

## Assessing Land-Use Driven Soil Degradation Potential and Biomass Production Dynamics in the Corogrojong Sub Sub-Watershed, Malang, Indonesia

Shofie Rindi Nurhutami<sup>1\*</sup>, Muchammad Bima Gegana Sakti<sup>2</sup>, Zenny Faridatus Sa'diyah<sup>3</sup>

<sup>1</sup> Agrotechnology Study Program, Faculty of Agriculture, Universitas Pembangunan Nasional “Veteran” Jawa Timur, Surabaya, Indonesia

<sup>2</sup> Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Arabia

<sup>3</sup> Agrotechnology Study Program, Faculty of Technology and Engineering, Universitas Sunan Gresik, Gresik, Indonesia

\*Correspondence author email: [shofie\\_rindi.agrotek@upnjatim.ac.id](mailto:shofie_rindi.agrotek@upnjatim.ac.id)

### Article Information

Received October 07<sup>th</sup> 2025

Accepted January 03<sup>rd</sup> 2026

Published January 29<sup>th</sup> 2026

Online January 29<sup>th</sup> 2026

### Keywords:

Agroforestry; Biophysical factors; GIS weighted overlay; Soil degradation; Watershed management

### Abstract

Soil degradation poses a critical threat to agriculture and ecosystem sustainability in tropical watersheds. This study focuses on the Corogrojong Sub-Sub-Watershed, located in Indonesia's Upper Brantas Basin, to assess soil degradation potential using GIS-based analysis combined with biophysical parameters such as land use, slope gradient, annual rainfall, and soil type. A weighted overlay method was applied to map soil degradation potential and recommend mitigation strategies for sustainable biomass production. The findings show that only 9.9% (59.06 ha) of the area is classified as having very low degradation potential, while the remaining 90.1% falls under low to moderate potential, with low-potential areas covering 39.7% (235.69 ha) and moderate-potential areas 50.4% (299.37 ha). Despite the challenging terrain—where steep slopes (>40%) cover 46% of the area and highly erodible Andisols dominate 77.7%—the presence of agroforestry and forest systems significantly reduces degradation potential. However, this balance remains fragile, as the watershed's stability relies on the preservation of these systems. Any loss of green cover due to land conversion could lead to extensive soil degradation. To mitigate this, the study proposes a zonal approach: active conservation efforts, including terracing, vetiver grass planting, and riparian filter strips in moderate-potential zones, and incentive-based mechanisms, such as Payment for Ecosystem Services (PES), in lower-potential areas to prevent land-use change. This study provides based for sustainable land management policies that harmonize agricultural development with ecosystem protection in the Upper Brantas Basin.

### 1. Introduction

The upstream regions of Java Island face serious threats of soil degradation driven by development pressures, agricultural intensification, and increasing energy demands. The shift in land use from forest to intensive agriculture has been proven to accelerate soil degradation by altering the soil's physical, chemical, and biological properties (Salvati et al., 2015; Azis et al., 2021). This degradation can manifest as soil erosion, salinization, pollution, desertification, waterlogging, and other forms, which directly impact biomass productivity and ecosystem functions (Adhikari and Hartemink, 2016; Lestariningsih et al., 2018; Yadav et al., 2022). Globally, approximately 20% of forest land, 30% of cropland, and 10% of grassland have experienced soil degradation

(Nkonya et al., 2016). Furthermore, Wan et al. (2022), Zhang et al. (2022), and Gao et al. (2025) emphasize that land-use change can exacerbate erosion, with soil loss rates up to 75 times higher than those in natural forests, potentially reducing crop yields by up to 50%. This situation threatens the sustainable supply of biomass due to uncontrolled declines in soil productivity.

Previous studies have indicated that the Upper Brantas Sub-Watershed has a very high erosion rate, with an erosion hazard index of 94.12% and a sedimentation rate reaching 22.97 mm year<sup>-1</sup> (Pratama et al., 2024; Rosidin et al., 2024). The Corogrojong Sub-Sub-Watershed, part of the Upper Brantas system in Malang Regency, is also susceptible to severe soil degradation due to land-use changes and management practices that often overlook conservation principles. This condition directly affects biomass production capacity, carbon storage, and ecosystem resilience, while also exacerbating the risks of flooding, sedimentation, and environmental degradation in downstream areas (Harini, 2015; Wiwoho et al., 2024).

Geographic Information Systems (GIS) offer a practical spatial approach for mapping the potential for soil degradation (Edwin et al., 2023; Chaaou et al., 2024; Hakim et al., 2024; Kaewlom et al., 2025). By integrating biophysical data such as slope, rainfall, soil type, and land use, GIS can accurately identify areas most vulnerable to degradation (Qurrahman et al., 2016; Sukwika and Firmansyah, 2020; Sumarsono et al., 2022; Alim et al., 2023). Its approach has proven effective in supporting conservation decision-making and watershed governance in various regions of Indonesia (Widiatiningsih et al., 2018; Azis et al., 2021; Mujiyo et al., 2022; Istiqomah et al., 2023; Putra et al., 2025). The application of GIS in this research provides a significant contribution by linking soil degradation analysis with strategies for sustainable biomass production. This area remains underexplored at the Sub-Sub-Watershed level.

Based on these conditions, this study is directed to: (1) identify and map the potential for soil degradation under various land uses in the Corogrojong Sub-Sub-Watershed using a GIS approach; and (2) recommend strategic measures for mitigating soil degradation to support sustainable biomass production in the Corogrojong Sub-Sub-Watershed. The findings of this research are expected to provide a scientific basis for formulating policies and landscape management strategies oriented towards sustainable agricultural productivity and the conservation of ecosystem functions in the Upper Brantas Watershed.

