Applying geospatial technology to identify soil erosion risks in the context of climate change in Yen Chau district, Son La province

Vu Van Truong*, Ha Tri Son, Nguyen Thi Bich Hao,
Nguyen Hai Hoa, Phan Van Dung, Nguyen Thi Thuy Anh
Vietnam National University of Forestry

Ứng dụng công nghệ địa không gian xác định nguy cơ xói mòn đất trong bối cảnh biến đổi khí hậu tại huyện Yên Châu, tỉnh Sơn La

Vũ Văn Trường*, Hà Trí Sơn, Nguyễn Thị Bích Hảo,
Nguyễn Hải Hòa, Phan Văn Dũng, Nguyễn Thị Thùy Anh
Trường Đại học Lâm nghiệp
**Corresponding author: truongvv@vnuf.edu.vn*

https://doi.org/10.55250/jo.vnuf.8.2.2023.147-158

Article info:
Received: 08/09/2023
Revised: 10/10/2023
Accepted: 03/11/2023

Keywords:
climate change, remote sensing technology, oil erosion, Yen Chau district.

ABSTRACT

This article presents the results of applying geospatial technology to assess soil erosion for Yen Chau district. Geospatial Technology was applied to build maps of factors affecting soil erosion such as: rain erosion coefficient map (R), soil erosion resistance coefficient map (K), terrain erosion coefficient map (LS), cover erosion coefficient map (C) and farming practices (P). Improved universal soil loss equation (RUSLE) due to Wischmeier and Smith was used to create soil erosion maps. The research results have determined the level of erosion and the proportion of eroded area corresponding to each level in Yen Chau district, Son La province. Research results showed that the majority of the area (59.79%) falls into the Slight or Moderate severity category, a significant portion of the area (39.53%) falls into the High and Very high severity categories, a small percentage of the area (0.69%) falls into the Severe category. In addition, the research team built two soil erosion maps for the study area under two climate change scenarios RCP4.5 and RCP8.5 (in terms of rainfall) for the period 2046-2065. According to the result, the data for slight, moderate, and high soil erosion levels all decrease in both scenarios. While, the data for high and very high soil erosion levels increase significantly in both scenarios. This suggests that the situation of soil erosion may become more severe in the future according to both climate scenarios RCP4.5 and RCP8.5.

Từ khóa:
biến đổi khí hậu, công nghệ viễn thám, huyện Yên Châu, xói mòn đất.

TÓM TẮT

Bài báo trình bày kết quả ứng dụng công nghệ địa không gian để đánh giá xói mòn đất cho huyện Yên Châu. Nghiên cứu đã ứng dụng công nghệ địa không gian để xây dựng các bản đồ các yếu tố ảnh hưởng tới xói mòn đất như: bản đồ hệ số xói mòn do mưa (R), bản đồ hệ số kháng xói mòn của đất (K), bản đồ hệ số xói mòn do địa hình (LS), bản đồ hệ số xói mòn do lớp phủ (C) và biện pháp canh tác (P), sử dụng phương trình mất đất phổ dụng cải tiến (RUSLE) do Wischmeier và Smith xây dựng thành lập bản đồ xói mòn đất. Kết quả nghiên cứu đã xác định được mức độ xói mòn và tỷ lệ diện tích bị xói mòn tương ứng với từng cấp độ tại huyện Yên Châu, tỉnh Sơn La. Cụ thể là: phần lớn diện tích (59,79%) ở mức không xói mòn hoặc xói mòn nhẹ, một phần đáng kể diện tích (39,53%) ở mức độ xói mòn trung bình và xói mòn mạnh, một tỷ lệ nhỏ diện tích (0,69%) ở mức độ xói mòn rất mạnh. Thêm vào đó, nhóm nghiên cứu đã xây dựng hai bản đồ xói mòn đất cho khu vực nghiên cứu theo hai kịch bản biến đổi khí hậu RCP4.5 và RCP8.5 (về lượng mưa) cho giai đoạn 2046-2065. Kết quả cho thấy mức độ không xói mòn, xói mòn đất nhẹ, và xói mòn trung bình đều giảm trong cả hai kịch bản. Trong khi đó, mức độ xói mòn đất mạnh và rất mạnh tăng với cả hai kịch bản. Điều này cho thấy tình trạng xói mòn đất có thể trở nên nghiêm trọng hơn trong tương lai theo cả hai kịch bản biến đổi khí hậu RCP4.5 và RCP8.5.

1. INTRODUCTION

Hydric soil erosion is a major concern for agricultural communities as it can lead to reduced soil fertility and decreased crop yields [1, 2]. In recent years, climate change has become a global phenomenon that has far-reaching impacts on the environment, including soil erosion [3]. Among different natural factors that affect soil erosion such as rainfall, soil type, topography, and vegetation cover [3][4], rainfall plays a crucial role in the process of soil erosion as it has the potential to dislodge soil particles and transport them away from their original location [5]. Main climatic factors such as amount, frequency, intensity, and duration of rainfall all contribute to the rate at which soil erosion occurs [6]. Particularly, there has been an agreement that climate change has evidently enhanced the intensity of precipitation [7].

Globally, remote sensing (RS) technologies and GIS (Geographic Information System) have emerged as effective tools for surveying, analyzing, and better managing natural resources [8]. Especially, since 1990s, this approach has been applied to evaluate the spatial and temporal variability of factors determining the susceptibility of soils to erosion [9]. In recent years, the integration among existing soil erosion models, remote sensing, and GIS has been increasingly utilized in studying soil erosion [10]. This combination not only calculates the possible loss of soil and illustrates the spatial distribution of erosion, but also generates precise maps of soil erosion risks. These results can be further used for developing a range of solutions to prevent and minimize the impacts of erosion. There has been a number of models developed to be combined with remote sensed data and GIS to estimate the loss of soil through erosion processes such as the Universal Soil Loss Equation (USLE) and its well – known adjusted versions including the MUSLE and the RUSLE [12], EUROSEM [13], and the SEMMED [15]. These soil erosion models differ in various degrees of complexity.

Among the previously mentioned models, the research team chose the RUSLE for the study at Yen Chau district. This model is an important and widely used tool for estimating soil erosion rates as well as for creating conservation strategies and managing erosion in many land-cover types of croplands, rangelands, and disturbed forest lands [2]. This model includes many factors that affect soil erosion including rainfall, soil erodibility, topography, land use, land cover, and support practices [12]. However, currently, data on the status of this process in Yen Chau district is still limited. Therefore, the study focused on finding the answer for the question of how can the integration of RS, GIS data, and RUSLE be effectively used to assess and predict soil erosion risks in Yen Chau district in the context of climate change? The results of this study will contribute to policy making process and help mitigate the negative impacts of soil erosion on the local environment and communities.

