




Research Article

Constructing a spatial analysis model in assessing the sensitivity of landscape erosion in mountainous regions of Vietnam



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Abstract

This study demonstrates the steps of building a spatial analysis model that is applicable in synthetically assessing the sensitivity of landscape erosion in mountainous regions. Field testing was carried out at Ngu Chi Son commune, Sa Pa district, Lao Cai Province, Vietnam. The primary basis is the application of the GIS spatial analysis model in mapping the landscape structure. Subsequently, depending on the landscape structure map, the analysis model of erosion levels due to erosion factors (rainfall, terrain, the thickness of soil layers, mechanical compositions, vegetation cover, and cultivation measures of human beings) was constructed. The employed algorithms included spatial overlay, spatial interpolation, attribute reclassification, and average indexes. The results of this study have indicated the erosion sensitivity of every landscape unit, which is categorized into five levels: very low, low, medium, high, and very high. Obtained appraisals and sensitivity categorization are important fundamentals to issue exploitation orientations and reasonable usages of resources within the researched region. This proves to be a new direction of research with overall potentials in assessing mountainous landscapes.

Keywords Model · Spatial analysis · Sensitivity · Landscape erosion · GIS

1 Introduction

The erosion sensitivity of landscapes is the overall erosion sensitivity levels of landscape compositions under the impact of natural factors such as terrain, rainfall, vegetation cover, flooding, and soil erosion [1]. A landscape unit–landscape type is a fundamental unit evaluating the sensitivity of landscape erosion. The erosion sensitivity of a landscape unit is dependent on the levels of soil erosion, erosion due to topographic factors, erosion due to rainfall, erosion due to the loss of vegetation, and erosion due to human cultivation. The erosion sensitivity of landscapes is considered as an important index in studying and assessing mountainous landscapes and ecologies in order to state the sustainability in exploitation and territorial utilization. In general studies regarding mountainous

landscapes, there are only a few researches mentioning landscape erosion sensitivity. Particularly, the erosion indexes of landscapes are detected in 50 out of 300 studies. Furthermore, most of those 50 studies merely focus on analyzing single landscape factors. Prominently, they are a study on soil erosion following the Universal Soil Loss Equation (USLE) of Wischmeier and Smith [2]; a study on soil erosion through the sensitivity of natural environments [3–8]; a study on landscape assessment according to quantitative methods with the calculation of erosion indexes following terrain and rainfall [9, 10]; a study on the landscape sensitivity in line with space and time based on landscape equilibrium indexes [11, 12]; soil erosion indexes were established based on the calculations of potential, practical soil loss indexes, and soil erosion susceptibility (soil erosion and conservation, models of

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soil erosion and land use, spatial patterns of soil erosion susceptibility) [13–15]; approaching landscape analysis in accordance with the analytical hierarchy process (AHP) [16–18]; constructing a model calculating erosion rates in terms of landscapes [19–23]; and a study on the geomorphic limitations on landscape sensitivity owing to the climate of tectonically active sites [24–26]. It can be seen that the erosion indexes of those studies are derived from only soil erosion or from studying separately on factors that are influential in erosion including terrain, geomorphology, rainfall, and vegetation cover. The research methodology primarily uses the application of mathematical models as a fundament to calculate erosion indexes. Consequently, the fact that there is no overall spatial analysis model in previous studies is a considerable limitation. Moreover, the lack of a method that accurately simulates the researched areas is also a shortcoming.

In recent years, the application of remote sensing technologies and geographic information system (GIS) in studying landscapes is increasing popularly. More and more studies on assessing landscapes by the utilization of remote sensing images and GIS have approached quantitative orientations, descriptions, and intuitive comparisons of researched space through various map systems. Specifically, the remarkable studies that have implemented remote sensing and GIS employment in analyzing mountainous landscapes can be reckoned as a study on assessing soil erosion in karst sites through the Enhanced Thematic Mapper (ETM) sensor of the Landsat 7 satellite and ArcGIS [27–29]; a study on the classification and supervision of mountainous landscapes through satellite images and digital elevation models (DEMs) [30, 31]; the integration of remote sensing, GIS, and rainfall data in analyzing erosion indexes in accordance with regional landscapes [32]; and a study on the alteration of vegetation in mountainous landscapes using sensing remote technologies [33–35]. It is evident that GIS technology allows the simulation of researched results and the clear expression of landscape indexes with an intuitive display. Moreover, the limitations in spatially simulating the examined regions are also resolved by GIS. Nevertheless, nowadays, there have not been any comprehensive research models that are specialized for assessing the sensitivity of landscape erosion based on the synthetic determination of impacting factors.