## 2. Research Methods

### 2.1. Research Location

This research was conducted in the Corogrojong Sub-Sub-Watershed, located in the Pujon District, Malang Regency, East Java, Indonesia. The study area is geographically situated between 112°27'03.7" to 112°29'55.9" East Longitude and 7°46'01.7" to 7°50'55" South Latitude, covering a total area of 594.12 hectares. Administratively, the region encompasses three villages: Ngroto, Madiredo, and Wiyurejo (Figure 1).

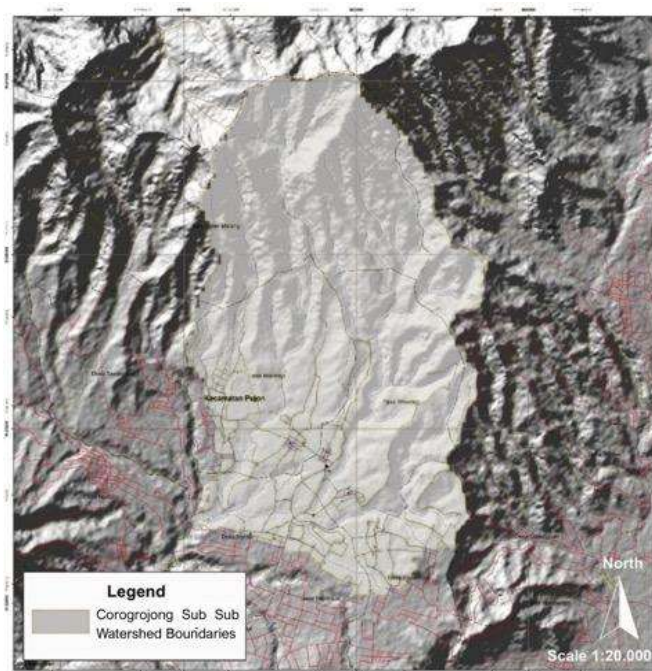


Figure 1. Research location

## 2.2. Research Implementation

This study employed a quantitative descriptive approach to assess the potential for soil degradation using a GIS. The evaluation was conducted in accordance with Indonesian Government Regulation No. 150 of 2000 and Indonesian Minister of Environment Regulation No. 7 of 2006. The methodology involved a weighted overlay and scoring of four thematic maps (land use, slope, rainfall, and soil type) using ArcMap 10.7, based on secondary data sources. The land use map was interpreted from Landsat 8 OLI (August 2024) using PCI Geomatica 2013. The slope map was generated from the National DEM (DEMNAS) provided by the Geospatial Information Agency (BIG). The rainfall map was produced by interpolating data collected from ten rainfall stations (Bareng, Kasembon, Pengajaran, Sekar, Ngantang, Wonosalam, Kedungrejo, Pujon, Ngaglik, and Junggo) between 2014 and 2024 using the Spline method. The soil type map was obtained from the Center for Agricultural Land Resources.

## 2.3. Data Analysis

### 2.3.1. Parameter Analysis

Each parameter was assigned a rating and an index to assess its contribution to soil degradation. Higher scores indicate a greater potential for degradation. The "Rating" refers to the degree of risk associated with each parameter category, ranging from 1 (very low) to 5 (very high). The "Index" represents the relative weight or importance of a parameter in influencing degradation (values 2–3). The "Score Range" is obtained by multiplying the rating by the index. The "Degradation Potential" describes the final interpretation of soil vulnerability based on the score. For example, bare land with a rating of 5 and an index of 2 yields a score of 10, indicating a very high potential for degradation. Conversely, forest areas with dense vegetation have a low rating (1) and thus have a very low potential for degradation. A summary is presented in Table 1.

Table 1. Soil degradation parameters and scoring

| Parameter                                       | Category                                | Rating | Index | Score<br>(Rating X Index) | Degradation<br>Potential |
|-------------------------------------------------|-----------------------------------------|--------|-------|---------------------------|--------------------------|
| Land use                                        | Forest                                  | 1      | 2     | 2                         | Very Low                 |
|                                                 | Paddy Field                             | 1      | 2     | 2                         | Very Low                 |
|                                                 | Alang Alang Grassland                   | 1      | 2     | 2                         | Very Low                 |
|                                                 | Agroforestry                            | 2      | 2     | 4                         | Low                      |
|                                                 | Shrubs                                  | 2      | 2     | 4                         | Low                      |
|                                                 | Grassland                               | 2      | 2     | 4                         | Low                      |
|                                                 | Shifting Cultivation                    | 3      | 2     | 6                         | Moderate                 |
|                                                 | Dry Land Farming                        | 4      | 2     | 8                         | High                     |
|                                                 | Bare Land                               | 5      | 2     | 10                        | Very High                |
| Slope<br>Gradient                               | 0-3 %                                   | 1      | 3     | 3                         | Very Low                 |
|                                                 | 3-8 %                                   | 1      | 3     | 3                         | Low                      |
|                                                 | 8-15 %                                  | 2      | 3     | 6                         | Moderate                 |
|                                                 | 15-25 %                                 | 3      | 3     | 9                         | High                     |
|                                                 | 25-40 %                                 | 4      | 3     | 12                        | Very High                |
|                                                 | 40-60 %                                 | 5      | 3     | 15                        | Very High                |
|                                                 | >60 %                                   | 5      | 3     | 15                        | Very High                |
| Annual<br>Rainfall<br>(mm. year <sup>-1</sup> ) | <1000                                   | 1      | 3     | 3                         | Very Low                 |
|                                                 | 1000-2000                               | 2      | 3     | 6                         | Low                      |
|                                                 | 2000-3000                               | 3      | 3     | 9                         | Moderate                 |
|                                                 | 3000-4000                               | 4      | 3     | 12                        | High                     |
|                                                 | >4000                                   | 5      | 3     | 15                        | Very High                |
| Soil Type                                       | Vertisols with an aquic moisture regime | 1      | 2     | 2                         | Very Low                 |
|                                                 | Oxisols                                 | 2      | 2     | 4                         | Low                      |
|                                                 | Alfisols                                | 3      | 2     | 6                         | Moderate                 |
|                                                 | Mollisols                               | 3      | 2     | 6                         | Moderate                 |
|                                                 | Ultisols                                | 3      | 2     | 6                         | Moderate                 |
|                                                 | Inceptisols                             | 4      | 2     | 8                         | High                     |
|                                                 | Entisols                                | 4      | 2     | 8                         | High                     |
|                                                 | Histosols                               | 4      | 2     | 8                         | High                     |
|                                                 | Spodosols                               | 5      | 2     | 10                        | Very High                |
|                                                 | Andisols                                | 5      | 2     | 10                        | Very High                |