2. RESEARCH METHODOLOGY

2.1. Study area

Yen Chau is a mountainous district in Son La province. It is located in the Northwest region of Vietnam and borders on Laos to the South. Yen Chau is characterized by the tropical climate with high rainfall and many types of feralite soil developed on rocky mountains.

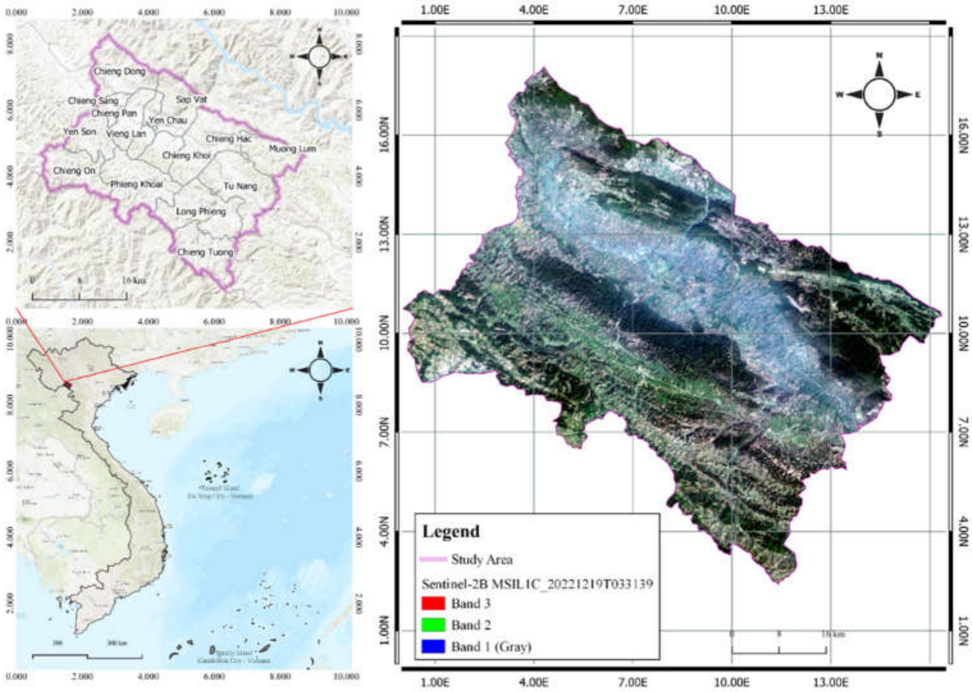


Figure 1. Location Yen Chau district in Son La province, Vietnam

2.2. Study methods

The study group utilized satellite images Sentinel–2B and a Digital Elevation Model (DEM) for generating maps of erosion in Yen Chau district.

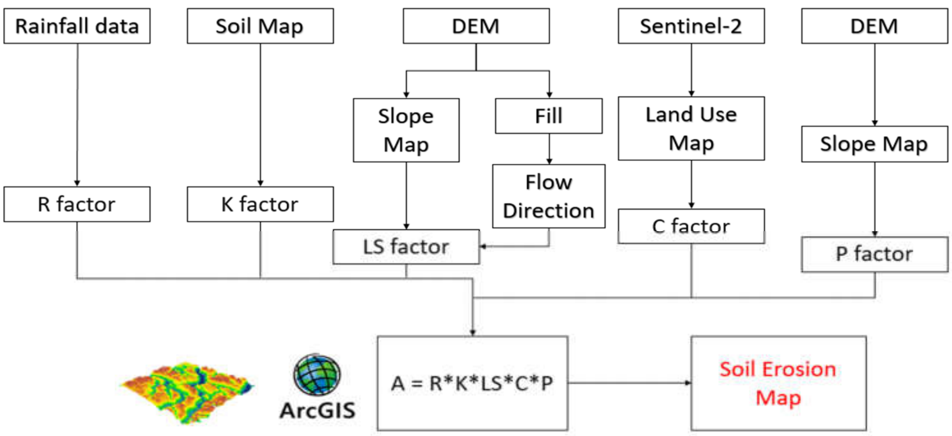


Figure 2. Flow chart methods of soil erosion mapping in Yen Chau district, Son La province

2.2.1. Satellite data collection in study area

Table 1. Data collection

No.	Images	Data	Resolution	Resources
1	S2B_MSIL1C_20221219T033139	Sentinel–2B	10 m	EESA
2	AP_04618_FBS_F0400_RT1	DEM	12.5 m	ASF
3	AP_04618_FBS_F0410_RT1	DEM	12.5m	ASF
4	AP_25667_FBD_F0400_RT1	DEM	12.5 m	ASF
5	AP_25667_FBD_F0410_RT1	DEM	12.5 m	ASF

Source: https://scihub.copernicus.eu ; https://search.asf.alaska.edu/

2.2.2. Data analysis and image processing

Preprocessed data: In this study, a Sentinel-2B image was utilized which was freely accessible from the EESA, as detailed in Table 1. The semi-automatic classification plugin in QGIS 3.16, which provides a complete set of processing tools, was used to facilitate the pre-processing stages for image classification [21]. The obtained Level-1C was orthorectified, top-of-atmosphere optical Sentinel-2 data was underwent atmospheric correction, and additional processing was applied for Level-2A product to yield a bottom-of-atmosphere corrected reflectance image [22].

Soil Erosion formula

In this study, ArcGIS 10.4.1 software and RUSLE equation were applied [12] to estimate the average annual soil loss by formula (1).

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where,

A is the average annual soil loss per unit area ($tons.ha^{-1}.year^{-1}$);

R is the rainfall erosivity factor ($mj.mm.ha^{-1}.hour^{-1}.year^{-1}$);

K is the soil erodibility factor ($tons.ha.hour.ha^{-1}.mj^{-1}.mm^{-1}$);

LS is the topography factor;

C is the vegetation cover factor;

P is the farming practices factor.