In Vietnam, landscape researching in general and the comprehension of soil erosion indexes in landscapes remain vague. In spite of the potential benefits, no specific studies mentioning models to establish erosion indexes have been well developed. There are only a few separate studies such as a study on assessing the sustainability of mountainous landscapes [36, 37]; an analysis of mountainous ecological landscape structures to serve

the sustainable development of agriculture and forestry [38–41]; a study on soil erosion [42, 43]. Resulted from such a shortcoming, this research aimed to construct a spatial analysis model to appraise the erosion sensitivity of landscapes in mountainous regions. The spatial analysis feature that GIS offers is capable of investigating the characteristics of spatial structures obtained from landscape units. Simultaneously, synthetic appraisals regarding landscape erosion sensitivity through hierarchical indexes are derived from input data. This research also resolved the limitations in describing spatially mountainous landscapes. Resultant indexes of landscape erosion were approached in synthetic viewpoints. As the tested field was at Ngu Chi Son commune, which is a typical mountainous region in Vietnam, the theoretical results and hypotheses were practically verified with high reliability and evident proofs to be applicable in spatially orienting the reasonable usages of resources and protecting the environment in mountainous regions of Vietnam.

2 Materials and methods

2.1 Research area

Ngu Chi Son is an alpine commune that belongs to Sa Pa district, Lao Cai Province, Vietnam. The place has a natural area of 8052,125 hectares and a population of 6183. As two primary compositions of the local population, the H'Mong ethnic group and Dao ethnic group account for over 94.6% (*Annual statistics, 2019*). This territory is evaluated to be rich in terms of natural resources. Particularly, there are diverse and plentiful climate types and beautiful natural landscapes, contributing to the development of local tourism. It is also believed to have certain advantages that potentially facilitate the sustainable development of local agriculture. Especially, the characteristics of topography and geomorphology of this region are diverse from floodplains of streams, valleys to limestone, and granite mountains, which result in an outstandingly plentiful soil set. The survey data also indicates that Ngu Chi Son Commune has five different types of soil including: sandy soil on the stream (Sa), silt soil on valleys (Si), humus soil on granite (HGa), humus soil on limestone (HLi), feralits soil (Fe). Local rainfall also shows differentiation and diversification. The annual average rainfall is 1850 mm. Therefore, regions with low terrains receive 1500 mm of rainfall each year, while central regions' annual rainfall fluctuates from 1500 to 2000 mm and high mountainous regions have a share of 2000 mm. Rainfall also varies in accordance with seasons. 90% of rainfall concentrates in the rainy season (April–November). For vegetation, this factor differs following altitudes and is significantly influenced by humans.

Satellite images and the data obtained from field survey indicate that the research area possesses an adequate set of vegetation forms such as natural forests, meadow, wild plants, milpa, crops, vacant land. Ngu Chi Son area often causes many types of natural disasters, flash floods, landslides, and soil erosion. Regional statistical data show that there were 13 flash floods, 21 points of landslide, and the soil erosion increased by about 22.8% in Ngu Chi Son commune from 2000 to 2019 (*Annual statistics, 2019*).

In spite of the diversity in terms of natural conditions, which are advantageous for social–economic development, indigenous economic activities are still suspended with hurdles. Livelihoods of local people are virtually in the form of self-sufficiency. The exploitation of natural resources is ineffective with low soil-using coefficients. The status of exploiting and utilizing the territory is unreasonable and dependent on natural conditions as well as obsolete cultivation customs of indigenous people. Additionally, due to the characteristic terrain, which mainly consists of hills and mountains with an average height of 1568.4 m (the highest point of 3024.5 m and the lowest point of 714.3 m) and a thin vegetation cover, the erosion phenomenon of not only soil but also other landscape compositions occurs drastically. That is why research on the sensitivity of landscape erosion at Ngu Chi Son commune is essential and helpful for future orientations for cultivation, proper utilization of resources, and protecting the environment as well.

2.2 Data and methodology

The study employed various research methods including data collection, GIS spatial analysis method, remote sensing image processing method, inheritance method of analyzed results, and field survey method.

