中華水土保持學報, 56(2):66-74(2025)
Journal of Chinese Soil and Water Conservation, 56 (2)*: 66-74* (2025)
DOI: 10.29417/JCSWC.202506_56(2).0003

Land Critical Level Degradation: Towards a Watershed Conservation Approach on A Continuous Basis

Naharuddin Naharuddin[1]* Rukmi Rukmi[1] Sudirman Daeng Massiri[1] Imran Rachman[1] Adam Malik[1] Golar Golar[1] Akhbar Akhbar[1] Ifert Ehrlick Tudon[1] Yahya Yahya[1]

ABSTRACT Land degradation, driven by levels of land criticality, is a global issue that significantly impacts land productivity, food security, and the environment. Land use that deviates from conservation principles contributes to surface runoff, erosion, and a range of economic and environmental consequences. This study aims to analyze the degree of land criticality as a basis for shaping sustainable conservation policies. The spatial analysis of critical land was conducted by overlaying erosion hazard maps, derived using the RUSLE method and Geographic Information Systems (GIS), with slope maps and land management maps in agricultural areas, protected forest areas, and zones outside protected forest areas. The study's findings revealed that the erosion hazard index in the Meko Sub-Watershed, Central Sulawesi, is primarily characterized by a very high erosion hazard level of 539.76 tons/ha/year in residential areas, while primary dryland forests exhibit a very low erosion hazard level of 0.32 tons/ha/year. High to very high erosion hazards were observed on lands with high erodibility values, particularly in residential areas with an erodibility index of 0.57. The definition of erodibility is the ability of soil to be easily eroded or transported by an erosion agent, namely water.The Meko Sub-Watershed is classified into four land criticality categories: non-critical 12,128.01 ha (23%), potentially critical 5,500.74 ha (10%), somewhat critical 34,961.60 ha (66%), and critical 608.54 ha (1%), out of a total area of 53,198.89 ha. In the context of land use planning, the analysis of erosion hazard levels and the spatial distribution of critical lands can serve as a conceptual framework for conservation policies in the Meko Sub-Watershed and the broader Poso Watershed. This is particularly relevant given the watershed's status as a priority area for conservation and sustainable management.
Key Words: Watershed, degradation, conservation, critical land, erosion hazard level

INTRODUCTION

Land degradation has been a global problem (Pimentel and Burgess, 2013; Albaladejo *et al.*, 2021) for thousands of years (Engdawork and Bork, 2014; Issaka and Ashraf, 2017). The high problem of land degradation, the United Nations Convention highlights the important role of research in this direction in achieving the indicators of sustainable development goals (Du *et al.,* 2024). Land degradation is defined as a critical land form or loss of biological or economic productivity caused by land use or human activities that are not in accordance with conservation principles (Shao *et al.,* 2020). Forest areas in watersheds have decreased by 38% worldwide which has a major impact on climate change and biodiversity (Newbold *et al.,* 2019; Steffen *et al.,* 2015). Inappropriate land use for conservation measures in watersheds affects surface runoff (Naharuddin *et al.,* 2024). High surface runoff affects soil erosion (Bettoni *et al.,* 2023), erosion ultimately impacts critical land (Rachman and Naharuddin, 2022). Land that is degraded to critical has an impact not only on the land system but also on the hydrological system (Nugroho *et al.,* 2022). Critical land is land (including forests) that has been damaged, resulting in loss or reduction of its function to a specified limit, the nature of its management is not in accordance with the principles of soil and water conservation (Naharuddin, 2021).

The decline in the quality of the environment and natural resources followed by an increase in land use conversion, especially from forests to agriculture and from agricultural land to settlements, which can result in high levels of erosion hazards. The global impact of high soil erosion hazards can reduce food crop yields by 33.7 million tons, with the consequence of a price increase of 0.4 to 3.5%, and an increase in abstraction water of 48 billion m^3(Sartori *et al.,* 2019).

Various research methods have been developed to analyze land degradation, particularly in areas classified as critically degraded lands. These include the use of remote sensing (Deteix et al., 2023), the integration of remote sensing and Geographic Information Systems (GIS) (Cetin et al., 2024; Fekete et al., 2015), terrestrial-based measurement techniques (Lima et al., 2024), and methods utilizing the Normalized Difference Vegetation Index (NDVI) (Yulianto et al., 2023).Although there has been much research for decades, there is no consensus on an adequate method to evaluate the level of land criticality, especially in the research location area in the Meko Sub-watershed, Poso Watershed.

To assess land degradation, especially land criticality, the right method is to use a combination method of several land cover/use parameters, overlay erosion hazard level maps using the RUSLE method, slope maps, and land management maps, then carry out a ground check process to compare field conditions with interpretation data from the overlay results so that the data is more accurate and up to date (Irwansah, 2021; Chaidar *et*

Faculty of Forestry, Tadulako University, Jl. Soekarno Hatta Km. 9, Palu 94118, Central Sulawesi, Indonesia
*corresponding author: nahar.pailing@gmail.com

al., 2017). This method has advantages because it uses the Revised Universal Soil Loss Equation (RUSLE) approach and has been used by the Ministry of Forestry of the Republic of Indonesia as a basis for part of the land criticality assessment in addition to slope factors, and land management so that it is considered feasible in evaluating land criticality as a basis for conservation and rehabilitation.

The Meko Sub-Watershed is part of the Poso Watershed and is one of the priority watersheds in need of restoration. Various issues have emerged, including extensive land conversion for plantation activities that do not adhere to soil and water conservation principles. Additionally, unsustainable agricultural practices have led to land degradation, resulting in an increased risk of erosion (Sukamdani and Sukwika, 2023). These changes have not only caused significant biophysical impacts, such as the expansion of critical land areas and a reduction in the land's carrying capacity, but have also adversely affected the social and economic conditions of the communities within the watershed area (Supriyono, 2018), contributing to increased surface runoff (Naharuddin *et al.*, 2024).

