The Impact of Land Use Change on Erosion in the Bangsal Sub-Watershed, Mojokerto Regency

10.18196/pt.v14i2.29943

Maroeto Maroeto*, Amanda Nur Fitria Ningrum, Bakti Wisnu Widjajani, Dinna Hadi Sholikah

Agrotechnology Study Program, Faculty of Agriculture, Veteran National Development University of East Java, Surabaya City, East Java, 60294, Indonesia

*Corresponding email: maroeto@upnjatim.ac.id

ABSTRACT

Land use change in the Bangsal subwatershed affects the rate of erosion, thereby adversely impacting land stability and productivity. This study was conducted to analyze the impact of land use change on erosion rates in the Bangsal Sub-watershed, using the USLE approach and ArcGIS. Data analysis was conducted based on three time periods, namely 2012, 2018, and 2024. The research was involved in collecting samples from five land-use types in the Bangsal Sub-Watershed. Primary research data were obtained from field observations and soil samples, while secondary data came from rainfall data, Landsat imagery, and supporting maps. Laboratory analyses conducted included organic carbon, texture, bulk density, particle density, and soil permeability. The results of the study showed that land-use changes that happened over these three periods had a significant impact on the rate of erosion in the Bangsal sub-watershed area. Changes from forest to shrubs, gardens, or dry land fields lead to a significant increase in erosion values, particularly in the periods 2018 and 2024. Conversely, increased vegetation cover due to land-use changes reduced erosion values despite higher rainfall intensity. This confirms that land-use change is a dominant factor in the dynamics of erosion hazard levels in the Bangsal Sub-watershed.

Keywords: Bangsal sub-watershed; erosion; land-use change; USLE

INTRODUCTION

A watershed is a land area where all precipitation converges into a shared outflow, such as a river, lake, or sea (Thilagam et al., 2023). Watersheds are crucial for sustaining the hydrological cycle and preserving the equilibrium of the adjacent ecosystem. Human activities contribute to multiple forms of environmental deterioration, including erosion, which results in diminished soil nutrients and decreased crop yield (Wasono et al., 2023). Actions like deforestation, unsustainable farming methods, infrastructure expansion, and urban growth frequently worsen soil erosion in river basins. The economic activities of local residents typically lead to changes in land use, which can heighten the strain on land resourcess (Hasanah et al., 2021). Moreover, alterations in land use can lead to transformations in the natural ecosystem, including changes in plant life, variations in soil water retention, and sediment deposition in rivers. Consequently, heightened river flow can result in natural calamities (Lestari et al., 2021).

Check for updates

open access

Article History
Received : 11 December 2025
Revised : 08 June 2026
Accepted : 17 June 2026
Published : 27 August 2026

The Bangsal sub-watershed is situated within the jurisdiction of Mojokerto Regency, downstream of the Brantas watershed, covering an area of approximately 135,849 km² (Parabudhi, 2017). The geological characteristics of the region significantly influence the connection between erosion and landslides. The Bangsal sub-watershed, which has relatively steep slopes, can heighten the risk of erosion and compromise slope stability, increasing the likelihood of landslides. One factor contributing to the deteriorating condition of the Bangsal riverbanks is the rise in rainfall and the volume of river water that floods during the rainy season.

This research utilizes the USLE and ArcGIS methodologies to assess the erosion rate within the Bangsal subwatershed, considering factors such as rainfall, soil type, land use, and topography (Rosidin et al., 2023). This approach systematically classifies erosion hazard levels and forecasts erosion rates, which is crucial for effective conservation and land management strategies (Erfarras et al., 2024). This research seeks to identify shifts in land use within the Bangsal subwatershed for the years 2012, 2018, and 2024, while also examining how these land use changes have influenced erosion rates over this time span. The chosen years are significant for tracking notable alterations in land use, starting with the condition of the land in 2012 and assessing its current state in 2024. Furthermore, this research intends to offer suggestions for effective land management informed by erosion hazard.

MATERIALS AND METHODS

The study was conducted in the Bangsal subwatershed area, Mojokerto Regency, by taking soil samples from five types of land use, namely forest, shrubs, dry fields, mixed gardens, and rainfed rice fields. Sampling was performed at two depths (0-30 cm and 30-60 cm). The materials used included ArcGIS, DEMNAS data, slope maps, Landsat imagery, and land-use maps from 2012, 2018, and 2024; daily and monthly rainfall data from 2007-2024 obtained from NASA POWER, which were used to estimate rainfall erosivity; and Microsoft Excel was used for data processing. Laboratory equipment included gauze, plastic bags, soil description sheets, and materials for soil-texture and C-organic analysis.

Land use classification was performed through Landsat imagery interpretation and spatial reclassification using ArcGIS. Five land use classes (forest, shrubs, dry fields, mixed gardens, and rainfed rice fields) were standardized using a consistent legend across 2012, 2018, and 2024 to ensure temporal comparability. The classification results were validated through field verification. Soil samples were analyzed in the laboratory to determine soil physical and chemical properties. Soil organic carbon (C-organic) was analyzed using the Walkley–Black method, while soil texture was determined using the hydrometer method. All analyses were conducted following standard soil laboratory procedures to ensure data consistency and reliability.

The study employed a descriptive-exploratory survey that included secondary data collection, spatial data processing, field map creation, sampling-point determination, field surveys, soil sampling, and analyses of soil physical and chemical properties (Farikha et al., 2023). Field surveys were conducted to observe land-use changes in 2012, 2018, and 2024 resulting from land conversion, which is suspected to influence erosion rates. Comparisons of changes in the area of each land cover were made using land use maps for each year.

