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Prediction of Forest and Land Rehabilitation Impacts on Peak Discharge, Erosion, and Sedimentation Reduction in The Piloliyanga Micro Catchment, Modelomo Watershed

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ABSTRACT

Watershed degradation contributes to increased peak discharge, erosion, and sedimentation in downstream areas. Forest and Land Rehabilitation (FLR) has become an important approach for restoring hydrological functions through increasing vegetation cover and controlling surface runoff. This study aimed to analyze the predicted impacts of FLR on peak discharge, erosion, and sedimentation in the Piloliyanga micro-catchment, Modelomo Watershed. The study employed a quantitative descriptive approach based on Geographic Information Systems (GIS), hydrological analysis, and land cover change simulation. Erosion analysis was conducted using the Universal Soil Loss Equation (USLE), while sedimentation was estimated using the Sediment Delivery Ratio (SDR) approach. The results showed that FLR has the potential to reduce peak discharge, erosion, and sedimentation through increased infiltration and vegetation interception. The novelty of this study lies in the integration of USLE, SDR, and land cover change simulation within a tropical micro-catchment watershed scale. The findings imply that watershed-based vegetative rehabilitation can improve hydrological stability and support land degradation control in the upstream area of the Modelomo Watershed.

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1. INTRODUCTION

A watershed is a hydrological system that plays an important role in regulating water balance, controlling erosion, and sustaining environmental resources. Land use changes — particularly the conversion of forests into cultivated land in upstream areas — have disrupted watershed hydrological functions by increasing surface runoff, accelerating soil erosion, and intensifying sedimentation downstream. This has reduced river channel capacity, increased flood risk, and degraded aquatic ecosystems. [1] confirmed that the expansion of cultivated land at the expense of forest, shrubland, and grassland has significantly increased surface runoff, sediment yield, and mean annual streamflow while simultaneously reducing groundwater recharge and evapotranspiration.

One key indicator of watershed degradation is the increase in peak discharge, which reflects an increasingly rapid hydrological response to extreme rainfall events. This typically occurs in watersheds dominated by open land and low infiltration, where surface flow becomes the dominant mechanism for water transfer to the outlet. Additionally, soil erosion and sedimentation are downstream consequences of increased surface flow energy and low soil surface stability.

The Modelomo Watershed is one of the watersheds in Gorontalo Province experiencing significant hydrological pressure due to land cover changes in upstream areas. The dominance of dry-land agriculture on steep slopes and the reduction of permanent vegetation have increased vulnerability to erosion and sedimentation. This contributes to fluctuations in river discharge and increasing sediment loads reaching downstream areas, including the coastal zone of Tomini Bay.

Forest and Land Rehabilitation (FLR) is a strategic approach to restoring watershed hydrological functions through increasing vegetation cover and improving the biophysical condition of land. This intervention helps increase rainfall interception, improve soil structure, and enhance infiltration capacity, thereby reducing the dominance of surface runoff. In tropical watersheds, the effectiveness of FLR is strongly influenced by the biophysical characteristics of the area, the scale of intervention, and the degree of hydrological connectivity within the watershed system.

Various studies have shown that land cover changes significantly affect watershed hydrological responses, including peak discharge, erosion, and sedimentation. Research by showed that slope characteristics, land use, and biophysical conditions of watersheds influence the magnitude of erosion and sedimentation potential in upper watershed areas. [2] demonstrated through SWAT modeling in a tropical forest watershed in Brazil that land use conversion, particularly total deforestation, increases runoff generation capacity, while vegetative cover plays a critical role in stabilizing watershed hydrological balance. [3] further showed that land use change — especially urbanization replacing forest and agricultural land — significantly amplifies flood peaks and volumes, with smaller-scale floods proving more sensitive to land cover modifications. However, micro-catchment-scale studies still show varying results due to differences in rehabilitation scale, biophysical characteristics, and the limited integration of hydrology, erosion, and sedimentation analyses within a unified modeling framework. Therefore, an approach capable of simultaneously integrating hydrological and sedimentation aspects remains an important need in tropical watershed research.

