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Regional Research Study

Land Use Change Impact on Erosion and Sedimentation in Kreo Sub-Watershed, Central Java

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Abstract

Ministry of Forestry has designated Kreo Sub-watershed, part of Garang Watershed, a critical area due to high erosion rates contributing to flooding in Semarang. Rapid land use changes accelerate environmental degradation, increasing erosion and sedimentation risks. This study measures erosion and sedimentation rates in Kreo Sub-watershed using SWAT (Soil and Water Assessment Tool), determines Erosion Hazard Index, and proposes erosion control solutions based on Land Rehabilitation and Soil Conservation Analysis (ARLKT) with vegetative conservation. ARLKT approach includes simulating new land use scenarios to assess their impact on erosion reduction. To ensure SWAT modelling accurately represents field conditions and not overestimate, allowing conservation recommendations based on ARLKT applied appropriately, a field-based sedimentation analysis also conducted. The study utilizes rainfall, soil type, slope, and land use data in 2019 and 2024 from satellite imagery and validated using a confusion matrix. Results indicate a shift in Erosion Hazard Index from predominantly 'Moderate' in 2019 to 'High' in 2024, underscoring urgent need for sustainable watershed management. By integrating remote sensing, field validation, and hydrological modeling, this study offers a precise, data-driven approach to erosion control. The findings serve critical reference for policymakers in developing effective conservation strategies to enhance watershed resilience.

Keywords: Conservation direction; erosion rate; land use changes; sedimentation

1. Introduction

The main problem that often leads to erosion is the significant changes in land use that reduce the infiltration area which then accumulates into sediment deposits (Kidane and Alemu, 2015). Massive population growth puts a lot of pressure on the demand for land. The increasing need for land has led to inappropriate land use, with paddy fields becoming residential areas and protected forests turning into agricultural land. This phenomenon also occurs in the Kreo Subwatershed. Kreo Subwatershed is located in Central Java province and covers 2 regencies and 1 city, including Kendal regency, Semarang regency, and Semarang city. The administrative area of Kreo Subwatershed is mostly dominated in Semarang City, which covers 44.8% of the total area of Kreo Subwatershed. Kreo Subwatershed is a part of the Garang Watershed and has outlet in Jatibarang Reservoir (Pramono et al., 2022).

Studies show that relatively stable forest area, increasing plantation land, and decreasing open land and shrubs have an effect on improving the hydrological response of the watershed in the river (Sunandar et al., 2015). Conversely, land clearing in the watershed for other purposes such as housing and industrial areas can lead to the potential for river sedimentation, erosion in the upstream area, and flooding in the downstream area (Sulfandi et al., 2016).

The phenomenon of regional development will gradually make land use incompatible with land capability, land carrying capacity, and its designation, resulting in land use change (Trimarmanti, 2014). Land use change where the land cover of upland (trees and vegetation) becomes agricultural land indicates that the water catchment area in the area is degraded (Apriliyana, 2015). The rapid change in land use in Semarang City has caused an increase in flood discharge and sediment in the Kreo Sub-watershed, which is the source of inflow to Jatibarang Reservoir, which can be a serious threat to the useful life of Jatibarang Reservoir. According to Pramono et al. (2022), the Kreo Sub-watershed contributes 30% of the total flood volume in Semarang. This significant contribution highlights the degraded condition of the Kreo Sub-watershed, suggesting the need for immediate intervention to address erosion, sedimentation, and land management issues in the area.

This research monitors land use changes over five years and assesses erosion and sedimentation rates in the Kreo Sub-watershed. Land Use and Land Cover (LULC) data is derived from satellite imagery with additional validation to ensure accuracy. Erosion and sedimentation are analyzed using the SWAT (Soil and Water Assessment Tool) model. SWAT is deemed suitable for this study as it aligns with the findings of Christanto et al. (2018) in the Serayu Hulu watershed, demonstrating its capability to accurately simulate hydrological processes with a model validation coefficient (R^2) of 0.94. This study proposes a precise, data-driven method to erosion management through the use of remote sensing, field validation, and hydrological modelling. The findings are significant for policymakers as they create successful conservation measures to improve watershed resilience.

2. Methods

2.1 Kreo Sub-Watershed

The Kreo sub-watershed is one part of the Garang watershed under the authority of the Pemali Juana River Basin Centre (BBWS). According to KEPPRES No. 12/2012, the Garang watershed is included in the Jratunseluna River Basin. The Kreo Subwatershed has a total watershed area of 50.65 km^2.

Kreo Subwatershed has a flow outlet at Jatibarang Reservoir which is located in Mijen Subdistrict, Semarang City. This reservoir was built with the main purpose of reducing the risk of flooding in Semarang City which is often caused by overflowing water from rivers flowing through the Garang watershed. Jatibarang Reservoir has an active storage of 20.4 million m^3, which functions as a flood control and raw water provider in the West Semarang area (Dhanisworo, 2022).

