Int. j. adv. multidisc. res. stud. 2026; 6(3):1190-1196

Received: 16-04-2026
Accepted: 26-05-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Soil Erosion and Land Degradation under Perennial Cropping Systems on Sloping Land in the Central Highlands of Vietnam: A GIS-Based Assessment

Tao Anh Khoi
Bao Loc College of Technology and Economics, Ministry of Agriculture and Environment, Vietnam

ORCID: https://orcid.org/0009-0008-7250-6920 Corresponding Author: **Tao Anh Khoi [Email:** anhkhoibaoloc@gmail.com**]**

Abstract
This study provides a GIS-based assessment of soil erosion and land degradation associated with farming on sloping land in the Central Highlands of Vietnam. Using field surveys, soil analysis, and the RUSLE model, erosion rates and soil quality indicators were evaluated across different crop systems and slope gradients. Results indicate that erosion rates exceeded 40 tons/ha/year in durian monoculture systems on slopes greater than 15°, accompanied by significant declines in soil quality. In contrast, agroforestry and tea systems demonstrated lower erosion and improved soil properties. Spatial analysis identified critical erosion hotspots linked to recent agricultural expansion. The findings highlight the need for slope-adapted farming practices and provide important insights for sustainable land-use planning in tropical highland regions.

Keywords: Soil Erosion, Sloping Land, Land Degradation, Central Highlands, GIS, Durian Cultivation, Sustainable Farming

1. Introduction

Soil erosion and land degradation are among the most critical environmental issues affecting tropical highland agroecosystems, particularly in regions undergoing rapid agricultural intensification. Globally, soil erosion poses a serious threat to agricultural sustainability, ecosystem stability, and food security (Pimentel *et al*., 1995; Lal, 2001; Borrelli *et al*., 2017) [23, 11, 1]. Recent global assessments have shown that soil erosion rates are increasing due to land-use change and intensified farming practices, especially in developing regions (Panagos *et al*., 2015; FAO, 2015) [21, 5].

In Vietnam's Central Highlands—a key agricultural zone characterized by undulating topography, high rainfall (1,800–2,500 mm/year), and volcanic soils—the expansion of commercial crops such as coffee (Coffea canephora), tea (Camellia sinensis), and more recently, durian (Durio zibethinus) has transformed vast areas of sloping land into monoculture plantations. These changes, often implemented with minimal soil conservation measures, have raised serious concerns regarding the sustainability of land use on vulnerable slopes (Nguyen & Tran, 2018; Do & Nguyen, 2020; Nguyen *et al*., 2021) [18, 4, 19].

Farming on sloped land in tropical regions inherently increases the risk of surface runoff, nutrient loss, and soil detachment, especially when natural vegetation is removed and replaced with sparsely canopied crops. In tropical environments, high rainfall intensity combined with steep slopes significantly accelerates erosion processes (Nearing *et al*., 2004; Morgan, 2005) [17, 16]. Studies across Southeast Asia have documented a strong relationship between slope gradient, cropping patterns, and soil erosion rates (Lee & Kim, 2019 [12]; Nguyen *et al*., 2019; Bui *et al*., 2020 [2]). In particular, the replacement of diversified agroforestry or forest systems with high-value monocultures—such as durian—has accelerated topsoil loss and disrupted soil physical and chemical balance (Maphosa & Dube, 2021; Le *et al*., 2022) [14, 13].

In the Central Highlands, the problem is exacerbated by limited adoption of slope-appropriate farming techniques. For example, many new durian plantations are established on slopes exceeding 15°, often without cover crops, terracing, or contour hedgerows. As a result, severe sheet and rill erosion has been observed, particularly in areas with high rainfall intensity during the early growing stages. Meanwhile, some coffee-growing regions have started implementing agroforestry practices, offering a useful contrast in terms of erosion control and soil resilience (Sharma *et al*., 2022; Dang *et al*., 2023 [3]).

Although numerous studies in Vietnam have quantitatively assessed soil erosion using RUSLE, GIS, and remote sensing approaches (Pham *et al*., 2018 [22]; Bui *et al*., 2020 [2]; Ha *et al*., 2023; Nguyen Le Duy *et al*., 2025), most of these studies have focused on single watersheds or specific land-use types. In addition, several studies have conducted model calibration using field measurements or plot-scale observations (Nguyen Van Dung *et al*., 2008; Nguyen Kien Dzung, 2019), demonstrating the applicability of RUSLE under Vietnamese conditions.

