International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 5s, 2025
https://www.theaspd.com/ijes.php

Ten-Year Changes in Soil Erosion in Nam Dong District, Central Vietnam Using USLE and GIS Techniques

Pham Gia Tung[1], Nguyen Hoang Khanh Linh[2] and Tran Thi Minh Chau[3]*
[1,2]International School – Hue University, Vietnam
[3]University of Agriculture and Forestry, Hue University, Vietnam
[1]phamgiatung@hueuni.edu.vn, [2]nhklinh@hueuni.edu.vn and [3]ttmchauhuaf@hueni.edu.vn

Abstract: *This study examines changes in soil erosion over a ten-year period (2013–2023) in Nam Dong District, Central Vietnam, using the Universal Soil Loss Equation (USLE) integrated with Geographic Information Systems (GIS). Soil erosion maps for 2013, 2018, and 2023 were developed using Landsat 8 imagery, a digital elevation model (DEM), and local weather and land use data. The analysis focused on variations in key USLE factors, particularly rainfall erosivity (R), vegetation cover (C), and conservation practices (P), which changed significantly over time. Results show that 2023 experienced the most severe erosion, with over 66% of the area classified as extreme, corresponding to high rainfall that year. In contrast, 2018 had the lowest erosion levels. Statistical analyses (ANOVA and regression) confirmed that changes in R and C factors were the primary drivers of soil loss, while the P factor had limited influence. These findings align with global research emphasizing the roles of rainfall intensity and vegetation cover in erosion processes. The study highlights the value of multi-temporal analysis for understanding erosion dynamics and supports the need for adaptive land management strategies in tropical mountainous regions facing climate variability.*

INTRODUCTION

Soil erosion is a critical environmental problem, particularly in tropical mountainous regions where intense rainfall and complex topography exacerbate land degradation. Globally, erosion processes are estimated to affect about 75 billion tons of soil annually, leading to reduced agricultural productivity and contributing to food insecurity (den Biggelaar et al. 2003; Pimentel et al. 1995). Soil erosion is a critical environmental problem in the mountainous regions of Vietnam, where annual soil loss rates can reach up to 100 t/ha/year on steep cultivated slopes, significantly affecting agricultural productivity and sustainability (Valentin, Poesen, and Li 2005). Concern to Thua Thien Hue province, soil erosion is a major environmental and agricultural challenge, particularly in its mountainous districts such as Nam Đông and A Lưới. The region's steep topography, high annual rainfall (often exceeding 2,700 mm), and widespread land use changes have contributed to significant soil loss and land degradation (Nguyen et al. 2023a). Using the Universal Soil Loss Equation (USLE) model and Geographic Information Systems (GIS), recent studies have estimated average annual soil loss rates in the A Sáp river basin (A Lưới district) to be around 18 t/ha/year, with natural forest areas experiencing the highest erosion rates of approximately 19 t/ha/year, while plantation forests and agricultural lands showed lower rates of 7 t/ha/year and 3.7 t/ha/year, respectively (Pham, Degener, and Kappas 2018). Erosion not only reduces soil fertility and limits agricultural output but also causes sedimentation in rivers and reservoirs, affecting water quality and increasing flood risks (Krasa et al. 2019). These processes are particularly problematic in regions with limited land resources and growing populations.

While many studies have used the Universal Soil Loss Equation (USLE) to estimate erosion, most assessments focus on a single time point. However, soil erosion is dynamic, influenced by variations in climate, land use, and vegetation cover over time (Li et al. 2021). Without long-term monitoring, erosion trends and the effectiveness of conservation practices cannot be adequately assessed. This is especially important in tropical developing countries where land use patterns change rapidly due to economic development and shifting cultivation practices(Panagos, Borrelli, and Meusburger 2015).

To address this gap, this study assesses changes in soil erosion in Nam Dong District across a 10-year period (2013–2023), using the USLE model integrated with GIS. The primary aim is to determine how rainfall, land cover, and farming practices have affected erosion rates over time, thereby informing sustainable land use planning. The study builds on previous work in similar ecosystems but extends the analysis across multiple years using spatial-temporal datasets and statistical modeling. By doing so, it provides a deeper understanding of erosion dynamics in central Vietnam and offers insights for adaptive soil conservation policies.