Erosion rates were estimated using the Universal Soil Loss Equation with the following formula (Musakkir et al., 2024):

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

Explanation:
A: Amount of Eroded Soil (tons/ha/year)
R: Rainfall Erosivity Factor (kJ/ha)
K: Soil Erodibility Factor
LS: Length Factor (m) and Slope Gradient (%)
C: Vegetation Factor
P: Conservation Action Factor
Erosivity Factor (R)

The R value was calculated using the equation proposed by Bols (1978), as cited in (Rampu et al., 2023):

$$Rm = 6{,}119 \times (rain)m^{1,27} \times (Days)m^{0,47} \times (MaxP)m^{0,53} \quad (2)$$

$$\mathrm{R} = \sum_{m=1}^{12} Rm \quad (3)$$

Explanation:
R: Average Annual Rainfall Erosivity
Rm: Average Monthly Rainfall Erosivity
Rain: average monthly rainfall (cm)
Days: average number of rainy days per month in a given month (days)
Max P: Maximum rainfall over 24 hours per month (cm)

Erodibility Factor (K)

The K value is influenced by soil texture, structure, organic matter, and permeability. The calculation using the Wischmeier and Smith (1978) formula is as follows (Muamalah et al., 2024):

$$K = \frac{1{,}292(2{,}1M^{1,14} \times 10^{-4}(12-a)+3{,}25(b-a)+2{,}5(c-3)}{100} \quad (4)$$

Notes:
K: Soil Erodibility (tons/kJ)
M: (% of silt and very fine sand) x (100 - % clay)
a: Organic Matter (%)
b: Soil Structure Code
c: Soil Permeability

Slope Length and Steepness Factor (LS)

The LS value was calculated using the following equation proposed by Asdak (2010), as cited in (Nurhawaidah et al, 2019).

$$LS = \sqrt{\frac{L}{100}} x(0.0138 + 0.00965\, S + 0.00138\, S^2) \quad (5)$$

Explanation:
LS: Slope length and slope factor
L: Slope length (m)
S: Slope gradient (%)

Vegetation Factor (C) and Conservation Measures (P)

The C factor indicates the influence of vegetation cover, soil-surface conditions, and land-management practices on erosion. The P factor represents the effectiveness of conservation measures by comparing erosion on land that has undergone conservation treatment and land without conservation.

Erosion Hazard Level (EHL)

The EHL is determined based on the annual erosion rate, which is then classified according to USDA standards in Permenhut No. P.32/Menhut-II/2009 (Putra et al., 2018).

Allowed Erosion (AHL)

AHL was calculated using the equation proposed by Hammer (1981) (Charismanda et al., 2024):

$$EDP = \frac{de \times fd}{RL} \times BI \times 10 \quad (6)$$

Explanation:
AHL = Tolerable erosion (tons/ha/year)
de = soil solum depth (mm)
fd = soil depth factor
BI = Bulk density (g/cm^3)
RL = Soil sustainability (300 years)

Erosion Hazard Index (EHI)

The erosion hazard index is the ratio of the erosion rate (A) to the tolerable erosion rate (AHL). The purpose of the EHI is to determine the threshold of erosion that must be controlled to maintain soil productivity. In addition, the EHI is used as a basis for determining soil conservation strategies for a region. The EHI calculation formula based on Wood and Dan's (1983) (Rastanto et al., 2022) is:

$$IBE = \frac{A}{EDP} \quad (7)$$

Data Analysis

The influence of erosion-causing factors was analyzed using multiple linear regression to identify the relationships between variables (R, K, LS, C, and P) and erosion rate (A) through regression coefficients and significance tests.

RESULTS AND DISCUSSION

Erosion rate for the 2012-2024 period

The Bangsal sub-watershed is situated within the Brantas watershed and is found in the upper sections. The research site encompasses two subdistricts: Pacet and Bumiaji. The majority of the sampling sites were established in the Pacet subdistrict, while a lesser number were situated in the Bumiaji subdistrict. The land utilization in the area under study comprises five types, with vegetation primarily consisting of various shrubs; corn; coffee; bananas; rice; and forest plants like bamboo and pine, as well as vegetables including pumpkin, carrots, potatoes, and chili peppers. The research area features a hilly landscape characterized by slope variations ranging from 5% to 35%. An evaluation of erosion rates across three times (2012, 2018, and 2024) reveals a consistent upward trend in erosion within the Bangsal sub-watershed. Despite some areas experiencing minor declines, the prevailing trend is an increase in erosion values. This trend corresponds with heightened rainfall erosivity (R); although land-use change is the predominant factor influencing erosion rate variability, vegetation cover (C) and conservation practices (P) exert significant control over erosion, with diminished values of both factors signifying more effective erosion mitigation (Sabathini et al., 2024).

Based on Table 1, the initial period (2012) acts as a reference point, where forest showed the lowest carbon values compared to shrubs, dry fields, gardens, and rice paddies. Forest vegetation effectively shielded soil from the rainfall, while mixed-garden areas exhibited a high erosion rate of 246.06 ton/ha/year, attributed to inadequate ground cover, poor conservation methods, and steep terrain. During this period, the levels of erosion hazard were primarily characterized by heavy and very heavy classifications, the majority of the values surpassed 50 ton/ha/year, underscoring the watershed's susceptibility to erosion and land degradation. The initial spatial distribution of erosion indicates that both the condition of land cover and the steepness of the terrain were significant factors influencing the intensity of erosion (Peng and Dai, 2022). Landscapes devoid of dense perennial vegetation were especially vulnerable to significant soil erosion, establishing the pathway for increased degradation in the following years.

During the second period (2018), changes in land use started to be observed at several sampling locations, including 1B, 2C, 2D, 3A, 3B, and 4B (Table 2). The transformation into forest cover, particularly at locations 2C, 3B, and 4B, led to significant declines in A values, all dipping below 50 ton/ha/year. These decreases validate the assertion that forest land is the most efficacious land use type for mitigating erosion, due to its dense protective canopy and root system that bolster soil stability. Conversely, sites that did not undergo land-use conversion generally recorded increases in erosion, driven by higher rainfall intensity, shifts in conservation practices, and inherent land susceptibility (Siagian et al., 2021).