However, there remains a limited number of studies that provide a comparative, region-wide assessment of soil erosion across different perennial cropping systems under varying slope conditions in the Central Highlands. In particular, the rapid expansion of high-value crops such as durian on steep slopes has not been sufficiently evaluated using spatially explicit approaches that integrate field-based soil indicators with GIS-based erosion modeling.

Therefore, this study aims to (i) quantify soil erosion rates across major perennial cropping systems under different slope gradients, (ii) evaluate associated changes in soil physical and chemical properties, and (iii) identify spatial hotspots of erosion risk using GIS-based analysis. By combining field data with spatial modeling, this study provides a more comprehensive understanding of land degradation processes in tropical highland agroecosystems.

This research was guided by the hypothesis that farming on slopes greater than 15°—particularly under monoculture systems such as durian and traditional coffee—significantly increases soil erosion rates and accelerates soil degradation compared to agroforestry systems or perennial crops grown on gentler slopes.

This study provides one of the first integrated assessments of soil erosion and land degradation across multiple perennial crop systems in the Central Highlands of Vietnam using a combination of field measurements and GIS-based modeling. Unlike previous studies that focused on single crop systems or localized sites, this research compares erosion dynamics across different land uses and slope gradients at a regional scale. The findings offer new spatial insights into erosion hotspots and provide practical implications for sustainable land-use planning in tropical highland agroecosystems.

2. Materials and Methods

2.1 Study Area

The study was conducted in the Central Highlands of Vietnam, covering five provinces: Lâm Đồng, Đắk Lắk, Đắk Nông, Gia Lai, and Kon Tum. This region represents one of the most important agricultural zones in Vietnam, characterized by elevations ranging from 400 to 1,800 m above sea level. The climate is tropical monsoon with distinct wet and dry seasons, and annual rainfall ranges from 1,800 to 2,500 mm, with the majority occurring between May and October (World Bank, 2021) [27].

Topographically, the region is dominated by undulating and mountainous terrain, with slope gradients ranging from 5% to over 25%. The dominant soil types are Ferralsols and Acrisols, which are generally fertile but highly susceptible to erosion under intensive land use (FAO, 2015; Lal, 2001) [5, 11]. Major crops in the region include coffee (*Coffea canephora*), tea (*Camellia sinensis*), durian (*Durio zibethinus*), as well as black pepper and avocado, reflecting rapid agricultural expansion in recent decades (Nguyen *et al*., 2021) [19].

2.2 Research Design and Sampling Strategy

A stratified sampling design was employed to capture variability in soil erosion and soil quality across different land-use systems and slope classes. A total of 45 sampling sites were selected based on three criteria: (i) crop system (durian monoculture, coffee monoculture, coffee agroforestry, and tea plantation), (ii) slope class (gentle: 5–10%, moderate: 10–15%, and steep: >15%), and (iii) land management type (monoculture vs. agroforestry).

Sampling locations were georeferenced using a handheld GPS device (Garmin eTrex 32x). Slope gradients were measured in the field using a clinometer and validated using GIS-derived slope layers from the Shuttle Radar Topography Mission (SRTM) digital elevation model (30-m resolution), a widely used dataset for terrain analysis (Pham *et al*., 2018; Bui *et al*., 2020) [22, 2].

2.3 Soil Sampling and Laboratory Analysis

At each sampling site, composite soil samples were collected from the 0–20 cm topsoil layer using a stainless-steel auger. Each composite sample consisted of five subsamples collected within a 10-m radius to ensure representativeness. Additionally, undisturbed soil cores (100 cm^3) were collected for bulk density determination.

Soil samples were air-dried, sieved through a 2 mm mesh, and analyzed following standard soil analysis procedures (FAO, 2017) [7]. Soil pH was measured in a 1:2.5 soil-to-water suspension using a glass electrode. Soil organic matter content was determined using the Walkley–Black dichromate oxidation method. Bulk density was measured using the core method after oven-drying at 105°C. Soil texture was analyzed using the hydrometer method, while available phosphorus (P) was extracted using the Bray I method and measured colorimetrically. Electrical conductivity (EC) was determined in a 1:5 soil-water extract using a conductivity meter.