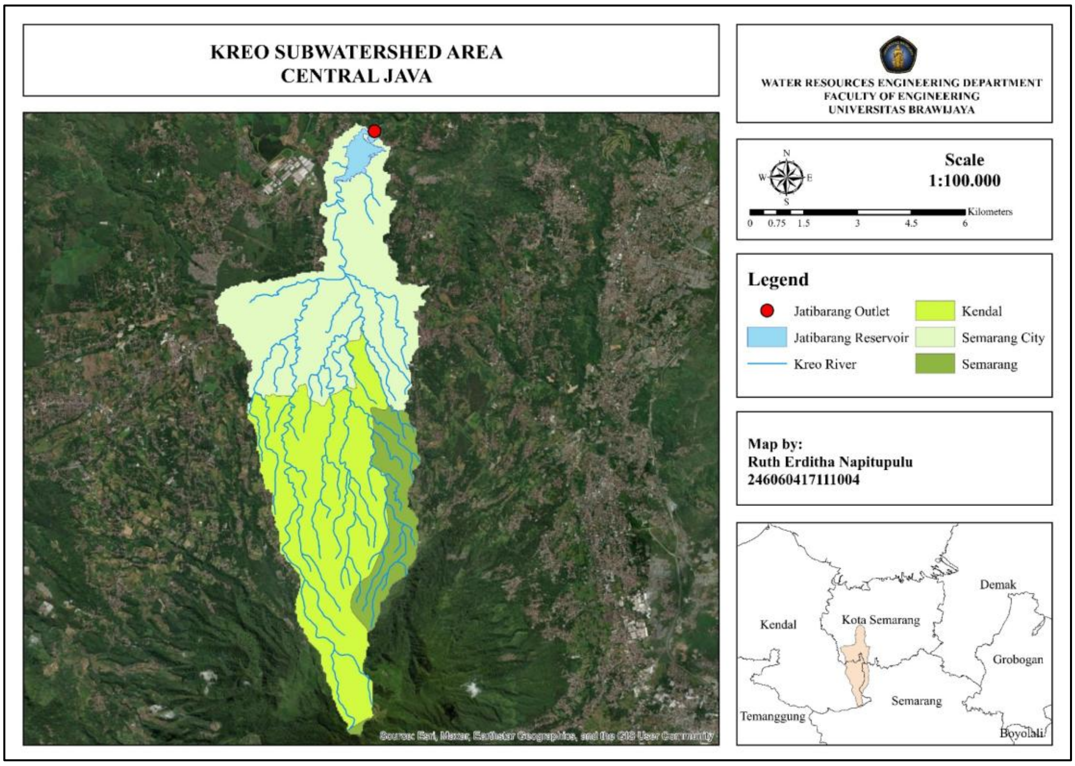

Figure 1. Kreo sub-watershed area

2.2 Land Use Land Cover

This research utilizes Remote Sensing to analyze land cover using Landsat 8 satellite imagery. The choice of classification method is critical for accurate digital remote sensing mapping (Septiani et al., 2019). For this study, the Supervised Classification method was employed, allowing for greater control and alignment with the analyst's domain knowledge. This approach provides higher accuracy than Unsupervised Classification due to the use of predefined training areas, enhancing classification precision (ESRI, 2019). Research indicates that Supervised Classification with the Maximum Likelihood algorithm can achieve up to 92% accuracy, compared to 82.07% for Unsupervised Classification (Septiani et al., 2020). In this method, criteria are established by the analyst, and clusters are formed based on spectral similarity of training area signatures (Indarto & Faisol, 2009).

Spatial analysis with Supervised Classification needs to calculate the validation and accuracy level of burnt areas generated from Landsat 8 imagery, this is done by comparing it (confusion matrix) to 100 random sample points and seeing how it matches the reference data. The reference data used in this study consists of satellite imagery from the specified years, 2019 and 2024, obtained through Google Earth or basemap sources. The equation used equation (1)-(5) (Congalton & Green, 2019):

$$\text{Overall Accuracy (\%)} = \frac{Number\ of\ Correctly\ Classified\ Pixels}{Number\ of\ Accuracy\ Test\ samples} \times 100\% \tag{1}$$

$$\text{Producer Accuracy (\%)} = \frac{Number\ of\ Test\ Samples\ for\ the\ Accuracy\ of\ a\ Class\ Correctly\ Classified}{Number\ of\ Accuracy\ Test\ Samples\ in\ a\ Class} \times 100\% \tag{2}$$

$$\text{User Accuracy (\%)} = \frac{Number\ of\ Test\ Samples\ for\ the\ Accuracy\ of\ a\ Class\ Correctly\ Classified.}{Number\ of\ Accuracy\ Test\ samples\ Classified\ as\ That\ Class} \times 100\% \tag{3}$$

$$\text{Error Omission (\%)} = 100\% - \text{Producer Accuracy} \tag{4}$$

$$\text{Error Commission (\%)} = 100\% - \text{User Accuracy} \tag{5}$$

The accuracy test is carried out by calculating the kappa value which shows the comparison between the tested classification results and the random classification results. In other words, the kappa value shows the consistency of the accuracy of the classification results (Pontius & Millones 2011). As a reference for evaluating agreement levels, the following table presents the interpretation of Kappa values based on Landis & Koch (1977):

Table 1. Kappa values

Kappa value	Agreement level	Interpretation
< 0.00	Poor	Very poor
0.00 – 0.20	Slight	Low
0.21 – 0.40	Fair	Moderate-low
0.41 – 0.60	Moderate	Moderate
0.61 – 0.80	Substantial	Good
0.81 – 1.00	Almost perfect	Very good

The Kappa Values (κ) assesses classification accuracy, with higher values indicating stronger agreement and $\kappa > 0.81$ considered almost perfect.

2.3 Theoretical Erosion and Sedimentation Analysis with SWAT

This research employs the SWAT model for theoretical analysis of erosion and sedimentation, simulating sediment transport, agricultural chemistry, and hydrological conditions following management practices. SWAT effectively evaluates water resource dynamics, precipitation impacts, and surface runoff (Arnold & Fohrer, 2005). The model divides the watershed into sub-basins and Hydrological Response Units (HRUs), accounting for spatial variability in land use, soil types, and topography, generating essential outputs like streamflow, sediment yield, and nutrient loads (Arnold et al., 1998).

In Indonesia, SWAT requires calibration and validation due to watershed variability. Model accuracy is assessed using statistical measures such as standard deviation and efficiency (Rau et al., 2015). Validation ensures outputs align with actual conditions, crucial for hydrological analysis (Rahmat et al., 2017). To ensure model accuracy, calibration is performed by comparing simulated streamflow with observed discharge data from field measurements, adjusting key parameters such as CN2 (Curve Number), Alpha-Bf (Baseflow Alpha Factor), and CH-K2 (Effective Hydraulic Conductivity of the Channel). This calibration process enhances the reliability of SWAT simulations for watershed management and conservation planning (Arnold et al., 2012).

Erosion and sedimentation calculations using SWAT generated theoretical discharge, which was validated with field data using the Nash-Sutcliffe Efficiency (NSE) and R^2 coefficients. The NSE ranges from $-\infty$ to 1, with values closer to 1 indicating better model performance, while an NSE above 0.5 suggests acceptable performance. The R^2 coefficient reflects the variance in observed data explained by the model; values closer to 1 indicate a strong correlation, with an R^2 above 0.7 considered good.

2.4 Field-Measured Sedimentation Calculation

Sediment sampling in the Kreo River was conducted to collect both suspended and bed load sediments. Given the river's 14-meter width, the sampling was divided into three cross-sectional zones—right, center, and left—ensuring spatial representation. Three sampling points were designated for each sediment type. The procedure followed the Standard Sampling Method (SNI 3414:2008) to ensure consistency and reliability. Sampling was conducted at the Automatic Water Level Recorder (AWLR) station in Cepoko, a key hydrological monitoring site.