2.2.1 Data collection

The study employed data originating from various sources: field surveys and investigations, statistics, observational data, remote sensing images, and the referential data of relevant studies. Particularly, data regarding slopes were constructed on a digital elevation model (DEM) and a topographic map of Sa Pa district with a scale of 1:25,000. Data regarding vegetation cover were obtained from images taken by Landsat 8 ETM Satellite. The information of rainfall in a period of 60 years (1958–2018) was collected from the database of a weather station in Sa Pa district. Details that correspond to the status of land utilization, characteristics of required samples, types of soil, layer thickness, and mechanical compositions were gathered directly from field surveys and the analyses of

32 soil horizon samples, which represented nine forms of landscapes that cover throughout the researched area.

2.2.2 GIS spatial analysis method

This was the primary method applied in analyses, establish landscape unit maps, and maps that evaluate the sensitivity of landscape erosion. There were two employed algorithms, which are the spatial overlaying algorithm [44] and the attribute reclassification algorithm [45, 46]. Spatial data were processed and analyzed simultaneously through ArcGIS software and subsequently used to construct maps by Mapinfo software. In addition, an employed digital elevation model (DEM) also contributed to analyzing topographic [47]. The DEM database of the study area was constructed from a 1:25,000 topographic map with a distance of contour lines of 100 m. The GIS spatial interpolation algorithm (inverse distance weighting) was also used to sketch soil unit maps [48].

2.2.3 Remote sensing image processing method

This method was executed by ENVI software, which is capable of processing satellite images (taken on 12th April 2017 and 20th October 2019) from the Enhanced Thematic Mapper of Landsat 8 with a resolution of 30 m. The processed images were then employed to graph the normalized difference vegetation index (NDVI) for the researched area. NDVI is a simple graphical indicator that analyzes remote sensing measurements, often from a space platform, assessing whether or not the target being observed contains live green vegetation. The study also selected two intensive processing methods that are the NDVI differencing and the post-classification [49, 50]. Owing to the NDVI differencing method, the understanding of radiation levels originating from vegetation was apprehended via the formula $\epsilon = 1.0094 + 0.047 \ln$ [43]. The NDVI values at the study area are calculated according to the formula: $NDVI = (IR - R) / (IR + R)$. In the formula, R and IR sequentially stand (Fig. 1) for the red and infrared channel.

2.2.4 Inheritance of analyzed results

The study inherited the analyses of 32 soil horizon samples that represented nine forms of soil throughout the researched area [51]. Each soil horizon sample was dug up and analyzed in place according to the manual of the FAO system (2006). The analyzed results of horizon soils indicated the characteristics of each sample, each type of soil, and each mechanical layer of soil distributed in the researched area.

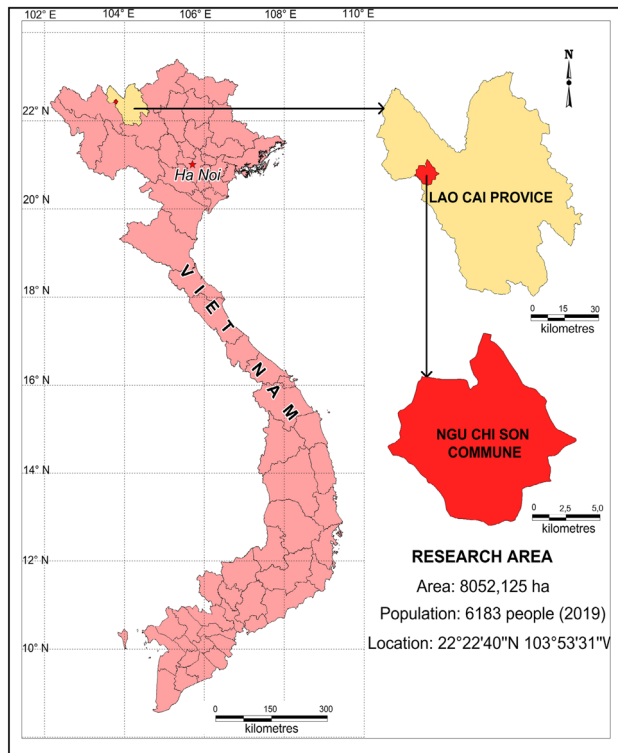


Fig. 1 Study area of Ngu Chi Son, Vietnam

2.2.5 Field survey

During the execution period of the study, the authors carried out numerous practical surveys researched area. The aim of field survey was to collect realistic data (regarding natural, social, and economic conditions), study the practices of cultivation of indigenous people, and detect factors causing erosion.

2.3 Spatial analysis model

Based on the fundamentals of the study methods listed above, the authors have constructed a spatial analysis model to apprehend the levels of landscape erosion following the spatially analytical functions of GIS. The model of landscape erosion sensitivity that serves reasonable usages of natural resources and the protection of nature is presented in four steps (Fig. 2).