The thematic maps for the previously mentioned factors were generated in accordance with the following steps: *ArcToolbox → Spatial Analyst Tools → Map Algebra → Raster calculator.*

After constructing five (5) types of thematic maps for R, K, LS, C, P, the results were then used to construct different map layers in the geographic information system. Based on TCVN 5299-2009 [23], the authors multiplied the coefficients together according to the formula (1), to get the result of constructing the soil erosion map for Yen Chau district.

Rainfall erosivity factor (R): R was estimated by the IDW interpolation method in ArcGIS 10.4.1 application. The estimation was based on the collection of meteorological data from the Yen Chau hydro-meteorological station and five (05) neighboring districts. The average monthly and annual rainfall were synthesized based on the data recorded for many years. Based on the meteorological data, the average annual rainfall distribution in the study area was calculated using the IDW interpolation algorithm. In the next step, the study applied the rainfall formula (R) [24] to calculate the rainfall occurring within Yen Chau district.

$$R = 0.548257*P - 59.5 \qquad (2)$$

where,

R: Rainfall erosivity ($MJ.\ mm.ha^{-1}.h^{-1}$);

P: Precipitations ($mm.year^{-1}$).

Erodibility factor (K): To construct the K factor, the study combined the soil map inherited from the study results of [25] and then assigned the K factor to each group, type, and object. Finally, the study achieved the K-Factor soil erosion resistance factor map.

Terrain erosivity factor (LS): The Slope-length coefficient (L) and steepness (S) are critical topographic parameters used in the USLE and RUSLE for estimating soil erosion. In this study, these parameters were derived from the DEM of the Yen Chau district. The slope map, which is crucial for calculating the LS terrain erosion factor, was created using the Spatial Analyst tool in ArcGIS 10.4.1. The degree of slope, which directly influences the degree of erosion, was classified and used in the calculation of the LS factor.

The LS factor was calculated using the Raster Calculator in ArcGIS 10.4.1, with slopes derived from the DEM data used to calculate Flow direction and Flow accumulation. The specific value of m = 0.4 was chosen based on previous research [27] and understanding of the study area's topography and soil characteristics, which suggested that this value would provide a reliable estimate of soil erosion. The formula of Moore and Burch [28]; Panagos *et al.* [29] is used based on the impact on neighboring areas.

$$LS = \left(\frac{FlowAccumulation\ \ cellsize}{22{,}13}\right)^{0.4} \times \left(\frac{Sin(S\ \ 0{,}01745)}{0{,}0896}\right)^{1{,}3} \quad (3)$$

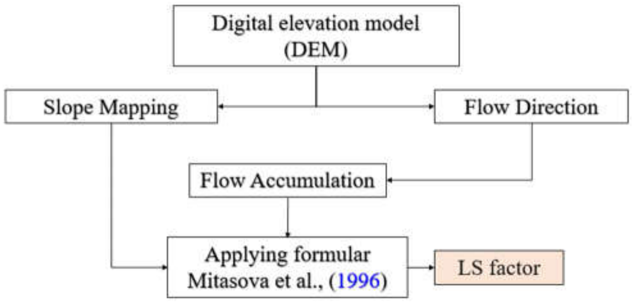


Figure 3. The mapping process for LS Factor

Cropping management factor (C): The C-factor, or vegetation cover factor, was derived from Sentinel-2 satellite images. These images were used to create a map of the Normalized Difference Vegetation Index (NDVI), which is a widely used index for measuring the health and density of vegetation. According to Ha *et al.* [30], NDVI is an effective index for evaluating the status of forests. The C-factor can be difficult to measure accurately because it depends on factors such as the type of crop and the duration of growth, which can vary locally and are subject to unpredictable changes [31]. To determine the C-factor, it can be helpful to consult studies that have reported values for similar land cover types [33]. Remote sensing data can also provide useful information for predicting the C-factor, and NDVI values derived from satellite imagery are commonly used as an indicator for calculating this factor [34], [36]. In this study, the C-factor is calculated using a method developed by Durigon *et al.* [37] that takes into account changes in NDVI values under tropical climate conditions with high rainfall.

$$NDVI = \frac{Band_{NIR} - Band_{RED}}{Band_{NIR} + Band_{RED}} \quad (4)$$

$$C = \left(\frac{-NDVI + 1}{2}\right) \quad (5)$$

Practice Support Factor (P): In Yen Chau, where farming is mainly done along contour lines, the P value was constructed based on the DEM model. The soil protection factor depends on the length and slope of the hillside and indicates soil loss rates for different types of cultivated land [38]. To achieve favorable results, the P factor depends on contour lines, and agricultural (fields, grasslands, etc.) to control soil erosion [27]. Depending on farming methods and slope conditions, reference values for the P factor are based on the method of assigning P factors by Wischmeier and Smith [12]. In this method, if there are no erosion mitigation measures, the maximum P value is 1, and $P < 1$ if there are erosion mitigation measures.

Soil Erosion under Climate change scenarios RCP4.5 and RCP8.5 in Yen Chau district

Climate change can affect soil erosion rates through changes in temperature and precipitation regimes, which can alter the erosivity of rainfall. To assess the potential impacts of climate change on soil erosion under scenarios RCP4.5 and RCP8.5 in the period 2046-2065.

3. RESULTS AND DISCUSSION

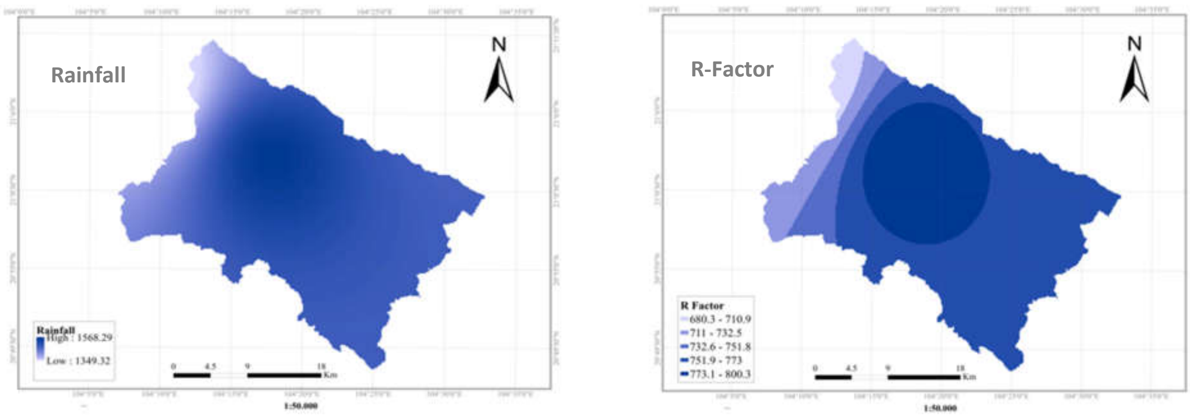
3.1 Soil erosion

The rainfall and runoff factor (R): Yen Chau district has a monsoon climate, with an average rainfall of 1568.3 mm. The rainfall distribution is quite even in space-time. With the average annual rainfall calculated for each region in Son La province in the table 2, and the rainfall and the R factor are shown in Figure 4.