Sediment analysis in the Kreo River included bed load and suspended load sampling, along with flow velocity measurements. Sediment samples for bed load were collected at a weight of 1 kg from each designated point, while suspended load samples were gathered at a volume of 1 liter from each location. Laboratory testing at Universitas Brawijaya provided D_{35}, D_{50}, and D_{90} values for bed load analysis using the MPM method, as well as soil specific gravity (Gs) and TSS for suspended sediment calculations. D_{35}, D50, and D90 refers to sediment particle distribution size indicating particle diameter required for bed load trasnport calculations using the MPM (Meyer-Peter and Müller) method. Soil Specific Gravity (Gs) refres to the ratio between the mass of soil in the dry state and the mass of water in the same volume at standard temperature. TSS refers to the total amount of suspended particles in water, which can be fine sediment, organic matter, or other pollutants.

In the calculation of sediment bed load, the formula (Meyer-Peter, E., & Müller, R., 1948) is used as follows:

$$q_b = \phi\, x \sqrt{\left\{\frac{(\rho s - \rho w)}{\rho w}\right\} x\, g. d_{50}{}^{3}} \quad (6)$$

With:

q_b = Bed Load (m^3/second)
ϕ = Sediment transport intensity
ρs = Sediment mass density (ton/m^3)
ρw = Water mass density (ton/m^3)
g = Acceleration of gravity = 9.81 (m/s^2)
d_{50} = Particle diameter (m)

As for the instantaneous sampling method used to measure suspended sediment in water flow using the formula which is derived from the calculation equation of drift sediment discharge using the USBR (United States Bureau of Reclamation) Method developed by (Strand, 1982):

$$q_s = k \times C_s \times Qw \quad (7)$$

With:

q_s = Suspended sediment discharge (ton/day)
C_s = Suspended sediment concentration (mg/l)
Qw = Discharge (m^3/sec)
k = Conversion factor to state the yield in tonnes/day (The conversion factor values used is 0.0864)

2.5 Validation on Theoretical and Field-Measured Sedimentation

Sediment yield refers to the sediment transported from erosion in rivers or catchments over time. It reflects watershed management impacts and depends on erosion rates, soil transport, and watershed characteristics (Asdak, 2007, p.403). SWAT sedimentation results require validation through field measurements and lab analysis for accuracy. As SWAT relies on estimated parameters, assumptions may not fully reflect real conditions. Comparing SWAT predictions with field data, such as the Meyer-Peter Müller (MPM) and instantaneous methods, helps assess reliability and identify discrepancies from local factors like riverbank erosion, land use changes, or human activities.

The deviation test in this study aims to determine the magnitude of the deviation of the theoretical sedimentation rate to the sedimentation rate in the field. The formula used in this test is (Triadmojo, 1992: 5):

$$d = \frac{E_1 - E_2}{E_1} \times 100\% \quad (8)$$

With:

d = Amount of deviation (%)
E_1 = Field sedimentation rate (m^3/year)
E_2 = Theoretical sedimentation rate (m^3/year)

In this study, the theoretical sedimentation rate refers to the calculation using SWAT modelling which will then be compared to its accuracy based on field sedimentation calculations. The result of the deviation test is a percentage deviation which is then grouped based on the volume error criteria. The volume of error becomes the criterion for the acceptability of a calculation result, with the following limits:

Table 2. Volume error criteria

Rate	Criteria
VE < 10%	Good
10% < VE < 20%	Acceptable
VE > 20%	Not acceptable

If the volume error is less than 10, it is considered acceptable; otherwise, it is deemed inaccurate and requires further evaluation and correction.

2.6 Erosion Hazard Index

Erosion assessment consists of two approaches: evaluating potential erosion risk and measuring actual erosion hazard levels. The Erosion Hazard Index compares the observed erosion rate with the allowable threshold within a watershed. Based on (Hammer, 1981), Erosion Hazard Index is classified into four categories: low, moderate, high, and very high. A high category indicates critical land conditions requiring urgent rehabilitation efforts. The Erosion Hazard Index (IBE) is determined by dividing total erosion by the Tolerable Soil Loss (TSL). In the Kreo Sub-watershed, the TSL value is 16 ton/ha/year, derived from Thompson's table on (Asdak, 2009).

2.7 Land Rehabilitation and Soil Conservation Direction (ARLKT)

In natural resource management, areas are categorized into three functions; protected areas, buffer areas, and cultivation areas. These distinctions are based on slope, soil type sensitivity to erosion, and average daily rainfall. According to Asdak (2010), specific erosion and sedimentation treatment measures apply to each category. The ARLKT serves as a valuable framework for guiding appropriate conservation practices to each area. ARLKT relies on systematic methods to assess and mitigate land degradation risks. ARLKT (Land Conservation Planning Directive) is essential for identifying and prioritizing areas most at risk of erosion and land degradation, ensuring effective conservation measures. This data-driven approach aids sustainable land management by guiding appropriate conservation strategies.

This study will simulate a conservation direction into a new land use framework. The proposed conservation land use will be developed based on the specific functions of the area and aligned with conservation strategies outlined in Asdak (2010). The new land use model will primarily emphasize vegetative conservation, prioritizing the utilization of vegetation as a key element in achieving sustainable land management objectives.

3. Result and Discussion

3.1 Land Use

3.1.1 Satellite Imagery-Based Land Use Analysis

This study employed land use data from 2019 and 2024, conducting evaluations of erosion, sedimentation, and land cover every five years to assess the effectiveness of forest and land rehabilitation (RHL) programs on watersheds. This aligns with Ministerial Regulation No. P.10/MENLHK/SETJEN/PLA.0/2/2022, which mandates outcome evaluations every five years and impact evaluations every ten years. Land use data was obtained through spatial analysis of Landsat 8 imagery using supervised classification. The image analysis results are as follows:

