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Spatial Analysis and Soil Biophysical Evaluation of Dryland Degradation in Pandansari Village, Warungasem Subdistrict, Batang Regency

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Abstract. *Dryland is vulnerable to degradation due to intensive land use and inadequate conservation practices. This study aimed to analyze the potential and status of dryland degradation in Pandansari Village, Batang Regency, based on spatial analysis and soil biophysical parameters. A quantitative descriptive approach was employed through GIS-based spatial analysis, field surveys, and laboratory soil analysis. Land degradation potential and status were assessed according to Government Regulation Number 150 of 2000 and Minister of Environment Regulation Number 07 of 2006. Spatial analysis was conducted by overlaying soil type, slope, rainfall, and land use maps, resulting in three Land Mapping Units (LMUs). Field verification was performed at nine sampling points, with three sampling points representing each LMU. Soil degradation status was evaluated using ten parameters, namely solum thickness, surface rock fragments, soil fraction composition, bulk density, total porosity, permeability rate, soil pH, electrical conductivity, redox potential, and total soil microbial population. The results showed that land degradation potential in Pandansari Village was classified into low (70.53 ha), moderate (109.84 ha), and high (1.23 ha) categories. Field verification indicated that the Low and Moderate Soil Degradation Potential LMUs were classified as Slightly Degraded (R.I), whereas the High Soil Degradation Potential LMU was classified as Moderately Degraded (R.II). The main limiting factors were soil fraction composition, surface rock fragments, permeability rate, and redox conditions. Recommended conservation measures include organic matter application, mulching, cover crops, conservation tillage, revegetation, and mechanical conservation practices to maintain sustainable land productivity.*

Keywords: *dryland, geographic information system, land degradation, Pandansari village, soil conservation.*

1. Introduction

Dryland constitutes one of the essential land resources that plays a significant role in supporting food security and sustainable agricultural development in Indonesia (Antriyandarti *et al*., 2023; Dako *et al*., 2026). According to data from Statistics Indonesia (2021), the area of dryland agriculture and mixed dryland agriculture with shrubs/mixed gardens in Indonesia reached approximately 34.27 million hectares in 2020, indicating the extensive utilization of dryland for agricultural cultivation, plantations, mixed gardens, and upland farming systems. However, the high intensity of land utilization without adequate implementation of soil and water conservation

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practices has accelerated land degradation in various regions. Dryland degradation is generally characterized by increasing soil erosion (AbdelRahman, 2023), declining soil organic matter content (Gao *et al*., 2024), soil compaction (Nawaz *et al*., 2013), reduced infiltration capacity (Nanda *et al*., 2026), and decreased water-holding capacity (Engman *et al*., 2025), which ultimately lead to reduced land productivity (Abdullah *et al*., 2022) and disruption of ecosystem balance (Rahman *et al*., 2025).

Batang Regency is one of the regions in Central Java Province dominated by dryland agricultural land use with diverse topographic conditions (Raharjo *et al*., 2015). One of the areas experiencing considerable land-use pressure is Pandansari Village, Batang Regency. According to Statistics Indonesia, dryland covers approximately 44.99 ha, or 24.77% of the total village area (Statistics of Batang Regency, 2023). Furthermore, agricultural activities in the area are characterized by intensive land utilization and the widespread use of chemical fertilizers (Statistics of Batang Regency, 2024, 2025). Combined with land cover changes and the limited adoption of vegetative and mechanical conservation practices, these conditions may accelerate soil degradation processes and increase the vulnerability of land resources. This condition is indicated by the emergence of less productive land, increasingly hardened topsoil layers, high surface runoff during rainfall events, and declining soil capacity to retain nutrients and water. If these conditions are not addressed immediately, they may potentially lead to more severe land degradation and threaten the sustainability of local agricultural systems (Felipe, 2025; Kartini *et al*., 2024).

Numerous studies have investigated dryland degradation using various approaches, including spatial analysis, land evaluation, and soil quality assessment. However, many studies have focused on regional-scale assessments or emphasized particular aspects of land degradation, such as spatial distribution, without fully integrating field verification and laboratory-based soil analyses. As a result, comprehensive evaluations that combine spatial information with direct measurements of soil biophysical properties remain relatively limited (Utami *et al*., 2023; Widyasunu *et al*., 2022). In addition, several previous studies mainly focused on spatial analysis without being supported by field verification and laboratory testing of soil biophysical parameters. In fact, land degradation assessment requires a comprehensive approach through the integration of spatial data, field observations, and laboratory analyses to obtain more accurate and objective results. The Indonesian government has established standardized criteria for soil degradation through Government Regulation (2000) and State Minister of Environment (2006) as guidelines for determining soil degradation status based on physical, chemical, and biological soil parameters. Therefore, research integrating Geographic Information Systems (GIS) approaches with direct field-based soil characteristic analyses is urgently needed.