Table 2. The value of average of rainfall (mm) in Son La province, Vietnam

No.	District	Coordinator		Average of rainfall (*mm*)
		Longitude	Latitude	
1	Son La	103.9058	21.3323	1382.7
2	Co Noi	104.1557	21.1332	1321.3
3	Moc Chau	104.6848	20.8339	1507.9
4	Yen Chau	104.2985	21.0470	1568.3
5	Phu Yen	104.6772	21.2031	1495.5
6	Bac Yen	104.4413	21.2450	1420.5

(Source: Son La province statistical yearbook, 2022)



(a) (b)

Figure 4. Rainfall (a) and R-Factor (b) in Yen Chau disstrict, Son La province

The soil erodibility factor (K): In Yen Chau district, most of the area has a high slope, and there are two main groups of soil: Ferralit soil and alluvial soil and steep valley [39]. The results were presented in the Figure 5.

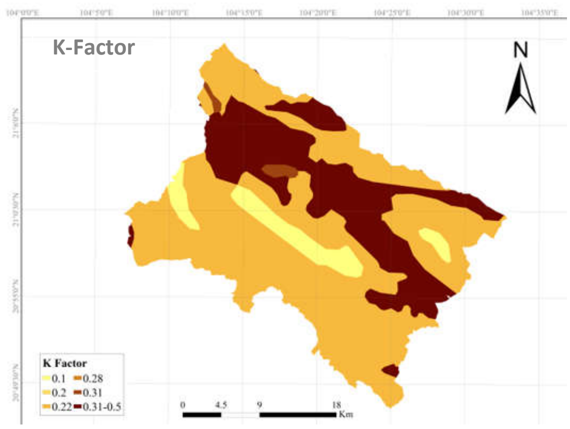


Figure 5. K Factor mapping

The Terrain erosivity factor (LS): The LS factor in the RUSLE equation plays an important role in accounting for the effects of slope length and steepness on soil erosion. By including this factor in the equation, RUSLE is able to provide more accurate estimates of soil loss for different slopes and landscapes [40]. The Flow accumulation map and Slope were created in ArcToolbox (Figure 6a, 6b, 6c). Finally, the LS Factor was estimated using the equation using the "Raster Calculator" and applying formula (3) of the spatial analyst. Accordingly, the topographic factor values in the study area vary from 0 to 53.5 (Figure 6d).

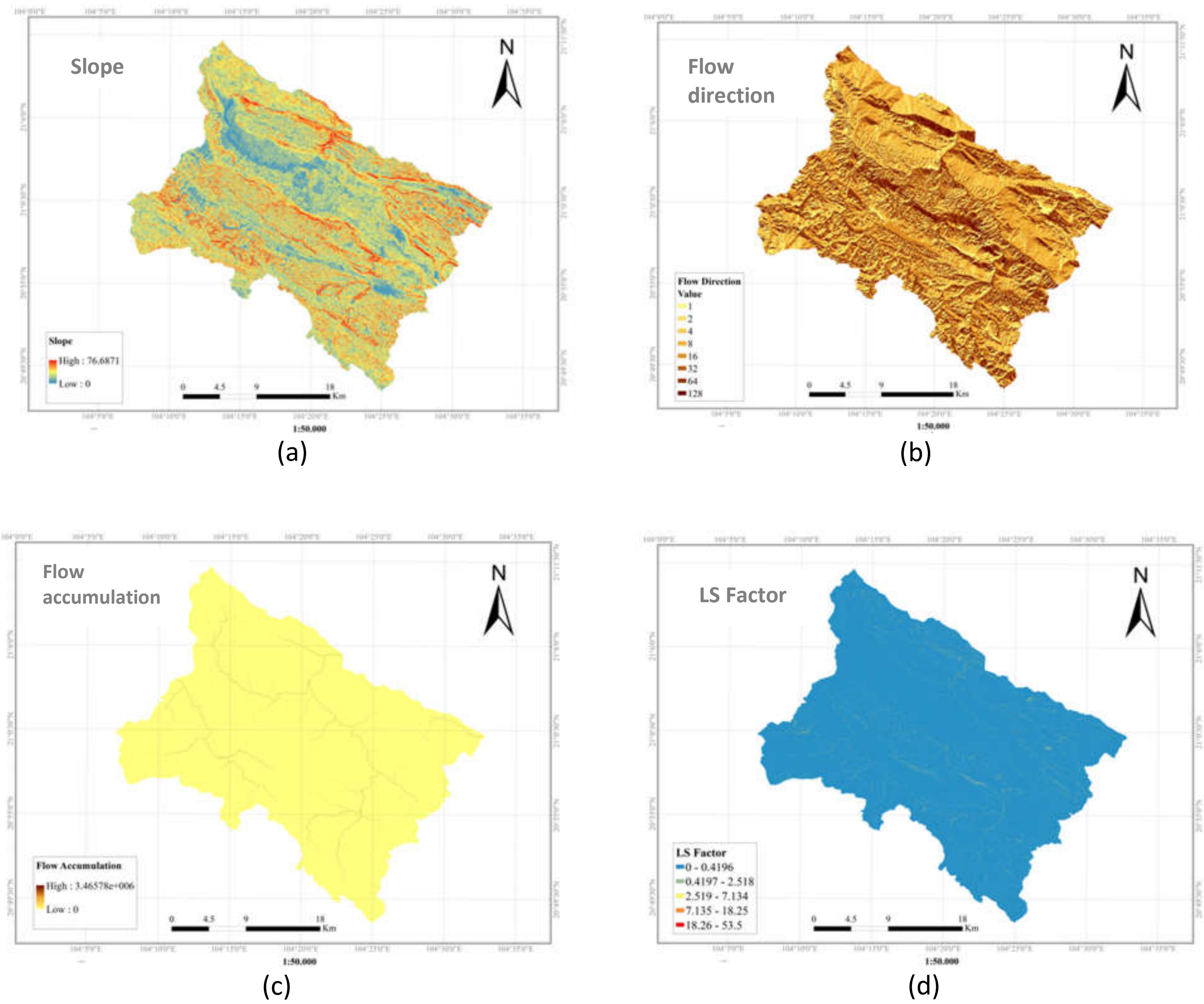


Figure 6. (a) Slope (b) Flow direction (c) Flow accumulation (d) LS Factor in Yen Chau district

