintaining the ecological balance of watersheds through erosion control, carbon storage, and hydrological cycle regulation. Plant roots stabilize soil and reduce sedimentation (Costandache et al., 2019). Forests are also significant carbon sinks, such as in the Lancang watershed, which stores 300.32 Tg of carbon depending on the type and height of the vegetation (Chen et al., 2016). In addition, vegetation directly influences hydrological processes by increasing transpiration rates, enhancing rainfall interception, and reducing surface runoff, thereby regulating water flow, minimizing peak discharge, and supporting the overall hydrological balance (Fu et al., 2024). Rapid land cover change, mainly due to the conversion of vegetative land to non-forest land uses, such as settlements and intensive agriculture, has been reported as a major cause of

increased land vulnerability in many watersheds in Indonesia (Salma et al., 2024; Safitri et al., 2021). Therefore, analyzing the distribution of vegetation cover is a crucial first step in understanding the ecological dynamics of a watershed and designing sustainable management strategies.

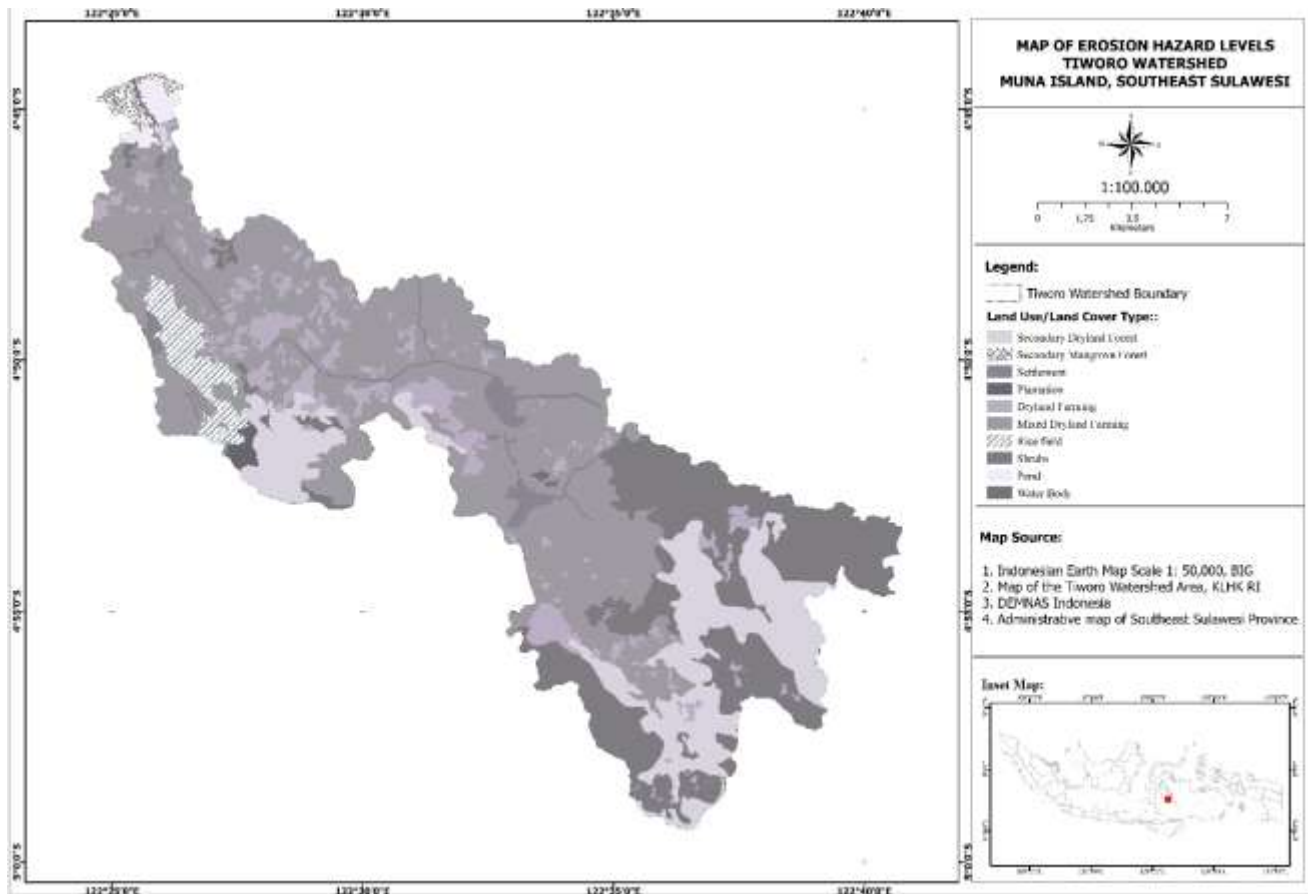
The interpretation of land cover data shows that most of the Tiworo watershed area is dominated by mixed dryland agriculture, covering approximately 15,880.59 ha or 62.40% of the total watershed area. The existence of mixed dryland agriculture as the dominant land cover reflects the high pressure on the natural vegetation. This is due to the characteristics of this agricultural system, which tends to be open and intensive and has great potential to accelerate soil degradation if not supported by conservation-oriented management practices. Shrub cover, which occupies approximately 4,532.18 hectares or 17.81% of the total watershed area, indicates the possibility of vegetation degradation or land cover transition. This phenomenon reflects the possibility of a transition in land cover from natural forest to other forms of use or reflects the initial phase of succession after the land was abandoned following its previous use.