The erosion hazard classification during this time period was primarily characterized by very

Table 1. Results of Erosion Rate Analysis for the Period 2012

Sample Code	R Value	K Value	LS Value	C Value	P Value	A Value (ton/ha/year)	EHL
1A	900.38	0.18	3.32	0.001	1	0.54	Very light
1B	904.62	0.17	2.62	0.005	0.07	0.15	Very light
2A	904.62	0.33	2.13	0.3	0.08	15.37	Very Heavy
2B	904.62	0.16	2.34	0.3	1	104.27	Very Heavy
2C	904.62	0.12	2.90	0.3	1	97.88	Very Heavy
2D	904.62	0.21	2.20	0.3	0.06	7.55	Light
3A	904.62	0.33	2.09	0.7	0.68	297.27	Very Heavy
3B	896.13	0.19	3.16	0.4	1	220.31	Very Heavy
3C	896.13	0.18	2.63	0.456	0.27	51.02	Heavy
3D	904.62	0.26	2.16	0.7	0.15	53.83	Heavy
4A	904.62	0.14	1.24	0.261	0.21	8.85	Very Light
4B	904.62	0.31	2.44	0.5	1	346.06	Very Heavy
5A	904.62	0.38	1.20	0.561	0.38	87.41	Heavy
5B	904.62	0.36	1.08	0.561	0.37	72.38	Heavy

Source: 1A: Forests–Forests-Forests, 1B: Forest-Shrub-Shrub, 2A: Shrub-Shrub-Shrub, 2B: Shrub-Shrub-Forest, 2C: Shrub-Forest-Forests, 2D: Shrub -Gardens-Gardens, 3A: Dry Fields-Gardens-Gardens, 3B: Dry Fields -Forests-Forests, 3C: Dry Fields-Dry Fields-Dry Fields, 3D: Dry Fields-Dry Fields-Gardens, 4A: Gardens-Gardens-Gardens, 4B: Garden-Forests-Forests, 5A: Rice Fields-Rice Fields-Rice Fields, and 5B: Rice Fields-Rice Fields-Dry Fields

heavy categories, which is indicative of both a high A value and the effect of soil depth on erosion intensity (Table 2). In many agricultural lands that have been converted, the reduction of deep-rooted plants diminished the ability of vegetation to stabilize over the period, it became clear that even minor land cover modifications could considerably change erosion dynamics. Regions with permanent vegetation continued to mitigate the impact of rising rainfall erosivity, while areas that have been converted or cultivated saw in ancrease in soil loss. These trends indicate a growing disparity between preserved and disturbed landscapes, with the latter undergoing accelerated degradation when protective vegetation is disturbed or removed.

Table 2. Results of Erosion Rate Analysis for the Period 2018

Sample Code	R Value	K Value	LS Value	C Value	P Value	A Value (ton/ha/year)	EHL
1A	1122.991	0.18	3.32	0.001	1	0.67	Very light
1B	1136.756	0.17	2.62	0.408	0.05	11.56	Very Light
2A	1136.756	0.33	2.13	0.3	0.1	24.14	Very Heavy
2B	1136.756	0.16	2.34	0.3	1	131.03	Very Heavy
2C	1136.756	0.12	2.90	0.035	1	14.35	Very Light
2D	1136.756	0.21	2.20	0.333	0.06	10.53	Light
3A	1136.756	0.33	2.09	0.383	0.68	204.57	Very Heavy
3B	1109.226	0.19	3.16	0.05	1	34.09	Very Heavy
3C	1109.226	0.18	2.63	0.456	0.33	76.33	Heavy
3D	1136.756	0.26	2.16	0.4	0.17	43.70	Heavy
4A	1136.756	0.14	1.24	0.261	0.26	13.79	Very Light
4B	1136.756	0.31	2.44	0.035	1	30.44	Very Heavy
5A	1136.756	0.38	1.20	0.561	0.38	109.83	Heavy
5B	1136.756	0.36	1.08	0.561	0.37	90.96	Heavy

Source: 1A: Forests–Forests-Forests, 1B: Forest-Shrub-Shrub, 2A: Shrub-Shrub-Shrub, 2B: Shrub-Shrub-Forest, 2C: Shrub-Forest-Forests, 2D: Shrub -Gardens-Gardens, 3A: Dry Fields-Gardens-Gardens, 3B: Dry Fields -Forests-Forests, 3C: Dry Fields-Dry Fields-Dry Fields, 3D: Dry Fields-Dry Fields-Gardens, 4A: Gardens-Gardens-Gardens, 4B: Garden-Forrests-Forests, 5A: Rice Fields-Rice Fields-Rice Fields, and 5B: Rice Fields-Rice Fields-Dry Fields

The latest period (2024) based on Table 3 illustrates the current landscape conditions and emphasizes the significant impact of land use changes on erosion dynamics. Several sites, including 2B, 3D, and 5B, underwent transformations in land use. A notably positive case occurred at site 2B, where scrubland was transformed into forest, resulting in a substantial decrease in the A value and changing the erosion hazard classification from very heavy to very light. This type of conversion is particularly advantageous on steep slopes and shallow soils, as forest vegetation can markedly lower erosion risk and mitigate land degradation (Maroeto et al., 2021). Conversely, other sites, such as point 3A, saw an increase in erosion, with values reaching 258.26 ton/ha/year due to the transition from dry fields to mixed gardens with inadequate vegetation cover. These situations reveal that changes in land use increase the C value and amplify land sensitivity to intense rainfall, which makes soil more vulnerable to detachment and transport, especially on steep slopes (Hasanah et al., 2023).

Table 3. Results of Erosion Rate Analysis for the Period 2024

Sample Code	R Value	K Value	LS Value	C Value	P Value	A Value (ton/ha/year)	EHL
1A	1407.62	0.18	3.32	0.001	1	0.85	Very light
1B	1435.11	0.17	2.62	0.408	0.05	14.60	Very Light
2A	1435.11	0.33	2.13	0.3	0.1	30.47	Very Heavy
2B	1435.11	0.16	2.34	0.005	1	2.76	Very Light
2C	1435.11	0.12	2.90	0.035	1	18.12	Very Heavy
2D	1435.11	0.21	2.20	0.333	0.06	13.30	Light
3A	1435.11	0.33	2.09	0.383	0.68	258.26	Very Heavy
3B	1380.14	0.19	3.16	0.05	1	42.41	Very Heavy
3C	1380.14	0.18	2.63	0.456	0.31	88.23	Heavy
3D	1435.11	0.26	2.16	0.4	0.18	58.35	Heavy
4A	1435.11	0.14	1.24	0.261	0.25	16.84	Very Heavy
4B	1435.11	0.31	2.44	0.035	1	38.43	Very Heavy
5A	1435.11	0.38	1.20	0.561	0.38	138.66	Heavy
5B	1435.11	0.36	1.08	0.7	0.37	143.28	Heavy