2. DATA AND METHODS

2.1. Research site

Nam Dong District features a complex topography with an average elevation of 409 m and a mean slope of 23°. The basin-like terrain is relatively flat in the central and northern areas, while other regions are mountainous. The climate is harsh, with temperatures ranging from 5°C to 41°C and an average annual rainfall of over 3,200 mm recorded at Khe Tre Town over the past decade. Land use is dominated by special-use and protection forests (over 65%), with only 9% allocated to agriculture and around 20% to production forests. As such, arable land is limited compared to other areas with similar conditions. The population grew from approximately 25,000 in 2013 to over 27,000 in 2023, with ethnic minorities comprising more than 60%. The district continues to face significant natural and socio-economic constraints. The research site was descripted by Figure 1.

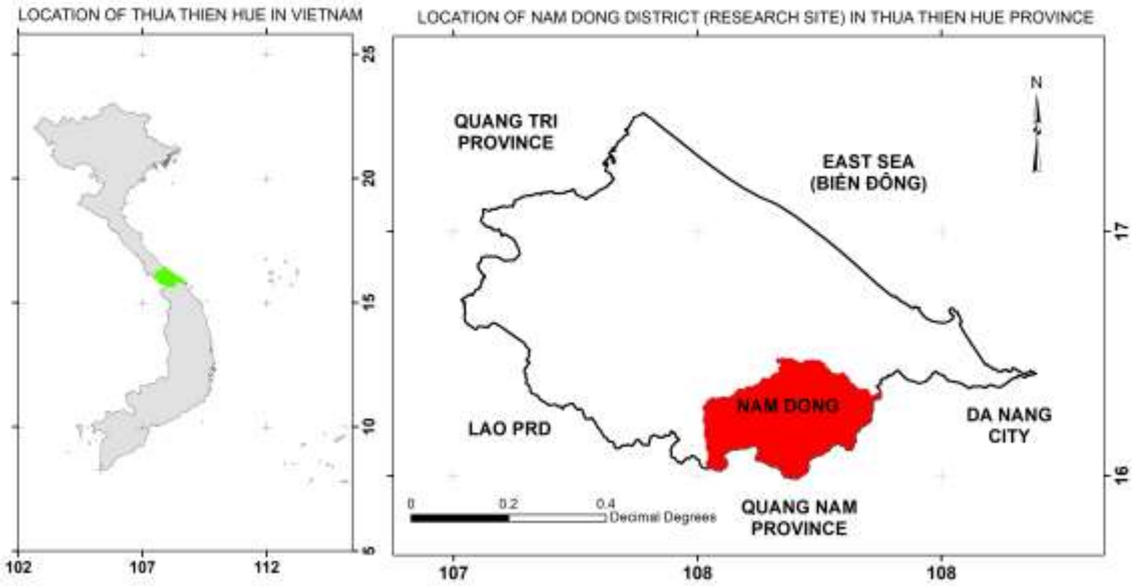

Figure 1. The location of Nam Dong district in Thua Thien Hue province (Sources: DHH2024-17-03)

2.2. The dataset

Primary data include Landsat 8 remote sensing imagery from April of the years 2013, 2018, and 2023, obtained from the United States Geological Survey (USGS), and a Digital Elevation Model (DEM) provided by the Japan Aerospace Exploration Agency (JAXA). These datasets are stored in raster format with a spatial resolution of 30 meters. Secondary data consist of weather records from nine meteorological stations across Thua Thien Hue, Quang Nam, and Da Nang provinces; land use status maps for the years 2013, 2018, and 2023, compiled and adjusted based on cadastral data; and the 2005 soil map of Thua Thien Hue Province provided by the Vietnam Institute of Agricultural Planning and Investigation.