### 2.3.2. Weighted Overlay and Determination of Soil Degradation Potential

The four thematic maps were integrated to create a Soil Degradation Potential Map. The classification is as follows: a higher total score (45–50) indicates a very high susceptibility to degradation, whereas a lower score (<15) denotes regions with a very low soil degradation potential (Table 2).

Table 2. Soil degradation potential classification

| No. | Degradation Potential | Total Score |
|-----|-----------------------|-------------|
| 1.  | Very Low              | <15         |
| 2.  | Low                   | 15-24       |
| 3.  | Moderate              | 25-34       |
| 4.  | High                  | 35-44       |
| 5.  | Very High             | 45-50       |

## 3. Results and Discussion

### 3.1. Result

#### 3.1.1. Land Use, Slope Gradient, Rainfall Annual and Soil Type

The assessment of soil degradation potential was based on four key parameters: land use, slope gradient, annual rainfall, and soil type, as detailed in Table 3 and Figure 2.

Table 3. Land use, slope gradient, annual rainfall, and soil type analysis

| Parameters                                  |                 | Area   |      | Rating | Index | Score (Rating X Index) | Degradation Potential |
|---------------------------------------------|-----------------|--------|------|--------|-------|------------------------|-----------------------|
|                                             |                 | ha     | %    |        |       |                        |                       |
| Land Use                                    | Forest          | 152.22 | 26   | 2      | 1     | 2                      | Very Low              |
|                                             | Agroforestry    | 223.34 | 38   | 2      | 2     | 4                      | Low                   |
|                                             | Bare Land       | 9.98   | 2    | 2      | 5     | 10                     | Very High             |
|                                             | Dryland Farming | 94.19  | 16   | 2      | 4     | 8                      | High                  |
|                                             | Settlement*     | 20.56  | 3    | -      | -     | -                      | -                     |
|                                             | Shrubland       | 93.83  | 16   | 2      | 2     | 4                      | Low                   |
| Slope Gradient                              | 0-3 %           | 30.34  | 5    | 1      | 3     | 3                      | Very Low              |
|                                             | 3-8 %           | 40.95  | 7    | 1      | 3     | 3                      | Low                   |
|                                             | 8-15 %          | 59.41  | 10   | 2      | 3     | 6                      | Moderate              |
|                                             | 15-25 %         | 83.18  | 14   | 3      | 3     | 9                      | High                  |
|                                             | 25-40 %         | 106.94 | 18   | 4      | 3     | 12                     | Very High             |
|                                             | 40-60 %         | 130.71 | 22   | 5      | 3     | 15                     | Very High             |
|                                             | >60 %           | 142.59 | 24   | 5      | 3     | 15                     | Very High             |
| Rain Fall Annual (mm. years <sup>-1</sup> ) | 1000-2000       | 594.12 | 100  | 2      | 3     | 6                      | Low                   |
| Soil Type                                   | Ultisols        | 132.17 | 22.3 | 3      | 2     | 6                      | Moderate              |
|                                             | Andisols        | 461.95 | 77.7 | 5      | 2     | 10                     | Very High             |

Notes: \* Settlement areas were not scored as they are non-agricultural land uses

Spatial and quantitative assessment (Table 3, Figure 2a) reveals that agroforestry (38%) and forest (26%) are the dominant land covers in the Corogrojong Sub-Watershed, encompassing approximately 375.56 hectares distributed across the northern and central regions. These two land cover types exhibit a very low to low potential for soil degradation. In contrast, dryland agriculture (16%) and open land (2%), which are concentrated in the southern and southeastern areas, demonstrate high to very high degradation potential. It is attributed to intensive cultivation practices, sparse vegetation, and increased surface runoff. Meanwhile, shrubland (16%) presents a low degradation potential, and settlement areas (3%) were excluded from the analysis as they constitute non-agricultural categories.

The analysis of slope gradient in the Corogrojong Sub-Watershed (Table 3, Figure 2b) indicates a highly variable topography, with slopes ranging from 0% to over 60%. Approximately 46% of the area in the northern and northeastern parts is characterized by steep to very steep slopes, which have a high potential for soil degradation. Moderately sloping terrain, covering approximately 24% of the area, exhibits moderate to high degradation potential. In contrast, gentle slopes, which constitute only 12% of the area, display low degradation potential due to relatively stable soil conditions. This spatial pattern indicates that steeper slopes are associated with a higher risk of soil degradation due to increased surface runoff and erosion.