Source: 1A: Forests–Forests-Forests, 1B: Forest-Shrub-Shrub, 2A: Shrub-Shrub-Shrub, 2B: Shrub-Shrub-Forest, 2C: Shrub-Forest-Forests, 2D: Shrub -Gardens-Gardens, 3A: Dry Fields-Gardens-Gardens, 3B: Dry Fields -Forests-Forests, 3C: Dry Fields-Dry Fields-Dry Fields, 3D: Dry Fields-Dry Fields-Gardens, 4A: Gardens-Gardens-Gardens, 4B: Garden-Forrests-Forests, 5A: Rice Fields-Rice Fields-Rice Fields, and 5B: Rice Fields-Rice Fields-Dry Fields

Although fluctuations in rainfall partly contribute to increased erosion, erosivity alone cannot fully explain the observed patterns. Areas experiencing changes in land cover saw significantly higher rates of erosion compared to those with stable vegetation. For instance, rice fields showed a rapid escalation in erosion compared to forested areas, which maintained low C values. This finding is consistent with studies indicating that transitioning land to intensive agriculture boosts surface runoff and diminishes soil's capacity to retain water, thereby increasing erosion (Dangol et al., 2023). Additionally, land conversion indirectly influences the LS factor, as the removal of vegetation and certain agricultural practices can destabilize slopes. In summary, the research indicates that the increase in erosion is driven not just by climatic factors but primarily by land conversion practices that neglect soil conservation methods (Sabathini et al., 2024). The removal of natural vegetation compromises soil structure and exacerbates erosion even in moderate rainfall conditions. Between 2019 and 2024, numerous sampling locations recorded classifications of heavy to very heavy erosion hazards, reflecting a decrease in land resilience. These results underscore the critical need to focus on soil- and water-conservation-based agricultural practices. Failure to implement such measures will likely escalate the risk of erosion in response to ongoing climate and land use challenges.

Multiple Linear Regression Test for the 2012-2024 Period

The results of the multiple linear regression studies between the three periods based on Table 4 suggest that the model increasingly elucidates erosion processes with enhanced predictive accuracy with time. The R2 values for the periods 2012 (53.26%) and 2018 (54.39%) provide moderate explanatory power, but the period 2024 exhibits a significant increase to 77.16%, indicating that the independent variables more accurately reflect the factor affecting erosion. The C (vegetation) and P (conservation) variables demonstrate substantial t-values and p-values <0.05 over all periods of time, signifying statistical significance and affirming that these variables have the most pronounced impact on the erosion. The K variable (soil erodibility) exhibits rising t-values over the periods and attains statistical significance in the 2024 period, aligning with its diminishing p-value (<0.05). Conversely, the R (erosivity) and LS (slope length and steepness) variables present low t-values and p-values exceeding 0.05, signifying their statistical insignificance and lack of meaningful contribution to erosion at the study site.

Table 4. Results of Multiple Linear Regression Test for the 2012-2024 Period

Period	R	R Suare	Adusted R	Standard Error	Significance F
2012	0.844	0.712	0.532	76.663	0.0420
2018	0.863	0.744	0.585	37.976	0.0273
2024	0.836	0.699	0.511	51.102	0.0489

The C and P factors exhibit constant significance ($p<0.05$) over all three periods, leading to the conclusion that land-use change and conservation practices are the principal predictors of erosion. Both coefficients are positive, signifying that higher C values, indicative of diminished vegetation quality, and higher P values are associated with significant increases in erosion. The K factor was initially not statistically significant during the first two periods; however, it became significant in the 2024 period, suggesting increased susceptibility of soil to erosion as land-use intensity heightened. The positive coefficient indicates that soils with high erodibility substantially contribute to the intensification of erosion. In contrast, the R and LS factors were found to be statistically insignificant ($p>0.05$) across all periods, indicating that variations in rainfall and topographic characteristics were not primary influences on erosion development at the study site. The negative R coefficient suggests a nonlinear relationship between rainfall dynamics and erosion, likely attributable to the predominant impact of land-use changes. Overall, the combination of p-values and coefficient signs confirms that year-to-year increases in erosion are driven primarily by vegetation degradation, suboptimal land-management practices, and elevated soil vulnerability, whereas climatic and geomorphological factors play only a secondary role. This finding is consistent with field conditions, which show increased land conversion from forests and shrubs to fields, gardens, and other agricultural land. The decline in vegetation factors and the increase in intensive cultivation activities have made the soil more vulnerable to erosion (Alief et al., 2024).

Erosion Hazard Index Calculations for the 2012-2024 Period

The results of the erosion hazard index analysis for the three periods based on Table 5 show increasing land vulnerability to erosion over time. There was a shift in EHI classes from the initial to the final period from very low to very heavy, resulting from increased erosion rates and changes in land-management practices. The spatial distribution of the Erosion Hazard Index (EHI) for the periods 2012, 2018, and 2024 is presented in Figure 1. In the 2012 period, several locations (e.g.,1A, 1B, 2D, and 4A) remained in the very low category, indicating that natural vegetation cover such as forests was still effective in reducing erosion rates. However, other locations such as 2C, 3B,4B, and 5A fell into the very heavy category. These locations are characterized by steep slopes and land uses with limited vegetation cover, such as shrubs, dry fields, gardens, and rice fields, which increase the kinetic energy of rainfall and make the topsoil more susceptible to detachment and transport, particularly on sloping terrain. During this time, the high EHI values show that the steps taken to protect the land were not enough to stop erosion, as the erosion rates went beyond what was considered acceptable (Mali et al., 2017).