Spatial analysis provides an effective tool for identifying areas potentially vulnerable to land degradation by integrating environmental variables such as soil type, slope, rainfall, and land use across a landscape (AbdelRahman *et al*., 2019). However, the actual condition of soil degradation cannot be determined solely from spatial indicators because soil properties may vary considerably within the same mapping unit due to differences in land management practices and local environmental conditions (Obade & Lal, 2013). Field verification and laboratory analyses are therefore essential to validate spatial predictions and quantify the biophysical characteristics of soils directly. The integration of GIS-based spatial assessment with field and laboratory evaluation enables a more comprehensive and reliable assessment of land degradation, thereby providing a stronger scientific basis for sustainable land management and soil conservation planning (Soniari *et al*., 2024).

Despite the increasing number of studies on land degradation, comprehensive assessments integrating GIS-based spatial analysis, field verification, and laboratory evaluation of soil biophysical properties remain limited, particularly at the local scale. This study addresses this gap by combining spatial assessment with field and laboratory analyses to evaluate both the potential and actual status of dryland degradation. The novelty of this study lies in the application of an integrated multi-stage framework combining land degradation potential mapping, field-based verification, and laboratory soil biophysical analysis using standardized national criteria. This study aims to analyze the potential and status of dryland degradation in Pandansari Village, Warungasem Subdistrict, Batang Regency, through integrated spatial and soil biophysical evaluation. The study contributes to improving land degradation assessment by demonstrating the complementary roles of spatial modeling and field-based measurements in producing more accurate and reliable results. The findings are expected to support the development of soil conservation strategies and sustainable land management practices in the study area.

2. Materials and Methods

2.1. Time and Study Area

This study was conducted from February to May 2025 in Pandansari Village, Warungasem Subdistrict, Batang Regency, Central Java Province, Indonesia, located at geographic coordinates of approximately 6º58’49” S and 109º42’45” E. The study area is characterized by an elevation of approximately 17 m above sea level, with generally undulating to rolling topography. Laboratory analyses of soil biophysical parameters were carried out at the Agrotechnology Laboratory, Faculty of Agriculture, University of Pekalongan.

2.2. Tools and Materials

The tools used in this study included a Global Positioning System (GPS), soil auger, measuring tape, ring sampler, pH meter, soil oven, analytical balance, soil sieve, and QGIS 3.22.14 software. The materials consisted of primary and secondary data. Primary data included soil biophysical parameters obtained from soil sample analyses collected through field surveys at predetermined observation points. Secondary data comprised soil type maps, slope maps, rainfall data, and land use maps of Pandansari Village obtained from relevant institutions and spatial data interpretation results.

2.3. Research Method

The study employed a quantitative descriptive method using field survey and Geographic Information System (GIS)-based spatial analysis approaches. All spatial datasets were standardized to a uniform coordinate reference system (WGS 84 / UTM Zone 49S), followed by digitization, reclassification, and spatial validation using secondary data sources. The research stages included spatial data collection, thematic map overlay analysis, determination of homogeneous land units (LMUs), field soil sampling, and laboratory analyses of soil biophysical parameters, namely solum thickness, surface rock fragments, soil fraction composition, bulk density, total porosity, permeability rate, soil pH, electrical conductivity, redox potential, and total soil microbial population. Soil sampling was conducted using purposive sampling with nine sampling points distributed across three LMUs, with three points representing each LMU, and samples were collected at a depth of 0–20 cm (topsoil layer). Soil degradation analysis was carried out based on standardized criteria defined in Government Regulation (2000) and State Minister of Environment (2006). This approach was applied to obtain a comprehensive understanding of dryland degradation conditions in the study area.

2.4. Determination of Soil Degradation Potential

The determination of soil degradation potential was carried out using a scoring and weighting method for spatial parameters consisting of soil type, slope gradient, rainfall, and land use. Each parameter was assigned a score based on its susceptibility to soil degradation in accordance with Government Regulation (2000) and State Minister of Environment (2006). The scoring results were subsequently analyzed using overlay techniques to generate a soil degradation potential map classified into five categories of soil degradation potential (Table 1).

The overlay results were used to delineate LMUs by integrating thematic layers of soil type, slope, rainfall, and land use using GIS overlay techniques. LMUs were defined as spatial units with relatively homogeneous land characteristics resulting from the intersection of multiple biophysical factors within a GIS environment, consistent with established land evaluation principles (Baja *et al*., 2002; Rossiter, 1996; Sambroek & Antoine, 1994). The resulting LMUs were then used as the basis for field surveys and soil sampling, and the soil degradation potential map was further applied to determine sampling locations.

Table 1. Soil Degradation Potential Classes.

Symbol	Soil Degradation Potential Class	Weighted Score
PR.I	Very Low	< 15
PR.II	Low	15-24
PR.III	Moderate	25-34
PR.IV	High	35-44
PR.V	Very High	45-50

Source: Government Regulation (2000) and State Minister of Environment (2006).

2.5. Determination of Soil Degradation Status

The determination of soil degradation status was conducted through field verification and laboratory analyses of soil samples collected from each homogeneous land unit. Soil sampling was carried out using a purposive sampling method based on the overlay results of the soil degradation potential map, which generated the Land Mapping Units (LMUs) (Ardyansyah *et al*., 2025). Soil samples were collected as individual samples (not composite samples) at a depth of 0–20 cm. Each LMU was represented by three sampling points selected purposively by considering land use characteristics, slope gradient, and actual soil conditions in the field. This approach was intended to ensure that the soil samples adequately represented the actual land conditions within each land unit. The analyzed soil biophysical parameters included solum thickness, surface rock fragments, soil fraction composition, bulk density, total porosity, permeability, pH, electrical conductivity, redox potential, and total soil microbial population. The measurement procedures, analytical protocols, and evaluation criteria for all parameters followed the standardized methods specified in Government Regulation (2000) and State Minister of Environment (2006), which serve as the official guidelines for soil degradation assessment in Indonesia. All parameters were compared with critical threshold values based on the standardized criteria for soil degradation as presented in Table 2.