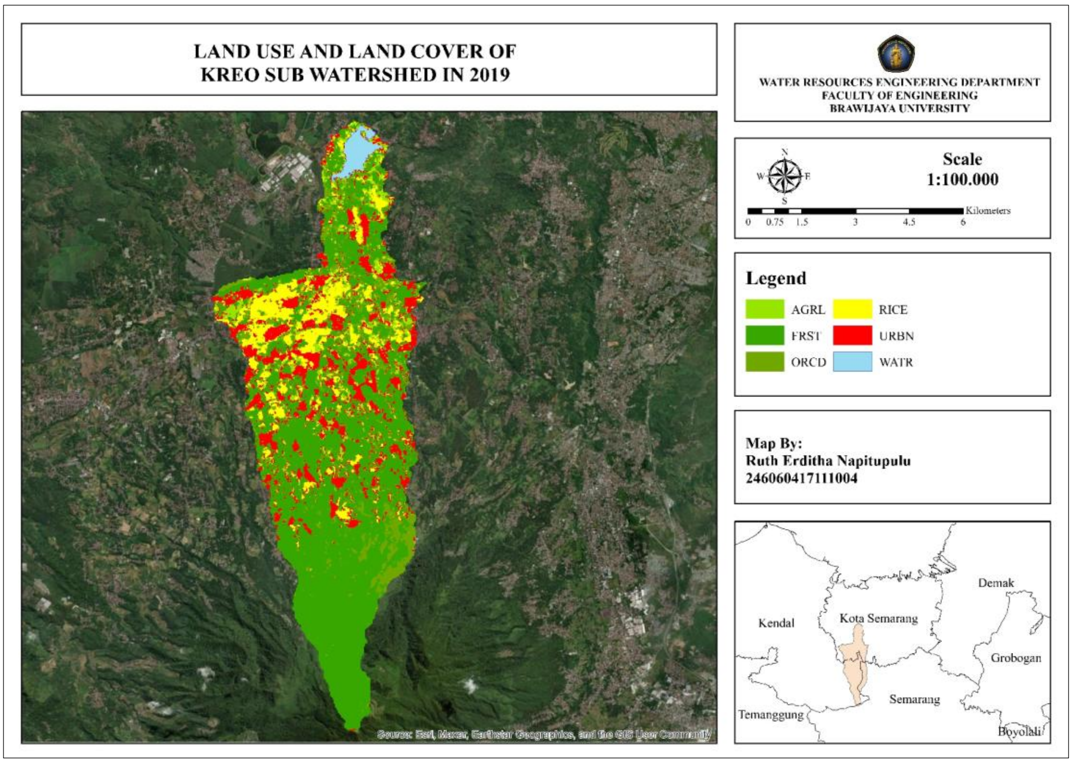

Figure 2. Land use land cover of Kreo Sub-Watershed in 2019

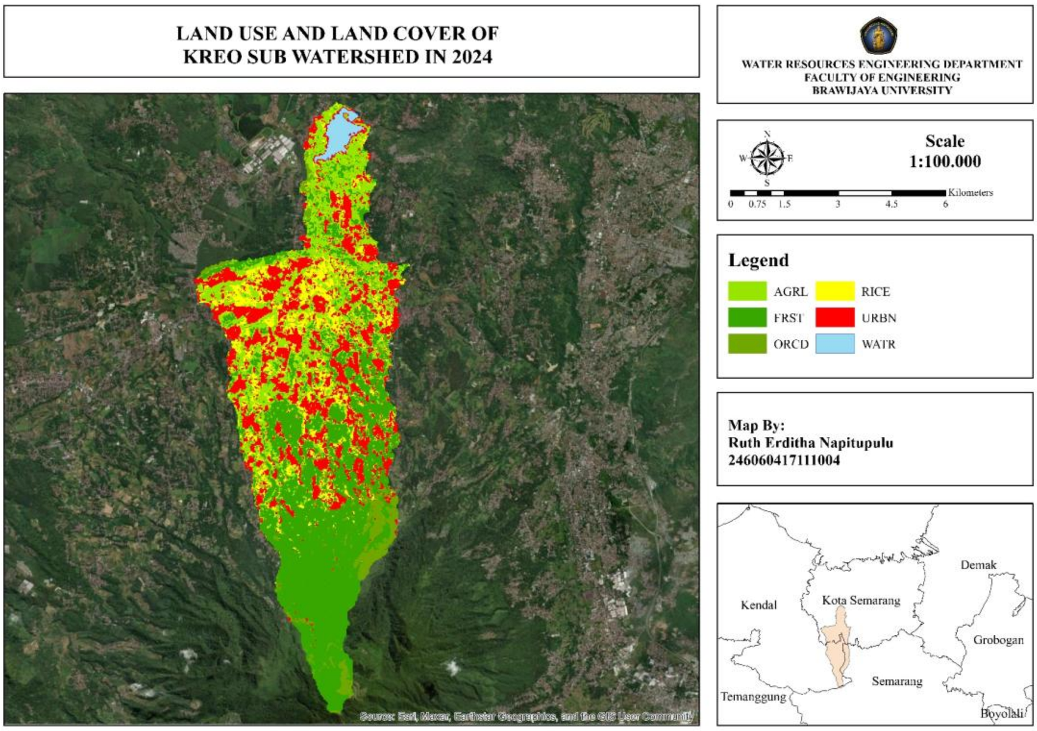

Figure 3. Land use land cover Kreo Sub-Watershed in 2024

For the naming of each LULC, the land use code is used in accordance with the database in SWAT, where AGRL stands for agriculture, URBN stands for urban, FRST stands for forest, ORCD stands for orcherd, RICE stands for rice or paddy field, and WATR stands for water or reservoir area. The table shows LULC changes from 2019 to 2024, with AGRL and URBN increasing while FRST decreased by 17.58%. WATR remained unchanged, while ORCD and RICE have a moderate growth. This transformation reduces the ecological function of forest areas as water catchments and sediment controllers, thus increasing erosion risks. This phenomenon aligns with national trends showing rapid urbanization and conversion of agricultural land into settlements (Trimarmanti, 2014). This condition requires serious attention for sustainable management.

Table 3. Land use land cover analysis result

No	LULC	2019		2024		Difference (%)
		Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	
1	AGRL	3.05	6.02	12.20	24.08	18.06
2	URBN	7.91	15.62	11.21	22.13	6.51
3	FRST	26.95	53.22	18.05	35.64	-17.58
4	ORCD	6.88	13.58	3.51	6.93	-6.65
5	RICE	4.98	9.84	4.81	9.50	-0.34
6	WATR	0.86	1.71	0.86	1.71	0.00
Total		50.65	100.0	50.65	100.0	

3.1.2 Accuracy Assessment of Satellite-Derived Land Use

The classification accuracy is assessed using the Kappa coefficient, which ranges from 0 to 1. In land cover mapping, an accuracy of 85% (0.85) is considered acceptable (Anderson, 1976). The Kappa coefficient evaluates assessment consistency by considering both producer's accuracy (omission error) and user's accuracy (commission error) derived from the confusion matrix.

Land use accuracy assessment is conducted with help of GIS Using random points to compare classified land cover with reference data, which are satellite imagery from 2019 and 2024, acquired through Google Earth or basemap datasets. This method ensures an unbiased evaluation of classification accuracy by systematically sampling different land cover types. The classification of land cover in 2019 and 2024 using supervised methods yielded high accuracy with Kappa values of 0.866 and 0.882 respectively, indicating strong agreement with field conditions. Full confusion matrices and accuracy assessments are provided in Supplementary Tables S1 and S2.