The Meko Sub-watershed is administratively included in the West Pamona District, Poso Regency, Central Sulawesi and is one of the targets of the watershed restoration project. The Meko Sub-Watershed area has experienced monthly flooding with high levels of erosion and sedimentation in recent years due to the influence of changes in land use, i.e. from forest land to plantation land that is not in accordance with conservation principles. The topography of the land in the Meko sub-Watershed is dominated by steep to very steep slopes, and the steep topography is one of the triggers for high flooding, erosion, and sedimentation. Floods and erosion are influenced by changes in land use and topography, and the impact of forest damage gives rise to complex problems, namely high flood discharge and surface runoff and erosion (Chimdessa *et al.,* 2018).

The Meko Sub-Watershed, which is part of the Poso Watershed, is designated as one of the 108 priority watersheds in Indonesia. This watershed encompasses Lake Poso, whose ecosystem service functions are increasingly under threat due to significant lake shallowing and heavy sedimentation. These issues are primarily driven by a high runoff coefficient. Increased erosion is directly proportional to the area of critical land around the Poso Watershed. This study aims to analyze the level of land criticality as a basis for sustainable conservation policy direction.

MATERIALS AND METHODS

The research was conducted from May to November 2023, after previously throughout 2022 a location survey of ten sub-Watersheds in the Poso watershed area had been conducted, so the Meko Sub-Watershed was selected as part of the upstream Poso watershed, Central Sulawesi which was degraded with a high level of land utilization and exploitation.

Of the ten sub-watersheds in the Poso Watershed (Kodina Sub-watershed, Wimbi Sub-Watershed, Taipa Sub-Watershed, Meko Sub-Watershed, Bancea-Panja Sub-Watershed, Toinasa Sub-Watershed, Salukaia Sub-Watershed, Peura-Sangele Sub-Watershed, Tokilo-Dulumai Sub-Watershed, and Saluopa-Mayakeli Sub-Watershed). The Meko Sub-Watershed experiences high levels of problems, seen from the contribution of sediment which results in shallowing in the downstream area of the watershed, so this becomes the basis for management priorities.

The Meko Sub-Watershed has the largest area, namely 53,199 ha of the Poso Watershed area from the total Poso Watershed area of 267,485 ha, with a main river length of 54.89 km and is the largest contributor to sediment discharge flowing into the Poso River. The Meko sub-Watershed, Poso Watershed is administratively located in West Pamona District, Poso Regency, Central Sulawesi with coordinates at 120 ° 31'29 "E and 1° 53'36" S, and an average altitude of 524 meters above sea level (Figure 1).

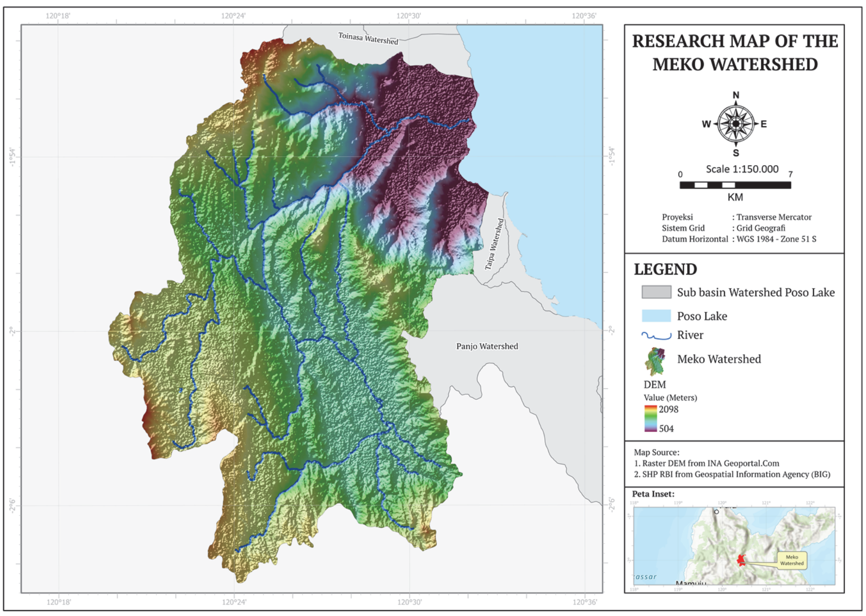


Fig.1 Research Location, Meko Sub-Waterhed, Central Sulawesi

The Meko Sub-Watershed has rainfall between 2,000–2,600 mm per years. This rainfall is included in the high category which can affect various hydrological processes, such as surface runoff, infiltration, and potential soil erosion. The Meko Sub-Watershed has a complex river network pattern with tributaries spread evenly. The main river flows towards Lake Poso forming the main outlet point in the western part of the watershed. Soil sample analysis was carried out in the laboratories of the Faculty of Forestry and Faculty of Agriculture, Tadulako University.

The research was carried out in several procedures, namely: Secondary data collection involved: (1) the collection of monthly rainfall data over a ten-year period sourced from the Meteorological, Climatological, and Geophysical Agency or the Kasiguncu Poso Meteorological Station, as well as location maps, soil type maps, slope maps, and land use maps; (2) calculation of the area and length of the Meko Sub-Watershed (Sub-Watershed Meko). Subsequently, primary data analysis was conducted, which included: (1) determination of the average annual maximum rainfall based on the rainfall data; (2) calculation of the Rain Erosivity Factor (R) using Equation 2 with the identified maximum monthly rainfall data; (3) calculation of the Soil Erodibility Factor (K) based on soil type maps for several land units within the Meko Sub-Watershed, Poso Watershed, which were then analyzed at the Soil Science Laboratory, Faculty of Agriculture, Tadulako University; (4) calculation of the Slope Length and Steepness Factor (LS); (5) calculation of the Land Cover (C) and Land Management Factor (P) based on land use map data; (6) calculation of the overall erosion rate using the RUSLE Method, which includes all relevant factors. The total erosion rate calculation can be performed once the values for all the required factors have been obtained.