This study was conducted in the micro-catchment of Piloliyanga Village, Tilamuta District, Boalemo Regency, which is the site of the 2025 FLR activities in the Modelomo Watershed. This area has steep topography dominated by erosion-prone soils, significantly contributing to sedimentation dynamics in the lower watershed. The novelty of this study lies in the integration of the Universal Soil Loss Equation (USLE), the Sediment Delivery Ratio (SDR), and GIS-based land cover change simulation to evaluate the impacts of FLR on peak discharge, erosion, and sedimentation at a micro-catchment scale in the Modelomo Watershed.

This study aims to: (1) analyze the biophysical characteristics of the Piloliyanga micro-catchment; (2) simulate changes in peak discharge under rehabilitation scenarios; (3) evaluate the impacts of rehabilitation on erosion and sedimentation; and (4) examine the hydrological implications of vegetative rehabilitation on watershed stability.

2. LITERATURE REVIEW

2.1 Forest and Land Rehabilitation (FLR)

Forest and Land Rehabilitation (FLR) is an effort to restore, maintain, and enhance forest and land functions so that environmental carrying capacity, land productivity, and hydrological functions return to optimal levels [4]. FLR activities are generally implemented on degraded lands and watersheds affected by land cover changes, deforestation, and cultivation activities that do not follow principles of soil and water conservation [4]. Vegetative rehabilitation through reforestation plays an important role in improving hydrological conditions by increasing permanent vegetation cover. Vegetation increases rainfall interception, enhances infiltration, reduces surface runoff, and strengthens soil stability on steep slopes [5].

2.2 *Watershed Hydrology and Peak Discharge*

A watershed is a land area topographically bounded by ridgelines that functions to collect, store, and channel rainwater toward a specific outlet through a river network [5]. Peak discharge is the maximum discharge occurring as a result of a watershed's response to a rainfall event. [6] emphasized that increased vegetation cover in tropical watersheds contributes to water balance stabilization by reducing surface flow and increasing soil moisture retention. [7] showed that forest cover recovery correlates with reduced river discharge fluctuations.

2.3 *Soil Erosion and the Universal Soil Loss Equation (USLE)*

Erosion is the process of detachment and transport of soil particles due to the kinetic energy of rain and surface flow [11]. Erosion prediction in this study uses the USLE:

$$A = R \times K \times LS \times C \times P,$$

where

- A = predicted annual soil loss (tons/ha/year),
- R = rainfall erosivity,
- K = soil erodibility,
- LS = slope length and gradient,
- C = land cover factor, and
- P = soil conservation factor.

According to [8], the land cover factor (C) is one of the most influential factors in erosion control, especially in tropical regions with high rainfall intensity.

2.4 *Sedimentation and Sediment Delivery Ratio (SDR)*

Sedimentation is the process of deposition of eroded materials transported via surface runoff toward rivers, reservoirs, and coastal areas [9]. Sedimentation estimation uses the Sediment Delivery Ratio (SDR) approach:

$$\text{Sediment Yield} = \text{Erosion} \times \text{SDR}.$$

SDR values are influenced by watershed area, slope conditions, river flow patterns, and land cover .

2.5 *Land Cover, Vegetation, and Watershed Stability*

Land cover is one of the main factors influencing watershed hydrological stability. Changes from permanent vegetation to open land can increase surface runoff, amplify erosion, and accelerate sedimentation [5]. Vegetation acts as a natural protector of soil against rainfall kinetic energy through canopy interception and increased soil infiltration [8]. A comprehensive review by [10] across multiple watersheds in Ethiopia confirmed that the conversion of forest to cultivated land consistently increased annual surface runoff and soil erosion rates while reducing groundwater recharge and evapotranspiration, reinforcing the critical function of vegetative cover in maintaining watershed hydrological and erosional balance.

2.6 *Surface Runoff and Infiltration*

Surface runoff occurs when the soil's infiltration capacity cannot accommodate rainfall intensity. Infiltration plays an important role in controlling surface runoff by reducing the volume of water flowing directly to rivers [5]. Vegetative rehabilitation acts as an indirect controlling factor that influences the balance between infiltration and runoff through changes in the physical properties of the soil.