2.3.1 Step 1: The construction of a database

The database consists of statistical data regarding landscape compositional factors (topography, geomorphology, climate, soil, rivers and streams, vegetation, and farming practices) and data of landscape erosion factors (rainfall, slopes, soil horizons, mechanical compositions of

soil, vegetation, and cultivation). After collected, all data are classified and systemized to create a GIS database.

2.3.2 Step 2: The analysis of spatial landscape structures

The analysis processes are conducted based on the establishment of compositional maps including slope maps and geomorphic maps, which were established based on the data provided by topographic maps, DEM analyses, and calibrations from field investigations; soil maps, which were established based on the employment of data regarding soil types of Sa Pa district, the inheritance of the analysis over 32 soil samples in the study area, the subsequent interpolation and determinations of soil types, soil horizons, and mechanical compositions, and the employment of inverse distance weighted interpolation; rainfall maps, which were constructed. The application of GIS spatial overlaying method to sketch landscape unit maps. Each landscape unit has characteristic attributes that correspond to each landscape structure.

2.3.3 Step 3: The assessment of landscape erosion sensitivity

Based on the association between the levels of erosion and landscape erosion factors at Ngu Chi Son commune, the model assessing the sensitivity of each factor, including annual average rainfall, slopes, soil horizons, mechanical composition, vegetation, and cultivation, is exhibited in Table 1. The rainfall factor that significantly influences landscape erosion has been studied and classified in many studies [5, 10, 19]. Most of those studies categorize rainfall systematically in terms of topographic heights. However, during the application of this classification in the researched area, the microclimate of the region proved an obstacle to the achievement of accurate data. Consequently, the annual average rainfall of this area was divided into six levels corresponding to values under 1000; 1000–1250; 1250–1500; 1500–1750; 1750–2000; and above 2000 mm/year. The exact evaluations were appended to each level based on realistic experimental results and the co-relation between annual average rainfall and erosion levels. Slopes, soil horizons, and mechanical compositions were also labeled with scoring indexes according to each corresponding level of the landscape classification criteria. While, the levels of vegetation and cultivation were dependent on a scale ranging from the lowest erosion level, which corresponded to primeval forests, to the highest level that corresponded to empty ground, equivalent to the value of NDVI from -0.35 to 0.7 [43].

The erosion sensitivity levels of Ngu Chi Son's landscapes were concluded using the comparisons between