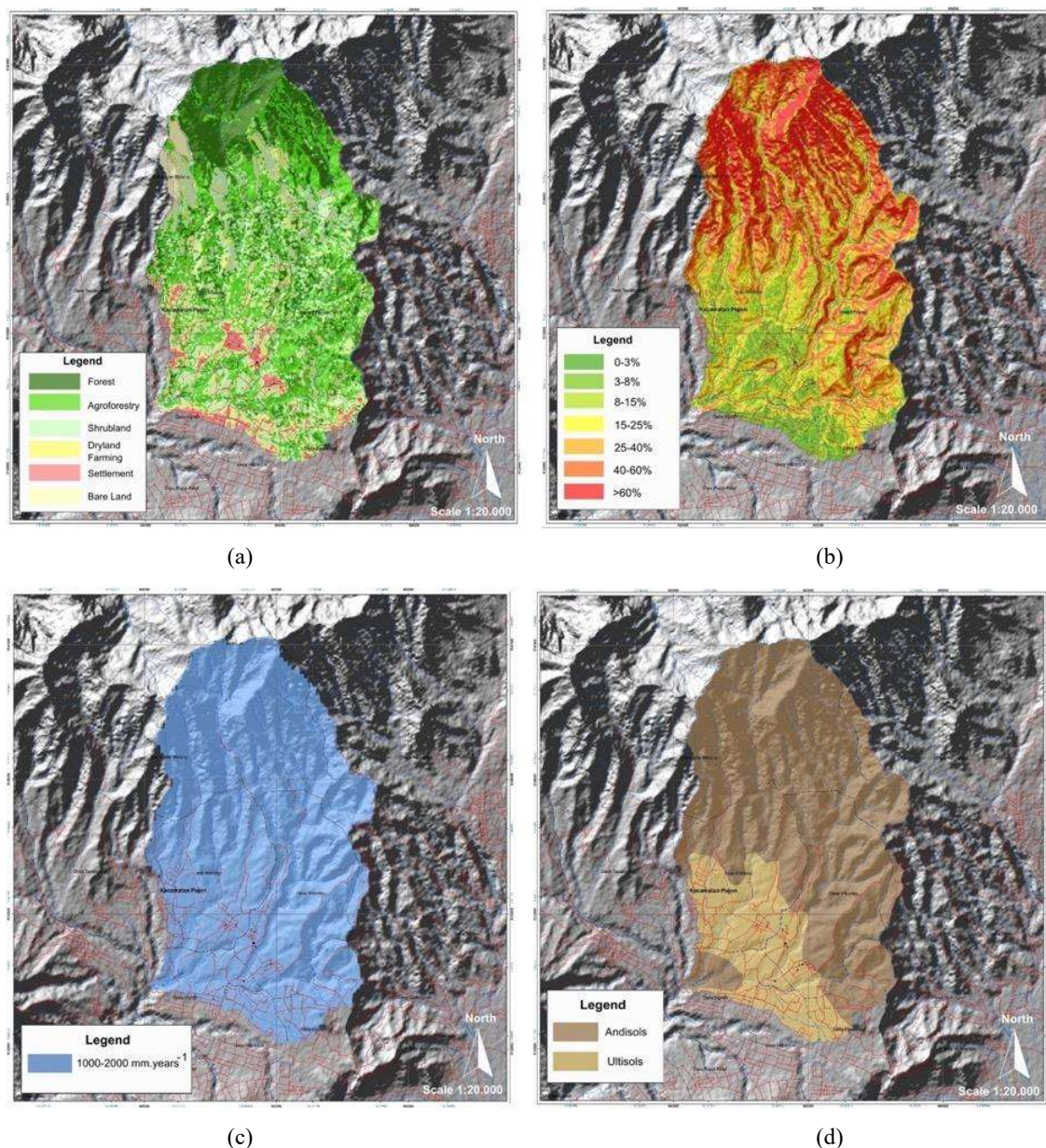


Figure 2. (a) Land use, (b) Slope gradient, (c) Annual rainfall, and (d) Soil type map of Corogrojong Sub-Sub Watershed

Climatic conditions and soil type further determine the susceptibility of the land to degradation in the Corogrojong Sub-Watershed. The region experiences moderate annual rainfall, ranging from 1,000 to 2,000 mm (Table 3, Figure 2c), resulting in a currently low degradation potential from this factor. From a pedological perspective, the Corogrojong Sub-Watershed, formed from the volcanic materials of Mount Anjasmoro, is dominated by Andisols (77.7%), distributed in the northern and central parts, and Ultisols (22.3%) in the southern part (Table 3, Figure 2d).

### 3.1.2. Corogrojong Sub-Sub-Watershed Soil Degradation Potential

Most of the Corogrojong Sub-Sub-Watershed was classified as having moderate potential for degradation, covering 299.37 ha (50.4%) of the total area (Table 4 and Figure 3). Areas with low degradation potential accounted for 235.69 ha (39.7%), indicating that a portion of the watershed maintained relatively stable soil conditions with minimal signs of degradation. The very low degradation category, representing the smallest portion of the watershed with the least risk, comprised 59.06 ha (9.9%).

Table 4. Soil degradation potential in Corogrojong Sub-Sub Watershed

| No. | Degradation Potential | Area          |            |
|-----|-----------------------|---------------|------------|
|     |                       | Ha            | %          |
| 1.  | Very Low              | 59.06         | 9.9        |
| 2.  | Low                   | 235.69        | 39.7       |
| 3.  | Moderate              | 299.37        | 50.4       |
|     | <b>Total</b>          | <b>594.12</b> | <b>100</b> |