2.7 *Soil and Water Conservation*

Soil and water conservation refers to land resource management efforts to prevent soil damage from erosion and maintain watershed hydrological functions. According to [11], vegetation-based conservation is one of the most effective approaches for reducing erosion rates and sediment yield in tropical watersheds. Integrating vegetative and mechanical conservation (e.g., terracing, drainage channels) is an important strategy for maintaining watershed stability.

2.8 *GIS in Watershed Analysis*

Geographic Information Systems (GIS) is a spatial-based technology used to manage, analyze, and visualize spatial data in watershed management [11]. The GIS approach supports spatial overlay analysis, critical land mapping, and simulation of land cover changes. [4] showed that a GIS-based approach can support identification of land criticality levels and evaluation of rehabilitation suitability in degraded watersheds. [3] demonstrated the application of a CA-Markov model integrated with HEC-HMS to predict hydrological responses to future land use changes, confirming that GIS-based simulation approaches effectively capture the spatial dynamics of land cover change and its hydrological consequences at the watershed scale.

3. METHODS

3.1 Study Location

The study was conducted in the micro-catchment of the FLR site in Piloliyanga Village, Tilamuta District, Boalemo Regency, Gorontalo Province, within the Modelomo Watershed which empties into Tomini Bay. The micro-catchment covers 725.40 ha; the rehabilitation area analyzed covers 22 ha (approximately 3.03% of total micro-catchment area). The study area has topography ranging from flat to very steep, dominated by dry-land agriculture and shrubland.

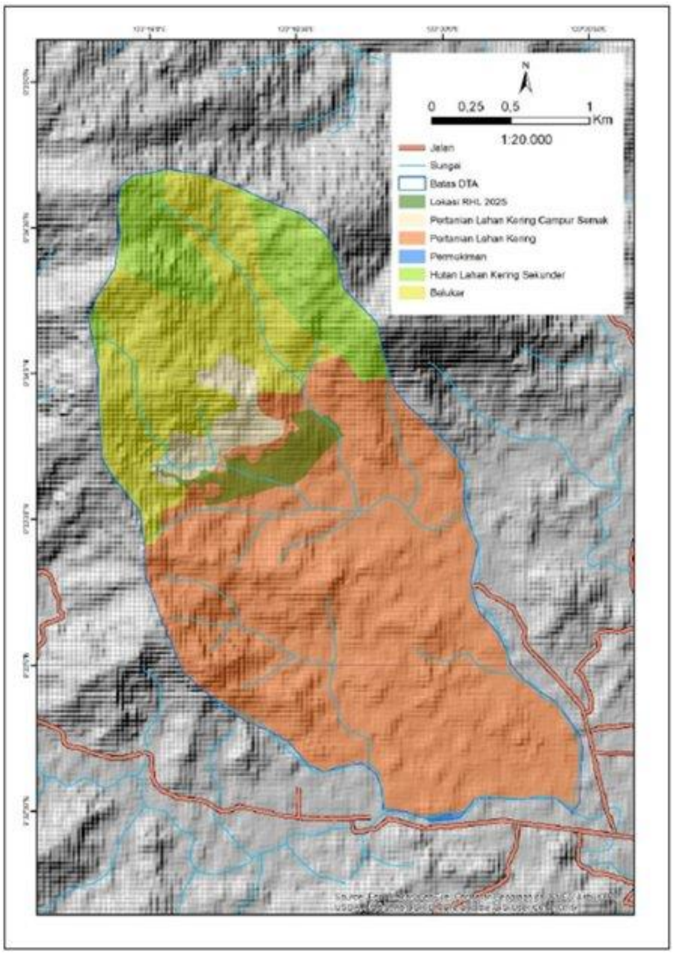

Figure 1. Research Location Map of Micro Catchment RHL, DAS Modelomo

3.2 Data Types and Sources

The study used secondary data: rainfall data, land cover map, slope map, soil type map, watershed morphometric data, 2025 FLR activity data, and technical literature on watershed rehabilitation. Spatial data were processed using GIS to produce biophysical analyses and land cover change simulations.

3.3 Rainfall Analysis

Areal rainfall analysis was performed using the Thiessen Polygon and Isohyet methods. The Thiessen method determined the weight of each rain gauge station's influence on the study area, while the Isohyet method described the spatial distribution of rainfall.