Table 2. Standard Criteria for Soil Degradation.

No	Parameter	Critical Threshold
1	Solum Thickness (s)	< 20 cm
2	Surface Rock Fragments (b)	> 40%
3	Soil Fraction Composition (f)	< 18% Colloids; > 80% Quartz Sand
4	Bulk Density (d)	> 1.4 g cm^{-3}
5	Total Porosity (v)	< 30%; > 70%
6	Permeability Rate (p)	< 0.7 cm $hour^{-1}$; > 8.0 cm $hour^{-1}$
7	pH (H_2O) (a)	< 4.5; > 8.5
8	Electrical Conductivity (e)	> 4.0 mS cm^{-1}
9	Redox Potential (r)	< 200 mV
10	Total Microbial Population (m)	< 10^2 CFU g^{-1} soil

Source: Government Regulation (2000) and State Minister of Environment (2006).

Following laboratory analyses, each parameter was compared with its critical threshold value to determine whether the soil condition was classified as degraded or non-degraded. Parameters exceeding the critical threshold were categorized as degraded and subsequently used in determining soil degradation status. The relative frequency (*RF*) of soil degradation for each parameter was then calculated using Equation (1).

$$RF\ (\%) = \frac{n}{N} \times 100 \quad (1)$$

Where: *n* represents the number of observations exceeding the critical threshold, and *N* represents the total number of observations within each LMU. The resulting RF values were assigned scores ranging from 0 to 4 according to the degree of soil degradation, as presented in Table 3. Higher RF values indicate a greater proportion of degraded observations and reflect a higher level of soil degradation within the study area, based on the criteria established by Government Regulation (2000) and State Minister of Environment (2006).

Table 3. Soil Degradation Scores Based on the Relative Frequency of Soil Degradation Parameters.

Relative Frequency of Soil Degradation (%)	Score	Weighted Score Classification
0-10%	0	Non-Degraded
11-25%	1	Slightly Degraded
26-50%	2	Moderately Degraded
51-75%	3	Severely Degraded
76-100%	4	Very Severely Degraded

Source: Government Regulation (2000) and State Minister of Environment (2006).

The scores of each parameter were subsequently accumulated to determine the final soil degradation status for each land unit. The accumulated scores were used to classify soil degradation levels into non-degraded, slightly degraded, moderately degraded, severely degraded, and very severely degraded categories, as presented in Table 4. The classification results were then used to develop a soil degradation status map illustrating the spatial distribution of soil degradation levels, dominant limiting factors, and the area extent of each soil degradation class within the study area.

Table 4. Soil Degradation Scores Based on the Accumulated Soil Degradation Score Values.

Symbol	Soil Degradation Status	Accumulated Soil Degradation Score
N	Non-Degraded	0
R.I	Slightly Degraded	1-12
R.II	Moderately Degraded	13-21
R.III	Severely Degraded	22-30
R.IV	Very Severely Degraded	31-36

Source: Government Regulation (2000) and State Minister of Environment (2006).

3. Result and Discussion

3.1. Land Degradation Potential

Pandansari Village covers an area of approximately 181.60 ha with highly diverse land biophysical characteristics, including soil type, slope gradient, rainfall, and land use. These variations influence the level of land vulnerability to degradation and soil damage processes. Identification of spatial land conditions constitutes an important stage in land degradation potential analysis because each parameter contributes differently to the degree of soil degradation that may occur (Dasrizal *et al*., 2026). The analysis of land degradation potential in this study began with the processing of spatial data, including soil type maps, slope maps, rainfall maps, and land use maps, which were used as the basis for determining the level of land degradation potential in Pandansari Village as presented in Figure 1.

