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# SPATIAL INTEGRATION FOR ASSESSING LAND CONDITIONS IN THE SILENG SUB WATERSHED, MAGELANG REGENCY

## *INTEGRASI SPASIAL UNTUK PENILAIAN KONDISI LAHAN PADA SUB DAS SILENG, KABUPATEN MAGELANG*

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## ABSTRACT

Land degradation in upland sub-watersheds poses serious threats to environmental sustainability, agricultural productivity, and disaster risk. This study aims to evaluate the land condition of the Sileng Sub-Watershed in Borobudur District, Central Java, using an integrated approach based on four key indicators: erosion index, land cover index, land use suitability, and landslide susceptibility. Field surveys and spatial analyses were conducted in 18 land system units, with supporting data derived from Sentinel-2 imagery and regional spatial planning maps. The results show that 61.1% of land systems are in good condition, 33.3% in fairly good condition, and 5.6% in moderate condition. While erosion risk is generally low, two land systems show critical erosion and landslide susceptibility due to steep slopes and minimal vegetative cover. The high land use suitability (88.36%) indicates strong adherence to spatial planning regulations, while the land cover index (63.71%) suggests moderate vegetation density. Overall, the integrated land condition index highlights both areas of ecological resilience and zones requiring rehabilitation. These findings offer valuable insights for sustainable watershed management and policy formulation, particularly in tropical highland areas vulnerable to land degradation and climate impacts.

***Keywords: Erosion, Land Conditions, Land Cover, Landslide, Landuse***

## ABSTRAK

Degradasi lahan pada sub-DAS di wilayah dataran tinggi menjadi ancaman serius bagi keberlanjutan lingkungan, produktivitas pertanian, dan peningkatan risiko bencana. Penelitian ini bertujuan mengevaluasi kondisi lahan Sub-DAS Sileng di Kecamatan Borobudur, Jawa Tengah, melalui pendekatan terintegrasi berdasarkan empat indikator utama: indeks erosi, indeks penutupan lahan, kesesuaian penggunaan lahan, dan kerentanan terhadap longsor. Survei lapangan dan analisis spasial dilakukan pada 18 satuan sistem lahan, didukung oleh citra Sentinel-2 dan peta rencana tata ruang wilayah. Hasil menunjukkan bahwa 61,1% satuan lahan berada dalam kondisi baik, 33,3% dalam kondisi agak baik, dan 5,6% dalam kondisi sedang. Risiko erosi secara umum rendah, namun dua satuan lahan menunjukkan erosi kritis dan kerentanan longsor tinggi akibat lereng terjal dan tutupan vegetasi yang rendah. Tingginya nilai kesesuaian penggunaan lahan (88,36%) menunjukkan kesesuaian terhadap tata ruang, sementara indeks penutupan lahan (63,71%) mengindikasikan kerapatan vegetasi sedang. Secara keseluruhan, indeks kondisi lahan terintegrasi mengungkapkan zona yang relatif stabil

dan wilayah prioritas untuk rehabilitasi. Temuan ini memberikan kontribusi penting dalam perencanaan pengelolaan DAS yang berkelanjutan, khususnya di daerah dataran tinggi tropis yang rentan terhadap degradasi dan perubahan iklim.

***Kata kunci: Erosi, Kondisi Lahan, Longsor, Penggunaan Lahan, Penutupan Lahan***

## INTRODUCTION

Watersheds are critical ecological units that serve as the primary source of water for agricultural, domestic, industrial, and ecological functions. As integral components of landscape hydrology, watersheds regulate surface water flow, groundwater recharge, and sediment transport (Chomphuwiset et al., 2024; Merlo-Galeazzi et al., 2024). In tropical regions such as Indonesia, watersheds also play a vital role in maintaining biodiversity, supporting rural livelihoods, and mitigating climate-induced disasters including floods and droughts (Wiwoho et al., 2023a). Despite their importance, many watersheds in Indonesia are experiencing significant degradation due to both anthropogenic pressures and natural factors. Unregulated land use, deforestation, poor conservation practices, and agricultural expansion have altered land cover and increased soil erosion, runoff, and landslide risks (M. Chen et al., 2024; Narendra et al., 2021). These changes not only reduce land productivity but also contribute to downstream sedimentation and deteriorating water quality. In particular, sub-watersheds within densely populated regions are highly vulnerable to these impacts.