Table 5. Results of Erosion Hazard Index Calculations for the 2012-2024 Period

Sample Code	2012			2018			2024		
	A (ton/ha/ year)	EHL	EHI	A (ton/ha/ year)	EHL	EHI	A (ton/ha/ year)	EHL	EHI
1A	0.54	34.4	0.016	0.67	34.4	0.020	0.85	34.4	0.025
1B	0.15	13.7	0.011	11.56	13.7	0.844	14.60	13.7	1.066
2A	15.37	19.6	0.785	24.14	19.6	1.234	30.47	19.6	1.557
2B	104.27	19.9	5.250	131.03	19.9	6.597	2.76	19.9	0.139
2C	97.88	12.8	7.624	14.35	12.8	1.118	18.12	12.8	1.411
2D	7.55	20.9	0.361	10.53	20.9	0.504	13.30	20.9	0.637
3A	297.27	20.0	14.888	204.57	20.0	10.245	258.26	20.0	12.934
3B	220.31	14.3	15.401	34.09	14.3	2.383	42.41	14.3	2.965
3C	51.02	28.7	1.778	76.33	28.7	2.659	88.23	28.7	3.074
3D	53.83	23.7	2.272	43.70	23.7	1.844	58.35	23.7	2.462
4A	8.85	32.3	0.274	13.79	32.3	0.427	16.84	32.3	0.521
4B	346.06	15.3	22.592	30.44	15.3	1.987	38.43	15.3	2.509
5A	87.41	39.1	2.237	109.83	39.1	2.811	138.66	39.1	3.549
5B	72.38	38.0	1.906	90.96	38.0	2.395	143.28	38.0	3.772

Source: 1A: Forests–Forests-Forests, 1B: Forest-Shrub-Shrub, 2A: Shrub-Shrub-Shrub, 2B: Shrub-Shrub-Forest, 2C: Shrub-Forest-Forests, 2D: Shrub -Gardens-Gardens, 3A: Dry Fields-Gardens-Gardens, 3B: Dry Fields -Forests-Forests, 3C: Dry Fields-Dry Fields-Dry Fields, 3D: Dry Fields-Dry Fields-Gardens, 4A: Gardens-Gardens-Gardens, 4B: Garden-Forrests-Forests, 5A: Rice Fields-Rice Fields-Rice Fields, and 5B: Rice Fields-Rice Fields-Dry Fields

Between 2013 and 2018, many areas went through changes in how the land was used, which affected the A values and caused them to move into different EHI categories. Some places that were once in the very light category moved to light or moderate, while those that were already in the very heavy category got worse. Erosion rates, particularly on farmland, increased, accompanied by significant changes in land cover. These land-use changes made erosion worse in several places by reducing the amount of protective vegetation and increasing water runoff (Jiang et al. 2024). As a result, the EHI levels rose sharply at points 2B, 3C, 5A, and 5B, all of which are now in the very heavy category.

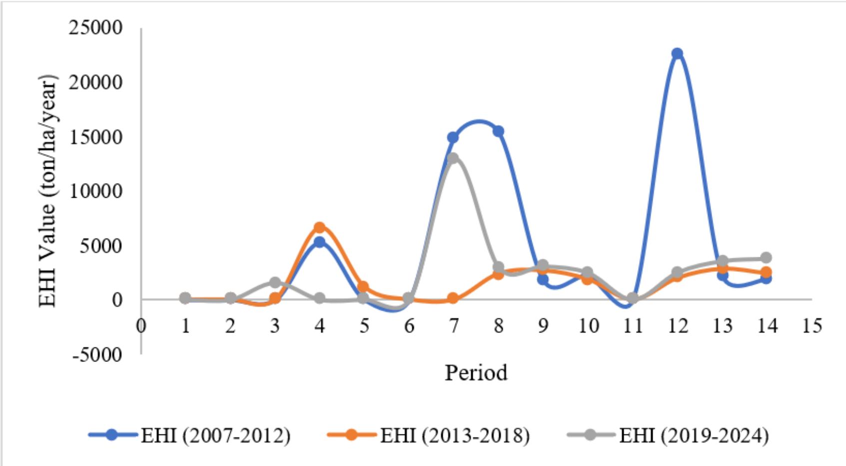

Figure 1. Dynamics of Changes in the Erosion Hazard Index Value of Bangsal Sub watershed

The years between 2019 and 2024 show a pattern that's much like before, because the impact of turning land into different uses and applying conservation methods still plays a big role, causing EHI categories to keep changing. At sample site 2B, shrubs were replaced by forest, which led to a major drop in EHI, moving it from the very heavy category to very light. The same thing is happening at site 1A, where the land remained as forest, and the EHI category remained in the very light class for all the time periods. This shows that using land for forests is the best way to reduce erosion, as the plants and their roots help keep the soil safe from damage (Karim et al., 2022). Meanwhile, sample site 3D shows an increase from the heavy to the very heavy category due to land conversion from dry fields to gardens. Gardens have more open land and less vegetation than dry fields, causing the soil to be more susceptible to erosion.

Overall, this period shows that many locations experienced an increase in EHI values compared to the previous two periods, indicating that the land is prone to degradation. During this period, the heavy avalanches in several locations were not only triggered by increased rainfall intensity but also by the expanding shift in land use from natural vegetation to intensive agriculture. This condition reinforces previous findings that vegetation cover and soil erodibility are the dominant variables influencing erosion magnitude (Sholikah et al., 2024), and are directly reflected in the EHI value. The rising EHI values over time show that the land is becoming less able to resist erosion, mainly because of poor vegetation cover, and more thoughtful soil conservation efforts are urgently needed.

Land Use Map for the 2012-2024 Period

Figure 2 illustrates the spatial distribution of land use in the Bangsal Sub-watershed for the years 2012, 2018, and 2024. Based on the land-use maps of the Bangsal Sub-watershed, there have been notable changes in how the land is used over the past 12 years. The area includes eight types of land use: forest, dry fields, built-up areas, mixed gardens, vacant land, grasslands, rainfed rice fields, and shrubs. The total area of the region did not change, but the way different types of land are distributed changed over time. The forest area grew from 2,244.71 hectares in 2012 to 2,374.90 hectares in 2018 and then to 2,394.69 hectares in 2024. This suggest that some areas are being reforested or natural vegetation is coming back. On the other hand, shrubs dropped a lot from 311.74 hectares in 2012 to 185.32 hectares in 2018 and then to just 48.16 hectares in 2024. This means most shrubs were turned into areas with more dense vegetation, like grasslands or mixed gardens. This trend matches the growth in the grassland area, which went up from 499.74 hectares in 2012 to 504.58 hectares in 2018 and then to 624.17 hectares in 2024.