Forest areas both in primary dry forest land and in secondary dry forest land with high vegetation density are one of the important factors that can minimize the rate of soil erosion, and the types and combinations of several types of vegetation that play an important role in regulating surface runoff and sediment yields. One opinion that confirms this is according to Cerdà et al., (2017), because of the complementary effects of different tree species, primary and secondary forests and other mixed forests can be more resistant to damage due to soil erosion compared to dry land agriculture or shrubs. Furthermore, the diverse vegetation distribution pattern, multispecies forests can reduce erosion due to high rainfall by reducing the kinetic energy of raindrops and strengthening soil stability (Wang et al., 2017). Land with low vegetation density tends to increase the number of potential discharge points, which increases the risk of soil erosion (Nanko et al., 2015, Goebes, 2015).

The land use in Meko sub-watershed

Understanding the relationship between soil erosion and land use in watershed landscapes is essential to optimize sustainable conservation. According to Sun et al., (2017) it is necessary to analyze the significant impact of land use changes on landscape patterns in watersheds on soil erosion and land criticality levels. Furthermore, a comprehensive understanding of this process is also needed to improve conservation strategies (Nicotra et al., 2015). Based on land use map data and ground check results in the Meko sub-Watershed (Figure 2) from a total of 53,199 ha, land use is dominated by primary dryland forest of 38,466 ha (72.31%), followed by secondary dryland forest land use of 8,122 ha (15.27%) while the lowest is dryland agriculture of 26 ha (0.05%) (Figure 3).

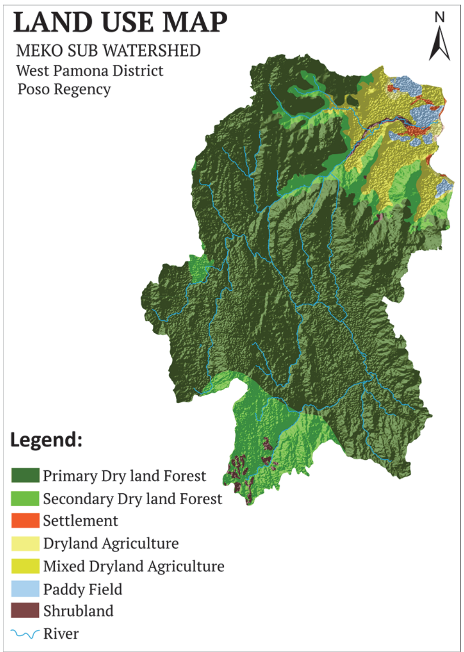


Fig.2 Land Use in the Meko Sub-Watershed, Central Sulawesi

In addition, species with the same ecological niche tend to increase competition for resources (e.g. light, soil moisture, and nutrients), which impacts vegetation growth and function, thereby increasing the risk of soil erosion (Lal, 2014). In addition to interactions between species, various driving factors influence soil erosion, such as climate, soil properties, topography, and vegetation characteristics (Anache et al., 2018).

In the research area of Meko Sub-Watershed, Watershed Poso generally in secondary dry forest land, the intensity of land use is high and even changed to other land uses such as gardens that do not comply with soil and water conservation principles so that they have the potential to become critical land. According to Rafif *et al*., (2024) continuous changes in land use contribute to erosion, a natural process in which soil is transported, causing sedimentation, and ultimately causing flooding.

Determination of spatial analysis of critical land in the Meko Sub-Watershed was carried out by overlaying several parameters for determining the level of land criticality, including a map of the level of erosion hazard previously analyzed using the RUSLE approach based on Geographic Information Systems (Naharuddin *et al.*, 2021; Naharuddin *et al.*, 2020), a map of slope gradients and their scoring, and a land management map (Ramadhan, 2024). The land management map was analyzed in agricultural cultivation areas, protected forest areas, and protected areas outside protected forest areas. Furthermore, to assess the level of land criticality, a scoring method was used for each parameter. In the analysis unit of the results of the spatial data overlay, the scores were then added up based on Table 1, so that the classification of the level of land criticality could be classified into non-critical, potentially critical, somewhat critical, critical, and very critical.

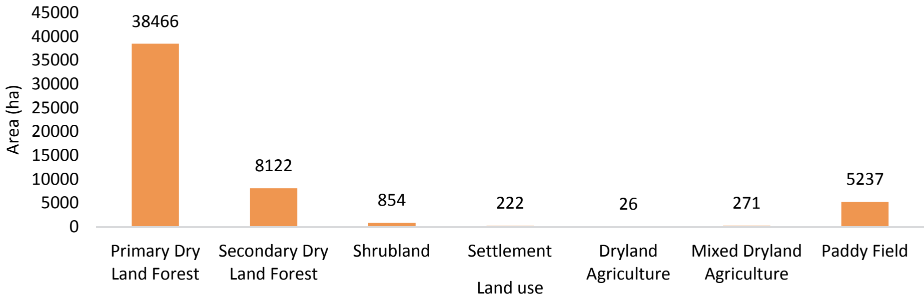


Fig.3 Area of land use in the Meko Sub-Watershed, Central Sulawesi

Before conducting critical land analysis, the determination of the erosion hazard level (EHL) is first analyzed, which is produced by overlaying erosion results with soil depth maps. The amount of erosion is calculated using the Revised Universal Soil Loss Equation (RUSLE) formula (Naharuddin *et al.,* 2021; Dunkerley, 2021), namely:

$$A = R * K * LS * C*P \quad (1)$$

Description: A is the amount of eroded soil (ton/ha/year), R is the average annual rainfall erosivity (MJ/ha) (mm/hour), K is the soil erodibility index (ton· ·ha · hour)/(ha · mega joule · mm), LS is the slope length and gradient index, C is the crop management index, P is the soil conservation effort index.

The rainfall erosivity index (R) was analyzed using the formula according to the instructions of Erwanto and Lestari, (2021); Lal and Elliot, (2017):

$$R = 6.119\ (\mathrm{Rain})\ m^{1.21}\ (\mathrm{Days})\ m^{-0.47}\ (\mathrm{Max\ P})\ m^{0.53} \quad (2)$$

With, R is an average rainfall erosivity index (units/month), Rain is the average amount of monthly rain (cm/month), Max P is the average maximum rainfall per day (cm), Days is the average number of rainy days per month, I30 is the maximum intensity 30 minutes (cm/hour), and E is the kinetic energy of rain (sec/ha/cm/hour).