2.3. Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE), originally proposed in 1978, was later refined into the Revised Universal Soil Loss Equation (RUSLE), which introduced modifications to the parameter values and required more detailed input data (Wischmeier and Smith 1978). Despite these advancements, the USLE remains widely preferred and applied in many parts of the world due to its simplicity and accessibility. The USLE was shown as:

$$A = R * LS * K * C * P$$

Where: A is the average annual soil loss (tons/ha/ year); R is the rainfall erosivity (MJ*mm/(ha*hour*year); K is the soil erodibility factor (t*hour/(MJ*mm); LS is the topographic factor (dimensionless); C is the cropping management factors (dimensionless), and P is the practice support factor (dimensionless)

In this research, the component factor of USLE were calculated as following methods:

***) R factor* (Nguyễn Trọng Hà 1996):**

$$R = 0.548257 * P\ (mm) - 59.9.$$

Where: R is the rainfall erosivity and P is annual rainfall.

***) LS factor* (Moore and Wilson 1992):**

$$LS = \left(\frac{A_s}{22.13}\right)^m * \left(\frac{Sin\ (Slope\ degree * 0.01744)}{0.09}\right)^n$$

Where, LS represents the topographic factor, A_s is the flow length, and Slope degree refers to the slope steepness measured in degrees. The value 22.13 corresponds to the slope length in the empirical USLE model, equivalent to 72 feet. The value 0.01744 is the conversion factor from degrees to radians for slope measurement. The value 0.09 represents the experimental slope steepness, equivalent to 9%. m and n are empirical exponents, with m = 0.5 and n = 1.3, as commonly adopted in studies conducted under similar topographic and climatic conditions.

**) K factor*: The K values were extracted base on the soil type map (National Institute of Agricultural Planning and Projection 2005) and the suggestion for K values in USLE for upland soil in Central Vietnam, which has been developed by previous research (Nguyễn Tử Siêm and Thái Phiên 1999).

**) C factor*: The C factor was calculate based on the Normalized Difference Vegetation Index, which has been produced from Landsat 8 image of each year, as the suggestion by (Durigon et al. 2014) as following equation:

$$C = \frac{(-NDVI + 1)}{2}$$

***) P values*:** This value was determined based on the land use type and terrain slope as suggested by (Shin 1999) , as in table 1.

Table 1. P values base on the land use type and slope

Land use type	Slope (Degrees)				
	0-5	**5-8**	**8-10**	**10-15**	**>15**
Bare land	1.0	1.0	1.0	1.0	1.0
Forest, perennial trees	0.55	0.60	0.80	0.90	1.0
Annual crops	027	0.30	0.40	0.45	0.50

2.4. Statistical analysis

All data (with each pixel considered as a data point) were processed using SPSS software, employing the Post Hoc Tests – Multiple Comparisons technique to identify significant differences in soil erosion across years. This analysis was conducted based on the following hypotheses and alternative hypotheses:

Null hypothesis (H_0): $A_{(2013)} = A_{(2018)} = A_{(2023)}$: (The mean soil erosion values in 2013, 2018, and 2023 are not significantly different at the 95% confidence level.)

Alternative hypothesis (H_1): $A_{(2013)} \neq A_{(2018)} \neq A_{(2023)}$: (The mean soil erosion values in 2013, 2018, and 2023 are significantly different at the 95% confidence level.)

3. RESULTS AND DISCUSSION

In 2023, the area of land experiencing extreme soil erosion was the highest, accounting for over 66% of the total study area, while 2018 recorded the lowest extent, with just over 43% (Figure 2 and Figure 3). This trend corresponds with annual rainfall variation, highlighting rainfall as a dominant driver of erosion processes, as also confirmed in previous studies in tropical regions (Li 2021; Valentin et al. 2005). Land affected by slight erosion accounted for less than 5% in 2023 and peaked at 8.10% in 2018, posing ongoing challenges to sustainable agricultural development.