The accuracy assessment of land use for 2019 and 2024 yields a Kappa index exceeding 0.85 (85%), indicating a high level of agreement with actual field conditions This implies that the LULC data used are reliable for further analysis, such as erosion and sedimentation modeling. This high accuracy ensures that detected changes are not due to classification errors but truly reflect field conditions (Congalton & Green, 2019).

3.2 Erosion and Sedimentation Analysis Using SWAT Method

The SWAT analysis begins with the delineation of the watershed, creation of Hydrological Response Units (HRUs), and execution of the model run. The results require calibration using several parameters mentioned in the methods section. After calibration, the 2019 land use data yielded an NSE of 0.83 and R^2 of 0.92, while the 2024 data showed an NSE of 0.80 and R^2 of 0.93. These results indicate that both outputs are well-calibrated and suitable for further analysis. Thus, for erosion and sedimentation result in both 2019 and 2024 for each land use are:

Table 6. Recapitulation of potential erosion rate values in 2019 and 2024

LULC	Erosion Rate 2019	Erosion Rate 2024
	ton/ha/year	
AGRL	14772.41	47005.25
URBN	0.00	0.00
FRST	20070.79	115754.47

LULC	Erosion Rate 2019	Erosion Rate 2024
	ton/ha/year	
ORCD	24803.22	40723.51
RICE	5238.71	38703.97
WATR	0.00	0.00
Average	10814.19	40364.53

Table 7. Recapitulation of sedimentation in 2019 and 2024

LULC	Sedimentation 2019	Sedimentation 2024
	m^3/year	
AGRL	3313.85	24288.88
URBN	0.00	0.00
FRST	4622.83	176461.00
ORCD	3150.20	51168.61
RICE	2536.60	2772.02
WATR	0.00	0.00
Average	42448.42	67813.93

The results of erosion and sedimentation analysis indicate significant land use changes over five years gives as much effect to the numbers shown. A considerable reduction in forest areas, alongside the expansion of settlements and agriculture, has contributed to increased erosion and sedimentation rates. The loss of natural vegetation reduces the land's ability to retain water and sediment, while urban and agricultural expansion accelerates surface runoff. This result is consistent with findings from Sulfandi et al. (2016) showing strong linkages between deforestation and increased erosion in watersheds. Increased sedimentation potentially accelerates siltation of Jatibarang Reservoir, decreasing water storage capacity and flood control efficiency.

The simulation results showing zero erosion and sediment for residential areas in the SWAT model can be explained by the impervious surface characteristic of urban areas. SWAT calculates sediment using the Modified Universal Soil Loss Equation (MUSLE), which factors in runoff volume, peak flow, and rainfall intensity. However, impervious surfaces like asphalt and concrete in residential areas prevent soil erosion, as there is no exposed soil to be eroded by rainfall or runoff. Despite high surface runoff, erosion and sediment values in these areas are recorded as zero or negligible, consistent with SWAT guidelines that recommend setting erosion and sediment for impervious surfaces to zero. This is supported by Neitsch et al. (2011), who state that impervious surfaces do not contribute to soil erosion. Similarly, Arnold and Fohrer (2005) explain that urban areas with hard surfaces do not produce sediment, and Gassman et al. (2007) emphasize that SWAT assumes no significant erosion in residential areas due to the lack of erodible soil.

3.3 Field-Based Sedimentation Analysis

3.3.1 Suspended Load Analysis

Suspended load was calculated based on the instantaneous method, which involves direct measurement of parameters that affect sediment transport over a short period of time. The instantaneous method is used in accordance with Minister of Forestry Regulation No. 61/2014. This method is used to calculate the sediment discharge carried by water flow in the form of particles that are in the water, not on the riverbed.

Suspended sediment analysis was conducted using the instantaneous method at three sampling points along the Kreo River. The results showed that Point 2 recorded the highest daily sediment transport, reaching 47118.19 m³/year, followed by Points 1 and 3. The total annual suspended sediment load amounted to 215,730 tons/year, or approximately 72542.20 m³/year, indicating the dominance of fine particles carried by streamflow. The detailed results of suspended sediment calculations, including concentrations, flow rates, and point-specific sediment loads, are provided in Supplementary Table S3.These findings highlight the significant role of suspended load in sediment transport and the need for effective erosion control to reduce sediment delivery into downstream reservoirs.

3.3.2 Bed Load Analysis

The Meyer-Peter-Müller (MPM) method analyzes sediment transport by considering flow velocity, sediment texture, and environmental dynamics. It involves sediment sampling, grain size analysis, and measuring flow conditions to understand sediment movement and accumulation.

Results revealed that bed load transport was significantly lower than suspended load, with a total annual bed load of only 7.41 m3/year. This low value reflects the nature of coarser and denser sediment particles that are less easily mobilized by normal river flow and are transported primarily during high-energy flow conditions. Bed load, primarily composed of sand and gravel, has a lower sedimentation yield due to its larger particle size and higher density, which makes it more challenging for water flow to transport. Bed load moves by particles roll, slide, or hop (saltate) along the riverbed without being suspended in the water column, so it can only be carried under strong flow conditions (Van Rijn, 1984). A complete breakdown of bed load transport calculations using the Meyer-Peter-Müller method can be found in Supplementary Table S4.

3.3.3 Total Load Analysis

Combining both suspended and bed load components, the total sediment load in the Kreo River was calculated at 72549.60 m³/year. The analysis confirmed that suspended load accounts for over 99% of the total sediment transported annually, while bed load contributes a minimal fraction. The combined suspended and bed load values across all sampling points are presented in Supplementary Table S5. This dominance of fine sediments emphasizes the importance of surface erosion control measures, particularly vegetative conservation and sustainable land use management, to effectively mitigate sediment yield in the watershed. This also highlights that fine sediments remain in suspension longer and are transported more extensively downstream. The dominance of suspended load over bed load in sediment transport indicates that fine particles are carried more extensively by water flow compared to coarse particles. This is influenced by soil texture and river flow velocity. Fine sediments remain longer in suspension, causing wider sedimentation downstream. This situation signals increased risk of reservoir and river channel siltation, requiring specific conservation approaches to control sediment sources (Van Rijn, 1984).

3.4 Deviation Analysis on Theoretical and Field Sedimentation

In the process of validating the sediment model, it is essential to match the location of field observations with the model outlet. However, in this study, the sediment sampling location was not located right at the outlet of the Sub-watershed previously used in the simulation, as the outlet location was located at a dam that did not allow for sediment sampling. This leads to a potential mismatch between the model results and observational data, making it necessary to adjust the study area for validation purposes.