The soil erodibility index (K) was analyzed according to the instructions of Ostovari et al, (2016) and Naharuddin et al., (2019) using the formula:

$$K=(7.71\times10^{-4}\cdot(12\text{-}0M)M^{1.14}+3.25(S-2)+2.5)(P-3)(/100) \quad (3)$$

Description: K is soil erodibility, OM is the percentage of organic matter, M is the percentage of particle size (% silt + very fine sand) x (100% clay), S is the soil structure classification code (granular, flat), P is soil permeability.

The slope length and slope (LS) index was analyzed using the formula according to the instructions of Almouctar *et al.,* (2021):

$$LS=\{FA\times(\text{cell size}/23.13)\}^{0.4}\times\{\sin(\text{slope of DEM}\times 0.01745)/0.09\}^{1.3}\times1.6 \quad (4)$$

Description: LS is the slope length and slope gradient factor, FA: flow accumulation, where both are inputs in the calculation of the LS factor. The LS factor describes the influence of topography on soil erosion. The results of the score addition are then classified to determine the level of land criticality in the Meko Sub-Watershed, the equation model according to the instructions of Makalalag et al. (2020), as follows:

CLL PFA: 0.5(LU/C)+0.2(SG)+0.2(EHL)=0.1 (LM) (5)

CLL ACA: 0.3(SG)+0.3(EHL)+0.4(LM) (6)

CLL PAOPFA: 0.5(LU/C)+0.1(KL)+0.1(EHL)= 0.3(LM) (7)

Description: CLL: Critical land level, PFA: Protected forest area, ACA: Agricultural cultivation area, PAOPFA: Protected area outside protected forest area, LU/C: Land use/ cover, SG: Slope gradient, EHL: Erosion hazard level, LM: Land management.

The calculation results based on equations 5, 6, and 7 will be in the Classification of land criticality levels, according to Table 1 in three areas, namely: Protected forest area, Agricultural cultivation area, and Protected area outside protected forest area.

Table 1 Classification of land criticality levels

Protected forest area (ha)	Agricultural cultivation area (ha)	Protected area outside protected forest area (ha)	Critical Land Criteria
120-180	115-200	110-200	Very critical
181-270	201-275	201-275	Critical
271-360	276-350	276-350	Somewhat critical
361-450	351-425	351-425	Critical potential
451-500	426-500	426-500	Not critical

RESULTS AND DISCUSSION

1. The mean annual soil loss

Soil erosion is a type of land degradation caused by the interaction of various factors, such as natural factors and human factors. Erosion is a process of soil erosion caused by the impact of rainwater, causing surface water runoff that carries material in the form of soil so that the soil degrades based on its function and productivity in maintaining the ecosystem of natural resources and the environment.

(1) Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) in the Meko sub-watershed is calculated using climatic data obtained from the Meteorology, Climatology, and Geophysics Agency or the Kasiguncu Poso Meteorological Station. The influence of climatic stations on the Meko Sub-Watershed is analyzed using the Thiessen Polygon method, which considers the areas affected by the climatic stations located within or around the Meko sub-watershed. Based on the analysis using the RUSLE method, an R value of 750 mm/hour was obtained for all land use types (see Table 2). The higher the R value in a region, the greater the potential for erosion due to the effects of rainfall.

(2) Soil Erodibility Factor (K)

Soil erodibility, which reflects the resistance of soil to erosion, is influenced by various soil characteristics, such as texture, aggregate stability, infiltration capacity, as well as organic matter content and chemical elements. These soil characteristics are dynamic and can change over time, influenced by changes in land use or cropping systems. Based on the soil type analysis in the Meko sub-watershed, the soil erodibility (K) values found are presented in Table 2. The highest erodibility value was observed in residential land use, with a value of 0.57.

(3) Slope Length and Steepness Factor (LS)

Slope length and steepness are topographic factors that significantly affect surface runoff and erosion. Slope length refers to the path of surface water flow, which is the location where erosion occurs and sediment deposition is likely to happen. In general, slope steepness is considered a relatively constant factor. Research shows that the highest LS value is found in dryland agricultural areas, with a value of 4.63, while the lowest LS value is observed in mixed agriculture, with a value of 0.68 (see Table 2). As the slope lengthens and steepens, coupled with high rainfall intensity, the potential for erosion increases. Therefore, the LS factor can be minimized through soil and water conservation measures, especially in areas with steep topography. The application of terracing on steep slopes and proper crop management to reduce erosion and landslides is highly recommended.

(4) Vegetation Management Factor (C)

Vegetation management (C) are factors that can be controlled to mitigate erosion. Vegetation management can be achieved by maintaining existing vegetation or replanting areas that have become barren due to illegal logging, landslides, or land clearing. The C factor reflects the influence of vegetation, litter, surface soil conditions, and land management practices on erosion levels.

(5) Soil and Water Conservation Factor (P)

Soil conservation measures are represented by the P factor, which indicates the effect of conservation practices on erosion compared to conditions without conservation measures. Research indicates that the smallest C and P value is found in primary forest land (see Table 2), which demonstrates that good vegetation management is highly effective in reducing erosion. In contrast, the largest C and P value is observed in residential areas, which are more exposed and vulnerable to erosion. According to Deribew et al., (2024) the combination of factors, the high C and P value will trigger a high level of soil loss in the river basin area.

This results in the accumulation of soil volume in certain locations such as drainage, reservoirs, and rivers. The accumulation of soil in the accumulation area and enlargement results in the risk of disaster. The research results show that there are five classes of erosion hazard, namely very low, low, medium, high, and very high (Table 2).

