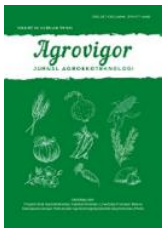
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Article

Impact of Land-Use Change on Soil Erosion Rates in Wonosalam Village, Wonosalam District, Jombang

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ABSTRACT

Land use conversion in the hilly area of Wonosalam, Jombang Regency, has significantly altered vegetation cover, leading to increased soil erosion rates. This study aims to analyze soil erosion magnitude across various land use types and assess the impact of land conversion on erosion levels in Wonosalam Village in 2014, 2019, and 2024. A quantitative approach was applied using the Universal Soil Loss Equation (USLE) model combined with spatial analysis through Geographic Information System (GIS). Data sources include Landsat 8 imagery, land use maps, rainfall data, slope maps, and laboratory analysis of soil physical and chemical properties. Each erosion factor (R, K, LS, C, and P) was analyzed to estimate soil loss (A) in tons/ha/year. The results indicate that the conversion of forest areas into agricultural and residential lands significantly increases erosion rates, especially on slopes steeper than 25%. Conversely, forested areas with dense vegetation show the lowest erosion rates. These findings demonstrate a strong correlation between land use change and erosion acceleration. The study provides valuable insights for soil conservation planning and sustainable land management in the hilly regions of Wonosalam

INTRODUCTION

Wonosalam Village, located in Wonosalam Subdistrict, Jombang Regency, is an area with hilly topography and high rainfall, making it highly susceptible to soil erosion. Along with population growth and economic development, this region has undergone significant changes in land use, particularly the conversion of forest and agricultural land into residential areas. Data from the Central Statistics Agency (2014, 2019, 2024) shows a decline in the area of state forests from 852.4 ha in 2013 to 107 ha in 2023. This land conversion phenomenon has led to a reduction in natural vegetation, which plays an important role in controlling the rate of erosion, making the soil surface more exposed and vulnerable to rainwater runoff. This condition is in line with the opinion of (Murdy & Nainggolan, 2020), who stated that the conversion of forest land into open land increases the risk of erosion due to the reduced ability of vegetation to retain water and reduce surface runoff.

Spatial analysis using Geographic Information Systems (GIS) is an appropriate approach to understand the spatial distribution and magnitude of the impact of land conversion on erosion. According to (Sestras et al., 2023), GIS is effective in predicting soil erosion based on land use changes because it can integrate spatial parameters such as slope, soil type, and rainfall. Therefore, the use of GIS in this study is expected to provide a comprehensive picture of the relationship between land use change and erosion levels in Wonosalam Village.

Erosion control is an important aspect in maintaining land productivity and environmental sustainability. Land use changes without proper planning can have negative impacts, such as decreased agricultural productivity, increased sedimentation, and disruption of the ecosystem balance. Therefore, this study is important to assess the extent of the influence of land use changes on the rate of erosion in Wonosalam Village and to provide a scientific basis for sustainable land use planning.

MATERIALS AND METHODS

The research was conducted from February to June 2025 in Wonosalam Village, Wonosalam District, Jombang Regency, East Java. Laboratory analysis was carried out at the Land Resources Laboratory, Faculty of Agriculture, Veteran National Development University, East Java.

The tools used included computers with ArcGIS software, GPS, clinometers, soil drills, sample rings, ovens, scales, permeameters, and other laboratory equipment. The materials used included soil samples, chemical solutions for analyzing the physical and chemical properties of soil ($K_2Cr_2O_7$, H_2SO_4, HCl, $Na_4P_2O_7$), as well as secondary data in the form of land use maps for 2014, 2019, and 2024, rainfall data (NASA POWER), and 30 m resolution Digital Elevation Model (DEM) data from the USGS.

The research used a quantitative approach with an exploratory descriptive method. The analysis was conducted by overlaying land use maps using GIS to determine changes in land use from 2014 to 2019 to 2024. Soil sampling was conducted using purposive random sampling based on land units that had undergone functional changes. Laboratory analysis was conducted to determine the physical and chemical properties of the soil, such as texture, organic matter, structure, permeability, and bulk density.