2.4 Soil Erosion Estimation

Soil erosion was estimated using the Revised Universal Soil Loss Equation (RUSLE), which is widely applied for predicting annual soil loss under different environmental conditions (Renard *et al*., 1997; Wischmeier & Smith, 1978) [25, 26]. The model is expressed as:

$$A = R \times K \times LS \times C \times P$$

Where A represents the estimated annual soil loss (tons ha^{-1} $year^{-1}$); R is the rainfall erosivity factor; K is the soil erodibility factor; LS is the slope length and steepness factor; C is the cover management factor; and P is the support practice factor.

Table 1: RUSLE parameter values used in this study

Factor	Description	Source/Method
R (Rainfall erosivity)	Calculated from long-term rainfall data (2000–2023) using empirical equations	Renard & Freimund (1994)
K (Soil erodibility)	Derived from soil texture, organic matter content, and soil structure parameters	FAO (2017) [7]; regional studies in Vietnam
LS (Slope length and steepness)	Computed from 30-m resolution DEM using terrain analysis in GIS	SRTM DEM; GIS analysis
C (Cover management)	Assigned based on land-use type and vegetation cover conditions	FAO (2016) [6]; Pham *et al.* (2018) [22]
P (Support practice)	Estimated based on observed conservation practices (e.g., contour planting, mulching, terracing)	Field survey

Note: RUSLE parameters were selected based on a combination of field observations, published literature, and standard guidelines. Where local calibration data were not available, parameter values were adapted from previous studies conducted under similar agroecological conditions in Vietnam.

The rainfall erosivity factor (R) was calculated using long-term daily rainfall data (2000–2023) obtained from five meteorological stations, following the approach of Renard and Freimund (1994). The soil erodibility factor (K) was derived from soil texture, organic matter, and structure parameters. The LS factor was generated from a 30-m resolution DEM using terrain analysis tools in ArcGIS 10.8. The C factor was assigned based on crop type and vegetation cover according to FAO guidelines (FAO, 2016) [6], while the P factor was estimated based on field observations of conservation practices such as terracing, mulching, and contour planting.

The integration of RUSLE with GIS has been widely recognized as an effective approach for spatially explicit soil erosion assessment (Ganasri & Ramesh, 2016; Mekonnen *et al*., 2015) [9, 15]. All calculations were performed using Microsoft Excel and R software (version 4.2), while spatial analysis and mapping were conducted using ArcGIS 10.8 and QGIS 3.28.

Model Validation and Limitations

Due to the lack of long-term measured soil erosion data (e.g., plot-scale measurements or sediment yield records), direct calibration and validation of the RUSLE model were not conducted in this study. Therefore, the estimated soil erosion rates should be interpreted as relative indicators of erosion risk rather than absolute values. This limitation is acknowledged and discussed in the Discussion section.

2.5 GIS-Based Spatial Analysis

Land use and land cover (LULC) classification was performed using Sentinel-2 satellite imagery (10-m spatial resolution) acquired during the 2023 dry season. A supervised classification approach using the maximum likelihood algorithm was applied through the Semi-Automatic Classification Plugin in QGIS. The classification accuracy was assessed using ground-truth points collected during field surveys. The overall classification accuracy reached 87.5%, with a Kappa coefficient of 0.83, indicating a high level of reliability.

Slope and elevation maps were derived from the SRTM DEM (30-m resolution). Spatial layers of estimated soil erosion (RUSLE outputs) were overlaid with LULC and slope maps to identify areas at high risk of erosion. Hotspot analysis was conducted using the Getis-Ord Gi* statistic to detect statistically significant clusters of high erosion intensity at confidence levels of 95% and 99% ($p < 0.05$ and $p < 0.01$).

3. Results

3.1 Soil Erosion Rates by Crop Type and Slope Class

Erosion rates varied significantly across crop types and slope gradients. Durian plantations established on steep slopes (>15°) in Lâm Đồng and Đắk Nông showed the highest soil loss, averaging 42.6 tons/ha/year, with peak values exceeding 50 tons/ha/year in unmanaged plots. In contrast, coffee plantations on moderate slopes (10–15°) in Gia Lai and Đắk Lắk had lower average erosion at 28.3 tons/ha/year, while tea farms on gentle slopes (<10°) in Lâm Đồng recorded erosion rates of 13.7 tons/ha/year.