3.4 Watershed Morphometric Analysis

Morphometric analysis determined the physical characteristics of the micro-catchment affecting hydrological response. Parameters analyzed included watershed area, main river length, elevation difference, river slope, and time of concentration (Tc).

3.5 Erosion Analysis Using USLE

Erosion prediction was performed using the USLE method ($A = R \times K \times LS \times C \times P$). The USLE method captures the influence of biophysical characteristics and land use on erosion levels.

3.6 Sedimentation Analysis

Sedimentation prediction used the SDR approach: Sediment Yield = Erosion × SDR. SDR values were determined based on watershed area using empirical relationships between watershed area and the sediment delivery ratio.

3.7 Simulation of FLR Impacts

Simulation compared existing conditions with post-rehabilitation conditions. Under the rehabilitation scenario, it was assumed that: vegetation resulting from FLR has developed into permanent vegetation, land cover has increased, the land cover factor (C) has decreased, and surface runoff has decreased due to increased infiltration. The simulation predicted changes in peak discharge, erosion, and sedimentation.

3.8 Data Analysis

Data were analyzed using a quantitative descriptive and spatial approach to evaluate the effects of rehabilitation on the recovery of watershed hydrological functions.

4. RESULTS AND DISCUSSION

4.1 Biophysical Characteristics of the Piloliyanga Micro-catchment

The biophysical characteristics of a watershed have an important influence on hydrological response. These conditions determine the watershed's capacity to respond to rainfall, control surface runoff, and resist erosion.

1. A.1 Watershed Morphometrics and Slope Classes

Analysis results showed that the Piloliyanga micro-catchment covers an area of 725.40 ha with a main river length of 5,460 meters. The morphometric conditions (Table 1) show a parallel drainage pattern with two main rivers, which has the potential to increase flow accumulation at river confluence points. The study area is dominated by steep to very steep slope classes (>45%), increasing the potential for surface runoff and erosion vulnerability.

Table 1. Morphometric Characteristics of the Piloliyanga Micro-catchment

Parameter	Nilai
Watershed Area	725,40 ha
Main River Length	5.460 m
Elevation Difference	475 m
River Slope	8,67 %
Time of Concentration	0,63 hour

Source: Bone Limboto Watershed Management Authority, 2025

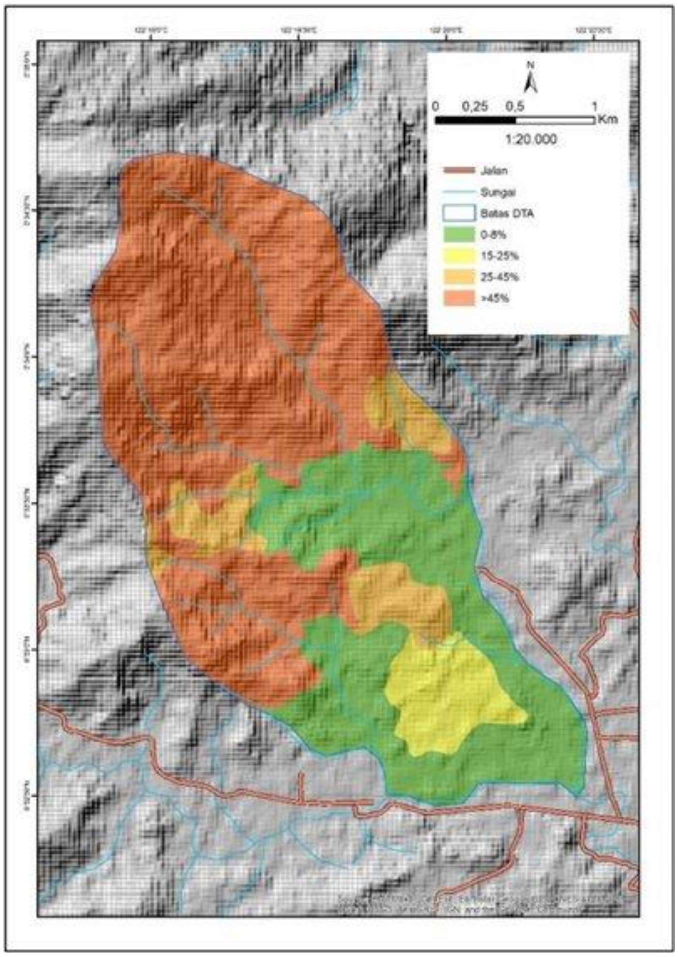

Figure 3. Slope Class Map of Micro Catchment RHL, DAS Modelomo

2. A.2 Soil Types

The soil types at the study site are dominated by Ustic Cambisols and Ustic Mediterranean (Rhodustalfs) as shown in Table 2. Ustic Cambisols have relatively young soil horizon development with moderate sensitivity to erosion. Ustic Mediterranean soils have an argillic horizon and structural characteristics vulnerable to degradation on open slopes.