The Sileng Sub-Watershed, located in Borobudur District of Magelang Regency, Central Java, exemplifies these concerns. As a part of the Progo-Opak-Serayu watershed management unit, this sub-watershed has been affected by land degradation caused by rapid land use change and inadequate conservation measures. Previous assessments from the Serayu Opak Progo Watershed Management Agency reported moderate to high erosion rates, patchy vegetation cover, and increasing susceptibility to landslides. Evaluating land conditions in degraded sub-watersheds is essential for designing effective rehabilitation strategies. One of the most comprehensive approaches to assess land condition is through the integration of multiple indicators, including erosion index, vegetation cover index, land use suitability, and landslide susceptibility (Peraturan Menteri Kehutanan Republik Indonesia, 2009). These indicators provide an evidence-based assessment of ecological function and land management sustainability.

However, studies that holistically evaluate land conditions in small sub-watersheds in Indonesia using such integrated approaches remain limited. Most research has focused on individual indicators, such as erosion modeling or NDVI analysis without linking these to land use planning or landscape vulnerability. Consequently, there is a lack of spatially explicit information that can guide local governments and stakeholders in sustainable watershed management. This study aims to fill that gap by evaluating the current land condition of the Sileng Sub-Watershed through an integrated analysis of erosion risk, vegetation cover, land use compatibility with regional planning, and landslide susceptibility. The findings of this research are expected to support local policymakers in prioritizing conservation efforts and enhancing ecosystem resilience in vulnerable upland areas.

## MATERIALS AND METHODS

This study was conducted in the Sileng Sub-Watershed, located in Borobudur District, Magelang Regency, Central Java Province, Indonesia. The research was carried out in December 2023. The area lies within the Progo–Opak–Serayu watershed management region and has been subject to significant land use changes and ecological degradation.

A field survey method was employed to collect primary data on land characteristics and conditions. Survey points were determined through purposive sampling, based on the distribution of land system units that reflect variability in soil type, land use, and slope classes. A land system map at a scale of 1:40,000 was developed as the basis for delineating the sampling framework. A total of 18 land system units were identified, with one representative sampling point per unit, resulting in 18 observation points across the sub-watershed. The erosion estimation method used is the USLE (Universal Soil Loss Equation) method. The Land Cover Index is calculated based on the area of permanent vegetated land. The Land Use Suitability Indicator is assessed based on several factors and classified into land capability classes. The land vulnerability index to landslides is seen from several factors Based on the Directorate General of RLPS (2009) and Paimin et al. (2010).

## RESULTS AND DISCUSSIONS

A. Erosion Index

The erosion index (EI) for each land system in the Sileng Sub-Watershed was calculated by comparing the estimated soil loss (A) to the permissible soil loss (TSL), as shown in Table 1. The results indicate that out of the 18 land systems evaluated, 16 land systems fall into the "Good" erosion class (EI < 1.6), one is classified as “Moderate” (EI between 1.6–4.5), and one system falls into the “Poor” category (EI > 4.5), suggesting a critical need for soil conservation interventions in that area.

Overall, the average erosion index across the sub-watershed remains within tolerable limits, with the exception of two systems that exceed threshold values. The relatively low erosion risk in most areas can be attributed to the deep solum soils (latosols and podzolics), which are known for their high infiltration capacity and good aggregate stability (Bisolo et al., 2024). These properties enhance soil resistance against raindrop impact and reduce surface runoff (Ma et al., 2022; Zhang et al., 2023).

The high erosion index recorded in unit PmCuLpl is particularly concerning. The combination of steep slopes, intensive land use, and limited vegetation cover in this unit contributes to high surface runoff and low infiltration, intensifying soil detachment and transport. This aligns with findings from similar sub-watersheds in Java, where erosion hotspots are closely linked to slope-agriculture mismatches and poor land management.