Natural vegetation cover types, such as secondary dryland forests, only cover 1,903.91 ha (7.48%), and secondary mangrove forests cover 232.96 ha (0.92%), indicating strong pressure on forest areas in this watershed. The distribution of swamp scrub in the Tiworo watershed is very limited, covering only approximately 59.96 ha or 0.24% of the total area, indicating that the existence of wetland ecosystems in this area is very minor. This limited area shows that areas with wet hydrological characteristics are minimal in the Tiworo watershed landscape. The limited area of the swamp forest indicates its minimal role in performing important ecological functions, such as hydrological regulation and providing natural habitats for biodiversity conservation. On the other hand, the 291.02 ha of settlement area and 441.75 ha of open land reflect increasing anthropogenic pressure on the Tiworo watershed landscape, which has the potential to accelerate ecosystem degradation if not balanced with sustainable land use strategies. The existence of 291.02 ha of residential land and 441.75 ha of open land reflects the intensification of anthropogenic activities that have the potential to exceed the ecological carrying capacity of the area. This increased pressure can accelerate environmental degradation if it is not accompanied by sustainable land-use planning. The type and extent of land cover/land use in the Tiworo watershed are shown in Figure 4.

This land use distribution shows that the Tiworo watershed is dominated by land with low and fragmented vegetation cover. If measures to restore vegetation cover and control land use change are not taken immediately, the capacity of the watershed to provide key ecosystem services, such as clean water supply, flood control, and protection against land degradation, will continue to decline significantly. Therefore, ecosystem-based policy interventions and conservation priority mapping that consider existing land cover are needed to maintain the overall sustainability of the watershed. The spatial distribution of land cover/use in the Tiworo watershed in 2022 is shown in Figure 5.



**Figure 4.** Types and areas of land cover/land use in the Tiworo watershed in 2022.



**Figure 5.** Spatial Distribution of Land Cover/Land Use in the Tiworo Watershed in 2022.

### 3.4 Tiworo Watershed Erosion Index

The Erosion Index is a quantitative measure that describes the extent to which soil is lost from the land surface owing to erosion processes within a certain period. This value was obtained using an analytical approach that considered environmental factors such as rainfall intensity (erosivity), soil physicochemical properties (erodibility), topography (land slope), and vegetation cover. The erosion index was assessed by comparing the average erosion rate (A), which was obtained through an estimation of soil loss, with the acceptable erosion threshold (ETOL). An increase in the erosion index value reflects a high rate of soil loss in an area. This condition can trigger various ecological and economic impacts, such as disruption of land stability, decline in agricultural production, and deterioration of water quality due to sedimentation and surface run-off.