Table 2. Soil Type Distribution in the Piloliyanga Micro-catchment

Soil Type	Area (ha)
Ustic Cambisols	233,72
Ustic Mediterranean	491,68
Total	725,40

Source: Bone Limboto Watershed Management Authority, 2025

3. A.3 Land Cover

Land cover is the most dynamic biophysical component and strongly influences watershed hydrological conditions. Changes from permanent vegetation to open land or intensive cultivation can increase surface runoff, amplify erosion, and accelerate sedimentation. FLR activities at the study site are directed toward increasing vegetation cover through reforestation to improve soil infiltration capacity and reduce surface flow.

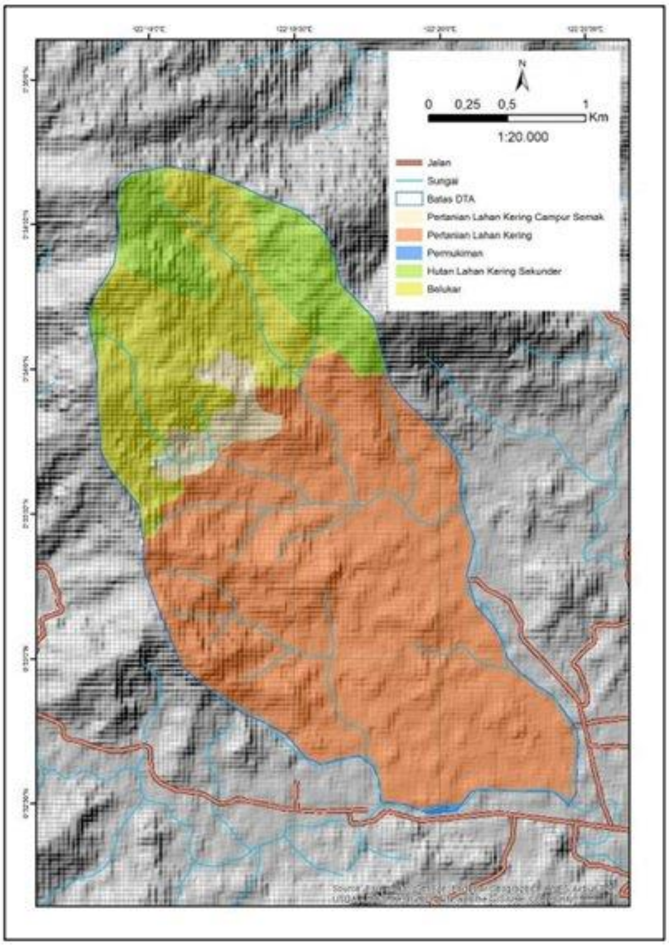

Figure 2. Land Cover Map of Micro Catchment RHL, DAS Modelomo

3.2 Predicted Impacts of FLR on Peak Discharge

Peak discharge is the primary indicator of watershed hydrological response to extreme rainfall events. Under open land cover conditions, most precipitation is converted to surface runoff due to low soil infiltration capacity, resulting in rapid flow response and high peak discharge. [2] stated that watershed characteristics and rainfall intensity influence the magnitude of peak river discharge.

Simulation results showed that implementing FLR in the Piloliyanga micro-catchment produced a reduction in maximum discharge from 44.67 m^3/s to 44.54 m^3/s (0.29%). Erosion and sedimentation reductions were also relatively small, at 0.30% and 0.37%, respectively. These changes consistently indicate the direction of hydrological response to increased vegetation cover at the micro-watershed scale.