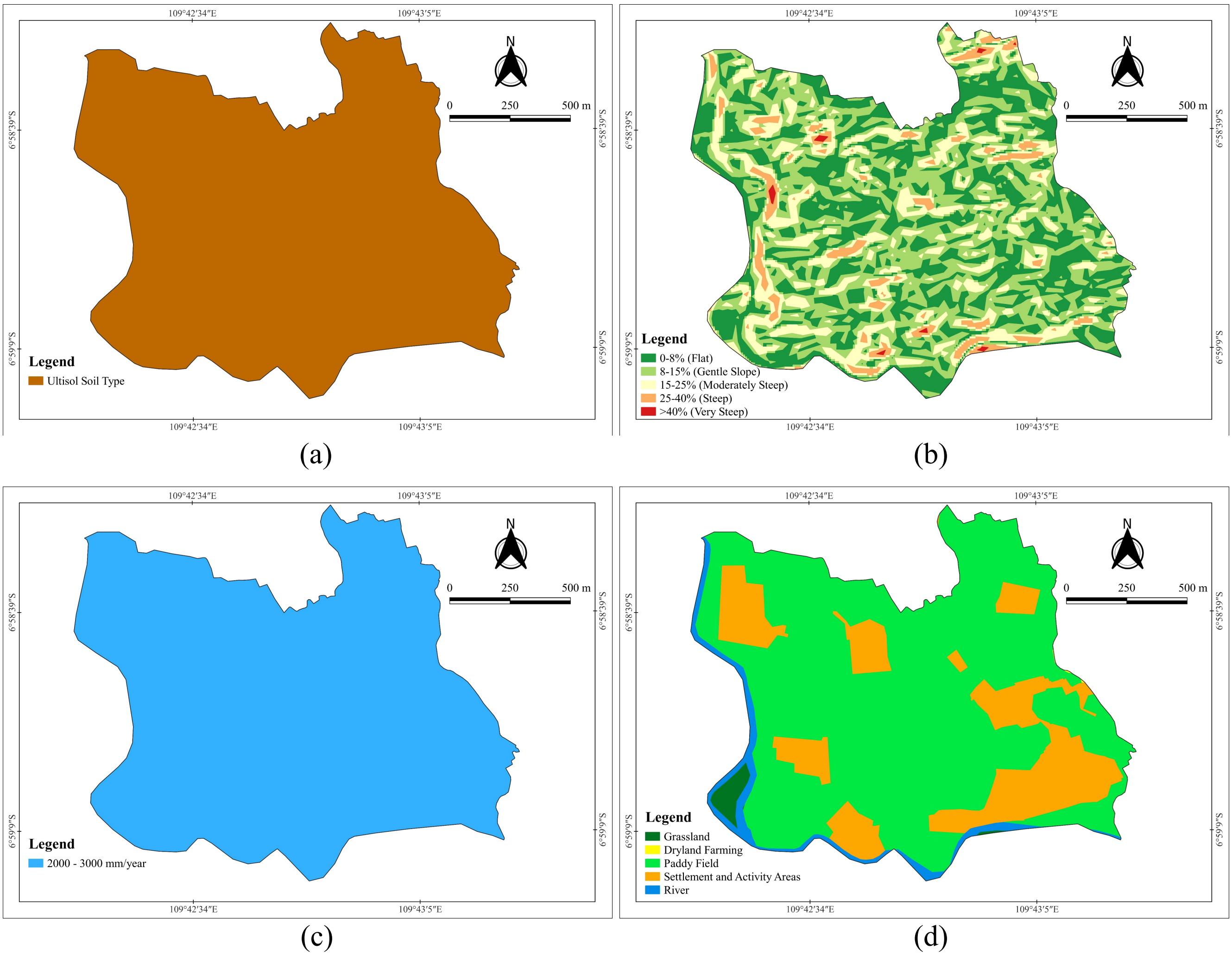

Figure 1. Spatial data of Pandansari Village: (a) soil type map, (b) slope map, (c) rainfall map, and (d) land use map.

Based on Figure 1, Ultisol is the only soil type identified within Pandansari Village, covering the entire study area. This soil type is categorized as a highly weathered soil generally characterized by low fertility due to intensive nutrient leaching processes. The characteristics of

Ultisols, including low organic matter content (Endriani *et al*., 2025; Zurhalena *et al*., 2023), low base saturation (Pratamaningsih *et al*., 2023), and soil texture relatively susceptible to erosion, make these soils vulnerable to degradation when managed without appropriate conservation measures (Marcatto & Thomaz, 2025; Yulnafatmawita & Adrinal, 2014). This spatial condition reflects a uniform soil type distribution across the study area based on GIS-based soil mapping results. These conditions place Ultisols within the moderate vulnerability category for soil degradation potential classification. The slope gradient variation in Pandansari Village is also highly diverse, ranging from flat to very steep classes. Five slope classes were identified, namely Flat (0–8%) covering 70.79 ha (38.98%), Gentle Slope (8–15%) covering 70.09 ha (38.62%), Moderately Steep (15–25%) covering 32.77 ha (18.06%), Steep (25–40%) covering 7.59 ha (4.18%), and Very Steep (>40%) covering 0.36 ha (0.20%). This distribution indicates that although flat and gentle slopes dominate the landscape, approximately 22.44% of the area falls within moderately steep to very steep classes, which contribute disproportionately to erosion risk and land degradation susceptibility.

Rainfall in Pandansari Village ranges from 2,000 to 3,000 mm per year, which falls into the moderate category within the soil degradation potential classification. Rainfall intensity at this level contributes to increased surface runoff and nutrient leaching processes (Simelane *et al*., 2024), particularly in areas with low vegetation cover and steep slopes. Land use in Pandansari Village is dominated by paddy fields covering 134.07 ha, while other land uses include settlements, rivers, dry fields, and grasslands. The dominance of paddy fields indicates that the study area still functions as an intensively utilized productive agricultural region. In this study context, agricultural land use represents a mixed landscape system within a dryland degradation assessment framework, where paddy fields and upland areas are analyzed collectively based on soil vulnerability characteristics. Differences in land use types influence the level of land vulnerability to soil degradation because they are associated with soil management intensity, vegetation cover conditions, and land capacity to retain surface runoff. Areas with low vegetation cover and intensive soil cultivation tend to exhibit higher degradation levels compared to areas with permanent vegetation cover (Ferreira *et al*., 2022).