Erosion rate estimation was performed using the Universal Soil Loss Equation (USLE) method formulated by Wischmeier and Smith (1978):

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

Where: A = Erosion rate (tons/ha/year); R = Rainfall erosivity factor (kJ/ha); K = Soil erodibility factor (tons/kJ); LS = Slope length and steepness factor; C = Vegetation cover factor; P = Management practice factor Each factor is calculated based on field and laboratory data:

- Erosivity (R) is calculated using the Abdurrachman (1989) formula based on monthly rainfall.
- Erodibility (K) is determined from soil texture, organic matter, structure, and permeability.
- Slope length and steepness (LS) are obtained from DEM data.
- Vegetation cover (C) and management (P) are determined based on actual conditions in the field and conservation value tables according to Arsyad (2010).

The data from the calculation of each USLE factor was processed using ArcGIS software through a weighted overlay process to produce an erosion distribution map. Multiple linear regression tests were

used to determine the effect of each erosion factor (R, K, LS, C, P) on the amount of soil erosion.

RESULTS AND DISCUSSION

General Characteristics of the Research Location

Wonosalam Village is located in Wonosalam Subdistrict, Jombang Regency, East Java, at coordinates approximately 7°42′31″ S and 112°22′30″ E. This area is located in the southern highlands of Jombang, forming a transition zone between the northern slopes of Mount Anjasmoro and Mount Welirang. Land use includes forests, plantations, rice fields, swamps, shrubs, and settlements. Slope gradients vary between 0–45%, making this area prone to erosion and land degradation, especially due to the conversion of forests into agricultural land.

Wonosalam Village has a humid tropical climate with an average annual rainfall of 192.94 mm, the highest in 2023 at 303.25 mm and the lowest in 2013 at 116.1 mm (NASA Power, 2023). Based on soil maps, this region is dominated by Andisol sequences with the main groups being Andic Dystrudepts and Typic Hapludands, as well as a small portion of Inceptisol and Entisol on the lower slopes. These conditions support agricultural activities, but still require prudent land management to maintain soil stability.

Correlation Between Physical Soil Factors and Erosion Rates

C-organic

Soils with high organic carbon content tend to have a more crumbly and stable structure, making them resistant to erosion. Conversely, soils with low organic carbon content become easily decomposed, compacted, and susceptible to erosion, which can reduce organic carbon content and soil fertility (Faradiba, 2023). The highest values were found at points TKK1 (4.72%), HHH3 (4.52%), TKK2 (4.16%), HKK1 (4.14%), and HHH1 (4.03%). These points are located in forested and mixed gardens with dense vegetation cover and high litter accumulation, so that the organic content is maintained. Conversely, the lowest values were found at points KST1 (1.82%) and SSK3 (1.93%), which are located on intensively cultivated fields with minimal organic matter and are directly exposed to rainwater and erosion.

Organic C content has a close relationship with the rate of soil erosion, where the relationship between the two is negative. According to The higher the organic matter content, the lower the rate of erosion. Conversely, soils with low organic carbon content generally have a more fragile structure and are easily dispersed, making them more susceptible to erosion, especially in areas with high slopes and intense rainfall.

Soil Permeability

Soil permeability is the rate of water infiltration in the soil under saturated conditions. The slower the permeability, the greater the soil erodibility. Permeability is related to the ability of the soil to pass water during a certain period (Putra et al., 2019). The results of soil permeability analysis at 30 sampling points in WonosaIam Village showed values ranging from 0.14 cm/hour to 3.69 cm/hour, with an average of 1.43 cm/hour.

The highest permeability values were recorded at points KST2 (3.69 cm/hour) and TKK1 (3.20 cm/hour), which are located on hardened land and mixed gardens with coarser soil texture and loose structure due to the presence of macro pores from plant roots. Conversely, the lowest values were found at points TTS3 (0.14 cm/hour), TTS2 (0.26 cm/hour), and SSS1 (0.30 cm/hour), which indicate compact soil structure, unstable aggregates, and the possibility of a dominant flat soil layer or soil compaction due to intensive tillage. In accordance with the research (Masria et al., 2018) states that soil with clay particles has many micro pores, resulting in slow permeability.

Soil Texture and Structure

Soil texture is the relative ratio between three fractions, namely sand, silt, and clay. The analysis results show that in the changes in land use in 2014, 2019, and 2024, the silt fraction dominates with a range of 49–73%, while the sand and clay fractions are relatively lower. Samples with the code HHH (Forest–Forest–Forest) had a stable soil structure with a high silt fraction and low sand fraction (3.55–8.87%). In codes HKK (Forest–Plantation–Plantation) and KKK (Plantation–Plantation–Plantation), there was an increase in the sand fraction and a decrease in clay, indicating a decrease in aggregate stability due to the conversion of forest to plantation.