Hydrologically, the reduction in peak discharge can be explained through a causal process chain:

precipitation → canopy interception → increased infiltration due to soil structure improvement by root systems → reduced surface runoff connectivity → increased flow concentration time → reduced peak discharge.

However, because the intervention area remains limited (3.03% of the total catchment area), the effect has not yet been spatially integrated at the watershed scale. This means most of the area is still dominated by fast flow pathways with high runoff connectivity. The hydrological signal from the rehabilitation area experiences dilution at the watershed scale. These findings are consistent with [12], [13], who confirmed that hydrological impacts become more apparent when the proportion of change reaches a certain level. At an intervention scale of <5% of watershed area, the hydrological response tends to be non-linear. [14] similarly found in a SWAT simulation of a Brazilian tropical watershed that replacing forest cover with cropland or pasture produced only marginal runoff changes, while complete deforestation — equivalent to the scenario of zero rehabilitation — produced the most significant increase in runoff generation. [3] further corroborated that land cover conversion toward reduced permeability consistently amplifies flood peaks and volumes, with smaller events being more sensitive, analogous to the micro-catchment scale dynamics observed in this study.

3.3 Predicted Impacts of FLR on Erosion

Analysis results using the USLE method showed that slope and land cover factors are the dominant factors influencing erosion potential. Areas with steep slopes and low vegetation cover have high LS and C values, resulting in greater erosion rates. Implementation of vegetative rehabilitation reduces the land cover factor (C), causing erosion rates to decrease. Permanent vegetation reduces rainfall energy and improves soil stability. These findings support [15], who stated that increasing vegetation cover is one of the most effective approaches for reducing soil erosion rates. This is further supported by [10] , whose review of LULC change impacts across Ethiopian watersheds showed that the expansion of cultivated land at the expense of forest and shrubland consistently increased mean soil erosion rates from 0.5 to over 31 $t \cdot ha^{-1} \cdot year^{-1}$, confirming that land cover degradation is the primary driver of accelerated erosion in tropical and sub-tropical watersheds with steep terrain — conditions highly comparable to the Piloliyanga micro-catchment .

3.4 Predicted Impacts of FLR on Sedimentation

High sedimentation in the Modelomo Watershed is influenced by steep slope conditions, high surface runoff, and dominance of open land use. Simulation results showed that vegetative rehabilitation has the potential to reduce sediment yield through erosion reduction and decreased sediment transport. Ecologically, reducing sediment delivery to water bodies plays an important role in maintaining watershed hydrological stability and reducing sediment accumulation flowing into the coastal area of Tomini Bay.

3.5 Hydrological Implications and Watershed Management

The Piloliyanga micro-catchment, dominated by steep slopes and erosion-prone soils, requires strengthening of permanent vegetation cover to improve watershed stability. Vegetative rehabilitation provides hydrological impacts through changes in runoff generation characteristics and improved soil stability. In the context of Modelomo Watershed management, FLR implementation needs to be prioritized in upstream areas with high erosion vulnerability.

This study uses a scenario-based simulation approach, so results require field validation through long-term hydrological monitoring. The relatively small rehabilitation area compared to the total micro-catchment area means changes in hydrological parameters are not yet statistically significant. Conceptually, these results suggest the existence of a "threshold response behavior" in vegetative rehabilitation, where hydrological impacts only become significant when the intervention area exceeds a certain threshold relative to the watershed's runoff connectivity structure. This threshold behavior is consistent with findings by [14], who showed that in a tropical forest watershed, the hydrological response to land use change becomes significant only when intervention covers a substantial proportion of the watershed area. Furthermore, [3] emphasized that sub-basin scale variability in land use change produces spatially heterogeneous hydrological responses, highlighting the importance of spatially explicit monitoring and management in micro-catchment rehabilitation programs.

5. CONCLUSION

Based on the research results, it can be concluded that: (1) The Piloliyanga micro-catchment has biophysical characteristics vulnerable to hydrological degradation, characterized by the dominance of steep slopes, erosion-prone soils, and dynamic land cover changes; (2) FLR has the potential to reduce peak discharge through increased vegetation interception and soil infiltration; (3) Implementation of vegetative rehabilitation can reduce erosion potential by decreasing surface runoff and increasing soil protection; (4) Erosion reduction contributes to decreased sediment delivery to the downstream water system, ultimately suppressing the rate of sedimentation in the main river; and (5) A watershed-based rehabilitation approach and strengthening of permanent vegetation are important strategies for restoring hydrological functions and controlling land degradation.