In an effort to reduce the potential mismatch of the study area for validation, a new catchment area will be established that represents the area that directly contributes to the sediment sampling point in the field. This new catchment area is determined based on topographic and surface flow analyses using GIS software and hydrological models. Once the new catchment area was established, the SWAT model was re-run with the same steps as previously run. The deviation analysis is specifically performed with the re-run SWAT methond with new catchment area in the 2024 data, as it is considered the closest representation of actual conditions.

Table 8. Theoretical and field sediment deviation analysis

Sedimentation		**Deviation Result (%)**	**Criteria**
SWAT (m^3/year)	65859.71	9.21	Good
Field (m^3/year)	72542.20	-	-

A deviation value of % indicates good agreement between SWAT model results and field data, suggesting the model can be trusted for sedimentation prediction in the Kreo Sub-watershed.. Thus, these results are valid and can serve as a reference for conservation planning.

3.5 Erosion Hazard Index

Erosion Hazard Index aims to assess erosion risk and guide land use planning. For a more detailed analysis, the Kreo Sub-watershed is divided into seven sub-basins. In analyzing the Erosion Hazard Index using SWAT, the average erosion value per sub-basin is used due to practical considerations. Mapping SWAT results based on individual HRUs is not feasible for large areas with numerous HRUs, as it would require highly detailed data that is difficult to implement. Using the average erosion per sub-basin provides a more efficient and representative approach, reflecting the overall erosion potential in each watershed segment. This method aligns with practices in hydrological studies, where sub-basin-level aggregation is commonly used for large-scale erosion analysis, as recommended by Gassman et al. (2007). Arnold et al. (2012) also support using aggregated sub-basin data for a more manageable and accurate assessment of erosion across a watershed.

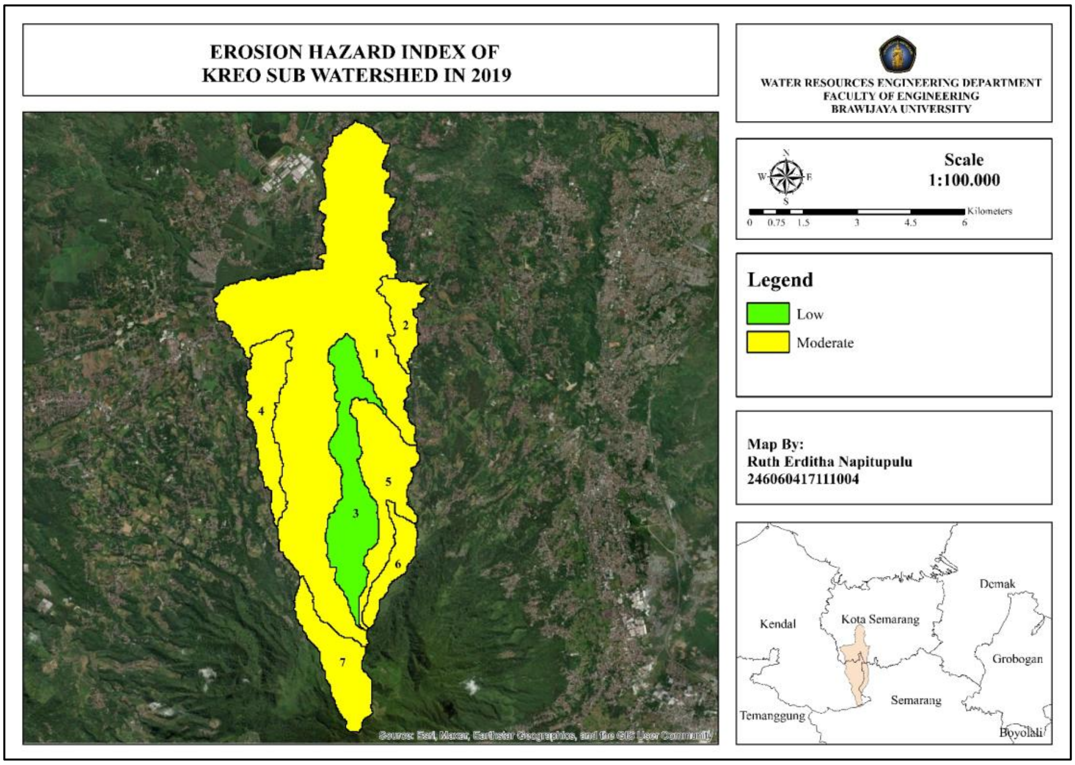

Figure 4. Erosion hazard index in 2019

From the results of the Erosion Hazard Index map for land use in 2019, it can be seen that the Erosion Hazard Index is classified into two categories: low and moderate, with the moderate category dominating 87.4% of the total area, highlighting the vulnerability of the landscape due to reduced vegetation cover and increasing land use pressures. These findings underscore the need for early conservation efforts even in 2019. The full sub-basin-level IBE results for 2019 can be found in Supplementary Table S6.