The combination of land use types such as KST (gardens–paddy fields–dry fields) and TTS (dry fields–dry fields–paddy fields) has a higher sand fraction than forest land, indicating the loss of fine fractions due to

intensive cultivation. A similar pattern is seen in TTSB (Dry Fields–Dry Fields–Scrub), which has a sand fraction of up to 6.66%, indicating soil structure degradation. Land conversion from forest to agriculture (gardens, rice fields, dry fields) affects soil texture, where an increase in sand and a decrease in clay can increase susceptibility to erosion due to reduced soil water retention and aggregate structure maintenance (Mulyadi et al., 2024).

Slope gradient

Slope is a topographic factor that can affect erosion rates through surface runoff. This is related to the kinetic energy of rainwater hitting the ground, which increases as the slope increases (Pasaribu et al., 2018) . Based on topographic measurements and LS factor calculations, the slope values ranged from 5% to 25%, with an average of 16.4%. Meanwhile, the length of the slope varies between 4.4 meters and 25 meters, with an average of 10.3 meters. The variation in these two parameters directly affects the LS factor value, which indicates the ability of the topography to increase the potential for erosion due to surface runoff.

The lowest LS values were found at points SSS1 (0.75) and HKK1 (0.85), which had gentle slopes (5–7%) and relatively short lengths (<7 meters). Meanwhile, the highest values were recorded at points TTSB1 (4.02) and SSK3 (3.54) with slopes of 21–25% and slope lengths >15 meters. The longer and steeper the slope, the more significant the increase in LS values and erosion potential. Flat land tends to be stable, but if the slope increases to 2–5%, soil loss increases rapidly, and at a slope of 10–15%, erosion increases several times (Osok et al., 2018).

Land Use Change 2014–2024

During the period 2014–2024, Wonosalam Village experienced significant changes in land use due to increased agricultural activity, settlement, and tourism development. In general, there was a decrease in the area of vegetated land (forests, mixed gardens, and moorland) and an increase in less protected land such as built-up land, scrubland, and open land.

Forest land showed a total decrease of 48.2 ha over ten years, mostly converted to built-up land and cultivated areas. Mixed gardens experienced the largest decrease, namely 89.2 ha, converted to settlements, dry fields, scrub, and a small portion of rice fields. Dry fields also decreased by 58.3 ha, reflecting a shift in community land use patterns.

Built-up land increased rapidly with a total increase of 54.5 ha, related to residential expansion and the development of tourist facilities. Scrubland increased sharply (±159 ha) as an indication of land that is no longer intensively managed, resulting in vegetation degradation. Rice fields declined until 2019, but then increased again to a total net increase of approximately −18.5 ha to +? depending on the final results (if calculated in total: initial 39.5 ha → 20.9 ha = a decrease of 18.6 ha). Open land changed relatively little but tended to increase. These changes during 2014–2024 indicate a decline in vegetation cover quality and increased anthropogenic pressure on hilly areas, which ultimately increases the potential for erosion and reduces land stability (Li et al., 2024).

The Impact of Land Use Change on Increased Erosion

Land use change during the period 2014–2024 has been shown to have a significant impact on the extent of erosion in Wonosalam Village. The correlation test results show that land use (variable C) is the most dominant factor, with a very strong correlation to erosion, as shown in Table 1: 0.914 (2014), 0.937 (2019), and 0.928 (2024). This consistency indicates that changes in land use—particularly the conversion of forests or mixed gardens into monoculture gardens, fields, or settlements—contribute significantly to increased erosion.

The multiple linear regression test shown in Table 2 reinforces these findings. The regression coefficient for variable C was recorded at 478.336 (2014), increasing to 868.076 (2019) and remaining high at 639.721 (2024). This large coefficient value indicates that changes in land use have a direct influence on the increase in erosion rates. Intensive land conversion causes a decline in soil quality, weakens aggregate structure, and reduces infiltration capacity, thereby increasing the potential for surface erosion.

Changes at the sampling points support the analysis results. Points that did not experience land use change, such as forests at HHH1–HHH3, showed low erosion due to good vegetation stability. Conversely, points that underwent successive conversions, such as KST1–KST3 (gardens → rice fields → moorland), showed a sharp increase in erosion due to the loss of vegetation cover and soil structure degradation.

In addition to land use, slope gradient (LS) also has a significant effect, especially on slopes >15%. Points with steep slopes such as TTSB1 and SSK3 (slopes up to 25%) show high LS values and greater erosion rates, especially after conversion to dry fields or settlements that lack protective vegetation.