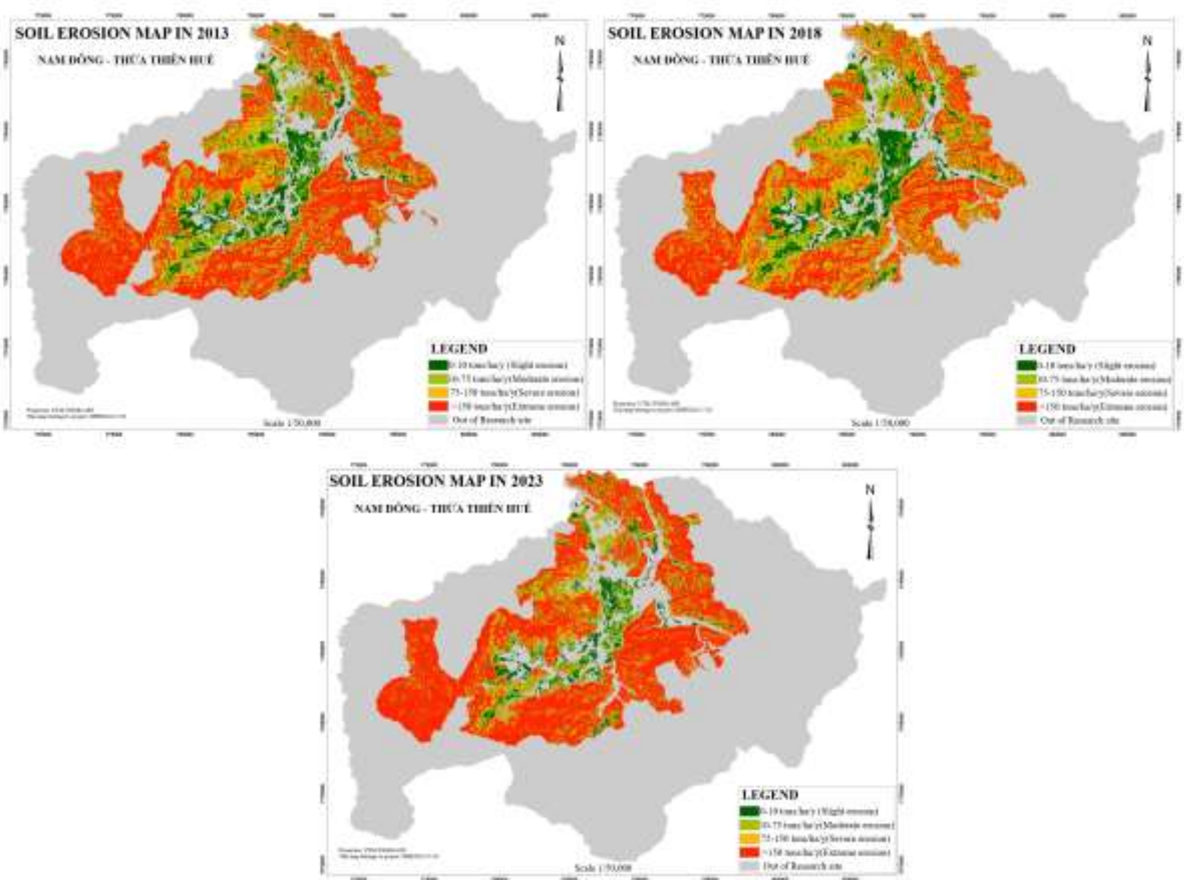

Figure 2. Soil erosion classification in 2013, 2018 and 2023.

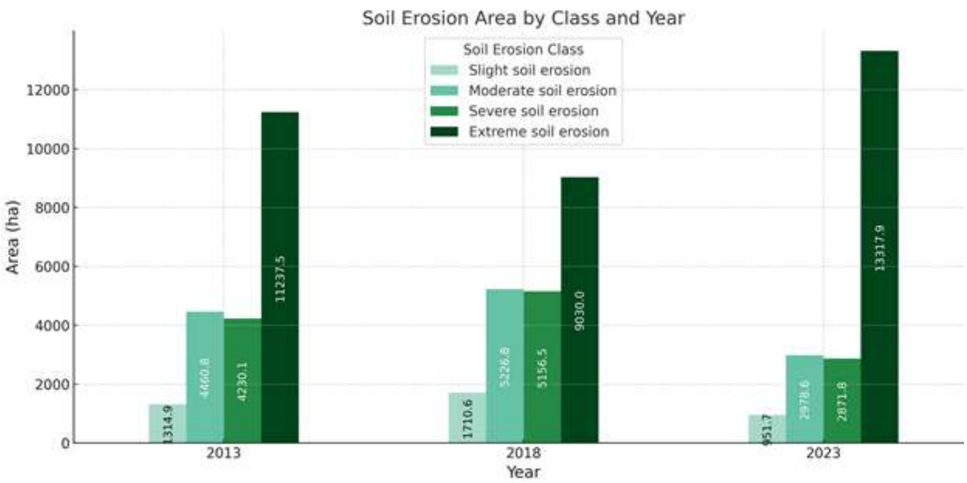

Figure 3. Statistical of soil erosion by area (hectare) in 2013, 2018 and 2023.