The spatial data consisting of soil type, slope gradient, rainfall, and land use were subsequently analyzed using an overlay method to determine the level of land degradation potential in Pandansari Village. Each parameter was assigned scores and weights according to its susceptibility to soil degradation based on the classifications established in Government Regulation (2000) and State Minister of Environment (2006). The overlay process was conducted using QGIS software, resulting in spatial information regarding the distribution of land degradation potential based on the combination of all analyzed parameters (Afiatan *et al*., 2024; Al Ramadhani *et al*., 2026). The results of the overlay analysis are presented in the form of a land degradation potential map of Pandansari Village, as shown in Figure 2.

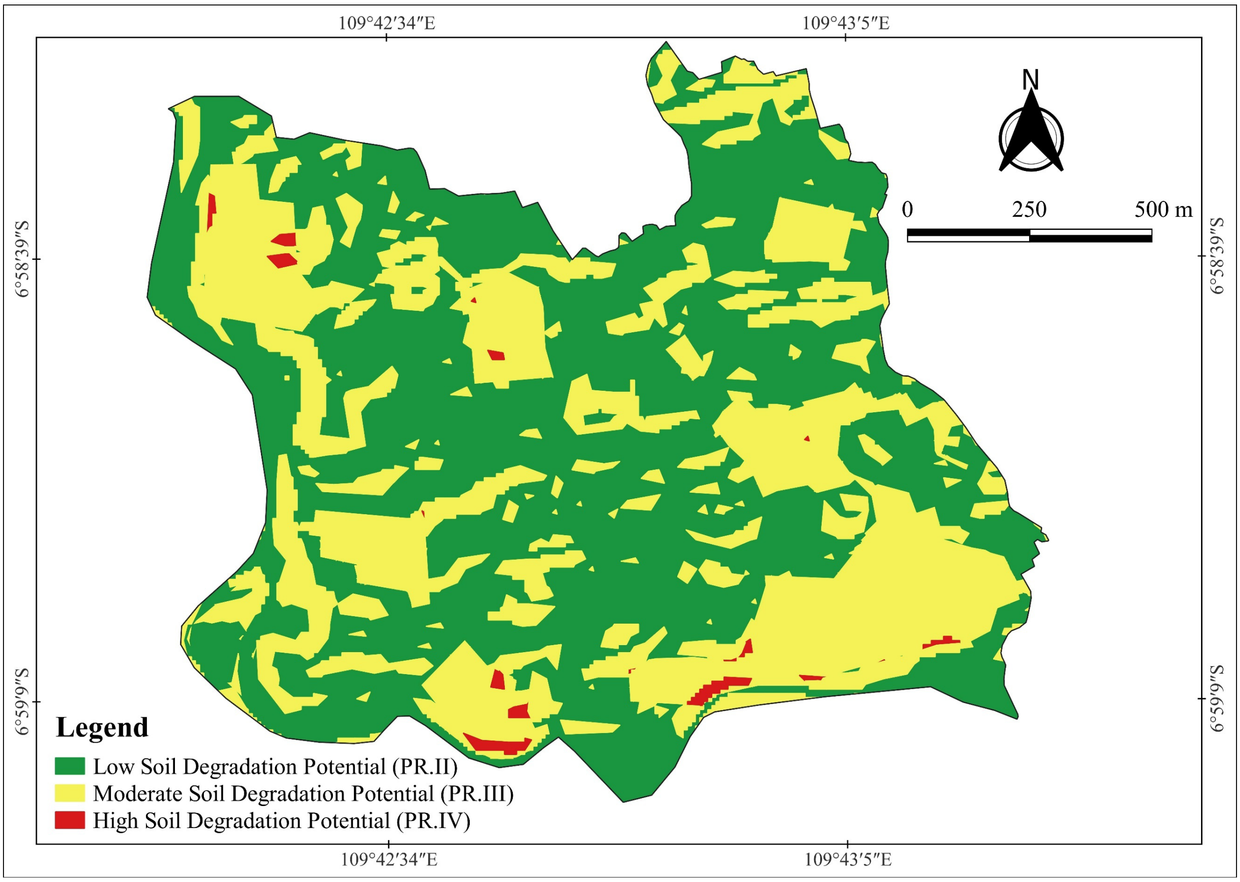

Figure 2. Land degradation potential map of Pandansari Village.

Based on the analysis results presented in Figure 2, the land degradation potential in Pandansari Village is classified into three categories, namely low potential (PR.II), moderate potential (PR.III), and high potential (PR.IV). The moderate degradation potential class (PR.III) dominates the study area, covering 109.84 ha or approximately 60.5% of the total area of Pandansari Village. The low degradation potential class (PR.II) covers 70.53 ha or approximately 38.8%, while the high degradation potential class (PR.IV) only covers 1.23 ha or approximately 0.7% of the study area. The PR.IV class is mainly associated with steeper slope conditions identified through the spatial overlay analysis. The dominance of the moderate degradation potential class indicates that most areas of Pandansari Village possess relatively high vulnerability to soil degradation if land utilization is not accompanied by appropriate conservation measures. These conditions demonstrate that sustainable land management and the implementation of soil conservation techniques are essential measures to suppress further land degradation in Pandansari Village.