Table 1. Erosion Index Classification in Sileng Sub-Watershed

| Land System | A (ton/ha/yr) | *TSL* (ton/ha/yr) | EI | Erosion Class | Score |
|---|---|---|---|---|---|
| HtAcLpl | 2,87 | 2,24 | 1,28 | Good | 1 |
| HtCuLpl | 3,13 | 2,24 | 1,40 | Good | 1 |
| HtDaAck | 0,30 | 2,24 | 0,13 | Good | 1 |
| HtLaLl | 0,53 | 2,24 | 0,24 | Good | 1 |
| HtScLpl | 7,27 | 2,24 | 3,24 | Good | 1 |
| PmAcLl | 50,02 | 4,48 | 11,17 | Good | 1 |

| | | | | | |
|---|---|---|---|---|---|
| PmCuLpl | 642,74 | 4,48 | 143,47 | Good | 5 |
| PmDaAck | 43,17 | 4,48 | 9,64 | Good | 1 |
| PmDaAck | 59,87 | 4,48 | 13,36 | Good | 1 |
| PmLaLl | 47,35 | 4,48 | 10,57 | Good | 1 |
| SwDaAck | 0,26 | 8,89 | 0,03 | Good | 1 |
| SwLaLl | 0,53 | 8,89 | 0,06 | Good | 1 |
| TgAcLl | 31,83 | 2,24 | 14,21 | Good | 1 |
| TgCuLpl | 28,86 | 2,24 | 12,89 | Good | 1 |
| TgDaAck | 3,54 | 4,48 | 0,79 | Good | 1 |
| TgDaAck | 2,20 | 4,48 | 0,49 | Good | 1 |
| TgLaLpl | 7,21 | 4,48 | 1,61 | Good | 1 |
| TgScLpl | 217,82 | 2,24 | 97,24 | Moderate | 3 |

B. Land Cover Index (LCI)

Land cover was analyzed using Sentinel-2 satellite imagery obtained in December 2023, employing the Normalized Difference Vegetation Index (NDVI) to distinguish permanent vegetation from non-vegetated or temporary-covered areas. Based on the analysis, the area of land covered by permanent vegetation in the Sileng Sub-Watershed was approximately 1,944.16 ha, while non-permanent vegetation cover accounted for 1,107.28 ha. With a total sub-watershed area of 3,051.44 ha, the weighted Land Cover Index (LCI) was calculated as follows:

$$LCI = \frac{1.944}{3.051,44} \text{ x } 100\%$$

$$LCI = 63,71\% \text{ (Score 3)}$$

This value is categorized as moderate vegetation cover, corresponding to a score of 3 according to RLPS classification criteria (Peraturan Menteri Kehutanan Republik Indonesia, 2009). The distribution of vegetation is shown in Figure 1. Moderate land cover conditions suggest a partial protection of the soil surface from erosive forces such as rainfall impact and surface runoff. The presence of permanent vegetation plays a crucial role in reducing surface flow, increasing infiltration capacity, and supplying organic matter that enhances soil aggregation (Técher & Berthier, 2023; Wu et al., 2024).

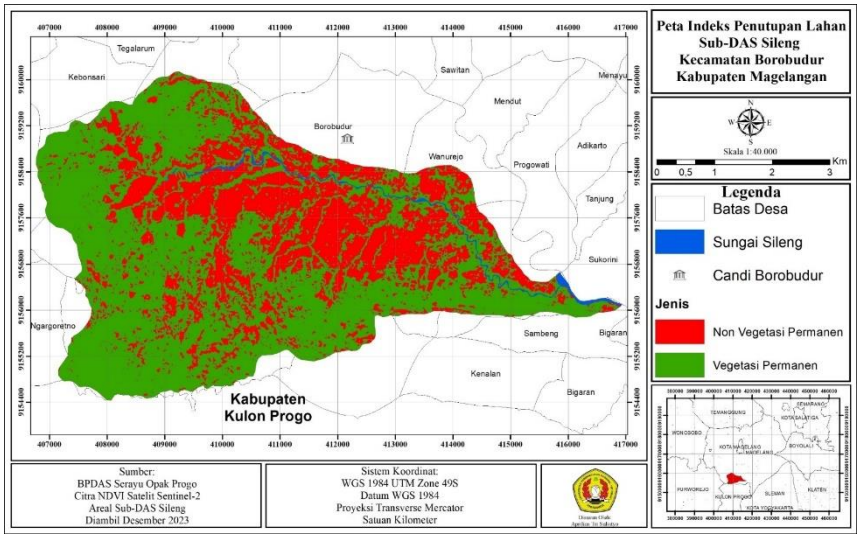


Figure 1. Land cover map

The moderate LCI value implies that although the land retains a substantial portion of vegetative cover, there is still a significant portion vulnerable to erosion, particularly in non-forested or open agricultural zones. Increasing the proportion of