The cover and management factor (C): Vegetation cover can reduce soil erosion by protecting the soil surface from raindrop impact, reducing runoff velocity, and increasing infiltration. As a result, areas with higher NDVI values (i.e., more green and healthy vegetation) are expected to have lower C-factor values (i.e., less soil erosion)

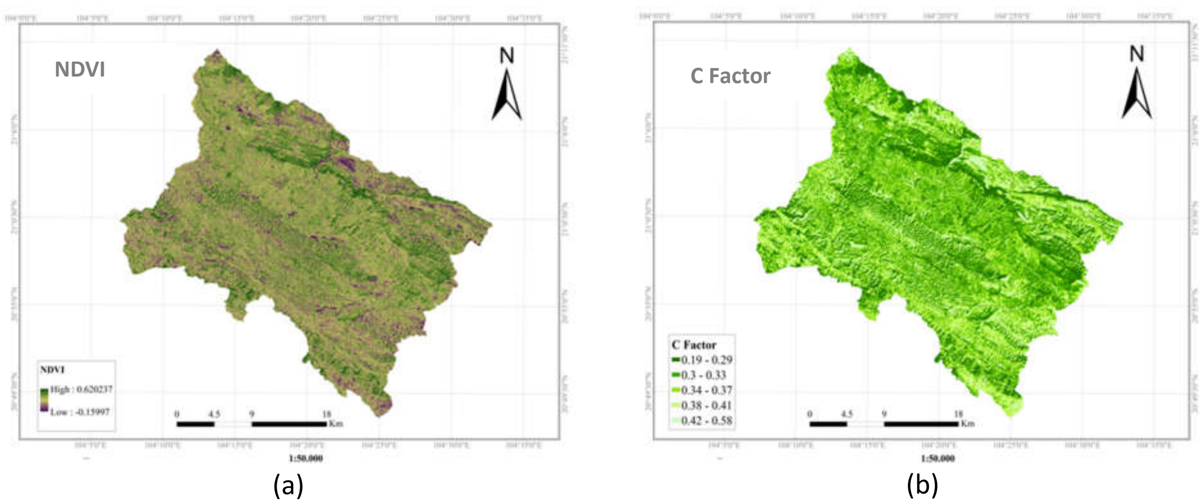


Figure 7. (a) NDVI and (b) C-Factor

The Practice Support Factor (P): The P-factor, represents the effect of soil conservation practices that reduce the amount and rate of water runoff and thus reduce soil erosion. These practices can include contour farming, strip cropping, terracing, and other measures that help to slow down water flow and increase infiltration. With the Figure 8, the value of the P Factor ranges from 0.5 to 1, with lower values indicating more effective soil conservation practices. In which, a minimum value of 0.5 would indicate that the soil conservation practices in place are reducing soil erosion by 50% compared to a similar area with no conservation practices.

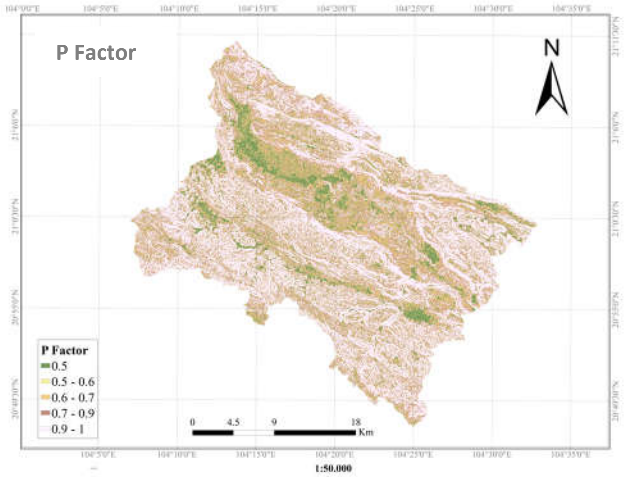


Figure 8. P- factor

(Building mapping based on RUSLE equation for soil erosion in Yen Chau district)

The result of constructing the soil erosion map of Yen Chau district is summarized in Table 3 and is indicated according to Figure 9.

Table 3. Spatial Distribution of Soil Erosion Classes

No.	Severity index	Rate of erosion (ton ha^{-1})	Area (ha)	Percentage of area (%)
1	Slight	0 - 1	21.010,88	24.76
2	Moderate	1 - 5	29.724,28	35.03
3	High	5 - 10	20.108,17	23.70
4	Very high	10 – 50	13.431.67	15 .83
5	Severe	> 50	582.14	0.69
Total			**84,857.14**	**100**

According to the table 3, the majority of the area (59.79%) falls into the Slight or Moderate severity categories, with erosion rates ranging from 0 to 5 (ton.ha^{-1}). This suggests that soil erosion is not a major concern in these areas. However, a significant portion of the area (39.53%) falls into the High and Very high severity categories, with erosion rates ranging from 5 to 50 (ton.ha^{-1}). This indicates that soil erosion is a more serious issue in these areas and may require intervention to prevent further degradation. A small percentage of the area (0.69%) falls into the Severe category. Comparison with research by Tran *et al.* [26] in Hoa Binh shows that: in Yen Chau district, Son La, the proportion of level 1 (Slight) area is much less than the proportion of level 1 area in Luong Son district, Hoa Binh province (65.09%). In addition, in Luong Son district does not have a level 5 (Servere) land area. Because the area of sloping land in Yen Chau district is larger than that in Luong Son district.

This suggests that soil erosion is a critical issue in these areas and immediate action may be necessary to prevent further damage. Overall, the table provides a useful overview of the distribution of soil erosion rates in the area and can help to identify areas where soil conservation measures may be needed.