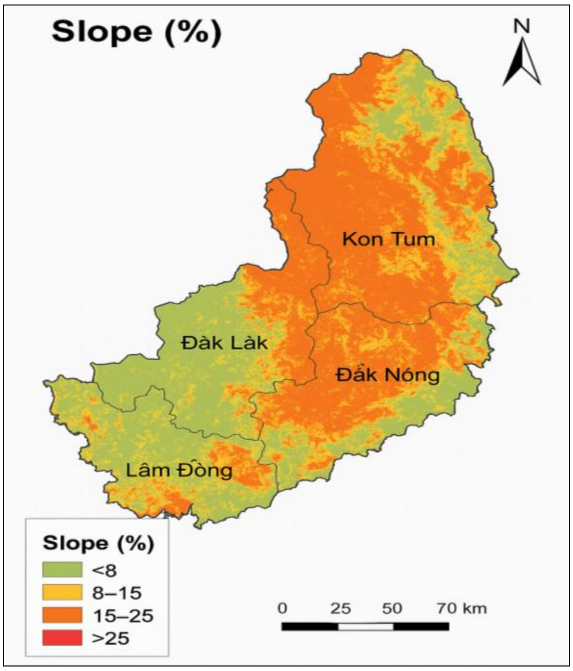

Fig 1: Slope vulnerability map of the Central Highlands region, illustrating the distribution of areas with steep slopes (>15%), which are more susceptible to erosion due to intensive cultivation and rainfall impact

Notably, land management practices significantly modified erosion intensity within the same slope class. In Gia Lai, coffee agroforestry systems with contour planting and intercropping exhibited 36% lower erosion than coffee monocultures. Erosion reduction in agroforestry systems was calculated based on mean differences between land-use types and confirmed using independent t-tests ($p < 0.05$), indicating statistically significant differences. In Đắk Nông, durian plantations with no grass cover or slope barriers experienced extreme sheet and rill erosion, visibly degrading surface structure.

The results revealed a clear correlation between slope gradient, cropping system, and soil erosion intensity across the Central Highlands. As shown in Table 1, durian plantations on steep slopes (15–25%) in Lâm Đồng and Đắk Nông exhibited the highest erosion rates, reaching 42.6 tons/ha/year, categorized as very severe based on FAO standards.

Table 2: Soil erosion rates by crop type and slope class in Central Highlands provinces

Province	Crop Type	Slope (%)	Erosion Rate (tons/ha/year)	Erosion Class
Lâm Đồng	Durian	18–25	42.6	Very Severe
Đắk Nông	Durian	15–22	39.8	Severe
Gia Lai	Coffee Monoculture	12–18	31.5	Severe
Đắk Lắk	Coffee Agroforestry	10–15	20.4	Moderate
Lâm Đồng	Tea Plantation	5–10	13.7	Low

Interpretation:

- The severe erosion in durian monocultures stems from poor ground cover, row spacing, and lack of slope protection measures.
- Agroforestry coffee systems in Đắk Lắk showed 35–40% lower erosion compared to monocultures in Gia Lai, thanks to the canopy cover, mulch, and contour planting.
- Tea plantations on gentle slopes exhibited erosion rates well within sustainable thresholds, reflecting the positive impact of perennial canopy and minimal disturbance.

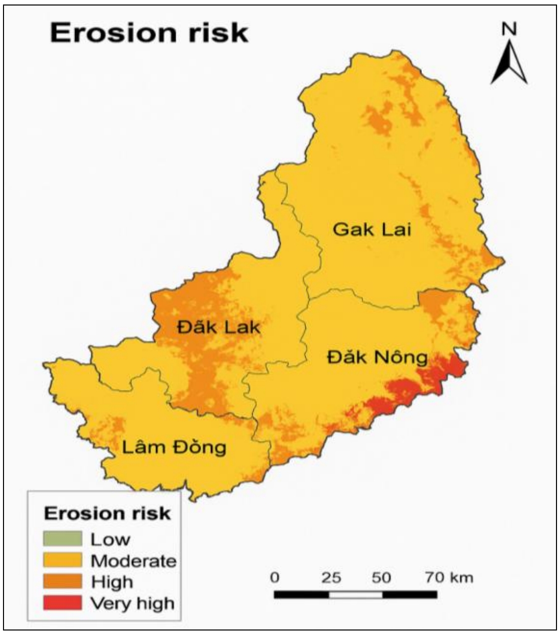

Fig 2: Soil erosion risk zones in the Central Highlands, categorized into low, moderate, high, and very high risk areas. Notably, Đắk Nông and southern Lâm Đồng exhibit the highest concentration of erosion-prone land