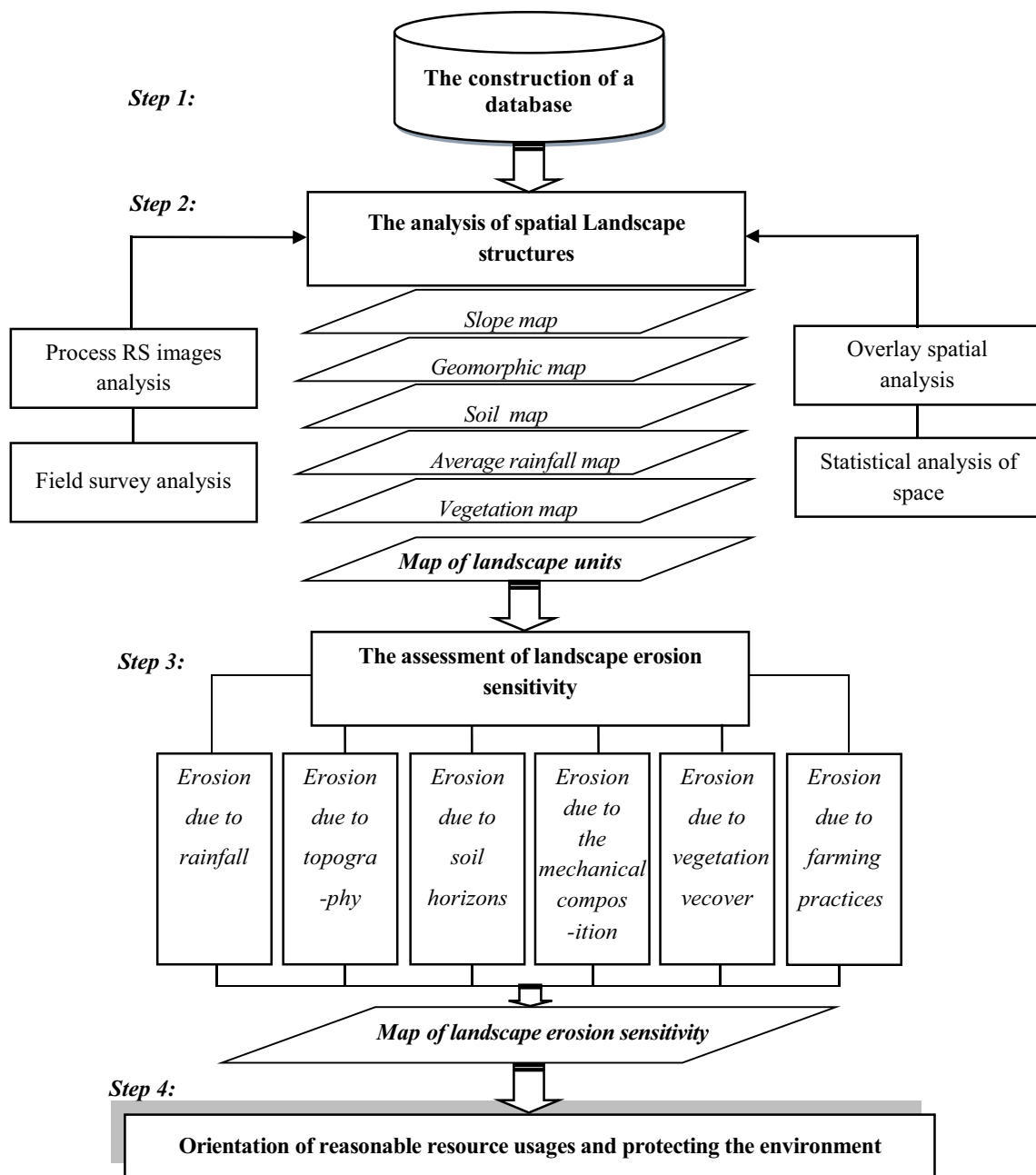


Fig. 2 Spatial analysis model assessing the sensitivity of mountainous landscape erosion

landscape units and the precise table assessing erosion sensitivity values as a basis. The average number of parameters resulted from the appraisals of erosion due to factors including rainfall, slopes, soil horizons, mechanical compositions, and vegetation was employed as the sensitivity value of landscape units. The results of erosion sensitivity levels were displayed in five levels as follows: Level I (0–1 score): “very low” landscape sensitivity value; Level II (1–2 scores): “low” landscape sensitivity value; Level III (2–3 scores): “medium” landscape sensitivity value; Level

IV (3–4 scores): “high” landscape sensitivity value; Level V (4–5 scores): “very high” landscape sensitivity value.

2.3.4 Step 4: The spatial orientation of reasonable resource usages and protecting the environment

As the foundation, the resultant appraisals of landscape erosion sensitivity and the structural characteristics of landscape units are integrated into proposing new

Table 1 Criteria table assessing erosion sensitivity values of the landscapes at Ngu Chi Son commune

No	Evaluation factor	Unit	Scores					
			0	1	2	3	4	5
1	Annual average rainfall	mm	< 1000	1000–1250	1250–1500	1500–1750	1750–2000	> 2000
2	Topographic slopes	degrees	0–3	3–8	8–10	10–15	15–20	> 20
3	Thickness	cm	> 100	70–100	50–70	30–50	10–30	< 10
4	Mechanical compositions	–	Original stone (a)	Heavily meaty (b)	Meaty (c)	Impuriti (d)	Sandy mixed (e)	Sandy (f)
5	Vegetation@(NDVI value)	–	Primary forest (0.45–0.7)	Planted Forest (0.28–0.45)	Rice field (0.22–0.28)	Crops, milpa (0.15–0.22)	Meadow wild plants (0.078–0.15)	Empty ground (–0.35–0.078)

cultivation formalities, reasonable resource usages, and future activities of protecting the environment.

3 Results and discussion

3.1 Structural characteristics of landscapes at the researched area

The application of a spatial analysis model, overlaying compositional maps, which consisted of geomorphic–terrain map, slopes map, soil map, annual average rainfall map, and vegetation map (Fig. 3), an overview map of landscape units at Ngu Chi Son commune was proposed with 20 soil horizons belonging to nine types of landscapes (Fig. 4).