Figure 2. Land Use Map of Bangsal Sub watershed

The mixed garden area has steadily grown, increasing from 70.49 hectares in 2012 to 83.87 hectares in 2018 and further to 89.42 hectares in 2024. This rise shows that the community is using land more intensively for growing various plants. At the same time, the amount of unused land dropped from 70.48 hectares in 2012 to 63.23 hectares in 2018 and then to 61.19 hectares in 2024. This means that areas that were once left unused are now being turned into grassland, mixed gardens, or forests. The area covered by built-up spaces, like buildings and roads, also went up from 8.56 hectares in 2012 to 9.92 hectares in 2018 and 10.76 hectares in 2024. This growth reflects an increasing population and more development projects. On the other hand, dry fields that rely on rainwater have been shrinking over time, possibly because people are moving away from traditional farming methods or turning these areas into more permanent land uses (Dewi et al., 2020). Taken together, these changes show a pattern of improving land quality through the expansion of grasslands, more mixed-garden areas, and efforts to restore forests. However, they also show that there is still pressure on the land from ongoing development. These changes in land use are closely linked to how erosion is happening in the region. The decline in scrub and vacant land tends to reduce erosion susceptibility, whereas the increase in built-up areas and the decline in agricultural land may alter surface-runoff patterns (Rahman et al., 2023).

Erosion Hazard Maps for the 2012-2024 Period

Figure 3 presents the spatial distribution of erosion hazard levels in the Bangsal Sub-watershed for the three observation periods. Based on the erosion hazard maps of the Bangsal Sub-DAS for the three time periods, the distribution of erosion hazard levels shows clear spatial variation influenced by landform, slope, and land use. In the 2012 period, light to very light erosion (scores 4–5, shown in green) predominated in the central and southern portions of the subwatershed, which are characterized by gentle to flat slopes and relatively well-preserved forest and dry field cover. Conversely, heavy to very heavy erosion (Scores 1–2, shown in red and yellow) was concentrated in the northern and eastern areas, which have steeper slopes and are more intensively affected by land-use activities. In the 2018 period, areas with very light erosion expanded, while areas with very heavy erosion decreased, particularly along the northern slopes near Pacet District. This pattern indicates land-use changes that reduced vegetation cover capacity, thereby increasing the land's vulnerability to surface erosion (Aditya et al. 2024).

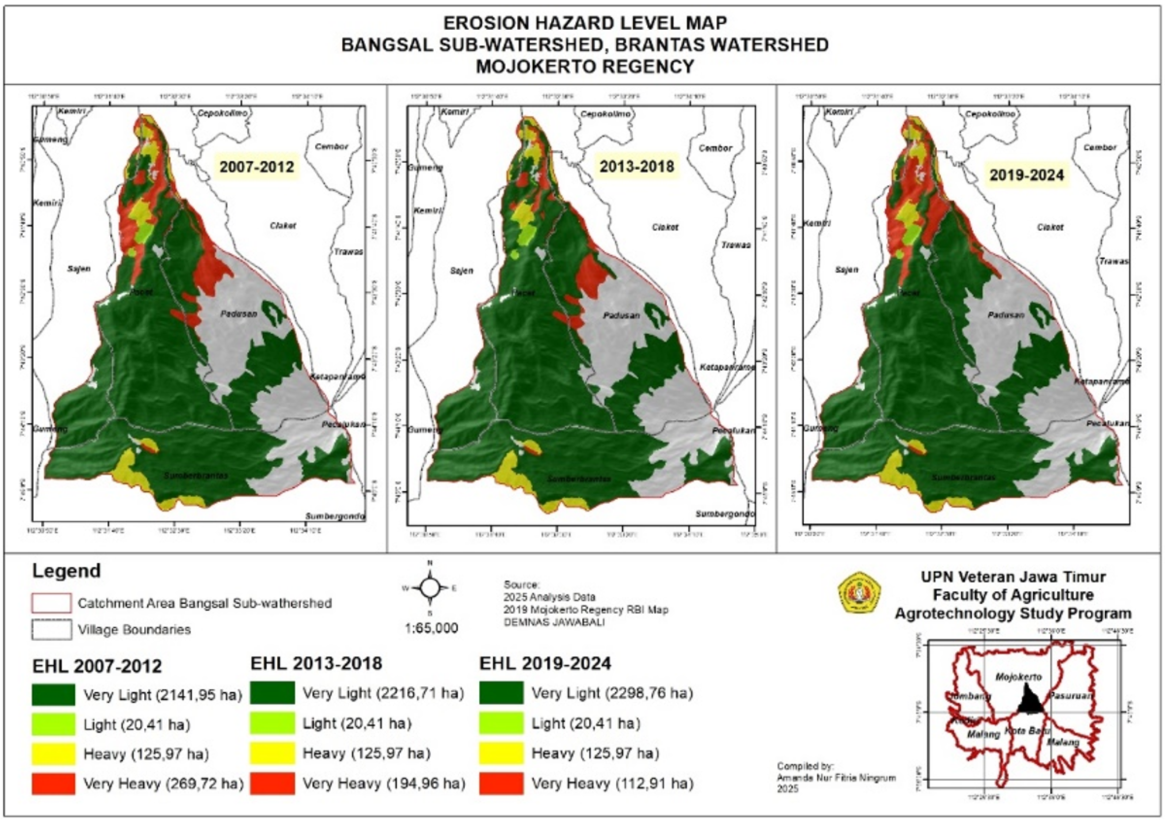

Figure 3. Erosion Hazard Level Maps of Bangsal Sub watershed

In the 2024 period, a similar pattern persisted, although some areas showed no change in erosion hazard levels. Land rehabilitation efforts, increased vegetation cover, or the application of soil conservation techniques on agricultural land likely contribute to this condition. However, areas on steep slopes remain in the heavy to very heavy categories and therefore still require conservation interventions. Year-to-year changes in erosion hazard levels indicate that slope steepness and land cover are the most influential factors. The steeper the slope and the more open the land cover, the higher the resulting erosion rates (Aliffian et al., 2024). Therefore, areas with heavy erosion classes should be prioritized for soil and water conservation measures. These findings are consistent with those of Yusuf et al. (2020), whose analysis of the erosion class distribution map and land cover map showed that areas with very low erosion rates were dominated by forest cover, followed by mixed gardens, fields, and open land.