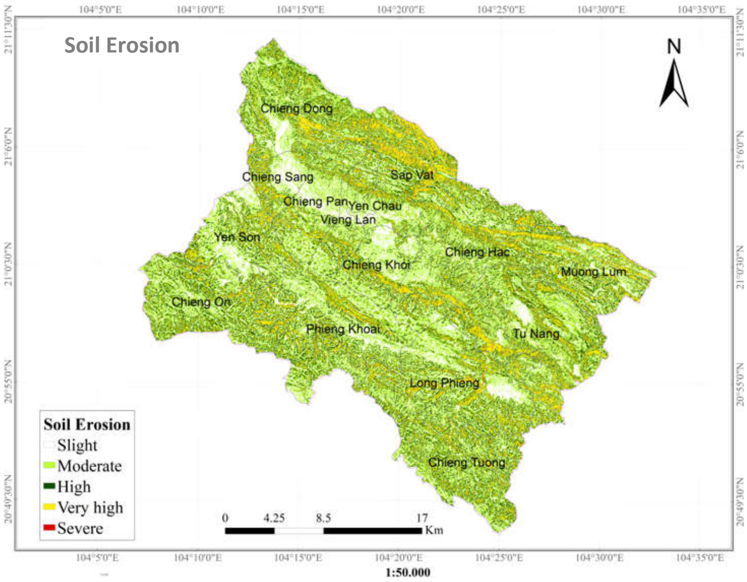
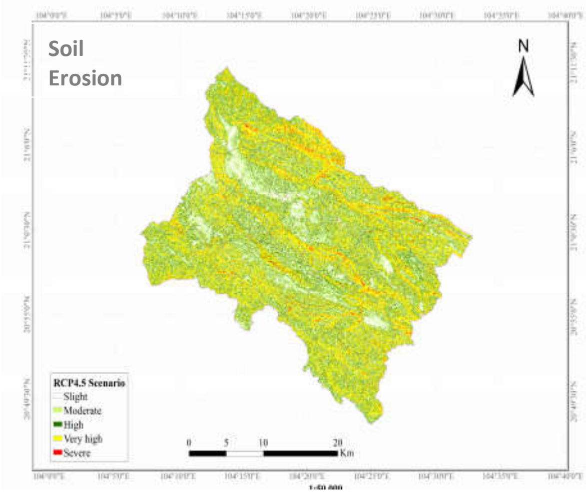


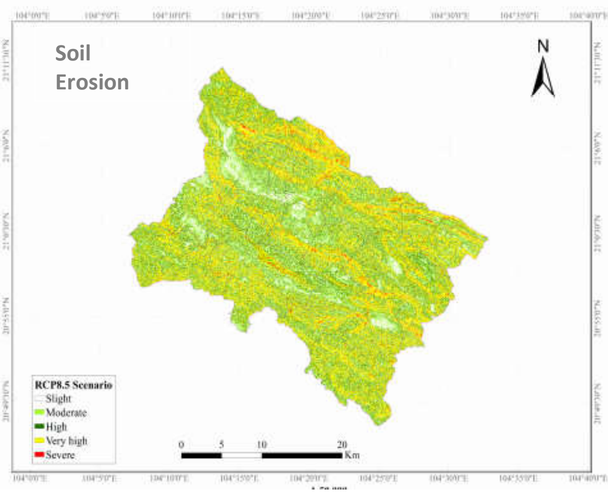
Figure 9. Soil Erosion

3.2. Soil Erosion under Climate change scenarios RCP4.5 and RCP8.5 in Yen Chau district

Soil erosion in 2022 and soil erosion according to two climate change scenarios RCP4.5 and RCP8.5 are shown in Figures 10, 11.



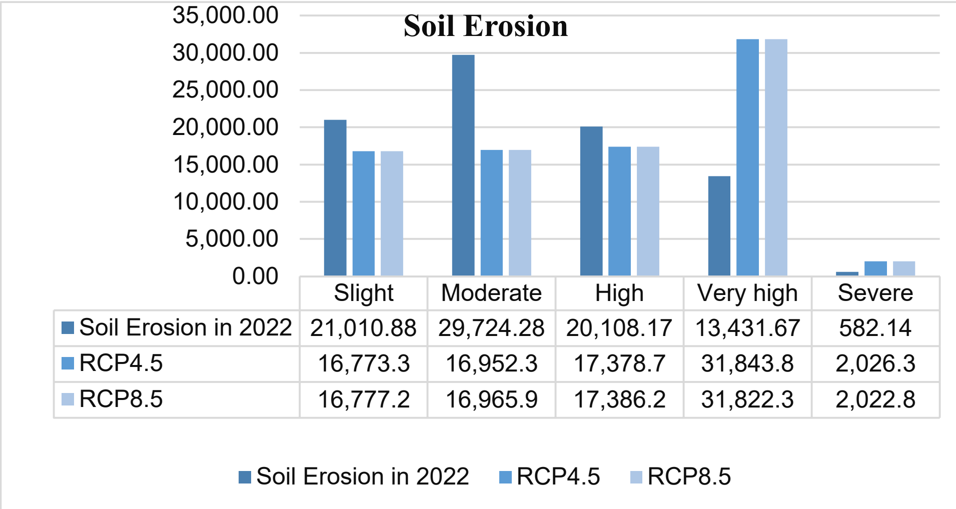
(a)



(b)

Figure 10. (a) Soil erosion under RCP4.5, (b) Soil erosion under RCP 8.5

Climate change can have both direct and indirect impacts on soil erosion rates. One direct impact is that changes in temperature and precipitation regimes can alter the erosivity of rainfall [41]. This could increase the amount of soil erosion caused by water runoff. In addition to the direct impact of changes in rainfall patterns, climate change can also have indirect impacts on soil erosion by affecting the stability of soil aggregates and thus the susceptibility of soil to erosion [42]. Climate change can affect soil erosion rates through changes in temperature and precipitation regimes, which can alter the erosivity of rainfall. To assess the potential impacts of climate change on soil erosion under scenarios RCP4.5 and RCP8.5 in the period 2046-2065.



	Slight	Moderate	High	Very high	Severe
Soil Erosion in 2022	21,010.88	29,724.28	20,108.17	13,431.67	582.14
RCP4.5	16,773.3	16,952.3	17,378.7	31,843.8	2,026.3
RCP8.5	16,777.2	16,965.9	17,386.2	31,822.3	2,022.8

Figure 11. Soil Erosion Projections for RCP4.5 and RCP8.5 Climate Scenarios

According to Figure 11, the data shows that the levels of Slight, Moderate, and High soil erosion all decrease in both scenarios compared to 2022.