Each type of landscapes possesses particular characteristics in terms of terrain, slopes, rock, types of soil, soil horizons, mechanical compositions, and vegetation (Table 2). In the nine types of landscapes at the researched area, the landscape type of limestones accounted for the largest area (51,97%). Therefore, the impact area of limestone corrosion was 2096.8 hectares, and the impact area of gravity slopes on limestone was 2167.2 hectares. Remarkably, the side attrition landscape on granite occupied 2176.5 hectares and scattered at most parts of the researched territory. The abrasion type of landscapes had an area of 1536.2 hectares, and the area of erosive accretion type was 1341.8 hectares. Besides, the total area of other landscape types (alluvial streams, valleys, old-growth forests, and rock mountains) was relatively insignificant. Exceptionally, primeval forests were the least occupant (72.1 hectares) as their distribution was only detected at the Western side of the commune. Besides, valleys (82.3 hectares) are an original landscape of that the concentration was recorded alternately with floodplains at the sides and downstream sites of Can Ho and Suoi Thau streams. Mountains that are higher than 1500 m occupied 198.17 hectares at the recording time and were only found around Ngu Chi Son mountainous region under the form

of limestone mountains, high-sloping gravity sides, and thriving natural forests.

The analysis results of structural characteristics of landscapes at Ngu Chi Son commune are matching with previous studies [36, 38]. Nevertheless, in this study, the descriptions of local landscapes are more specific. Topographic characteristics were classified into six levels in terms of topographic slopes (0–3; 3–8; 8–10; 10–15; 15–20, and above 20 degrees). This classification resembles many studies regarding the approach to landscape geomorphology [24, 25] and suits the attributes of Ngu Chi Son. The characteristics of soil were described following the characteristics of soil horizon samples, types of soil, thickness, and mechanical compositions (FAO, 2006). According to the classification, there were six types of the thickness index (under 10; 10–30; 30–50; 50–70; 70–100; and above 100 cm) with the mechanical compositions ranging from “sandy” to “heavily meaty” [15]. Thickness levels and mechanical compositions were also the two parameters selected to determine landscape erosion sensitivity. Besides, vegetation was also recorded according to the integration of realistic status and analysis results from vegetation maps.

3.1.1 The analysis results of landscape erosion sensitivity at the researched area

Applying the constructed spatial analysis model, study results and erosion sensitivity classification of Ngu Chi Son’s landscapes are exhibited spatially in Fig. 5, Fig. 6 and graphically in Table 3.

Table 3 and Fig. 5 show that the alluvial stream (type 1) and valley (type 2) landscapes, which are the ground-level terrain with a low slope and the primeval forest landscapes collectively share the “very low” level of erosion sensitivity. This assessment is analogous to that of other studies regarding the impact of topography and geomorphology on the landscapes of mountainous regions (Bahadur et al. 2009; D’Arcy et al. 2014; Roda et al. 2017) as well as studies regarding the influence of vegetation cover on soil erosion

Fig. 3 Compositional maps of landscape in Ngu chi-son commune **a** Geomorphic-terrain map. **b** Slopes map. **c** Soil maps. **d** Annual average rain-fall map. **e** vegetation map