3.2 Soil Quality under Different Land Uses

Across all provinces, soil quality indicators deteriorated with increasing slope and farming intensity. In high-slope durian plantations, soil pH dropped below 4.8, and organic matter content was as low as 1.2%, reflecting high leaching, oxidation, and erosion losses. In contrast, tea plantations maintained higher pH (5.1) and organic matter (2.6%) due to denser canopy, ground cover, and reduced tillage.

Bulk density, a proxy for compaction, was significantly higher (1.47 g/cm³) in durian farms compared to 1.22 g/cm³ in tea systems. High compaction correlates with lower porosity and root penetration, exacerbating surface runoff.

Soil degradation was further confirmed by analysis of physical and chemical properties under different land uses. As shown in Table 3, durian plantations on steep slopes had the lowest soil pH (4.8), lowest organic matter (1.2%), and higheqst bulk density (1.47 g/cm³)—all indicators of severe degradation.

Table 3: Soil physical and chemical properties across land use systems

Land Use	pH (H_2O)	Organic Matter (%)	Bulk Density (g/cm³)	Available P (mg/kg)	EC (dS/m)
Durian (steep slope)	4.8	1.2	1.47	5.3	0.23
Coffee Monoculture	5.0	1.7	1.38	6.1	0.28
Coffee Agroforestry	5.2	2.3	1.29	7.6	0.21
Tea Plantation	5.1	2.6	1.22	8.4	0.20
Native Forest (ref.)	5.5	3.8	1.08	10.1	0.18

Analysis:

- Durian systems have high compaction and acidity, likely from rainfall impact, erosion loss, and fertilizer misuse.
- Coffee agroforestry and tea plantations retain higher SOM and P availability, supporting long-term fertility.
- Bulk density and EC values suggest that land under perennial cover has better structure and salinity resistance.

3.3 Spatial Distribution of Erosion Risk

GIS-based erosion mapping revealed critical zones of erosion risk overlapping with:

- Durian expansion belts in Đạ Huoai – Lâm Đồng, and Tuy Đức – Đắk Nông
- High-slope coffee monocultures in Ea H'leo – Đắk Lắk
- Steep tea hills in Cầu Đất – Lâm Đồng with road access and intensive harvesting

These areas showed a combination of:

- Steep slopes >15°
- High RUSLE C values (low vegetation cover)
- Minimal conservation practices

High-resolution slope and erosion overlays (Fig 1) revealed a strong positive relationship between slope gradient and soil erosion rates. A strong positive correlation ($r = 0.81$, $p < 0.01$) was identified using Pearson correlation analysis.

A GIS-based overlay of slope, land use, and rainfall data identified erosion hotspots in the Central Highlands. Table 4 summarizes high-risk areas, indicating that Lâm Đồng and Đắk Nông are the most affected provinces, with more than 18–21% of cultivated land at high erosion risk.

Table 4: Estimated erosion-prone areas by province (GIS analysis)

Province	High-risk Area (ha)	% of Province Cultivated Land	Main Crop Risk Factors
Lâm Đồng	12,300	21.5%	Durian, tea (steep hills)
Đắk Nông	9,850	18.2%	Durian, pepper
Gia Lai	7,200	14.7%	Coffee monoculture
Đắk Lắk	6,400	11.1%	Coffee monoculture
Kon Tum	4,800	9.3%	Cassava, coffee

Interpretation:

- These erosion hotspots typically overlap with new expansion areas, poorly managed perennial crops, and mechanized land use without slope treatment.
- Satellite and drone imagery confirmed increasing bare soil exposure during dry seasons in Lâm Đồng and Đắk Nông.

4. Discussion

4.1 Mechanisms and Degradation Pathways

The combined effects of steep topography, high rainfall (1,800–2,500 mm/year), and land clearing without conservation lead to rapid surface runoff, detachment of topsoil, and loss of fertility. Durian plantations on steep slopes act as erosion amplifiers due to low canopy coverage, row planting along slope, and absence of hedgerows.