Table 2 The Mean Annual Soil Loss and Classification of Erosion Hazard Index in Meko Sub-Watershed, Central Sulawesi

Land Use	R	K	LS	C	P	A (ton/ha/year)	Criteria
Primary Dry Land Forest	750	0.14	1.88	0.002	0.8	0.32	Very low
Secondary Dry Land Forest	750	0.23	1.95	0.007	1	2.35	Low
Shrubland	750	0.19	3.32	0.68	0.43	138.33	Medium
Settlement	750	0.57	2.14	1	0.59	539.76	Very high
Dryland Agriculture	750	0.37	4.63	0.4	0.7	359.75	High
Mixed Dryland Agriculture	750	0.33	0.68	0.2	0.8	26.93	Low
Paddy Field	750	0.23	1.17	0.2	0.6	24.22	Low

Note: Classification of Erosion Hazard Index based on the instructions of Novita *et al,* (2024); Naharuddin *et al.,* (2021)

Table 2 shows that the classification of the erosion hazard index in the Meko Sub-watershed, is dominated by a very high erosion hazard level of 539.76 tons/ ha/year in residential areas, while very low is in primary dryland forests of 0.32 tons/ ha/year. Data on high to very high erosion hazard levels occur in lands with high erodibility values, for example in residential areas with an erodibility index of 0.57. The greater the erosion that occurs in an area, the higher the chance of critical land emerging in the watershed, in line with the opinion of Chen et al, (2021) that critical land needs to be conserved. The distribution of erosion hazard levels in the Meko Sub-watershed, is presented in Figure 4.

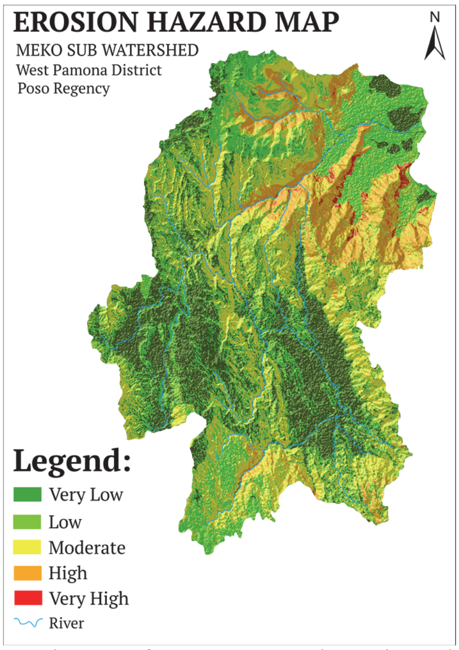


Fig. 4 Distribution of Erosion Hazard Levels in the Meko Sub-Watershed, Central Sulawesi

High intensity of land use will result in increased degradation. land especially the level of criticality of the land caused by the rate of erosion that occurs in each land unit. Dryland agriculture and settlements show high to very high erosion potential because the land is more open, less vegetation at the tree level in minimizing surface runoff which causes erosion to occur compared to tree canopies in primary dryland forests and secondary dryland forests. This phenomenon occurs because the root system of plants in dryland agricultural land is not as good as primary dryland forests in withstanding the damaging power of rainwater. This is evidence that land use/cover has become an important factor in erosion. Furthermore, slope gradient and land management factors also influence the high and low levels of erosion hazard.

2. Land Criticality Level

The determination of the critical level of land is obtained from the overlay of critical land determining parameters, each score of each parameter is multiplied by its respective weight. The results of the analysis show that there are four classes of land criticality levels in the Meko sub-watershed, namely not-critical at 12,128.01 ha (23%), potentially critical at 5,500.74 ha (10%), somewhat critical at 34,961.60 ha (66%), critical at 608.54 ha (1%) of the total area of the Meko sub-watershed of 53,198.89 ha (Table 3).

Table 3 Area of Critical Land Level in Meko Sub-watershed, Central Sulawesi

Class	Area (Ha)	Percentage (%)
Not Critical	12,128.01	23
Potentially critical	5,500.74	10
Somewhat Critical	34,961.60	66
Critical	608.54	1
Total	53,198.89	100

Soil erodibility refers to the capacity of soil to resist erosion. However, even if the soil has low erodibility, its location on steep slopes still presents a risk of erosion. In addition to soil erodibility (K), erosion is influenced by other factors such as rainfall (R), slope length and steepness (LS), vegetation cover (C), as well as human activities or land management practices (P). Field surveys and soil erodibility analyses conducted on several land units in the Meko sub-watershed reveal that, in general, areas with high erodibility are those that are devoid of vegetation cover (Table 2). Lands with high erodibility are more susceptible to erosion, while soils with low erodibility are more resistant to erosion. This may have significant implications for the land's criticality status.

Table 3 and Figure 5 show the area and distribution of non-critical land of 12,128 ha (23%) are in the primary dryland forest area and secondary dryland forest. This shows the importance of land cover for watershed management. The Meko Sub- watershed has land with high vulnerability to erosion, high slope steepness, and high rainfall erosivity factors according to the results of erosion predictions using the RUSLE approach, the high level of erosion hazard will also increase the chances of critical land emerging so that it can reduce the hydrological function of the watershed. The existence of dryland agriculture and quite large vegetation felling by human activities in the Meko Sub-watershed area, then the area can be considered a high priority area to be managed to reduce soil loss, most of which occurs in the upstream part of the Meko Sub-watershed.