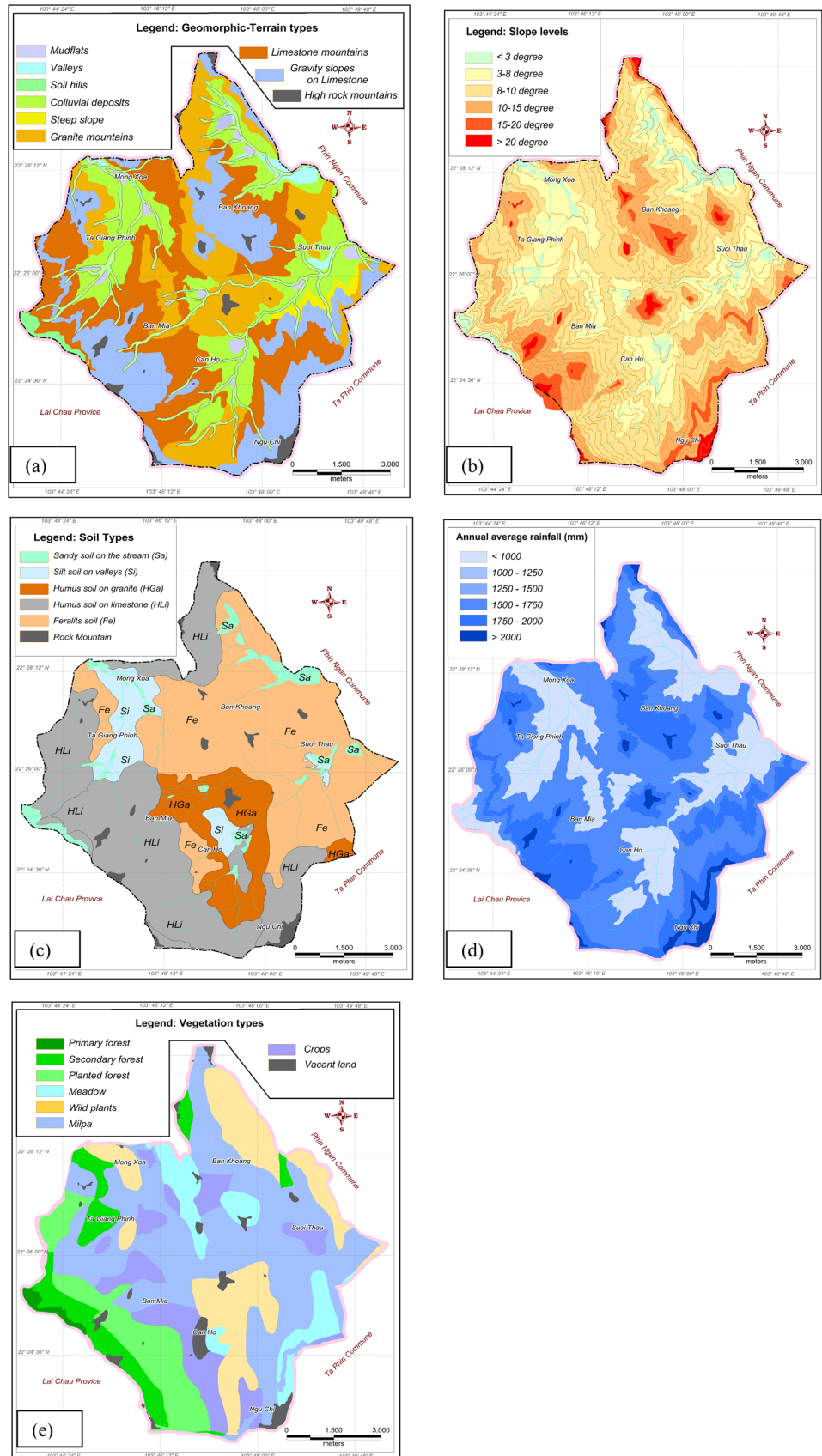
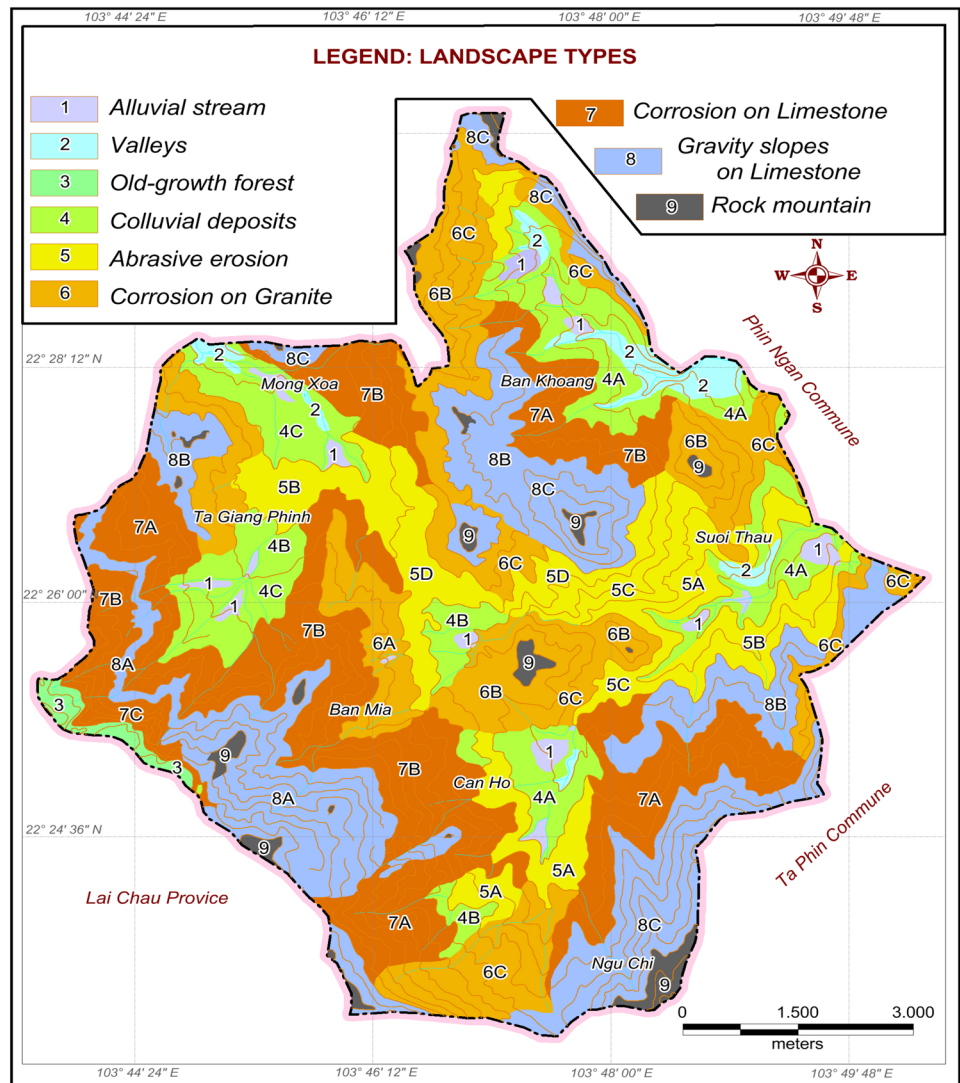