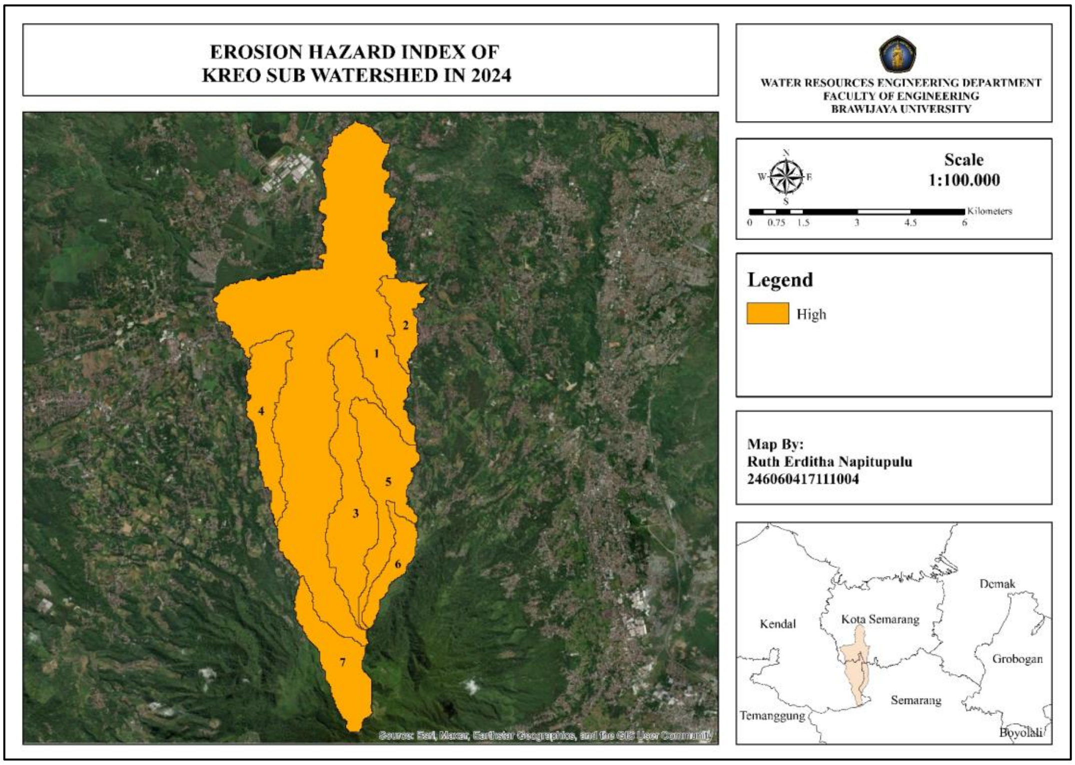

Figure 5. Erosion hazard index in 2024

From the results of the IBE analysis for land use in 2024, it can be seen that the Erosion Hazard Index is classified into only one categories: high, reflecting the compounded effects of forest loss, urban expansion, and agricultural intensification. This marked shift highlights a worsening trend of land degradation that requires urgent and targeted watershed management. Detailed IBE calculations for 2024 are available in Supplementary Table S7.

The predominance of 'High' erosion hazard categories indicates land conditions highly vulnerable to soil degradation. The significant increase in IBE values from 2019 to 2024 reflects the urgency for conservation interventions to prevent further environmental damage. These findings support the urge of conservation and land use management based on area functions, as evidenced by the ARLKT simulations reducing erosion rates.

3.6 Conservation Direction

The 2024 land use data (LULC) indicates a dominant 'Very High' Erosion Hazard Index, reflecting significant levels of erosion and sedimentation in the Kreo Sub-Watershed. This underscores the need for appropriate conservation measures to address these issues and ensure the sustainability of the ecosystem. In response, a new land use simulation based on area functions is proposed.

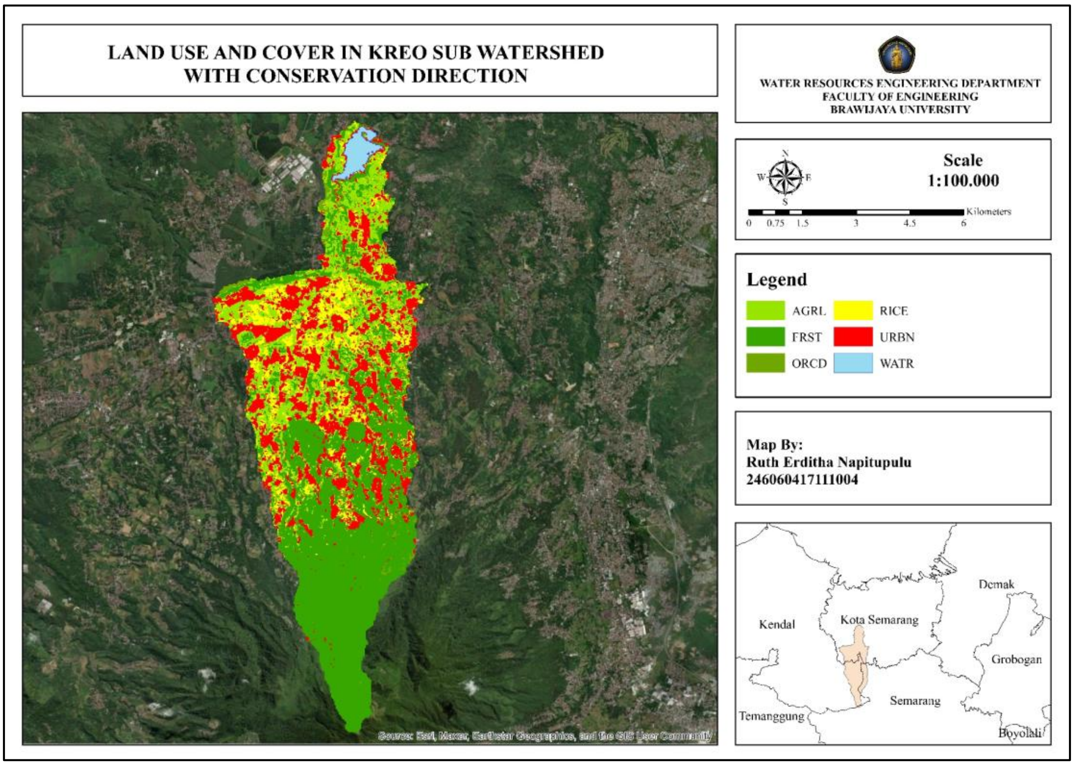

Figure 6. Land use land cover with conservation direction

Table 14. Comparison between land use land cover 2024 with conservation direction

No	LULC	2024		Conservation		Difference (%)
		Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	
1	AGRL	12.20	24.08	10.87	21.47	-2.61
2	URBN	11.21	22.13	11.21	22.13	0.00
3	FRST	18.05	35.64	21.28	42.01	6.37
4	ORCD	3.51	6.93	1.93	3.80	-3.13
5	RICE	4.81	9.50	4.50	8.89	-0.62
6	WATR	0.86	1.71	0.86	1.71	0.00

The application of area functions and ARLKT reveals a 6.37% increase in forest area, primarily targeting steep and very steep slopes. This strategic focus is crucial, as these regions are prone to high erosion rates, emphasizing the importance of enhancing forest cover to mitigate erosion risks effectively. This conservation land use then serves as a basis for conducting erosion and sediment analyses to evaluate the effectiveness of vegetative conservation using ARLKT. The findings from these analyses on the conservation land use revealed:

Table 15. Recapitulation of erosion and sedimentation with coservation direction

LULC	Erosion Rate 2024	Erosion Rate Conservation	Sediment Rate 2024	Sediment Rate Conservation
	ton/ha/year		m^3/year	
AGRL	47005.25	17168,20	24288.88	62422,17
URBN	0.00	0.00	0.00	0.00
FRST	115754.47	41877.08	176461.00	115666.80

LULC	Erosion Rate 2024	Erosion Rate Conservation	Sediment Rate 2024	Sediment Rate Conservation
	ton/ha/year		m³/year	
ORCD	40723.51	14343.77	51168.61	5333.34
RICE	38703.97	50964.20	2772.02	125037.34
WATR	0.00	0.00	0.00	0.00
Total Reduction (%)	**-48.65**		**-24.19**	

The results of the analysis with the LULC conservation showed a good reduction in erosion value, which was 54.58% of the total erosion generated in 2024, but the sedimentation reduction results only showed 35.43% of the total sediment. This highlights the need for targeted strategies to improve sediment control and reinforce the benefits of reduced erosion such as check dams and riverbank reinforcement are also needed to trap finer sediments . The analysis is then continued by determining the Erosion Hazard Index in each sub-basin.