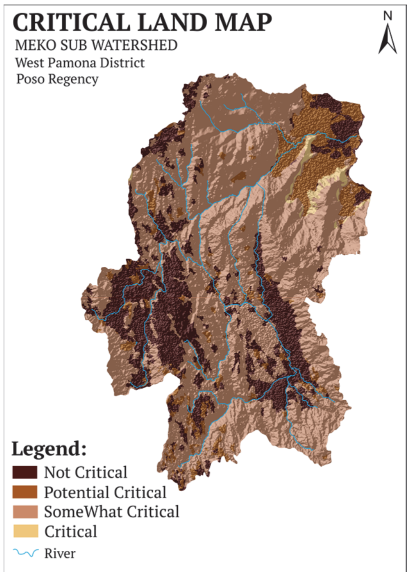
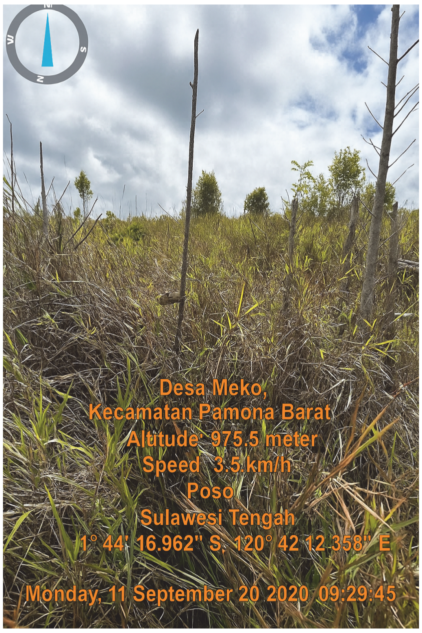
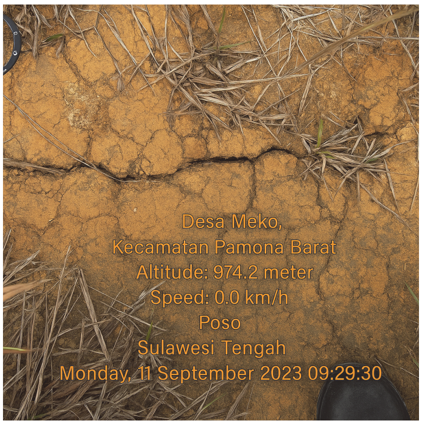


Fig.5 Critical Land Distribution Map in the Meko Sub-Watershed

The main characteristics of critical land are bald, appear arid and even rocks appear on the surface of the ground and are generally located in areas with hilly or steep slope topography (Aktab et al., 2021). Based on this statement, the research location is often found mainly in dry land agricultural land as with the dominant land cover of cogongrass (Imperata cylindrica) and red-yellow podzolic soil type, sandy clay soil texture, low soil fertility, yellowish red in color, and does not contain high organic matter (Figure 6).



(A)



(B)

Fig.6 Critical land area in the Meko Sub-Watershed, Central Sulawesi; (A) dominant plant type land coverImperata cylindrica; (B) Conditions red yellow podzolic soil

The high level of land criticality in the Meko sub-Watershed, especially outside primary forest land and secondary forest due to the lack of ground cover vegetation in the form of tree stands as a source of organic material, resulting in the effect of erosion, as well as poor land management. High land cover with vegetation density, especially in primary forest land and secondary forest, plays an important role as a regulator of water management, and an important part of the hydrological cycle, with a dense canopy that can reduce the kinetic energy of rainwater and increase the infiltration rate and minimize erosion. This opinion is further emphasized by Budiastuti *et al.*, (2020) that plant variations using trees to increase the high canopy layer and plants at lower levels inhibit the speed of rainwater, reduce the impact force and erosive effects when water reaches the ground surface.

In relation to soil and water conservation on critical land, tree vegetation functions to control the speed of rainwater falling through the canopy through the branch-leaf system or the stem flow process. According to Naharuddin, (2021) vegetation different tree levels based on their architecture create different canopy gaps which ultimately determine the effect of rainwater on the ground surface. Understanding the process of critical land occurrence and the factors that influence it is very necessary as a reference for implementing land management, especially critical and very critical land. Therefore, in land use planning, critical land and the factors that influence it are problems that should be addressed first before further efforts are made, especially since changes in land use that are currently occurring certainly greatly affect the rate of critical land levels.

Conclusion

High to very high erosion hazard levels occur on land with high erodibility values, namely on residential land with an erodibility index of 0.57. The greater the erosion that occurs in the Meko sub-watershed, the higher the chance of critical land emerging. Classification of the level of criticality of land in the Meko Sub-watershed, is the highest, slightly critical at 34,962 ha and critical at 609 of the total area of the Meko Sub-watershed of 53,198.89 ha, generally the distribution of critical land is in less productive dry land agricultural areas. Determination of the level of criticality that is somewhat critical or critical based on the results of the scoring value is the basis for determining the watershed that needs to be restored in conservation efforts. Soil erosion as an accumulation of the causes of critical land is a serious problem in the Meko Sub-watershed. Therefore, it is needed as data for land use and sustainable soil and water conservation management. In controlling critical land in the Meko Sub-watershed, efforts are needed to conserve soil and water based on vegetation, namely by implementing a planting system that combines trees with agricultural crops, namely an agroforestry system involving the community as the main key to the program.

This study contributes scientifically to the mapping of erosion hazard levels and the identification of critical lands in the Meko Sub-Watershed. The results of soil erodibility analysis and land criticality classification provide a strong foundation for planning land restoration through sustainable soil and water conservation efforts. Furthermore, this research emphasizes the importance of implementing agroforestry systems as a vegetation-based conservation solution that involves local community participation. This contribution is expected to serve as a reference for designing effective and environmentally friendly land management policies in the Meko Sub-Watershed and surrounding area.

Acknowledgments

This research was carried out with the support of the Tadulako University Excellent Research grant according to the decree of the Rector of Tadulako University No. 6805/UN28/KU / 2023, dated May 25, 2023. Therefore, gratitude is expressed to the Rector of Tadulako University, Director of the Tadulako University Postgraduate Program, Independent Learning Campus Independent Students of the Faculty of Forestry, Tadulako University, and the Central Sulawesi Watershed Forum Team.

Conflict of Interest

All authors declare no personal or financial interests that might have influenced the work reported in this article.

References

[1] Aktab, B.A., Susanti, F., and Lestari, S.A.P. (2021). "The Level of Critical Land in West Lombok Using Geographic Information Systems." In *2nd Borobudur International Symposium on Science and Technology (BIS-STE 2020)* (311-316). Atlantis Press.

[2] Albaladejo, J., Diaz-Pereira, E., and de Vente, J. (2021). "Eco-holistic soil conservation to support land degradation neutrality and the sustainable development goals." *Catena*, 196, 104823.

[3] Almouctar, M.A.S., Wu, Y., Zhao, F., and Dossou, J.F. (2021). "Soil erosion assessment using the RUSLE model and geospatial techniques (Remote Sensing and GIS) in South-Central Niger (Maradi Region)." *Water*, 13(24), 3511.