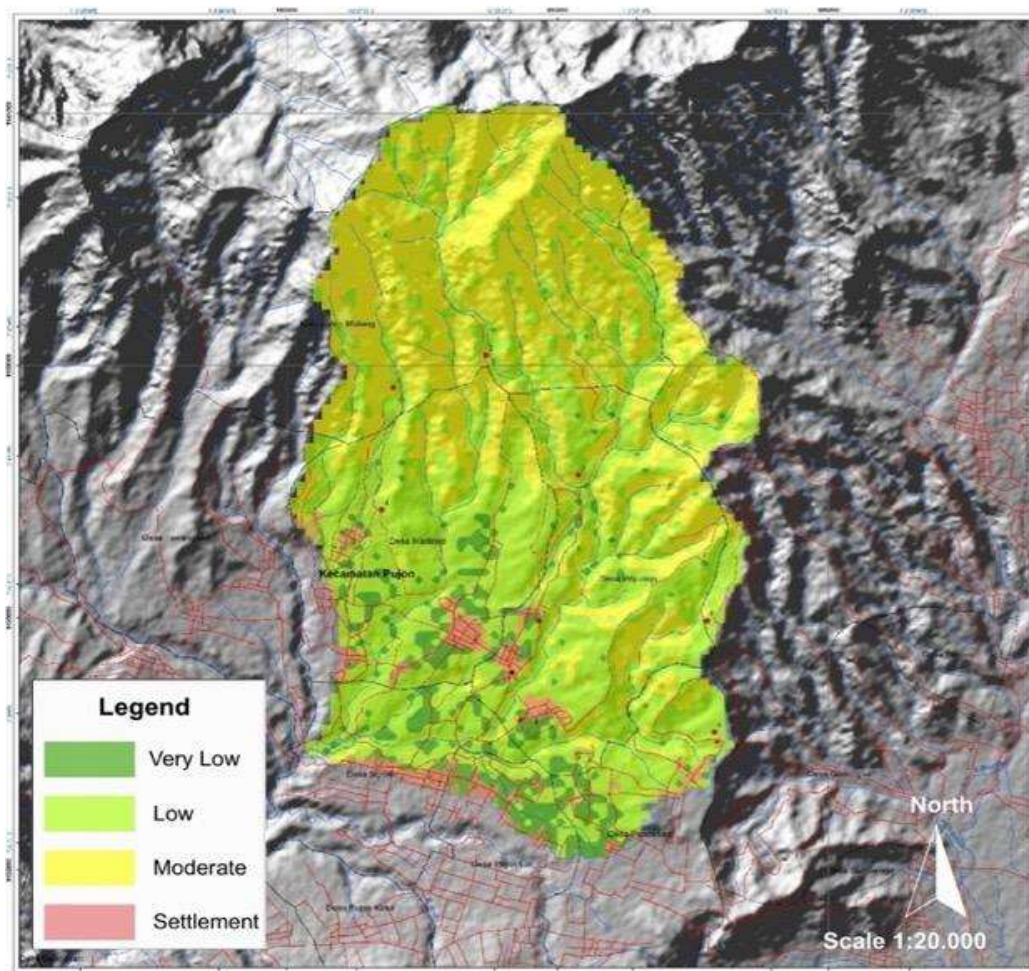


Figure 3. Spatial mapping of soil degradation potential in the Corogrojong Sub-Sub-Watershed

### 3.2. Discussion

More than half of the Corogrojong Sub-Sub Watershed had a moderate potential for soil degradation for biomass production (Figure 3). This spatial pattern indicates that the combination of land cover, topography, climate, and soil type is the primary factor determining a land's susceptibility to degradation. The highest risk was identified in the southern region, which is characterized by steep slopes and open agricultural systems. In contrast, the northern and central areas are relatively more stable because of the prevalence of agroforestry (38%) and forests (26%), which serve as natural protective covers against soil erosion. These findings align with those of Fahad et al. (2022) and Marques et al. (2022), which suggest that forests and agroforestry systems act as ecological buffers against land degradation, as evidenced by their very low degradation potential values. Dense canopy vegetation dissipates the kinetic energy of rainfall, reduces surface runoff, and enhances water infiltration into soil. Consequently, forests and agroforestry systems exhibit higher soil stability and lower erodibility than dryland agricultural areas. This result is supported by Chofyan and Andriani (2020), who state that erosion rates in agroforestry lands are significantly lower than those in plantation and dryland farming systems. Conversely, drylands and open areas in the southern and southeastern regions showed high to very high degradation levels owing to sparse vegetative

cover and intensive cultivation practices. This condition is exacerbated by the application of conventional farming systems that have not integrated soil conservation principles, thereby accelerated erosion processes and led to a decline in nutrients, organic matter, and biodiversity (Minasny et al., 2017; Tahat et al., 2020; Cárceles Rodríguez et al., 2022; Dewi and Nurhutami, 2023).

Topography plays a crucial role in exacerbating soil degradation. Approximately 46% of the Corogrojong sub-sub-watershed is characterized by steep to very steep slopes, which increases the risk of topsoil loss. Setyawan et al. (2019) and Kumar et al. (2022) demonstrated that the slope gradient is a dominant factor accelerating erosion, particularly in areas with limited vegetation cover. This finding is consistent with Adhikari and Hartemink (2016) and Rosidin et al. (2024), who found that land with slopes exceeding 25% is highly vulnerable to organic matter loss and decreased biomass productivity. Climatic factors also warrant consideration, although the annual rainfall in this region is classified as moderate (1,000–2,000 mm year<sup>-1</sup>). Mandal and Roy (2024) warned that increasing rainfall intensity due to climate change has the potential to accelerate future erosion and nutrient loss.

Furthermore, soil characteristics influence vulnerability to degradation. Andisols, which dominate the northern and central regions, have a loose, highly porous physical structure, making them susceptible to erosion by surface runoff. Chemically, these soils exhibit a high phosphorus (P) fixation capacity due to their high aluminum (Al) and iron (Fe) content, coupled with a low cation exchange capacity (CEC), which collectively limits nutrient availability (Juarti, 2016; Suyana et al., 2019). Meanwhile, Ultisols, distributed in the southern part, show a more controlled degradation potential but are inherently low in fertility. These soils are acidic, with high levels of Al, Fe, and Mn, strong P adsorption capacity, and low organic carbon content and CEC, which cumulatively restrict the availability of essential nutrients, such as N, P, K, Ca, Mg, and Mo (Taisa et al., 2019; Purwanto et al., 2021).