In addition, the levels of Very high and Severe erosion increase, possibly due to an increase in human activities such as deforestation, agricultural cultivation without soil protection measures, increased rainfall... will increase soil erosion in these areas. Especially, the communes with the largest areas such as Tu Nang, Long Phieng, Phieng Khoai, and Chieng Hac should be prioritized in planning and implementing soil management and protection measures. These measures could include the application of appropriate farming methods to minimize erosion. This suggests that soil erosion may become more severe in the future under both RCP4.5 and RCP8.5 climate scenarios.

Research results help the People's Committee of Yen Chau district, the People's Committees of communes and people living in areas with serve and very high soil erosion levels have effective plans to protect soil and prevent erosion.

4. CONCLUSION

Research results of the project applying geospatial technology to assess soil erosion in Yen Chau district have built maps of soil erosion coefficients R, K, LS, C, P. From the results of multiplying the erosion coefficient map, we have identified the soil erosion potential map and statistically calculated the level of erosion for the entire area of Yen Chau district, Son La province as follows: with the Slight level accounting for 24.76% of the area, equivalent to about 21,010.88 hectares; with Moderate level erosion accounts for 35.03% of the natural land area, an area corresponding to 29,724.28 hectares; with High level erosion covers an area of 20,107.17 hectares, accounting for 23.70%; with Very high level erosion covers an area of 13,431.67 hectares, accounting for 15.83%; with Servere level erosion covers an area of 582.14 hectares, accounting for 0.69%. Especially, under the two climate change scenarios RCP4.5 and

RCP8.5, it shows that soil erosion may become more serious in the future.

Research shows the quantification of soil erosion according to the RUSLE incorporates geospatial technology an effective solution. The results of the study are scientific basis to develop reduction measures to minimize and prevent erosion, protect and use appropriately land resources, responding to climate changes (especially rainfall) in the future.

Acknowledgments

This research was funded by the Vietnam National University of Forestry during the period of 2022-2023. The authors also would like to thank the Forest Ranger, the District People's Committee, and the local people in Yen Chau district for supporting us in the process of collecting data.

REFERENCES

[1]. Tarigan, R.A. (2022). Impact of Climate Change on Soil Erosion. Jurnal Agroteknologi dan Ilmu Pertanian. 7(1): 28-35. https://doi.org/10.31289/agr.v7i1.9427

[2]. Cheruto, M., Mucheru-Muna, M., & Muriu, F.W. (2023). The potential of Zai pit technology and Integrated soil fertility management to enhance crop productivity in semi-arid regions of Sub-Sahara Africa: A review. Felista Waihuini Muriu's Lab. https://doi.org/10.22161/ijeab.81.8

[3]. Singh, R. (2023). Impact of Climate and Land Use Land Cover Changes on Soil Erosion. Soil and Water Conservation Structures Design. https://doi.org/10.1007/978-981-19-8665-9_14

[4]. Jemai, S., Kallel, A., Agoubi, B. & Abida, H. (2021). Soil Erosion Estimation in Arid Area by USLE Model Applying GIS and RS: Case of Oued El Hamma Catchment, South-Eastern Tunisia. Journal of the Indian Society of Remote Sensing. 49(1977): 1-13. https://doi.org/10.1007/s12524-021-01320-x

[5]. Holz, D. J., Williard, K. W. J., Edwards, P. J., & Schoonover, J. E. (2015). Soil Erosion in Humid Regions: A Review. Journal of Contemporary Water Research & Education. 154(1): 48–59. https://doi.org/10.1111/j.1936-704x.2015.03187.x

[6]. Bullock, P. (2005). Climate change impact. Encyclopedia of Soils in the Environment: 254-262. https://doi.org/10.1016/B0-12-348530-4/00089-8

[7]. Blenkinsop, S., MunizAlves, L., & Smith, A.J.P. (2021). Science Brief Review: Climate change increases extreme rainfall and the chance of floods. Critical Issues in Climate Change Science. https://doi.org/10.5281/zenodo.4779119

[8]. Shandilya, K., Shukla, S.P. & Pathak, V. (2013). Applications of Remote Sensing. Horizons in Earth Science ResearchEdition.1 Chapter: 7

[9]. King, C. & G, Delpont (1993). Spatial Assessment of Erosion: Contribution of Remote Sensing, a Review. Remote Sensing Reviews. 7: 223-232.

[10]. Fernandez, C., Wu, J.Q., McCool, D.Q., & Stockle, C.O. (2003). Estimating water erosion and sediment yield with GIS, RUSLE and SEDD. Journal of Soil and Water Conservation. 58(3): 128-136.

[11]. Wischmeier, W.H., Smith, D.D., & Uhland, R.E. (1958). Evaluation of factors in the soil-loss equation. Agricultural Engineer. 39: 458–462.

[12]. Wischmeier W.H. & Smith D.D (1978). Predicting Rainfall Erosion Losses, USDA Agr. Res. Serv. Handbook. 537.

[13]. Quinton, J. N. (1997). Reducing predictive uncertainty in model simulations: a comparison of two methods using the European Soil Erosion Model (EUROSEM). CATENA. 30(2-3): 101–117. https://doi.org/10.1016/S0341-8162(97)00022-2

[14]. Morgan, R. P. C., Quinton, J. N., Smith, R. E., Govers, G., Poesen, J. W. A., Auerswald, K., & Styczen, M. E. (1998). The European Soil Erosion Model (EUROSEM): A Dynamic Approach for Predicting Sediment Transport from Fields and Small Catchments. Earth Surface Processes and Landforms. 23: 527-544. https://doi.org/10.1002/(SICI)1096-9837(199806)23:6%3C527::AID-ESP868%3E3.0.CO;2-5

[15]. De Jong, S. M., Paracchini, M. L., Bertolo, F., Folving, S., Megier, J., & de Roo, A. P. J. (1999). Regional assessment of soil erosion using the distributed model SEMMED and remotely sensed data. CATENA. 37(3-4): 291–308.

[16]. Ganasri, B.P. & Ramesh, H. (2016) Assessment of Soil Erosion by RUSLE Model Using Remote Sensing and GIS—A Case Study of Nethravathi Basin. Geoscience Frontiers. 7:953-961. https://doi.org/10.1016/j.gsf.2015.10.007

[17]. Kidane, M., Bezie, A., Kesete, N. & Tolessa, T. (2019). The impact of land use and land cover (LULC) dynamics on soil erosion and sediment yield in Ethiopia. Heliyon. 5(12). https://doi.org/10.1016/j.heliyon.2019.e02981

[18]. Thapa, P. (2020). Spatial estimation of soil erosion using RUSLE modeling: A case study of Dolokha district, Nepal. Environmental Systems Research 9(15).