3.2. Land Degradation Status

The determination of land degradation status was conducted through field verification and laboratory analyses of soil biophysical parameters within each Land Mapping Unit (LMU). The establishment of LMUs was based on the overlay results of the land degradation potential map, which generated three LMU classes, namely Low Soil Degradation Potential LMU, Moderate Soil Degradation Potential LMU, and High Soil Degradation Potential LMU. Each LMU was subsequently verified through soil sampling and measurement of ten soil biophysical parameters to determine the actual level of land degradation. The results of the relative frequency analysis and soil degradation status for each LMU are presented in Table 5, while the spatial distribution of land degradation status in Pandansari Village is shown in Figure 3.

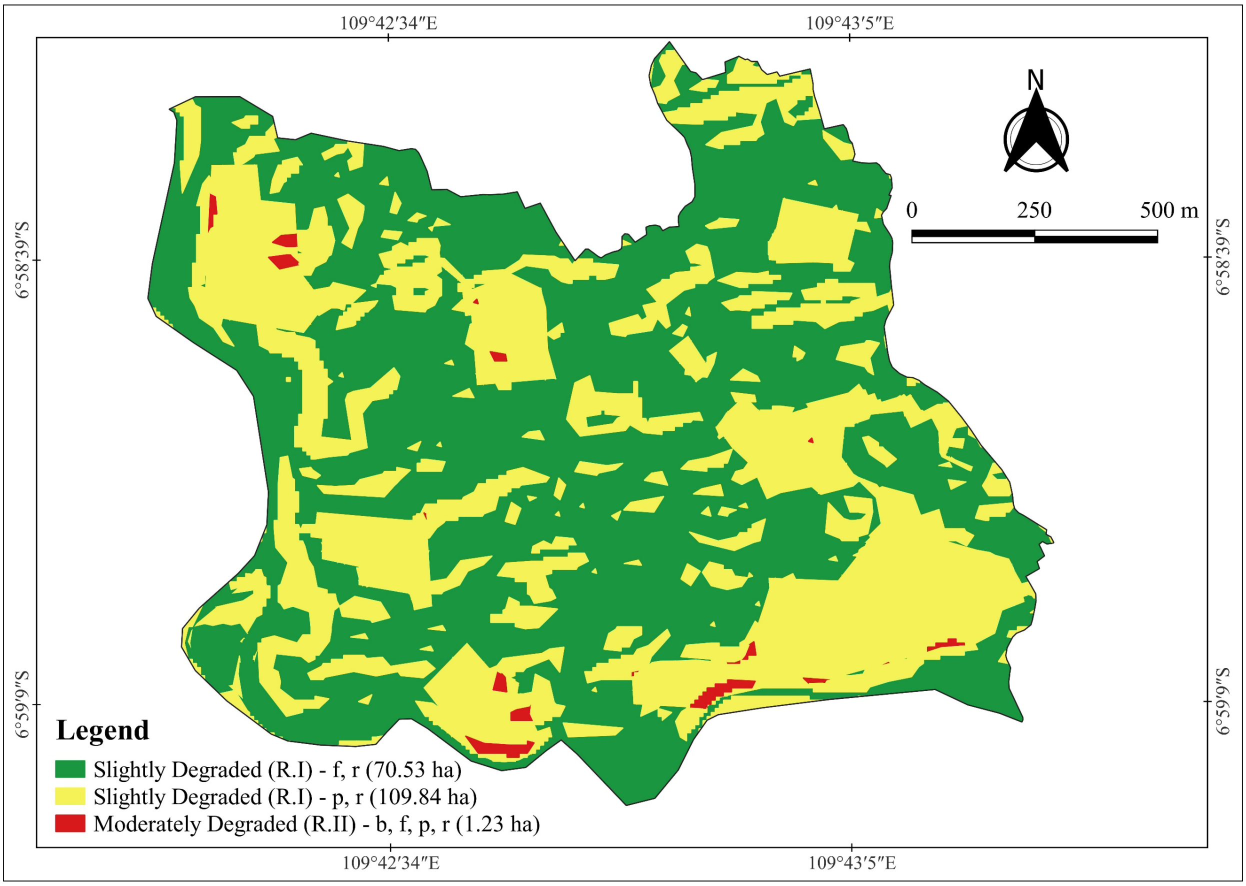

Figure 3. Land degradation status map of Pandansari Village.