CONCLUSION

Land-use change in the Bangsal subwatershed significantly influences erosion dynamics. Forest conversion into shrub, dry fields, and mixed gardens consistently increases erosion, while reforestation lowers erosion despite rising rainfall erosivity. Regression results show vegetation cover (C) and conservation practices (P) as the dominant factors, with soil erodibility (K) becoming increasingly important. Erosion hazard and land-use analyses confirm that conservation-focused land management is essential to reduce erosion risk and maintain long-term watershed stability.

ACKNOWLEDGMENTS

The author would like to thank all parties involved in the research, including lecturers, the research team, family, and friends for their support and assistance so that the research ran smoothly.

AUTHORS' CONTRIBUTIONS

M conceived and designed the research, determined the study location, conducted data analysis, prepared and revised the manuscript, and approved the final version of the manuscript. ANFN conducted field surveys and soil sampling, performed laboratory analyses, prepared thematic maps, analyzed research data, drafted the manuscript, and approved the final version of the manuscript. BWW contributed to the research design and planning, provided scientific ideas and technical input, assisted in interpreting the research findings, and reviewed the manuscript. DHS supervised the map preparation process, provided technical guidance in spatial analysis and map development, and reviewed the manuscript. All authors reviewed, revised, and approved the final version of the manuscript.

COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Aditya, H. F., Yuhdistira, M. F., Sholikah, D. H., Harliando, D. P., & Wijayanti, F. (2024). Analisis erosi aktual menggunakan software ArcGIS pada Sub DAS Durensewu, Waduk Gadjah Mungkur Wonogiri. *G-Tech: Jurnal Teknologi Terapan, 8*(4), 2744–2754. https://doi.org/10.70609/gtech.v8i4.5358

Alief, M. R., Y. Khairullah, & Fadhliani. (2024). Land use change analysis and the impact on the streamflow of the Keureuto River. *IOP Conference Series: Earth and Environmental Science, 1311*(1). https://doi.org/10.1088/1755-1315/1311/1/012035

Aliffian, R. F. N., M. I. Rendra, & Zainuddin. (2024). Pemetaan laju erosi dengan pendekatan sistem informasi geografis di Kecamatan Kedewan Kabupaten Bojonegoro. *Jurnal Teknik, 18*(1), 1–6. https://doi.org/10.31849/teknik.v17i1

Charismanda, M.L., Purwadi., & Wijaya, K. (2024). Pendugaan erosi tanah pada berbagai penggunaan lahan dan kemiringan lereng di Kecamatan Wonosalam, Kabupaten Jombang. *J. Solum, XXI*(1), 1–13. https://doi.org/10.25077/jsolum.21.1.1-13.2024

Dangol, Susheel, Umesh, & Kumar M. (2023). Application of geo-informatics for soil erosion mapping. *Journal on Geoinformatics,* 1–9

Dewi, E., Haryanto, R., & Sudirja, R. (2020). Pengaruh penggunaan lahan dan posisi lereng kandungan c-organik dan beberapa sifat fisik tanah Inceptisols Jatinangor, Jawa Barat. *Agrosainstek: Jurnal Ilmu dan Teknologi Pertanian, 4*(1), 49–53. https://doi.org/10.33019/agrosainstek.v4i1.37

Erfarras, N. N., Harisuseno, D., & Suhartanto, E. (2024). Pemetaan peta spasial hujan rancangan dengan memanfaatkan data Satelit GPM Di Sub DAS Brangkal Kabupaten Mojokerto. *Jurnal Teknologi dan Rekayasa Sumber Daya Air, 4*(2), 1275–1285. https://doi.org/10.21776/ub.jtresda.2024.004.02.131

Farikha, A., Wijaya, K., & Purwadi. (2023). Analisis erosi dan indeks bahaya erosi pada berbagai penggunaan lahan di Sub DAS Opak Hulu-Tengah. *Jurnal Ecosolum, 12*(2), 128–144. https://doi.org/10.20956/ecosolum.v12i2.29361

Hasanah, Faujatul, Setiawan, I., Noor, T. I., & Yudha, E. P. (2021). Pemetaan sebaran tingkat alih fungsi lahan sawah di Kabupaten Serang. *Jurnal Agrica, 14*(2), 171–82. https://doi.org/10.31289/agrica.v14i2.5039

Hasanah, U., A. A. Amami, & R. Amelia. (2023). Forest conversion to agricultural lands: impact on soil physical characteristics. *IOP Conference Series: Earth and Environmental Science*, *1253*(1). https://doi.org/10.1088/1755-1315/1253/1/012027

Jiang, Kaixin, Mo, S., Yu, K., Li, P., & Li, Z. (2024). Analysis on the relationship between runoff erosion power and sediment transport in the Fujiang River Basin and its response to land use change. *Ecological Indicators. 159*, 111690. https://doi.org/10.1016/j.ecolind.2024.111690

Karim, Irawati, Sofyan, A., & Ishak, L. (2022). Prediksi erosi tanah dengan menggunakan metode *universal soil loss equation* di bagian tengah-hilir DAS Oba. *Jurnal Penelitian Pendidikan Geografi, 7*(4), 127–135. https://doi.org/10.36709/jppg.v7i4.72

Lestari, M., Mira., Prasetyo, S.R.Y., & Fibriani, C. (2021). Analisis daerah rawan banjir pada daerah aliran sungai tuntang menggunakan skoring dan *inverse distance weighted*. *Indonesian Journal of Computing and Modeling, 4*(1), 1–9. https://doi.org/10.24246/icm.v4i1.4615

Mali, Maria S., Jehunias L. Tanesib, & Redi K. Pingak. (2017). Pemetaan daerah rawan erosi dengan menggunakan aplikasi penginderaan jauh dan sistem informasi geografi di Kabupaten Timor Tengah Selatan Propinsi Nusa Tenggara Timur. *Jurnal Fisika : Fisika Sains dan Aplikasinya, 2*(2), 58–65. https://doi.org/10.35508/fisa.v2i2.546