[19]. Balouei, F., Mohammadi, S. & Kopaei, S.S. (2021). Simulating the Effects of Land-use Changes on Soil Erosion Via RUSLE Model in Ilam province's Doiraj Basin. Journal of Research on Science and Technology of Desert Ecosystems. https://doi.org/10.22052/deej.2021.10.31.39

[20]. Kolli, M.K., Opp, C. & Groll, M. (2021). Estimation of soil erosion and sediment yield concentration across the Kolleru Lake catchment using GIS. Environmental Earth Sciences. 80:161. https://doi.org/10.1007/s12665-021-09443-7

[21]. Congedo, L. (2020). Semi-Automatic

Classification Plugin documentation. Release 6.4.0.2.243p.

[22]. Castillo, J. a. A., Apan, A., Maraseni, T., & Salmo, S. G. (2017). Estimation and mapping of above-ground biomass of mangrove forests and their replacement land uses in the Philippines using Sentinel imagery. Isprs Journal of Photogrammetry and Remote Sensing. 134: 70–85. https://doi.org/10.1016/j.isprsjprs.2017.10.016

[23]. Ministry of Science and Technology (2009). TCVN 5299: 2009, Soil quality – Method for determination of soil erosion by rain.

[24]. Nguyen Trong Ha (1996). Identify the factors effect to soil erosion and forecast soil erosion on slope land. Water Resources University of Vietnam, Doctoral dissertation, 187 pages.

[25]. Nguyen Manh Ha, Nguyen Van Dung & Hoang Huyen Ngoc (2013). Applying the Universal Soil Loss Equation (USLE) and Geographic Information System (GIS) to evaluate soil erosion potential in the Central Highlands and propose solutions to minimize erosion. Journal of Earth Sciences. 35(4): 403-410.

[26]. Tran Thi Thom, Le Hung Chien, Nguyen Thi Oanh, Ho Van Hoa & Trinh Hai Van (2023). Applying remote sensing technology and geographic information system (GIS) to evaluate soil erosion potential in Luong Son district, Hoa Binh province. Journal of Forestry Science And Technology. (1): 95-103. https://doi.org/10.55250/jo.vnuf.2023.1.095-103

[27]. Kieu Quoc Lap (2019). Application of gis technology into hierarchical mapping of soil erosion in Van Ban district, Lao Cai province. TNU Journal of Science and Technology. 207(14): 91 – 97.

[28]. Moore, I.D. & Burch, G.J. (1986). Physical Basis of the Length-slope Factor in the Universal Soil Loss Equation. Soil Science Society of America Journal. 50: 1294–1298. https://doi.org/10.2136/sssaj1986.03615995005000050042x

[29]. Panagos, P., Borrelli, P. & Meusburger, K. (2015). A new European slope length and steepness factor (LS-Factor) for modelling soil erosion by water. Geosciences. 5(2): 117-126.

[30]. Ha Tri Son, Nguyen Hai Hoa & Vu Van Truong (2023). Mangrove cover-based vegetation indices mapping using Planetscope data in Tien Yen district, Quang Ninh province. Journal of Forestry Science And Technology 15: 127-139. https://doi.org/10.55250/jo.vnuf.2023.15.127-138

[31]. Nearing, M.A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., Le Bissonnais, Y., Nichols, M.H., Nunes, J.P., Renschler, C.S., Souchere, V. & Oost, K.V. (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. CATENA. 61: 131–154. https://doi.org/10.1016/j.catena.2005.03.007

[32]. Kuo, K.T., Sekiyama, A. & Mihara, M. (2016). Determining C factor of Universal Soil Loss Equation (USLE) based on remote sensing. Int. J. Environ. Rural Dev. 7: 154–161. https://doi.org/10.32115/ijerd.7.2_154

[33]. Benavidez, R., Jackson, B., Maxwell, D. & Norton, K. (2018). A review of the (Revised) Universal Soil Loss Equation ((R)USLE): With a view to increasing its global applicability and improving soil loss estimates. Hydrol. Earth Syst. Sci. 22: 6059–6086. https://doi.org/10.5194/hess-22-6059-2018

[34]. Lin, C.-Y., Lin, W.-T. & Chou, W.-C. (2002). Soil erosion prediction and sediment yield estimation: The Taiwan experience. Soil Tillage Res. 68: 143–152. https://doi.org/10.1016/S0167-1987(02)00114-9

[35]. Karaburun, A.C (2010). Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed. Ozean J. Appl. Sci. 3: 77–85.

[36]. Van der Knijff, J. M., R. J. A. Jones, & L. Montanarella. (2000). Soil Erosion Risk Assessment in Europe. Ispra: European Soil Bureau. Joint Research Centre. EUR 19044 EN.

[37]. Durigon, V. L., Carvalho, D. F., Antunes, M. a H., Oliveira, P. T. S., & Fernandes, M. M.(2014). NDVI time series for monitoring RUSLE cover management factor in atropical watershed. International Journal of Remote Sensing. 35(2): 441-453. https://doi.org/10.1080/01431161.2013.871081

[38]. Shiferaw, H.M. (2021). Study on the influence of slope height and angle on the factor of safety and shape of failure of slope based on strength reduction method of analysis. Beni-Suef University Journal of Basic and Applied Sciences. 10(31). https://doi.org/10.1186/s43088-021-00115-w

[39]. Bui Manh Hung, Nguyen Thi Bich Phuong & Nguyen Thi Thao (2021). Variation in vegetation cover and relationship with natural and social factors in Yen Chau, Son La. Journal of Forestry Science and Technology. (3): 31-40.

[40]. Tran Quoc Vinh & Hoang Tuan Minh (2010). Applying geographic information system (GIS) to build LS coefficient maps in soil erosion research in Tam Nong district (Phu Tho province). Journal of Science and Development. 8(4): 667-674.

[41]. Borrelli, P., Robinson, D. A., Panagos, P., Lugato, E., Yang, J. E., Alewell, C. & Ballabio, C. (2020). Land use and climate change impacts on global soil erosion by water (2015-2070). Proceedings of the National Academy of Sciences. 202001403. https://doi.org/10.1073/pnas.2001403117

[42]. Met Office. (2018). UKCP18 Guidance: Representative Concentration Pathways. Retrieved from https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance—representative-concentration-pathways.pdf