land under permanent vegetation—such as community forest programs or perennial cropping systems, would further enhance land stability and improve watershed health. Spatial analysis also revealed that areas with lower LCI values correspond to zones with higher erosion indices, reinforcing the inverse relationship between vegetation density and erosion risk, a trend consistent with findings from similar tropical watershed studies (Wiwoho et al., 2023b).

C. Land Use Suitability Index (LUSI)

The Land Use Suitability Index (LUSI) was evaluated through spatial overlay analysis between the actual land use map of the Sileng Sub-Watershed and the official Regional Spatial Plan (RTRWK) of Magelang Regency. The objective of this analysis was to assess the extent to which current land uses align with designated conservation and cultivation zones, as per regional land use regulations. The results showed that 2,696.34 hectares (88.36%) of the sub-watershed area were classified as suitable, meaning their current use corresponds with RTRWK designations. In contrast, 355.10 hectares (11.64%) were identified as unsuitable, reflecting a mismatch between current land use and its spatial designation.

$$\text{LUSI} = \frac{2.696,34}{3.051,44} \text{ x } 100\%$$

$$\text{LUSI} = 88,36\% \text{ (Score 1)}$$

According to the Peraturan Menteri Kehutanan Republik Indonesia, (2009) classification, a land use suitability index above 85% is categorized as *Good*, with a score of 1. This suggests that land management in the Sileng Sub-Watershed is, to a large extent, aligned with spatial planning objectives. The high suitability score can be attributed to the relatively well-maintained delineation of land zones in the area, including proper allocation for conservation forests, agricultural land, and settlements. Maintaining this alignment plays a key role in sustaining ecosystem services and preventing land degradation. Several studies have confirmed that congruence between land use planning and actual land utilization significantly reduces environmental risk, particularly in erosion-prone and upland areas (Guo et al., 2024; Nauman et al., 2022).

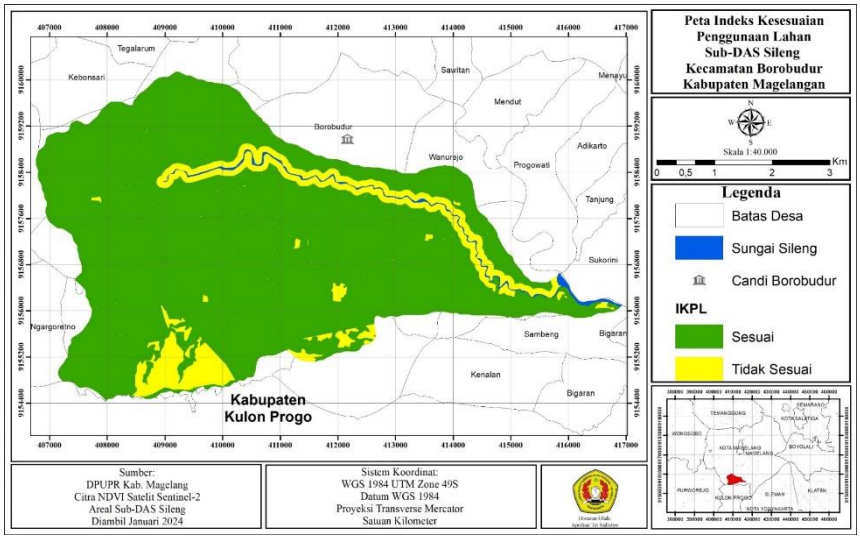


Figure 2. Land suitability map

However, the remaining 11.64% of land categorized as unsuitable use must not be overlooked. These areas often represent encroachment into protected zones or unsustainable agricultural expansion into steep slope areas, which can lead to increased

erosion, biodiversity loss, and elevated landslide risks (Li et al., 2022). Targeted policy enforcement and land rehabilitation in these mismatch zones should be a priority for local authorities. Integrating land use suitability analysis into watershed monitoring provides valuable insights for decision-makers. It bridges the gap between spatial planning and on-the-ground reality, enabling more adaptive and sustainable land resource management (Thoidou, 2021).