RECOMMENDATIONS

Rehabilitation activities need to be prioritized in steep slope areas with high erosion rates. Permanent vegetation strengthening through reforestation and agroforestry should be integrated with soil conservation techniques. Monitoring of land cover changes and hydrological conditions should be conducted periodically using spatial and remote sensing approaches. Further research is needed for field validation of simulation results. Modelomo Watershed management should be conducted in an integrated manner through collaboration among government, communities, and watershed management institutions.

REFERENCES

[1] A. Alfianto and S. Cecilia, “Pemodelan potensi erosi dan sedimentasi hulu Danau Limboto dengan WaTEM/SEDEM,” *J. Tek. Hidraul.*, vol. 11, no. 2, pp. 67–82, 2020.

[2] K. Amri, B. Besperi, and C. A. Negara, “Analisis Hidrologi Untuk Mendapatkan Debit Puncak Sungai Bengkulu Denganmenggunakan Hidrografsatuansintetik Nakayasu,” in *FROPIL (Forum Profesional Teknik Sipil)*, 2018, pp. 82–87.

[3] Y. Gao, J. Chen, H. Luo, and H. Wang, “Prediction of hydrological responses to land use change,” *Sci. Total Environ.*, vol. 708, p. 134998, 2020.

[4] Q. Hasmaulia, “ANALISIS RAWAN KEKERINGAN DI DESA GIRICAHYO, KECAMATAN PURWOSARI, GUNUNG KIDUL,” *J. Geogr.*, vol. 21, no. 2, pp. 172–187, 2025.

[5] S. Arsyad, *Konservasi tanah dan air*. Pt Penerbit Ipb Press, 2009.

[6] C. Asdak, *Hidrologi dan pengelolaan daerah aliran sungai*. Ugm Press, 2023.

[7] W. Sukmantoro, “Penyusunan Business Plan pada Kawasan Konservasi di Sulawesi dengan Pendekatan Partisipatif EPASS Project Component 2.2 Target Year 2017 Business Plan of the Sulawesi Protected Area Developed through Participatory Approach,” *Bappenas-UNDP-ICRAF*, 2019.

[8] L. A. Bruijnzeel, “Hydrological functions of tropical forests: not seeing the soil for the trees?,” *Agric. Ecosyst. Environ.*, vol. 104, no. 1, pp. 185–228, 2004.

[9] R. Lal, “Soil degradation by erosion,” *L. Degrad. Dev.*, vol. 12, no. 6, pp. 519–539, 2001.

[10] A. Negese, “Impacts of land use and land cover change on soil erosion and hydrological responses in Ethiopia,” *Appl. Environ. Soil Sci.*, vol. 2021, no. 1, p. 6669438, 2021.

[11] E. Prahasta, “Sistem informasi geografis konsep-konsep dasar,” *Bandung Inform. Bandung*, 2009.

[12] C. Zhang *et al.*, “Launching a new low-carbon, healthy journey,” *Chinese Sci. Bull.*, vol. 70, no. 32, pp. 5417–5423, 2025, doi: 10.1360/CSB-2025-0525.

[13] S. Mechram, M. Mawardi, and P. Sudira, “Aplikasi model AVSWAT2000 untuk prediksi limpasan permukaan, erosi, dan sedimentasi di Sub DAS Keduang: DAS Bengawan Solo Hulu,” *Agritech*, vol. 32, no. 3, pp. 325–330, 2012.

[14] M. E. Lucas-Borja, B. G. Carrà, J. P. Nunes, L. Bernard-Jannin, D. A. Zema, and S. M. Zimbone, “Impacts of land-use and climate changes on surface runoff in a tropical forest watershed (Brazil),” *Hydrol. Sci. J.*, vol. 65, no. 11, pp. 1956–1973, 2020.

[15] R. Webster, “Morgan, RPC Soil Erosion and Conservation, Blackwell Publishing, Oxford, 2005. x+ 304 pp.£ 29.95, paperback. ISBN 1-4051-1781-8.” Wiley Online Library, 2005.