Based on the analysis results presented in Table 5 and Figure 3, the Low Soil Degradation Potential LMU obtained a total score of 6 and was classified as Slightly Degraded (R.I) with an area of approximately 70.53 ha. The main limiting factors in this LMU were soil fraction composition (f) and redox potential (r), indicating imbalances in soil texture and suboptimal soil aeration conditions. Redox potential was consistently identified as a limiting factor across all LMUs as one of the evaluated parameters, indicating variations in soil aeration conditions influenced by differences in soil moisture status, drainage capacity, and micro-topographic conditions within both paddy fields and dryland areas and therefore contributes to the overall soil degradation status assessment based on the relative frequency approach together with other measured parameters. Changes in soil fraction composition are generally influenced by erosion processes that transport fine soil particles, thereby reducing the soil's capacity to retain water and nutrients (Hofbauer *et al*., 2023). In this study, low redox values should be interpreted as an indicator of reduced soil oxygen availability under varying field moisture and drainage conditions (Zhang & Furman, 2021), rather than being solely interpreted as a direct indicator of soil degradation, but they still function as one of the evaluated parameters in the soil degradation status assessment. Conservation measures that can be applied in this LMU include the addition of organic matter, mulching, planting cover crops, and improving drainage systems to enhance soil aggregate stability and soil aeration. The integrated implementation of these conservation techniques can improve soil aggregate stability and promote a more friable and porous soil structure. Such conditions play an important role in enhancing soil aeration, facilitating water movement within the soil, and supporting optimal plant root development (Karami *et al*., 2012; Sadiq *et al*., 2025).

The Moderate Soil Degradation Potential LMU obtained a total score of 6 and was also classified as Slightly Degraded (R.I), covering an area of 109.84 ha, making it the dominant land degradation class in Pandansari Village. The main limiting factors in this LMU were permeability rate (p) and redox potential (r). A permeability rate exceeding the critical threshold of >8.0 cm/hour indicates that the soil allows water to pass through too rapidly, resulting in the leaching of water and nutrients into deeper soil layers (Jin *et al*., 2025). This condition is generally influenced by the dominance of sandy fractions, low organic matter content, and weak soil water retention capacity, thereby reducing the efficiency of water uptake by plants (Ibrahimi & Alghamdi, 2022; Zhang *et al*., 2016). Low redox values also indicate limited oxygen exchange within the soil, which affects biological activity and soil nutrient balance (Dayo-Olagbende *et al*., 2020; Siedt *et al*., 2023). Conservation techniques that may be implemented include the addition of organic matter, mulching, planting cover crops, and the application of conservation tillage practices to improve soil water retention capacity and enhance soil structural stability (Fan *et al*., 2023; Sadiq *et al*., 2024).

Table 5. Relative frequency and soil degradation status in Pandansari Village.

LMU	Sample	s (cm)	b (%)	f (%) Colloids	f (%) Quartzitic Sand	d (g cm^{-3})	v (%)	p (cm hour^{-1})	a	e (mS cm^{-1})	r (mV)	m (CFU g^{-1})	Total Score	Land Degradation Status	Limiting Factor
Low Soil Degradation Potential	1	36	6.50	18.83	38.43	0.93	52.50	6.06	6.50	0.20	**131.9**	2.30×10^{5}	6	R.I	f, r
	2	24	12.75	39.26	13.27	0.94	58.86	0.83	6.50	0.14	**78.9**	6.10×10^{6}			
	3	38	15.75	**1.73**	1.77	0.95	54.50	3.45	7.00	0.20	**51.6**	1.13×10^{7}			
	RF	0	0	33.33		0	0	0	0	0	100	0			
	Score	0	0	2		0	0	0	0	0	4	0			
Moderate Soil Degradation Potential	1	33	12.75	31.40	29.17	1.20	46.35	**10.71**	6.50	0.18	**70.5**	3.30×10^{5}	6	R.I	p, r
	2	32	19.00	41.78	9.97	1.19	50.14	7.89	6.50	0.19	**90.3**	1.25×10^{6}			
	3	34	28.50	33.78	37.07	1.07	47.61	7.08	6.50	0.11	**60.7**	1.29×10^{7}			
	RF	0	0	0		0	0	33.33	0	0	100	0			
	Score	0	0	0		0	0	2	0	0	4	0			
High Soil Degradation Potential	1	31	**56.50**	40.64	16.60	1.19	45.40	**15.33**	6.00	0.16	**53.8**	2.30×10^{5}	14	R.II	b, f, p, r
	2	32	**44.00**	38.26	13.23	1.20	45.08	**0.07**	5.50	0.17	**38.4**	5.80×10^{5}			
	3	41	**50.25**	**2.38**	5.42	1.20	45.71	**10.00**	6.00	0.11	**80.4**	2.55×10^{6}			
	RF	0	100	33.33		0	0	100	0	0	100	0			
	Score	0	4	2		0	0	4	0	0	4	0			

Note: Values shown in bold indicate parameters classified as degraded, as they exceed the standard criteria for soil degradation. RF = Relative Frequency, s = Solum Thickness, b = Surface Rock Fragments, f = Soil Fraction Composition, d = Bulk Density, v = Total Porosity, p = Permeability Rate, a = pH (H_2O), e = Electrical Conductivity, r = Redox Potential, m = Total Microbial Population, R.I = Slightly Degraded, R.II = Moderately Degraded.