Comparative Resilience of Cropping Systems

The hierarchy of soil degradation is:

Durian monoculture > Coffee monoculture > Coffee agroforestry > Tea plantation > Native forest

Agroforestry improves soil quality via litter input, shade, erosion buffering, and enhanced microbial activity. Tea, being a dense perennial, provides long-term slope stabilization when well managed.

Implications for Land Use Policy

- Lands with >15° slope should be zoned for agroforestry or forest restoration, not annual or fruit monoculture.
- Durian cultivation must be prohibited or strictly regulated on high slopes unless erosion control is proven.
- Payment for ecosystem services (PES), slope-based zoning laws, and subsidized hedgerow planting should be promoted.

Analysis:

- Durian systems have high compaction and acidity, likely from rainfall impact, erosion loss, and fertilizer misuse.
- Coffee agroforestry and tea plantations retain higher SOM and P availability, supporting long-term fertility.
- Bulk density and EC values suggest that land under perennial cover has better structure and salinity resistance.

4.2 Erosion Dynamics in Highland Agroecosystems

The results of this study clearly demonstrate that slope gradient and land-use type are the primary determinants of soil erosion intensity in the Central Highlands of Vietnam. Erosion rates exceeding 40 tons ha^{-1} $year^{-1}$ in durian monoculture systems on slopes greater than 15% indicate unsustainable land-use practices under current management conditions. These values exceed commonly accepted soil loss tolerance thresholds for tropical upland systems, highlighting the severity of land degradation.

These findings are consistent with previous studies in tropical highland environments, where steep slopes combined with intensive cultivation significantly accelerate soil erosion processes (Nearing *et al*., 2004; Lee & Kim, 2019; Do & Nguyen, 2020) [17, 12, 4]. High rainfall intensity, coupled with inadequate soil protection, enhances surface runoff and soil detachment, leading to rapid topsoil loss (Morgan, 2005; Borrelli *et al*., 2017) [16, 1].

In particular, the early growth stages of durian plantations—characterized by limited canopy cover and minimal ground vegetation—represent a critical period for soil vulnerability. The absence of protective measures such as mulching, terracing, or vegetative barriers significantly increases the risk of rill and sheet erosion, as observed in field sites in Lâm Đồng and Đắk Nông.

4.3 Cropping Systems and Their Soil Conservation Capacity

A clear gradient of soil degradation was observed among different cropping systems. Durian monocultures exhibited the highest levels of erosion and soil quality decline, characterized by low organic matter content, high bulk density, and acidic soil conditions. Coffee monocultures on moderate slopes also showed signs of degradation, although to a lesser extent.

In contrast, agroforestry systems integrating shade trees (e.g., *Gliricidia sepium*, *Leucaena leucocephala*) with coffee plantations significantly improved soil conservation. Erosion rates were reduced by up to 35% compared to monoculture systems, confirming the important role of vegetation cover, litter input, and root systems in stabilizing soil structure (Maphosa & Dube, 2021; Le *et al*., 2022) [14, 13]. These findings are consistent with broader studies highlighting agroforestry as an effective strategy for reducing erosion and enhancing soil resilience in tropical systems (Keesstra *et al*., 2016) [10].

Tea plantations on gentle slopes (<10%) showed the most favorable soil conditions, with higher organic matter content and lower bulk density. This can be attributed to permanent canopy cover, reduced soil disturbance, and continuous litter input. However, the potential long-term impact of mechanized harvesting on soil compaction warrants further investigation.

4.4 Soil Quality Degradation Indicators

The observed changes in soil physical and chemical properties provide strong evidence of degradation under intensive slope farming. Low pH values (<5.0) and reduced organic matter content (<1.5%) in durian plantations suggest significant nutrient depletion, leaching, and soil acidification, potentially exacerbated by excessive fertilizer use (Lal, 2001; FAO, 2017) [11, 7].

Bulk density values exceeding 1.45 g cm^{-3} indicate soil compaction, which reduces porosity, limits root penetration, and increases surface runoff. These conditions further accelerate erosion processes and reduce long-term soil productivity.