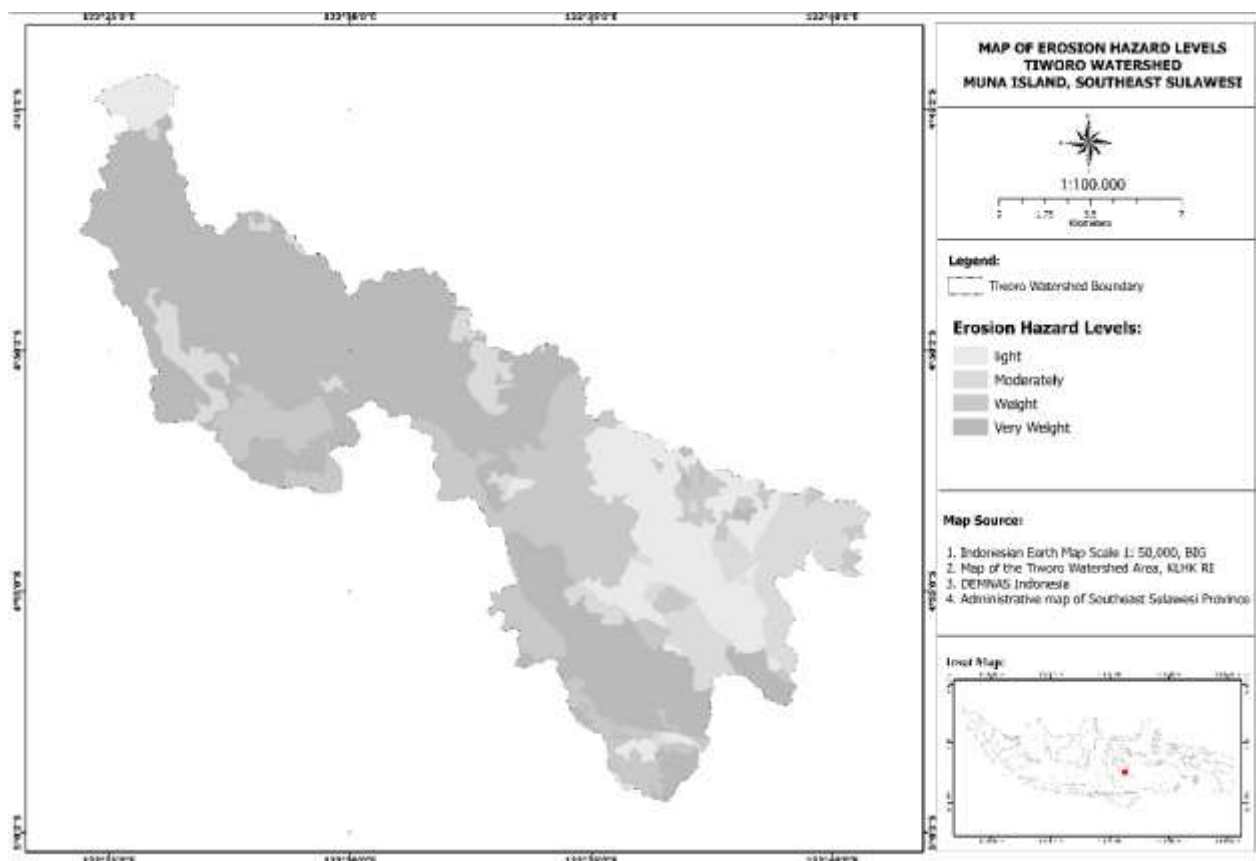
**Table 6.** Erosion Hazard Levels, Erosion Rate, and Weighted Average Erosion in the Tiworo Watershed in 2022

No	Erosion Rate (tons/ha/year)	Erosion Hazard Level	Area (ha)	Average Erosion (A) (tons/ha/year)	A Weighed (tons/ha/year)
1	< 15	Very Light	0	7,5	33,45
2	15 - 60	Light	3589,85	37,5	120,67
3	60 - 180	Moderate	3295,81	120	347,48
4	180 - 480	Heavy	5317,53	330	926,98
5	> 480	Very Heavy	13242,64	550	33,45
	Total		25445,84		376,02

Source: Analysis Results

The spatial analysis of erosion hazard levels in the Tiworo watershed, shown in Table 5, indicates that only four erosion hazard classes were manifested from the five general categories used to assess land vulnerability to erosion. These categories cover soil loss levels ranging from mild to extremely severe. Areas classified as having a low erosion hazard, with soil loss ranging from 15 to 60 tons per hectare per year, cover approximately 14.11% of the total area of the Tiworo watershed. This percentage represents areas experiencing erosion that remain relatively low in intensity and can still be effectively managed through the application of basic soil and water conservation measures. Meanwhile, land with moderate erosion levels, between 60 and 180 tons/ha/year, covered approximately 12.95%. The distribution of land with high soil loss potential in the Tiworo watershed was most prominent in the heavy and very heavy erosion hazard classes. These two categories cumulatively dominate the area, reflecting significant erosional pressure on watershed biophysical stability. The distribution pattern of erosion hazard levels reflects the importance of implementing land management strategies that are responsive to local biophysical conditions, with an emphasis on soil and water conservation. Areas with severe erosion levels (180–480 tons/ha/year) cover almost one-

fifth of the region (20.90 %). The most concerning condition is indicated by the dominance of the very severe erosion hazard class, which is an area with a soil loss rate exceeding 480 tons per hectare per year. This category covered more than half of the total area of the Tiworo Watershed (approximately 52.04%). This high proportion is a strong indicator of extreme erosional pressure, which has the potential to cause widespread land degradation, increased sedimentation in water bodies, and a decline in the overall ecological function of watersheds. The spatial distribution of the erosion hazard levels in the Tiworo watershed is shown in Figure 6.