In general, the current potential for land degradation in the Corogrojong sub-watershed is classified as moderate. However, this condition cannot be overlooked as it has the potential to worsen without appropriate preventive and restorative measures. Without planned mitigation efforts, ongoing degradation will reduce the soil's capacity to support biomass production and threaten the sustainability of its ecological functions. In the long term, this situation will pose a serious obstacle to achieving sustainable development goals at both the national and global levels. Nationally, land degradation has the potential to hinder the achievement of the second National Development Priority, which focuses on strengthening food, energy, and water security, as well as developing green and blue economies (Wisnubroto et al., 2024). Globally, uncontrolled land degradation threatens the achievement of Sustainable Development Goal (SDG) 15, which concerns the protection and restoration of terrestrial ecosystems, and SDG 13, which emphasizes climate action through adaptive and sustainable land management.

Integrated mitigation, control, and rehabilitation strategies are crucial for sustaining biomass production and ensuring the long-term stability of the Corogrojong Sub-Sub-Watershed ecosystem. Mitigation efforts should be prioritized through a zonal approach based on degradation potential. In the moderate-risk zone (50.4% of the area), characterized by dryland agriculture on slopes of 25–40%, active conservation interventions are crucial. Vegetative measures, such as riparian filter strips, can effectively reduce surface runoff, erosion, and nutrient loss, thereby improve soil stability and maintain productivity (Satriawan et al., 2017). Meanwhile, in the low-risk zone (49.6% of the area), which is mainly under agroforestry, preventing land-use conversion is key. Incentive-based mechanisms that integrate conservation goals with local livelihood needs have been shown to sustain behavioral changes even after financial support ceases, indicating the importance of aligning ecosystem service schemes with community values (Hayes et al., 2021).

From a technical standpoint, management actions must address site-specific vulnerabilities. For Andisols (77.7% of the area), the application of organic matter and selective liming improves aggregate stability and reduces phosphorus fixation (Suyana et al., 2019). On steep slopes (>40%), controlled drainage systems and the planting of vetiver grass (*Chrysopogon zizanioides*) can reinforce terraces and minimize erosion (Sriwati et al., 2018). The long-term success of these interventions relies on integrating spatial vulnerability mapping with strong local institutions and participatory governance. Strengthening spatial planning, fostering market-based incentives, and expanding agroforestry systems are therefore vital to secure the sustainable management of the Corogrojong watershed.

#### 4. Conclusion

The Corogrojong Sub Sub Watershed has very low to moderate soil degradation potential but is increasingly susceptible to stress. It necessitates zonal management strategies aligned with SDGs 13 and 15, which focus on climate adaptation, land productivity, and ecosystem integrity. Low-risk zones should utilize ecosystem service incentives to preserve vegetation and enhance carbon sequestration. In contrast, moderate-risk zones require the integration of vegetative and civil engineering techniques to prevent erosion. This targeted approach aligns with Indonesia's Asta Cita vision and is crucial for ensuring that soil ecosystems continue to support local livelihoods and long-term watershed stability.