Overall, the analysis results show that land use change is a major factor accelerating erosion in Wonosalam. The decline in protective vegetation reduces organic matter and infiltration capacity, making the soil more vulnerable to destruction by rain energy. Therefore, sustainable land management is essential through the implementation of soil and water conservation, such as critical land rehabilitation, cover vegetation planting, terracing on steep slopes, and strengthening riverbank vegetation. This strategy is important to maintain soil stability and ensure the sustainability of productivity and the ecosystem of Wonosalam Village.

Table 1. Correlation Test Results for 2014, 2019, and 2024

No	Variable	Year					
		2014		2019		2024	
		Correlation coefficient (r)	Sig. (p-value)	Correlation coefficient (r)	Sig. (p-value)	Correlation coefficient (r)	Sig. (p-value)
1	K	-0,218	0,246	-0,063	0,743	-0,298	0,109
2	LS	0,378	0,039	0,362	0,050	0,213	0,257
3	C	0,914	0,000	0,937	0,000	0,928	0,000
4	P	0,025	0,896	-0,008	0,967	0,018	0,926

source: processed data

Table 2. Multiple Linear Regression Test Results for 2014, 2019, and 2024

No	Variable	Unstandardized Coefficients (B)			t-value			Sig.		
		2014	2019	2024	2014	2019	2024	2014	2019	2024
1	K	184.176	230.613	108.516	1.172	1.242	0.898	0,252	0,226	0,378
2	LS	52.237	76.828	49.972	3.597	4.314	4.661	0,001	0,000	0,000
3	C	478.336	868.076	639.721	12.912	17.359	16.505	0,000	0,000	0,000
4	P	130.169	210.527	109.922	2.659	3.501	2.944	0,013	0,002	0,007

source: processed data

Implications of Land Management in WonosaIam Village

The conversion of forest land to gardens and fields in Wonosalam Village has led to increased erosion and a decline in soil organic matter, thereby reducing soil quality. This situation highlights the need for land management based on soil and water conservation. Priority measures include planting cover crops such as Arachis pintoi (Sumiahadi et al., 2023) and Centrosema pubescens (Handayani et al., 2022), which are effective in reducing runoff, increasing infiltration, and improving soil structure and organic matter. The use of cover crops can reduce erosion by more than 70% (Tang et al., 2021).

On steep slopes, the use of terraces (bench terraces or gulud) is important to slow surface runoff. Their effectiveness is increased when combined with reinforcing vegetation such as vetiver or elephant grass to stabilize the slopes. Additional strategies such as organic mulch and agroforestry also play a role in improving soil physical properties, maintaining moisture, and adding organic matter. Agroforestry helps stabilize slopes while providing economic benefits without damaging ecological functions. Overall, the implementation of integrated soil and water conservation has the potential to reduce erosion by 50–60% on critical land, improve soil quality, reduce sedimentation, and maintain the sustainability of agricultural production.

CONCLUSION

Soil erosion in Wonosalam Village was found to be significantly influenced by land use type. Forest land consistently showed the lowest erosion rate because stable vegetation cover was able to retain surface runoff and maintain soil structure. In contrast, more open land such as gardens, fields, rice paddies, and shrubbery experience much higher erosion, especially in areas with steep slopes. An increase in erosion has also been observed from year to year in locations that have experienced vegetation disturbance, illustrating that changes in land conditions have a direct effect on the amount of soil loss.

In addition, land use changes that occurred during the study period had a significant impact on the increase in erosion. The conversion of land from forests and mixed gardens to monoculture gardens, fields, rice paddies, scrubland, and settlements caused a decline in soil physical quality and a reduction in vegetative protection. The correlation test results showed that land use had a very strong relationship with erosion in the three years of observation, while the regression analysis confirmed that land use was the most dominant factor in determining the extent of erosion compared to other physical soil factors. Locations that underwent successive conversions showed the highest increase in erosion, while locations that remained as forests had low and relatively stable erosion. These findings indicate that land conversion during 2014–2024 significantly accelerated soil degradation and increased land vulnerability to erosion in Wonosalam Village.

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AUTHORS CONTRIBUTIONS

DSB considered and planned the problem, collecting field data, analyzing data, interpreting results, and drafting the article. S contributed to the design of the research methodology, data validation, scientific supervision, and manuscript editing. M contributed to refining the analysis, evaluating the results, academic discussion, and correcting the substance of the manuscript. All the authors have read and approved the final manuscript.

CONFLICT OF INTEREST

"The authors declare no conflict of interest."

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