The High Soil Degradation Potential LMU obtained a total score of 14 and was classified as Moderately Degraded (R.II) with an area of approximately 1.23 ha. The limiting factors within this LMU included soil fraction composition (f), surface rock fragments (b), permeability rate (p), and redox potential (r), indicating that the land experienced more complex degradation conditions compared to the other LMUs. High surface rock fragment content and permeability rates exceeding the critical threshold cause water to move rapidly through the soil profile, thereby reducing the soil's capacity to retain water and nutrients. These conditions increase the susceptibility of the soil to nutrient leaching, drought stress within the root zone, and reduced effectiveness of plant water uptake (Jin *et al*., 2025). Reductive conditions resulting from low redox values also limit oxygen availability within the soil, thereby reducing soil biological activity and inhibiting optimal plant growth (Dayo-Olagbende *et al*., 2020; Siedt *et al*., 2023). Conservation measures required in this LMU include terracing on sloping areas (Deng *et al*., 2021), planting permanent cover vegetation (Koudahe *et al*., 2022), application of organic matter (Larney & Angers, 2012), revegetation of open land (Chen *et al*., 2018), and runoff control through conservation drainage channels (Fiener & Auerswald, 2003) to improve the soil's water retention capacity and sustainably reduce the rate of land degradation.

The results demonstrated a relatively consistent relationship between the land degradation potential derived from spatial analysis and the land degradation status obtained through field verification. The Low Land Degradation Potential LMU (PR.II) and Moderate Land Degradation Potential LMU (PR.III) were both classified as Slightly Degraded (R.I), whereas the High Land Degradation Potential LMU (PR.IV) was classified as Moderately Degraded (R.II). These findings indicate that the Geographic Information System-based spatial analysis integrating soil type, slope gradient, rainfall, and land use parameters was sufficiently effective in identifying land vulnerability levels prior to field verification. Similar findings have been reported in recent GIS-based land degradation studies, which demonstrated that spatial modelling approaches can reliably delineate degradation-prone areas and support field-based validation of land degradation status (AbdelRahman, 2023). The results further suggest that areas with higher degradation potential tend to exhibit more complex limiting factors and more pronounced degradation conditions than areas with lower degradation potential (Ambarwulan *et al*., 2021).

Overall, land degradation in Pandansari Village was primarily influenced by limiting factors related to soil physical properties and soil aeration conditions, namely soil fraction composition, surface rock fragments, permeability rate, and redox potential. The dominance of the moderate degradation potential class, which was verified as Slightly Degraded, indicates that most of the area still has considerable potential to maintain its productivity through the implementation of appropriate conservation measures. In contrast, areas classified as Moderately Degraded require priority management because they exhibit a greater number of limiting factors and are more susceptible to further degradation if not managed sustainably. The integration of spatial analysis and soil biophysical evaluation proved effective for identifying land degradation levels and determining priority conservation areas, thereby providing a scientific basis for sustainable land management in Pandansari Village. This finding is consistent with recent studies emphasizing that the integration of GIS-based spatial assessment, soil quality indicators, and field verification provides a robust framework for identifying degradation hotspots and supporting sustainable land management planning (Kaliraj *et al*., 2026; Mikhailova *et al*., 2024; Soliman *et al*., 2026; Workie & Teku, 2025).

4. Conclusion

Based on the analysis of land degradation potential and status in Pandansari Village, Warungasem District, Batang Regency, the study area was classified into three land degradation potential categories, namely low degradation potential covering 70.53 ha, moderate degradation potential covering 109.84 ha, and high degradation potential covering 1.23 ha. Field verification and laboratory analyses showed that the Low Soil Degradation Potential LMU and Moderate Soil Degradation Potential LMU were classified as Slightly Degraded (R.I), whereas the High Soil Degradation Potential LMU was classified as Moderately Degraded (R.II). The main limiting factors affecting land degradation status were soil fraction composition, surface rock fragments, permeability rate, and soil redox conditions, indicating disturbances in soil physical properties, water retention capacity, and soil aeration. The consistency between the land degradation potential classes derived from GIS-based spatial analysis and the actual degradation status obtained through field verification demonstrates that areas with higher degradation potential tend to exhibit more complex limiting factors and more severe degradation conditions. The integration of GIS-based spatial analysis and soil biophysical evaluation constitutes the main scientific contribution of this study, providing a comprehensive and reliable framework for land degradation assessment and supporting the identification of priority areas for sustainable land management.

Abbreviations

LMU	Land Mapping Unit
PR.I	Very Low Soil Degradation Potential
PR.II	Low Soil Degradation Potential
PR.III	Moderate Soil Degradation Potential
PR.IV	High Soil Degradation Potential
PR.V	Very High Soil Degradation Potential
N	Non-Degraded Soil Status
R.I	Slightly Degraded Soil Status
R.II	Moderately Degraded Soil Status
R.III	Severely Degraded Soil Status

R.IV	Very Severely Degraded Soil Status
s	Solum Thickness
b	Surface Rock Fragments
f	Soil Fraction Composition
d	Bulk Density
v	Total Porosity
p	Permeability Rate
a	pH (H2O)
e	Electrical Conductivity
r	Redox Potential
m	Total Microbial Population

Data Availability Statement

Data will be available upon request.

CRediT Authorship Contribution Statement

Farchan Mushaf Al Ramadhani: Conceptualization, Methodology, Software, Validation, Formal analysis, Funding acquisition, Writing – original draft, Writing – review & editing, Visualization. **Eka Adi Supriyanto**: Investigation, Supervision, Validation. **Muhammad Akmal Faza**: Investigation, Methodology, Project administration, Resources, Software, Data curation.

Declaration of Competing Interest

The authors declare that they have no conflict of interest or competing interests.

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