## References

- Adhikari, K., Hartemink, A.E. 2016. Linking soils to ecosystem services — a global review. *Geoderma* 262, 101–111. <https://doi.org/10.1016/j.geoderma.2015.08.009>
- Alim, S., Munawar, A., Mulyanto, D. 2023. Status kerusakan tanah untuk produksi biomassa pada lahan bekas galian industri batu bata. *Jurnal Tanah dan Air* 19(1), 1–14. <https://doi.org/10.31315/jta.v19i1.9460>
- Azis, A.A.A., Mujiyo, Cahyono, O. 2021. Mapping of soil degradation potential in Nnguntoronadi District Wonogiri Regency. *IOP Conference Series: Earth and Environmental Science* 905(1), 012085. <https://doi.org/10.1088/1755-1315/905/1/012085>
- Cárceles Rodríguez, B., Durán-Zuazo, V.H., Soriano Rodríguez, M., García-Tejero, I.F., Gálvez Ruiz, B., Cuadros Tavera, S. 2022. Conservation agriculture as a sustainable system for soil health: a review. *Soil Systems*, 6(4), 87. <https://doi.org/10.3390/soilsystems6040087>
- Chaaou, A., Chikhaoui, M., Naimi, M., Miad, A.K.El, Bokoye, A.I., Ennasr, M.S., Harche, S.EI. 2024. Potential of land degradation index for soil salinity mapping in irrigated agricultural land in a semi-arid region using landsat-oli and sentinel-msi data. *Environmental Monitoring and Assessment* 196(9), 843. <https://doi.org/10.1007/s10661-024-13030-1>
- Chofyan, I., Andriani, D.I. 2020. Soil erosion in agroforestry development in south bandung region, indonesia. *Journal of Physics: Conference Series*, 1469(1), 012122. <https://doi.org/10.1088/1742-6596/1469/1/012122>
- Dewi, W.S., Nurhutami, S.R. 2023. Carbon farming in paddy soil to increase soil C and soil health as an implementation of soil carbon 4 per mille. 8th International Conference on Climate Change 1165(1), 1–10. <https://doi.org/10.1088/1755-1315/1165/1/012023>
- Edwin, M., Suptrapti, H., Sulistyorini, I.S., Aliri, A. 2023. Potensi dan status kerusakan tanah untuk produksi biomassa di Kabupaten Kutai Timur (studi kasus Kecamatan Long Masangat, Batu Ampar dan Rantau Pulung). *Jurnal Tanah dan Sumberdaya Lahan*, 10(1), 1–13. <https://doi.org/10.21776/ub.jtsl.2023.010.1.1>
- Fahad, S., Chavan, S.B., Chichaghare, A.R., Uthappa, A.R., Kumar, M., Kakade, V., Pradhan, A., Jinger, D., Rawale, G., Yadav, D.K., Kumar, V., Farooq, T.H., Ali, B., Sawant, A.V., Saud, S., Chen, S., Poczai, P. 2022. Agroforestry systems for soil health improvement and maintenance. *Sustainability* 14(22), 14877. <https://doi.org/10.3390/su142214877>
- Gao, M., Hu, W., Zhang, X., Li, M., Yang, Y., Che, R. 2025. Land degradation decreased crop productivity by altering soil quality index generated by network analysis. *Soil and Tillage Research* 246, 106354. <https://doi.org/10.1016/j.still.2024.106354>
- Hakim, D.L., Adji, R., Satwhikawara, R., Alam, S. 2024. Identification of soil damage due to biomass production in Bekasi Regency, Indonesia. *Jurnal Budidaya Pertanian* 20(1), 1–7. <https://doi.org/10.30598/jbdp.2024.20.1.1>
- Harini, S. 2015. The influence of land use in controlling potential damage of the upper Brantas River basin. *Applied Mechanics and Materials* 747, 298–301. <https://doi.org/10.4028/www.scientific.net/AMM.747.298>
- Hayes, T., Murtinho, F., Wolff, H., López-Sandoval, M.F., Salazar, J. 2021. Effectiveness of payment for ecosystem services after loss and uncertainty of compensation. *Nature Sustainability* 5(1), 81–88. <https://doi.org/10.1038/s41893-021-00804-5>
- Istiqomah, N.M., Cahyono, O., Mujiyo, M., Ariyanto, D.P., Maro'ah, S., Romadhon, M.R., Irmawati, V. 2023. Assessment of potential soil degradation on various land uses in Keduang watershed. *IOP Conference Series: Earth and Environmental Science* 1241(1), 012014. <https://doi.org/10.1088/1755-1315/1241/1/012014>
- Juarti, J. 2016. Analisis indeks kualitas tanah andisol pada berbagai penggunaan lahan di Desa Sumber Brantas Kota Batu. *Jurnal Pendidikan Geografi* 21(2), 58–71. <https://doi.org/10.17977/um017v21i22016p058>
- Kaewlom, P., Udomkun, P., Rupngam, T., Masso, C., Messiga, A.J., Müller, J., Boonupara, T. 2025. Degradation mapping in Southeast Asia using a partial soil health index based on physicochemical indicators. *Applied Soil Ecology* 215, 106480. <https://doi.org/10.1016/j.apsoil.2025.106480>
- Kumar, S., David Raj, A., Kalambukattu, J.G., Chatterjee, U. 2022. Climate Change Impact on Land Degradation and Soil Erosion in Hilly and Mountainous Landscape: Sustainability Issues and Adaptation Strategies. In: Chatterjee, U., Akanwa, A.O., Kumar, S., Singh, S.K., Dutta Roy, A. (eds) *Ecological Footprints of Climate Change*. Springer Climate. Springer, Cham. pp. 119–155. [https://doi.org/10.1007/978-3-031-15501-7\\_5](https://doi.org/10.1007/978-3-031-15501-7_5)
- Lestariningsih, I.D., Widiyanto, W., Agustina, C., Sudarto, S., Kurniawan, S. 2018. Relationship between land degradation, biophysical and social factors in Lekso watershed, East Java, Indonesia. *Journal of Degraded and Mining Lands Management* 5(3), 1283–1291. <https://doi.org/10.15243/jdmlm.2018.053.1283>
- Mandal, D., Roy, T. 2024. Climate Change Impact on Soil Erosion and Land Degradation. In: Pathak, H., Chatterjee, D., Saha, S., Das, B. (eds) *Climate Change Impacts on Soil-Plant-Atmosphere Continuum*. *Advances in Global Change Research*, vol 78. Springer, Singapore. pp. 139–161. [https://doi.org/10.1007/978-981-99-7935-6\\_5](https://doi.org/10.1007/978-981-99-7935-6_5)
- Marques, M.A., Anjos, L.H.Cdos., Sanchez Delgado, A.R. 2022. Land recovery and soil management with agroforestry systems. *Spanish Journal of Soil Science* 12, 10457. <https://doi.org/10.3389/sjss.2022.10457>