The statistical indicators (Table 2) showed that soil loss followed a normal distribution (Skewness < 1), permitting ANOVA with Tukey's test. The results confirmed statistically significant differences in soil loss among the years studied (Sig. = 0.000 < 0.05). Similar findings were reported by (Pham et al. 2018) in the A Sap Basin and by (Panagos et al. 2015) in European landscapes, indicating temporal changes in R and C factors as key contributors.

Table 2. Statistical Analysis of soil erosion in 2013, 2018 and 2023

Criterion	2023	2018	2013
Mean of soil erosion rate (tons/ha/year)	254.07	131.71	168.01
Lowest soil erosion rate (tons/ha/year)	0	0	0
Highest soil erosion rate(tons/ha/year)	1,202.11	737.40	996.54
Standard Deviation	197.32	108.11	135.49
Skewness value	0.652	0.665	0.635

Further analysis revealed that among the USLE factors, R (rainfall erosivity), C (vegetation cover), and P (conservation practices) significantly influenced inter-annual erosion variability (Table 3). The P factor had minimal impact, whereas R had the strongest effect between 2023 and 2018—consistent with the high rainfall in 2023. Conversely, C factor was most influential between 2018–2013 and 2023–2013, underlining the critical role of vegetation in mitigating erosion (Durigon et al. 2014; Krasa et al. 2019).

Table 3. The impacts of each factor on soil erosion rate between 2013, 2018, 2023

Compared years		Beta	t	Sig.	Collinearity Statistics	
					Tolerance	VIF
2018-2013	(Constant)		11.664	.000		
	R1813	.040	19.633	.000	.972	1.029
	C1813	.285	141.042	.000	.972	1.029
	P1813	.042	21.265	.000	1.000	1.000
2023-2018	(Constant)		127.138	.000		
	R2318	-.229	-114.268	.000	.999	1.001
	C2318	.146	72.810	.000	.999	1.001
	P2318	.011	5.591	.000	1.000	1.000
2023-2013	(Constant)		79.329	.000		
	R2313	-.140	-66.858	.000	.915	1.093
	C2313	.194	92.903	.000	.915	1.093
	P2313	-.008	-4.007	.000	1.000	1.000

These findings align with global literature indicating that increased precipitation intensities, land use conversion, and vegetation loss can accelerate erosion (Nguyen et al. 2023b; Pimentel et al. 1995). Therefore, erosion control strategies must prioritize improving vegetative cover and adapting land management to climate extremes. The results reinforce the value of using multi-temporal remote sensing and statistical modeling in erosion monitoring, as demonstrated in similar efforts by den Biggelaar et al. (2003) and Shin (1999).

4. CONCLUSION

This study assessed the spatiotemporal dynamics of soil erosion in Nam Dong District over a ten-year period using the USLE model integrated with GIS techniques. By analyzing erosion rates in 2013, 2018, and 2023, the results revealed clear temporal shifts driven primarily by rainfall intensity and land cover conditions. The most severe erosion occurred in 2023, coinciding with the highest recorded rainfall, while 2018 showed the lowest erosion levels.

Statistical analyses confirmed significant differences in erosion rates between the years, with the R and C factors playing dominant roles in explaining these variations. Notably, vegetation cover changes had substantial influence across two time intervals, emphasizing the importance of maintaining adequate plant cover for erosion control. Conversely, the conservation practice (P) factor showed limited impact, suggesting either suboptimal implementation or limited effectiveness under local conditions.