**Figure 6.** Spatial Distribution of Erosion Hazard Levels in the Tiworo Watershed in 2022.

The tendency for the category of severe to very severe erosion to dominate the distribution of the Tiworo watershed is further reinforced by the weighted average erosion value of 352.75 tons/ha/year. This figure quantitatively reflects the intense pressure of soil degradation in most watershed areas. The largest contribution comes from the very severe category, which accounts for more than 70% of the total weighted value, whereas the severe and moderate categories also show significant values. This pattern confirms that the intensity of soil loss is not only spatially widespread but also high in intensity, thus driving the urgent need for more structured, conservation-based land management that is responsive to the biophysical dynamics of the area.

The tolerable erosion rate (ETOL) is the maximum acceptable rate of soil loss that does not cause permanent land degradation. Determining this value takes into account a number of important factors, such as effective soil depth, soil characteristics that affect erosion resistance, and the minimum depth that still allows plant roots to grow optimally. In addition, the useful life of the land as a production resource was considered in determining the ETOL value. Based on previous studies in the Tiworo watershed, the average ETOL value was set to 27.55 tons per hectare per year (La Baco Sudia et al., 2001). When compared to the weighted average erosion value in the Tiworo watershed, which reached 368.48 tons/ha/year, the resulting erosion index (EI) was 13.65. This figure far exceeds the tolerance threshold ( $EI > 2.0$ ), indicating that the rate of soil loss in the area is in the very high category with a score of 1.5, and shows conditions that require serious and immediate conservation intervention.

### 3.5 Carrying Capacity of Tiworo Watershed Land Conditions

The evaluation of land carrying capacity is an important approach to understanding the extent to which land can sustain its ecological role, particularly when faced with pressure from land use and environmental change. The land carrying capacity was measured using three main parameters: the percentage of critical land, percentage of vegetation cover, and erosion index. These three parameters represent the pressure on land quality, the protective role of natural vegetation, and the rate of soil loss due to erosion. These three parameters, namely land degradation, vegetative protection, and soil loss rate, provide complementary perspectives for assessing the physical capacity of an area to withstand environmental pressures. When natural vegetation is reduced, the potential for soil damage increases, which can ultimately trigger an ecosystem imbalance. Therefore, maintaining the balance between these three elements is key to preserving the long-term stability of the landscape. The erosion index describes the erosional pressure on the land and the extent to which the actual conditions exceed the tolerable threshold. Table 6 shows the carrying capacity of the Tiworo watershed in 2022.

**Table 7.** Land carrying capacity conditions in the Tiworo watershed in 2022.

No	Land Condition	Weight	Score	Weight*Score
1	Percentage of Critical Land (PCL)	50	0,75	37,5
2	Percentage of Vegetation Cover (PVC)	25	0,5	12,5
3	Erosion Index (EI)	25	1,5	37,5
Land Condition Carrying Capacity Value				87,5

Source: Analysis Results

#### 4. Conclusion

The land carrying capacity assessment indicated that the Tiworo Watershed is generally classified as good and sustainable, with a composite sustainability score of 87.5, suggesting that the watershed is still capable of supporting ecosystem functions and human activities under current conditions. However, this overall sustainability status is accompanied by significant spatial variability and localized ecological pressures. The sustainability value is strongly influenced by the high proportion of potentially critical land (65.4%), including 8.14% categorized as critical to very critical, which increases the vulnerability of the watershed to further degradation. Although vegetation cover remains relatively high (89.57%) and contributes positively to land sustainability, ongoing land-use change threatens the stability of this condition. The erosion index, which reached 13.65 and exceeded the tolerable threshold in more than half of the watershed area, emerged as the main limiting factor in reducing land sustainability. These results demonstrate that while the overall land carrying capacity remains sustainable, targeted management interventions are required to address erosion-prone and critical areas of concern. Integrating land carrying capacity sustainability into spatial planning, controlling land conversion, prioritizing soil and water conservation, and rehabilitating degraded land through reforestation and agroforestry are essential for maintaining and enhancing long-term watershed sustainability in the Tiworo Watershed.

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