[4] Anache, J.A., Flanagan, D.C., Srivastava, A., and Wendland, E.C. (2018). "Land use and climate change impacts on runoff and soil erosion at the hillslope scale in the Brazilian Cerrado." *Science of the Total Environment*, 622, 140-151.

[5] Bettoni, M., Maerker, M., Bosino, A., Conedera, M., Simoncelli, L., and Vogel, S. (2023). "Land use effects on surface runoff and soil erosion in a southern Alpine valley." *Geoderma*, 435, 116505.

[6] Budiastuti, M.T.S., Purnomo, D., Hendro, H., Sudjianto, U., and Gunawan, B. (2020). "Rehabilitation of critical land by Implementing complex agroforestry at the prioritized subwatersheds in the Muria Region." *Sains Tanah-Journal of Soil Science and Agroclimatology*, 17(1), 63-70.

[7] Cerdà, A., Borja, M.E.L., Úbeda, X., Martínez-Murillo, J.F., and Keesstra, S. (2017). "Pinus halepensis M. versus Quercus ilex subsp. Rotundifolia L. runoff and soil erosion at pedon scale under natural rainfall in Eastern Spain three decades after a forest fire." *Forest ecology and management*, 400, 447-456.

[8] Cetin, M., Ozcan Tatar, C., Ozturk, Y., Agacsapan, B., Khoda Karimi, Z., Ozenen Kavlak, M., and Cabuk, S.N. (2024). "Assessing earthquake-induced vulnerability of critical infrastructure in kahramanmaraş using geographic information systems and remote sensing technologies." *Journal of the Indian Society of Remote Sensing*, 1-15.

[9] Chaidar, A.N., Soekarno, I., Wiyono, A., and Nugroho, J. (2017). "Spatial analysis of erosion and land criticality of the upstream citarum watershed." *Geomate Journal*, 13(37), 133-140.

[10] Chen, S., Liu, W., Bai, Y., Luo, X., Li, H., and Zha, X. (2021). "Evaluation of watershed soil erosion hazard using combination weight and GIS: A case study from eroded soil in Southern China." *Natural Hazards*, 109, 1603-1628.

[11] Chimdessa, K., Quraishi, S., Kebede, A., and Alamirew, T. (2018). "Effect of land use land cover and climate change on river flow and soil loss in Didessa River Basin, South West Blue Nile, Ethiopia." *Hydrology*, 6(1), 2.

[12] Deribew, K.T., Arega, E., and Moisa, M.B. (2024). "Prediction of the topo-hydrologic effects of soil loss using morphometric analysis in the upper Bilate watershed." *Bulletin of Engineering Geology and the Environment*, 83(5), 162.

[13] Deteix, L., Salou, T., Drogué, S., and Loiseau, E. (2023). "The importance of land in resource criticality assessment methods: a first step towards characterising supply risk." *Science of the Total Environment*, 880, 163248.

[14] Du, Z., Yu, L., Chen, X., Gao, B., Yang, J., Fu, H., and Gong, P. (2024). "Land use/cover and land degradation across the Eurasian steppe: Dynamics, patterns and driving factors." *Science of The Total Environment*, 909, 168593.

[15] Dunkerley, D. (2021). "Rainfall intensity in short events: Evaluating the "I30 is equal to twice the rainfall depth approach advised for use with the Universal Soil Loss Equation by Wischmeier and Smith (1978)." *CATENA*, 207, 105659.

[16] Engdawork, A., and Bork, H R. (2014). "Long-term indigenous soil conservation technology in the Chencha Area, Southern Ethiopia: origin, characteristics, and sustainability." *Ambio*, *43*, 932-942. *Forest Meteorology*, 156, 18-30.

[17] Erwanto, Z., and Lestari, N. (2021). "Study of rainfall erosivity and erosion rate with MUSLE method using geographic information system in Badeng Watershed." In *International Conference on Innovation in Science and Technology (ICIST 2020)* (pp. 346-353). Atlantis Press.

[18] Fekete, A., Tzavella, K., Armas, I., Binner, J., Garschagen, M., Giupponi, C., and Serre, D. (2015). "Critical data source; tool or even infrastructure? Challenges of geographic information systems and remote sensing for disaster risk governance." *ISPRS International Journal of Geo-Information*, 4(4), 1848-1869.

[19] Goebes, P. (2015). "Mechanisms of Soil Erosion in Subtropical Forests of China-Effects of Biodiversity, Species identity, Tree architecture and Spatial variability on Erosivity." *Doctoral dissertation*, Universität Tübingen.

[20] Irwansah, A. (2021). "Analysis of critical land using forest canopy density method in the agropolitan development area of Lamongan regency, Indonesia." *Jurnal Geografi*, 19-26.

[21] Issaka, S., and Ashraf, M.A. (2017). "Impact of soil erosion and degradation on water quality: a review." *Geology, Ecology, and Landscapes*, 1(1), 1-11.

[22] Lal, R. (2014). "Soil conservation and ecosystem services." *International soil and water conservation research*, 2(3), 36-47.

[23] Lal, R., and Elliot, W. (2017). "Erodibility and erosivity." In *Soil erosion research methods* (181-210). Routledge.

[24] Lima, A.F., Ferreira, G.F., Veról, A.P., and Miguez, M.G. (2024). "Prioritizing Urban River Restoration Management Practices: A Cross-Evaluation Using the Criticality Index for Watershed Restoration (CIWR) and Opportunity Layers." *Land (2012)*, 13(12).

[25] Makalalag, M.F.M., Takumansang, E.D., and Tarore, R.C. (2020). "Analisis spasial sebaran lahan kritis di Kawasan

Danau Mooat Kabupaten Bolaang Mongondow Timur." *Spasial*, 7(3), 313-324.

[26] Naharuddin, N. (2021). "Erosion Levels at Tree Architecture Model Plots of Attims (*Eucalyptus deglupta*), Corner (*Arenga pinnata*), and Rauh (*Arthocarpus teysmanii*)." *Jurnal Ilmu Kehutanan*, 15(1), 28-41.