D. Landslide Susceptibility Index (LSI)

The Landslide Susceptibility Index (LSI) in the Sileng Sub-Watershed was assessed through a multi-criteria weighted overlay approach, combining biophysical and anthropogenic factors including slope gradient, soil type, land use, vegetation cover, and population density. Each factor was assigned a score and weight based on its relative influence on landslide occurrence. The results of the scoring process of various parameters that affect the level of land vulnerability to landslides and the weighting process based on the predetermined percentages obtained the results that 10 land systems were at a low level of vulnerability, 4 land systems at a moderate level of vulnerability and 4 land systems at a high level of vulnerability. The results of these calculations indicate that the land in the Sileng Sub Watershed is mostly not vulnerable to landslides. This can happen because the majority of land in the Sileng Sub Watershed area has a good level of vegetation density and land conservation measures. Good land management makes the soil more difficult to disperse by rainwater (Xu et al., 2023)

The factor that can trigger an increase in the possibility of landslides is the slope level. The Sileng Sub Watershed area has a slope that varies from flat to very steep. Land on the slopes of the Menoreh hills tends to have a steep to very steep slope. The higher the slope level of the landslide, the greater the possibility of landslides. The existence of faults that are spread across almost all areas of the Sileng Sub Watershed can also increase the potential for landslides. Tectonic forces acting on faults can create lateral pressure on the slope, which will then cause cracks and release of landslide material (Y. Chen et al., 2022; Zheng et al., 2024). Mitigation of the risk of damage due to land mass movement can be done by controlling surface flow, reducing the load on the slope by not building buildings on it and making slope retaining walls.

The results of landslide vulnerability measurements in this study were also compared with landslide incident data at the location. Landslide incident data that occurred in the last 90 days show that the location of the landslide was indeed in a location with a high to moderate level of landslide vulnerability. This indicates the need for improvements in land management that has a high level of landslide vulnerability, to reduce the risk of landslides in the future.

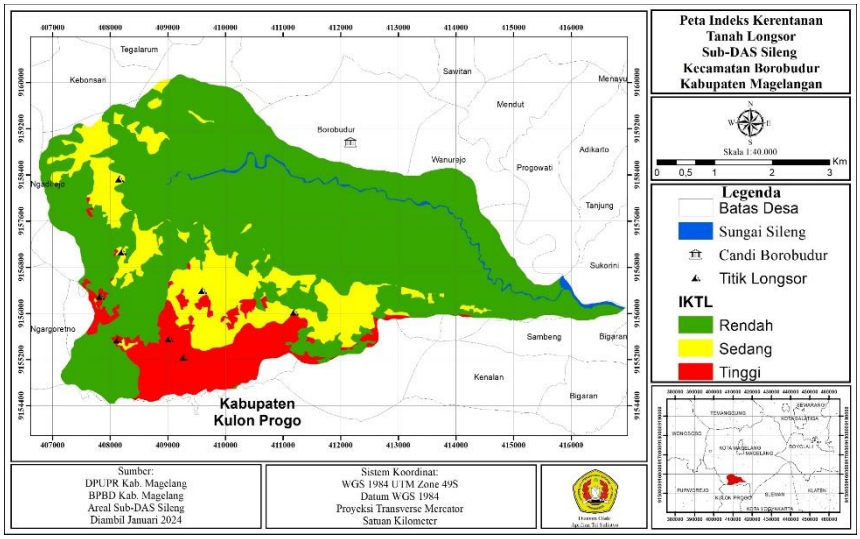

Figure 3. Map of Landslide Susceptibility Index

E. Land Condition Index (LCI)

The overall land condition in the Sileng Sub-Watershed was assessed using a composite index derived from the four primary indicators: Erosion Index (EI), Land Cover Index (LCI), Land Use Suitability Index (LUSI), and Landslide Susceptibility Index (LSI). Each land system unit was assigned a score based on its classification under each indicator, and the final land condition score was obtained by averaging the four component scores for each unit. The results indicate that; (a) 11 land system units (61.1%) are categorized as in Good condition (average score ≤ 1.5); (b) 6 land systems (33.3%) fall into the Fairly Good condition category (average score between 1.6–2.5), (c) 1 land system (5.6%) is classified as in Moderate condition (average score > 2.5–3.5).