These findings are consistent with regional and global studies and highlight the utility of long-term monitoring for identifying erosion trends and informing land management strategies. The integration of remote sensing, GIS, and statistical techniques provided a robust framework for tracking erosion dynamics. Future land use planning in Nam Dong and similar mountainous regions should prioritize adaptive strategies focused on increasing vegetative cover and mitigating the effects of increasingly variable climate conditions. Continuous monitoring and localized conservation interventions will be essential for sustainable soil resource management in the context of climate change.

ACKNOWLEDGE
The authors gratefully acknowledge the financial support provided by Hue University for this study through the research grant number DHH2024-17-03

REFERENCES

Den Biggelaar, Christoffel, Rattan Lal, Keith Wiebe, Hari Eswaran, Vince Breneman, and Paul Reich. 2003. "The Global Impact Of Soil Erosion On Productivity*." Pp. 49–95 in.

Durigon, V. L., D. F. Carvalho, M. A. H. Antunes, P. T. S. Oliveira, and M. M. Fernandes. 2014. "NDVI Time Series for Monitoring RUSLE Cover Management Factor in a Tropical Watershed." International Journal of Remote Sensing 35(2):441–53. doi:10.1080/01431161.2013.871081.

Krasa, Josef, Tomas Dostal, Barbora Jachymova, Miroslav Bauer, and Jan Devaty. 2019. "Soil Erosion as a Source of Sediment and Phosphorus in Rivers and Reservoirs – Watershed Analyses Using WaTEM/SEDEM." Environmental Research 171:470–83. doi:10.1016/j.envres.2019.01.044.

Li, Li, J. L. ,. Sun, R. H. ,. Xiong, M. Q. 2021. "Methodology of Time Series of Soil Erosion Dataset in Water Erosion Area of China in Five-Year Increments (2000–2015)." Journal of Global Change Data & Discovery 5(2). doi:10.3974/geodp.2021.02.13.

Moore, Ian D., and John P. Wilson. 1992. "Length-Slope Factors for the Revised Universal Soil Loss Equation: Simplified Method of Estimation." Journal of Soil and Water Conservation 47(5):423–28.

National Institute of Agricultural Planning and Projection. 2005. Soil Map of Thua Thien Hue Province.

Nguyen, Son Hoang, Dan Ngoc Nguyen, Nhung Nguyen Thu, Hai Hoang Pham, Hang Anh Phan, and Cham Dinh Dao. 2023a. "Current Soil Degradation Assessment in the Thua Thien Hue Province, Vietnam, by Multi-Criteria Analysis and GIS Technology." Sustainability 15(19):14276. doi:10.3390/su151914276.

Nguyễn Trọng Hà. 1996. "Xác Định Các Yếu Tố Gây Xói Mòn và Khả Năng Dự Báo Xói Mòn Trên Đất Dốc." Luận án Tiến sĩ, Đại học Thủy lợi Hà Nội.

Nguyễn Tử Siêm, and Thái Phiên. 1999. Đất Đồi Núi Việt Nam: Suy Thoái và Phục Hồi. Hà Nội: Nhà xuất bản nông nghiệp.

Panagos, Panos, Pasquale Borrelli, and Katrin Meusburger. 2015. "A New European Slope Length and Steepness Factor (LS-Factor) for Modeling Soil Erosion by Water." Geosciences 5(2):117–26. doi:10.3390/geosciences5020117.

Pham, Tung Gia, Jan Degener, and Martin Kappas. 2018. "Integrated Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Erosion Estimation in A Sap Basin: Central Vietnam." International Soil and Water Conservation Research 6(2):99–110. doi:10.1016/j.iswcr.2018.01.001.

Pimentel, David, C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. "Environmental and Economic Costs of Soil Erosion and Conservation Benefits." Science 267(5201):1117–23. doi:10.1126/science.267.5201.1117.

Shin, G. J. 1999. "The Analysis of Soil Erosion Analysis in Watershed Using GIS." Ph.D. Dissertation, Gang-won National University.

Valentin, C., J. Poesen, and Yong Li. 2005. "Gully Erosion: Impacts, Factors and Control." CATENA 63(2–3):132–53. doi:10.1016/j.catena.2005.06.001.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting Rainfall Erosion Losses. A Guide to Conservation Planning. Agriculture Handbook No.537. Washington.