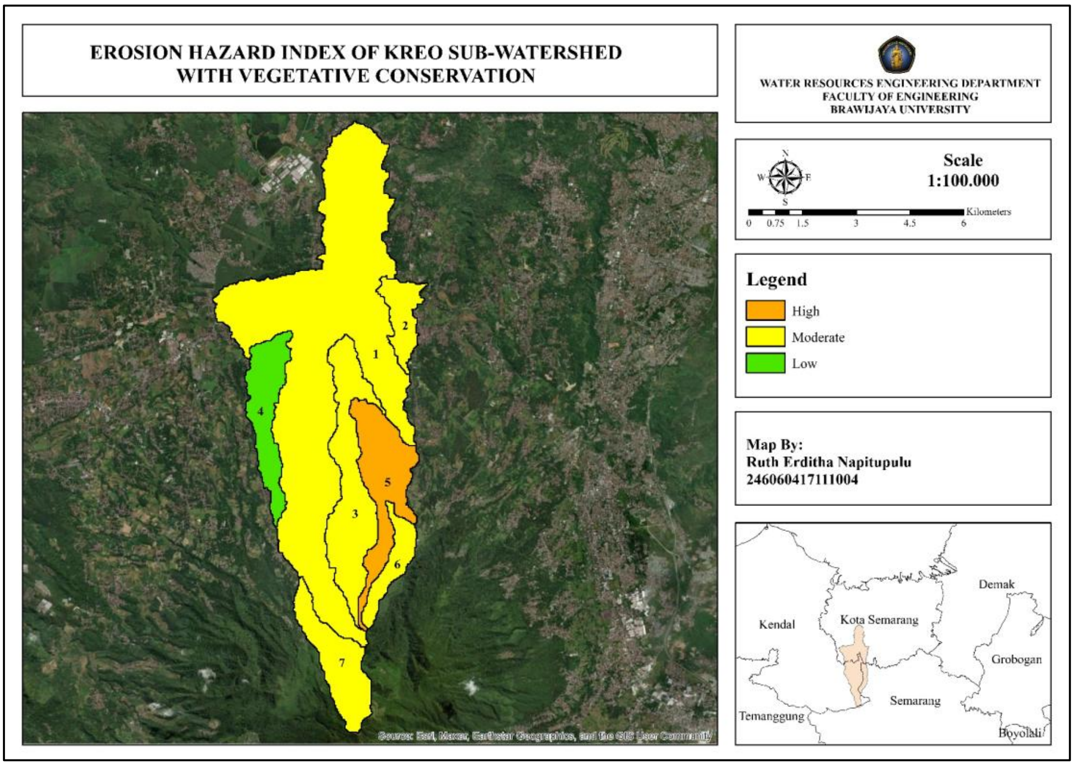

Figure 7. Erosion hazard index with conservation direction

The calculation of the Erosion Hazard Index after implementing conservation measures demonstrates a notable improvement in erosion risk across the Kreo Sub-watershed. Several sub-basins previously categorized as 'High' risk have shifted to 'Moderate' or 'Low' categories, indicating the positive impact of vegetative conservation efforts such as reforestation and land rehabilitation (ARLKT). Erosion Harzard Index after conservation resulting in total 9.56% of the area has a "high" IBE category, followed by a "moderate" category of 83.34%, and a low category with 7.11% of the total area. This reduction is primarily attributed to increased vegetation cover, which enhances soil cohesion and infiltration capacity, thereby decreasing surface runoff and erosion potential. However, spatial variability in the effectiveness of conservation is evident, with some sub-basins still showing moderate to high erosion hazard, likely due to factors such as slope steepness and soil properties. These residual risks highlight the need for integrated conservation strategies, combining vegetative measures with mechanical interventions such as check dams and contour farming. Overall, the decrease in erosion hazard contributes significantly to watershed stability, reduces sediment load to downstream reservoirs, and supports flood mitigation efforts. It is important to note that while model predictions are promising, continuous field monitoring is essential to validate outcomes and refine conservation practices for sustainable watershed management.

4. Conclusions

Significant land use changes in the Kreo Sub-Watershed have escalated erosion and sedimentation risks. SWAT model analysis indicates that erosionand sedimentation have increased rapidly within five years, where 2019 erosion rate is 64885.13ton/ha/year then excalated to 242187.20 ton/ha/year in 2024. Along with increased erosion, sedimentation value in 2019 starting in 254690.51 m^3/year continously increasing to 406883,60 m^3/year in 2024. Erosion Hazard Index also has increased from 'Moderate' in 2019 to 'High' in 2024, driven by forest cover loss (53.22% to 35.64%) and agricultural expansion (6.02% to 24.08%). This land degradation reduces rainfall absorption and sediment retention, contributing up to 30% of Semarang's total flood volume.

Model calibration with field data confirms that deforestation and urbanization intensify surface runoff and sediment transport. The SWAT model, with NSE values of 0.83 (2019) and 0.80 (2024) and R^2 above 0.90, proves reliable in predicting sedimentation trends, making it a valuable tool for conservation planning. Implementing vegetative conservation and Land Rehabilitation and Soil Conservation (ARLKT) strategies significantly reduced erosion by 48.65% and sedimentation by 24.19%, demonstrating their effectiveness in restoring watershed stability. These measures, including reforestation, contour farming, and agroforestry, enhance soil retention and water infiltration, mitigating flood risks. Additionally, land use simulations indicate that increasing vegetation cover can lower the Erosion Hazard Index, reducing overall environmental degradation. However, since sediment reduction was less pronounced, integrating mechanical conservation, such as check dams, sediment traps, and riverbank stabilization, is recommended to further minimize sediment transport. A combined approach is expected to yield more substantial and long-term improvements in watershed resilience and sustainability.

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