Conversely, agroforestry and tea systems maintained more favorable soil conditions, with higher organic matter levels (>2.0%) and lower bulk density (<1.30 g cm^{-3}). These characteristics are associated with improved soil structure, enhanced water retention, and greater resilience to erosion. The relatively stable levels of available phosphorus and electrical conductivity also suggest more balanced nutrient cycling in these systems.

4.5 Spatial Patterns and Policy Implications

The GIS-based analysis revealed distinct spatial patterns of erosion risk, with hotspots concentrated in southern Lâm Đồng, Đắk Nông, and parts of Gia Lai. These areas correspond closely with regions experiencing rapid agricultural expansion, particularly of durian and pepper on steep slopes. Similar spatial patterns have been reported in other studies using GIS-based erosion modeling in Vietnam (Pham *et al*., 2018; Dang *et al*., 2023) [22, 3].

The increasing exposure of bare soil during dry seasons, as observed from satellite imagery, further exacerbates erosion risk under subsequent rainfall events. These findings highlight the urgent need for integrating spatial planning with sustainable land management practices.

Slope-based land-use zoning should be prioritized, with areas exceeding 15% slope restricted to agroforestry systems or reforestation. Where monoculture plantations are maintained, the adoption of soil conservation measures—such as contour planting, mulching, and terracing—is essential. In addition, policy instruments such as payment for ecosystem services (PES) and targeted agricultural extension programs could play a critical role in promoting sustainable practices.

4.6 Comparison with Other Tropical Highland Regions

The results of this study are consistent with findings from other tropical highland regions, including Southeast Asia and Sub-Saharan Africa. For example, studies in northern Thailand and Ethiopia have reported similar levels of soil erosion and organic matter loss under intensive cultivation on steep slopes (FAO, 2016; Poesen, 2018) [6, 24].

Agroforestry systems have consistently been identified as one of the most effective low-cost strategies for mitigating soil erosion in these environments. By enhancing vegetation cover and improving soil structure, agroforestry provides both ecological and economic benefits, making it a suitable approach for sustainable land management in the Central Highlands.

Overall, this study highlights the urgent need to integrate slope-based land-use planning with sustainable agricultural practices. Agroforestry systems and perennial crops such as tea demonstrate strong potential for reducing soil erosion and maintaining soil fertility. Future agricultural development strategies in the Central Highlands should therefore prioritize ecological suitability alongside economic returns to ensure long-term sustainability.

4.7 Limitations of the Study

This study has several limitations. First, the RUSLE model was not calibrated using direct field measurements, which may affect the accuracy of absolute erosion estimates. Second, the number of sampling sites (45) may not fully capture spatial variability across the entire Central Highlands. Third, the use of 30-m resolution DEM and satellite imagery may introduce uncertainties in terrain and land-use classification. Despite these limitations, the study provides valuable insights into relative erosion patterns and land-use impacts.

5. Conclusion

This study indicates that soil erosion rates can exceed 40 tons ha^{-1} $year^{-1}$ in durian monoculture systems on slopes greater than 15%, suggesting a high risk of land degradation under current management practices in the Central Highlands of Vietnam. In contrast, agroforestry systems and tea plantations showed relatively lower erosion rates and improved soil quality indicators, including higher organic matter content and lower bulk density.

The spatial analysis revealed that erosion risk is strongly associated with slope gradient and land-use type, with high-risk areas concentrated in recently expanded plantation zones lacking adequate soil conservation measures. These findings highlight the importance of adopting slope-adapted land-use strategies, particularly the promotion of agroforestry systems and improved management practices such as contour planting, mulching, and vegetative cover.

However, the results should be interpreted with caution, as the RUSLE model was not calibrated using direct field measurements, and the sampling size may limit full spatial representation. Therefore, the estimated erosion rates primarily reflect relative patterns rather than absolute values.

Future research should focus on long-term field monitoring, model calibration using measured erosion data, and the integration of climate variability scenarios to improve prediction accuracy and support sustainable land-use planning.

6. Declarations

Consent to Publish declaration: Not applicable.

Ethics and Consent to Participate declarations: Not applicable.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

7. Acknowledgements

The authors would like to express their sincere gratitude to the local agricultural authorities and farmers in the Central Highlands of Vietnam for their valuable support and cooperation during the fieldwork. We also acknowledge the assistance of the GIS and Remote Sensing Laboratory at Bao loc college of economics and technology for providing technical support in spatial data analysis. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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