[27] Naharuddin, N., Malik, A., and Ahyauddin, A. (2021). "Soil loss estimation for conservation planning in the Dolago Watershed Central Sulawesi, Indonesia." *Journal of Ecological Engineering*, 22(7), 242-251.

[28] Naharuddin, N., Malik, A., Rachman, I., Muis, H., Hamzari, H., and Wahid, A. (2020). "Land use planning for post-disaster soil liquefaction area based on erosion hazard index." *International Journal of design & Nature of ecodynamics*, 15(4), 573-578.

[29] Naharuddin, N., Rukmi, R., Massiri, S.D., Toknok, B., and Korja, I.N. (2024). "Estimation of peak current as a basis for sustainable watershed conservation using the number-curve land conservation." *Global Journal of Environmental Science and Management*, 10(3), 1017-1028.

[30] Naharuddin, Wahid. A., Rukmi, Sustri 2019. "Erosion Hazard Assessment in Forest and Land Rehabilitation for Managing the Tambun Watershed in Sulawesi, Indonesia." *Journal of Chinese Soil and Water Conservation*, 50(3), 124-130.

[31] Nanko, K., Giambelluca, T.W., Sutherland, R.A., Mudd, R.G., Nullet, M.A., and Ziegler, A.D. (2015). "Erosion potential under Miconia calvescens stands on the Island of Hawai 'i." *Land Degradation & Development*, 26(3), 218-226.

[32] Newbold, T., Adams, G.L., Albaladejo Robles, G., Boakes, E.H., Braga Ferreira, G., Chapman, A.S., and Williams, J. J. (2019). "Climate and land-use change homogenise terrestrial biodiversity, with consequences for ecosystem functioning and human well-being." *Emerging Topics in Life Sciences*, 3(2), 207-219.

[33] Nicotra, A.B., Beever, E.A., Robertson, A.L., Hofmann, G.E., and O'Leary, J. (2015). "Assessing the components of adaptive capacity to improve conservation and management efforts under global change." *Conservation Biology*, 29(5), 1268-1278.

[34] Novita, D., Wijaya, K., and Sasongko, P.E. (2024). "Directions for Land Conservation Based on Determining the Erosion Hazard Index (EHI) Using the RUSLE Method in Sub-Watersheds Gunting, Jombang." *Jurnal Agrinika: Jurnal Agroteknologi dan Agribisnis*, 8(1), 1-11.

[35] Nugroho, H.Y.S.H., Basuki, T.M., Pramono, I.B., Savitri, E., Indrawati, D.R., Wahyuningrum, N., and Nandini, R. (2022). "Forty Years of Soil and Water Conservation Policy, Implementation, Research and Development in Indonesia: A Review." *Sustainability*, 14(5), 2972.

[36] Ostovari, Y., Ghorbani-Dashtaki, S., Bahrami, H.A., Naderi, M., Dematte, J.A.M., and Kerry, R. (2016). "Modification of the USLE K factor for soil erodibility assessment on calcareous soils in Iran." *Geomorphology*, 273, 385-395.

[37] Pimentel, D., and Burgess, M. (2013). "Soil erosion threatens food production." *Agriculture*, 3(3), 443-463.

[38] Rachman, I., and Naharuddin, N. (2022). "Soil Erosion Rate and Surface Run Off on Various Forms of Culture." *Journal of Experimental Agriculture International*, 44(9), 123-131.

[39] Rafif, M.A., Widiarti, W.Y., Hidayah, E., Saifurridzal, S., and Ma'ruf, M.F. (2024). "Effects of Land Use Change on Soil Erosion and Land Critical Level Using GIS in the Mayang Watershed." *Geosfera Indonesia*, *9*(2).

[40] Ramadhan, A. (2024). "Critical Land Mapping of Protected Forest Areas in Sukamakmur District, Bogor Regency." *Journal of Geographical Sciences and Education*, 2(3), 99-109.

[41] Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L., and Panagos, P. (2019). "A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion." *Land use policy*, 86, 299-312.

[42] Shao, Y., Jiang, Q.O., Wang, C., Wang, M., Xiao, L., and Qi, Y. (2020). "Analysis of critical land degradation and development processes and their driving mechanism in the Heihe River Basin." *Science of the Total Environment*, 716, 137082.

[43] Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., and Sörlin, S. (2015). "Planetary boundaries: Guiding human development on a changing planet." *science*, 347(6223), 1259855.

[44] Sukamdani, N.B., and Sukwika, T. (2023). "Erosion prevention through empowerment of human resources to support food security around the Kambaniru watershed, East Nusa Tenggara." In *IOP Conference Series: Earth and Environmental Science* (1133(1), 012061). IOP Publishing.

[45] Sun, Z., Lotz, T., and Chang, N.B. (2017). "Assessing the long-term effects of land use changes on runoff patterns and food production in a large lake watershed with policy implications." *Journal of environmental management*, 204, 92-101.

[46] Supriyono, S. (2018). "Critical Land Detection Watershed River Bengkulu and Effect of Coastal Area using Geographic Information System." *Sumatra Journal of Disaster, Geography and Geography Education*, 2(1), 30-37.

[47] Wang, D., Yu, X., Zhang, J., Jia, G., Zhang, H., Liu, Z., and Hou, G. (2017). "The impacts of Robinia pseudoacacia litter cover and roots on soil erosion in the Loess Plateau, China." *Chemistry and Ecology*, 33(6), 528-542.

[48] Yulianto, F., Raharjo, P.D., Pramono, I.B., Setiawan, M.A., Chulafak, G.A., Nugroho, G., and Budhiman, S. (2023). "Prediction and mapping of land degradation in the Batanghari watershed, Sumatra, Indonesia: utilizing multi-source geospatial data and machine learning modeling techniques." *Modeling Earth Systems and Environment*, 9(4), 4383-4404.

2025 年 02 月 21 日　收稿
2025 年 03 月 27 日　修正
2025 年 06 月 24 日　接受