Maroeto, Priyadarshini, R., & Santoso, W. (2021). Integration gis and multicriteria analysis critical land farming in Welang Watershed. *Bulgarian Journal of Agricultural Science, 27*(2), 242–252

Muamalah, A. S., Tjoneng, A., & Syarif, M. M. (2024). Penentuan nilai erodibilitas tanah pada kemiringan lereng di atas 15% pada Das Jenelata Kabupaten Gowa Provinsi Sulawesi Selatan. *AGrotekMAS Jurnal Indonesia: Jurnal Ilmu Peranian, 5*(1), 100–108. https://doi.org/10.33096/agrotekmas.v5i1.502

Musakkir., Tjoneng, A., & Syarif, M. (2024). Menentukan nilai erodibilitas tanah (K) pada jenis tanah di SUB DAS Jenelata. *Agrotekmas Jurnal Indonesia: Jurnal Ilmu Peranian, 5*(2), 203–213. https://doi.org/10.33096/agrotekmas.v5i2.611

Nurhawaidah, A., Tjoneng, A. & Hasan, I. (2019). Arahan pengelolaan daerah aliran sungai berdasarkan indeks bahaya erosi (IBE) Sub DAS Pitu Riase Kabupaten Sidrap. *Agrotek: Jurnal Ilmiah Ilmu Pertanian*, *3*(1), 24-39. https://doi.org/10.33096/agr.v3i1.70

Parabudhi, Pandu. (2017). *Analisa dan rasionalisasi kerapatan jaringan stasiun hujan dan pos duga air dengan metode stepwise Di Sub Das Bangsal Provinsi Jawa Timur*. Sarjana thesis, Universitas Brawijaya. https://repository.ub.ac.id/id/eprint/7773

Peng, X., & Dai, Q. (2022). International soil and water conservation research drivers of soil erosion and subsurface loss by soil leakage during karst rocky deserti fi cation in SW China. *International Soil and Water Conservation Research, 10*(2), 217–227. https://doi.org/10.1016/j.iswcr.2021.10.001

Putra, A., Triyatno, Syarief, A., & Hermon, D. (2018). Penilaian erosi berdasarkan metode USLE dan arahan konservasi pada DAS Air Dingin bagian hulu Kota Padang-Sumatera Barat. *Jurnal Geografi, 10*(1), 1–13. https://doi.org/10.24114/jg.v10i1.7176

Rahman, A.D., Bakti, L. A. A., & Bustan. (2023). Pemetaan alih fungsi lahan di Gili Tarawangan Desa Gili Indah Kecamatan Pemenang Kabupaten Lombok Utara dengan menggunakan sistem informasi geografis (SIG). *Journal of Soil Quality and Management, 2*(1), 85–98. https://doi.org/10.29303/jsqm.v2i1.148

Rampu, J.R.K., Sukmono, A., & Bashit, N. (2023). Analisis laju erosi daerah aliran sungai Cacaban menggunakan sistem informasi geografis pada periode 2013-2022. *Jurnal Geodesi Undip, 12*(3), 241–250. https://doi.org/10.14710/jgundip.2023.38054

Rastanto, R. N. A., Sisinggih, D., & Hendrawan, A. P. (2022). Analisa laju erosi dan arahan konservasi lahan menggunakan aplikasi ArcMap pada DAS Pekalen Hulu Kabupaten Probolinggo Jawa Timur. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *3*(1), 369-380 https://doi.org/10.21776/ub.jtresda.2023.003.01.32

Rosidin, D. A., Suhartanto, E., & Andawayanti, U. (2023). Pemetaan sebaran indeks bahaya erosi dan arahan penggunaan lahan di Sub DAS Brantas Hulu Kota Batu berbasis sistem informasi geografis. *Jurnal Teknologi dan Rekayasa Sumber Daya Air, 3*(1), 198–212. https://doi.org/10.21776/ub.jtresda.2023.003.01.018

Sabathini, D. B. S., Ichsan, A. C. & Sari, D. P. (2024). Prediksi erosi dengan metode *universal soil loss equation* (USLE) di daerah aliran sungai Malimbu Kabupaten Lombok Utara. *Jurnal Pendidikan, Sains, Geologi, dan Geofisika, 5*(3), 557–571. https://doi.org/10.29303/goescienceed.v5i3.407

Sholikah, D. H., Naufal, R., Wicaksono, K. S., & Soemarno. (2024). Analisis erodibilitas tanah dan hubungannya dengan produktivitas tanaman kopi Di Kecamatan Wajak, Kabupaten Malang. *Jurnal Tanah dan Sumberdaya Lahan, 11*(1), 125–134. https://doi.org/10.21776/ub.jtsl.2024.011.1.14

Siagian, M. T., Sinaga, N., & Djuunaa, I. A. F.. (2021). Analisis perubahan tutupan lahan pada daerah aliran sungai (DAS) Pami di kabupaten Manokwari. *Jurnal Kehutanan Papuasia, 7*(1), 121–134. https://doi.org/10.46703/jurnalpapuasia.vol7.iss1.243

Thilagam, K. V., S. Manivannan, & O. P. S. Khola. (2023). Deriving land management practices for reduced nutrient movement from an agricultural watershed using the AGNPS model. *Sustainability (Switzerland), 15*(5),1–14. https://doi.org/10.3390/su15054001

Wasono, A., Sari, Y.K., Sangkawati, S., & Nugroho, H. (2023). Analisis erosi Sub-DAS Bendungan Way Sekampung berbasis sistem informasi geografis (SIG). *Jurnal Aplikasi Teknik Sipil*, *21*(2), 191-196

Yusuf, S.M., Murtilaksono, K., & Lawaswati, D. M. (2020). Pemetaan sebaran erosi tanah prediksi melalui integrasi model USLE ke dalam sistem informasi geografis. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan (Journal of Natural Resources and Environmental Management), 10*(4), 594–606. https://doi.org/10.29244/jpsl.10.4.594-606