- Minasny, B., Malone, B.P., McBratney, A.B., Angers, D.A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z.-S., Cheng, K., Das, B.S., Field, D.J., Gimona, A., Hedley, C.B., Hong, S.Y., Mandal, B., Marchant, B.P., Martin, M., McConkey, B.G., Mulder, V.L., O'Rourke, S., Richer-de-Forges, A.C., Odeh, I., Paradian, J., Paustian, K., Pan, G., Poggio, L., Savin, I., Stolbovoy, V., Stockmann, U., Sulaeman, Y., Tsui, C.-C., Vågen, T.-G., van Wesemael, B., Winowiecki, L. 2017. Soil carbon 4 per mille. *Geoderma* 292, 59–86. <https://doi.org/10.1016/j.geoderma.2017.01.002>
- Mujiyo, Prasetyo, A.N., Herawati, A., Ariyanto, D.P., Widijanto, H. 2022. Mapping of soil degradation status on various land slope in Paranggupito, Wonogiri. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan* 12(1), 46–54. <https://doi.org/10.29244/jpsl.12.1.46-54>
- Nkonya, E., Mirzabaev, A., von Braun, J. 2016. *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*. Springer International Publishing. 686 p. <https://doi.org/10.1007/978-3-319-19168-3>
- Pratama, A.A., Suripin, S., Wulandari, D.A., Marupa, I. 2024. Impact of monitoring land use changes to anticipate management of erosion rates in the Brantas Hulu watershed. *Jurnal Presipitasi: Media Komunikasi dan Pengembangan Teknik Lingkungan* 21(3), 825–837. <https://doi.org/10.14710/presipitasi.v21i3.825-837>
- Purwanto, S., Gani, R.A., Suryani, E. 2021. Characteristics of ultisols derived from basaltic andesite materials and their association with old volcanic landforms in Indonesia. *Sains Tanah* 17(2), 135–143. <https://doi.org/10.20961/STJSSA.V17I2.38301>
- Putra, A., Hermon, D., Dewata, I., Barlian, E., Triyanto. 2025. USLE method for erosion prediction and conservation measures at the Air Dingin watershed of the upstream part in Padang City, Indonesia. In *Erosion Measurement, Modeling, and Management*. Apple Academic Press. pp. 123–148. <https://doi.org/10.1201/9781003494508-6>
- Qurrahman, B.F.T., Suriadikusumah, A., Haryanto, R. 2016. Evaluasi kriteria kerusakan tanah untuk produksi biomassa pada lahan kering di Kabupaten Subang. *SoilREns* 14(1), 1-5. <https://doi.org/10.24198/soilrens.v14i1.9266>
- Rosidin, D.A., Suhartanto, E., Andawayanti, U. 2024. 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>
- Salvati, L., Smiraglia, D., Ceccarelli, T., Bajocco, S., Perini, L. 2015. Planning for sustainable agro-forest systems: Protected areas and soil degradation hotspots in Italy (1990–2010). *Soil Science and Plant Nutrition* 61(3), 404–413. <https://doi.org/10.1080/00380768.2014.978729>
- Satriawan, H., Fuady, Z., Mayani, N. 2017. Soil conservation by vegetative systems in oil palm cultivation. *Polish Journal of Soil Science* 49(2), 223-235. <https://doi.org/10.17951/pjss.2016.49.2.223>
- Setyawan, C., Lee, C.-Y., Prawitasari, M. 2019. Investigating spatial contribution of land use types and land slope classes on soil erosion distribution under tropical environment. *Natural Hazards* 98(2), 697–718. <https://doi.org/10.1007/s11069-019-03725-x>
- Sriwati, M., Pallu, S., Selintung, M., Lopa, R. 2018. Bioengineering technology to control river soil erosion using vetiver (*Vetiveria zizanioides*). *IOP Conference Series: Earth and Environmental Science* 140, 012040. <https://doi.org/10.1088/1755-1315/140/1/012040>
- Sukwika, T., Firmansyah, I. 2020. Pemetaan dan strategi kebijakan: dampak kerusakan tanah untuk produksi biomassa di Kota Depok. *Jurnal Pendidikan Geografi* 25(2), 114–127. <https://doi.org/10.17977/um017v25i22020p114>
- Sumarsono, S., Kusumaningrum, E., Jumiaty, J., Susetyaningsih, R. 2022. Kajian kerusakan tanah berdasarkan analisis spasial di Pundong Kabupaten Bantul. *Jurnal Geografi Geografi dan Pengajarannya* 20(1), 31–40. <https://doi.org/10.26740/jggp.v20n1.p31-40>
- Suyana, J., Komariah, Nugraheni, Lestariningsih, N.P. 2019. The effectiveness of maize stalks mulch on runoff, erosion, sediment enrichment ratio (ser), and the growth of cabbage and red beans in andisols, Central Java, Indonesia. *Tropical and Subtropical Agroecosystems* 22(3), 675–692. <https://www.revista.ccbba.uady.mx/ojs/index.php/TSA/article/view/2869>
- Tahat, M.M., Alananbeh, K.M., Othman, Y.A., Leskovar, D.I. 2020. Soil health and sustainable agriculture. *Sustainability* 12(12), 1–26. <https://doi.org/10.3390/SU12124859>
- Taisa, R., Maulida, D., Salam, A.K., Kamal, M., Niswati, A. 2019. Improvement of soil chemical properties and growth of maize due to biochar application on ultisol. *Journal of Tropical Soils* 24(3), 101–107. <https://doi.org/10.5400/jts.2019.v24i3.101-107>
- Wan, W., Liu, Z., Li, B., Fang, H., Wu, H., Yang, H. 2022. Evaluating soil erosion by introducing crop residue cover and anthropogenic disturbance intensity into cropland C-factor calculation: Novel estimations from a cropland-dominant region of Northeast China. *Soil and Tillage Research* 219, 105343. <https://doi.org/10.1016/j.still.2022.105343>

- Widiatiningsih, A., Mujiyo, M., Suntoro, S. 2018. Soil erosion hazardous level in Jatipurno sub-district of Wonogiri District. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan* 8(3), 383–395. <https://doi.org/10.29244/jpsl.8.3.383-395>
- Wisnubroto, K.W., Nuraini, R., Rauf, T. 2024. Tantangan Besar, Asta Cita, dan Keberlanjutan Pembangunan. <https://indonesia.go.id/kategori/editorial/8747/tantangan-besar-asta-cita-dan-keberlanjutan-pembangunan?lang=1>
- Wiwoho, B.S., McIntyre, N., Phinn, S. 2024. Assessing future land-uses under planning scenarios: A case study of The Brantas River Basin, Indonesia. *Environmental Challenges* 15, 100873. <https://doi.org/10.1016/j.envc.2024.100873>
- Yadav, B., Malav, L.C., Jiménez-Ballesta, R., Kumawat, C., Patra, A., Patel, A., Jangir, A., Nogiya, M., Meena, R.L., Moharana, P.C., Kumar, N., Sharma, R.P., Yadav, L.R., Obi Reddy, G.P., Mina, B.L. 2022. Modeling and assessment of land degradation vulnerability in arid ecosystem of Rajasthan using analytical hierarchy process and geospatial techniques. *Land* 12(1), 106. <https://doi.org/10.3390/land12010106>
- Zhang, J., Zheng, F., Li, Z., Feng, Z. 2022. A novel optimal data set approach for erosion-impacted soil quality assessments— A case-study of an agricultural catchment in the Chernozem Region of Northeast China. *Land Degradation & Development* 33(7), 1062–1075. <https://doi.org/10.1002/ldr.4231>