These results suggest that, in general, the Sileng Sub-Watershed maintains a relatively healthy land condition status, with the majority of the area demonstrating good ecological functionality. This reflects the cumulative impact of relatively low erosion rates, moderate to high vegetation cover, strong alignment between land use and spatial planning, and low landslide susceptibility in most land systems. Notably, the one land system categorized as in moderate condition (PmCuLpl) corresponds to the same unit identified earlier as having the highest erosion index and high landslide susceptibility, compounded by inadequate vegetative cover. This reinforces the importance of targeting specific land systems with tailored rehabilitation strategies.

The improvement in land condition observed in this study compared to 2020 data is likely due to ongoing rehabilitation efforts initiated in 2021. These efforts included reforestation, agroforestry development, and soil conservation practices such as terracing and vegetative barriers. Such integrated watershed management strategies have proven effective in enhancing soil stability and restoring degraded land. High land cover reflects improving vegetation health (Cai et al., 2022; Y. Chen et al., 2024), while the good level of land use suitability demonstrates compliance with spatial planning, reducing anthropogenic stress. A low LSI further suggests reduced disaster risk, enhancing the overall resilience of the watershed.

Table 2. Land Condition Index in Sileng Sub Watershed

| Land System Unit | Erosion Index Score | Land Cover Index Score | Land Use Suitability Score | Landslide Susceptibility Score | Average Score | Land Condition Class |
|---|---|---|---|---|---|---|
| HtAcLpl | 1 | 3 | 1 | 1 | 1,5 | Good |
| HtCuLpl | 1 | 3 | 1 | 1 | 1,5 | Good |
| HtDaAck | 1 | 3 | 1 | 1 | 1,5 | Good |
| HtLaLl | 1 | 3 | 1 | 1 | 1,5 | Good |
| HtScLpl | 1 | 3 | 1 | 1 | 1,5 | Good |
| PmAcLl | 1 | 3 | 1 | 5 | 2,5 | Fairly good |
| PmCuLpl | 5 | 3 | 1 | 5 | 3,5 | Fairly bad |
| PmDaAck | 1 | 3 | 1 | 1 | 1,5 | Good |
| PmDaAck | 1 | 3 | 1 | 1 | 1,5 | Good |
| PmLaLl | 1 | 3 | 1 | 3 | 2 | Fairly good |
| SwDaAck | 1 | 3 | 1 | 1 | 1,5 | Good |
| SwLaLl | 1 | 3 | 1 | 3 | 2 | Fairly good |
| TgAcLl | 1 | 3 | 1 | 3 | 2 | Fairly good |
| TgCuLpl | 1 | 3 | 1 | 5 | 2,5 | Fairly good |
| TgDaAck | 1 | 3 | 1 | 1 | 1,5 | Good |
| TgDaAck | 1 | 3 | 1 | 1 | 1,5 | Good |
| TgLaLpl | 1 | 3 | 1 | 3 | 2 | Fairly good |
| TgScLpl | 3 | 3 | 1 | 5 | 3 | Fairly good |

## CONCLUSIONS

This study assessed the land condition of the Sileng Sub-Watershed using an integrated indicator-based approach, encompassing erosion index, land cover index, land use suitability, and landslide susceptibility. The findings reveal that the majority of land systems in the watershed are in good ecological condition, supported by low erosion risk, moderate to high permanent vegetation cover, high compliance with spatial planning, and low to moderate landslide vulnerability. One land unit showed moderate degradation, indicating the need for targeted interventions. Improvements in land condition compared to previous assessments suggest that recent rehabilitation efforts, such as vegetative reforestation and land conservation practices, have been effective. The integration of spatial and field-based indicators proved valuable in diagnosing land health and identifying priority areas for management. These findings contribute to the broader understanding of land degradation dynamics in tropical upland watersheds and offer practical insights for watershed planning and restoration policies. Future research should incorporate temporal monitoring and climate resilience parameters to further support sustainable land management strategies in similar environments.

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