Fig. 4 Landscape map of Ngu Chi Son commune



(Mogan 2005; Cunliffe et al. 2016; Tarolli et al. 2020). The total area of “very low” sensitivity regions was recorded at 744.28 hectares, which accounted for 9.25% of the commune’s area. Compared to the “very low” level area in 2018 documented in a previous study, the number remarked a decrease of 912.4 hectares [38]. This fact results that the aggregation in assessing landscape erosion (Fig. 7) factors can clarify the limitations and be appropriate for practical landscape erosion indexes.

Landscapes with the “low” level of erosion sensitivity occupy a total area of 1885.00 hectares, which account for 33.41%. This type of landscapes distributes primarily at Deluvi colluvium terrains (Type 4A, 4B, and 4C) with a slope less than 10 degrees, 70–100 cm of thickness, and annual average rainfall less than 1500 mm. Some particular regions with a slope higher than 10 degrees (Type 6A and 7C) jointly have the “low” level of erosion owing to vegetation, which are cultivated forests or secondary

forests. In addition, artificial landscapes (Type 5A and 5B), which are feasible for cultivating on slopes and terraces, also belong to the “low” erosion sensitivity level due to the shale characterizing the area’s sample.

The erosion sensitivity of the “medium” level shares the most tremendous area of 2.906,01 hectares, which is 36% occupancy over the total area. This type of landscapes includes abrasion sides on granite (Type 5C and 5D) and attrition sides on limestones (Type 6C, 7A, and 7B) that have slopes ranging from 10 to 20 degrees and an annual average rainfall of 1500–2000 mm. Exceptionally, the erosion sensitivity of the type 8A of landscapes is also at the “medium” level though this type consists of high slopes and 2000 mm of average rainfall. The main reason is because of afforestation areas and a plentiful vegetation system. This statement has been mentioned in previous studies that examined the impact of vegetation cover on landscape erosion levels [36, 43].

Table 2 Structural characteristics of Ngu Chi Son's landscapes

No	Landscape type	Characteristics of landscape units							
		Terrain form	Slope (deg)	Rock	Types of soil	Thickness (cm)	Mechanical compositions	Vegetation (NDVI value)	
1	Alluvial stream	1	Mudflats	0–3	A-P	Sa	50–70	b	0.22–0.28
2	Valleys	2	Valley	0–3	D-P	Si	50–70	b	0.22–0.28
3	Old-growth forest	3	Forest	3–8	Limestone	HLi	50–70	b	0.45–0.7
4	Colluvial deposits	4A	Deluvi	8–10	Granite	HGa	> 100	c	0.28–0.45
		4B	Deluvi	8–10	Granite	HGa	> 100	c	0.22–0.28
		4C	Deluvi	8–10	Granite	HGa	> 100	d	0.15–0.22
5	Abrasive erosion	5A	Mountain	10–15	Granite	HGa	> 100	d	0.078–0.15
		5B	Mountain	10–15	Granite	HGa	> 100	d	0.15–0.22
		5C	Mountain	10–15	Shale	HGa	> 100	d	0.45–0.7
		5D	Mountain	10–15	Shale	HGa	70–100	c	0.28–0.45
6	Corrosion on granite	6A	Mountain	10–15	Granite	HGa	70–100	d	0.28–0.45
		6B	Mountain	10–15	Granite	HGa	70–100	d	0.078–0.15
		6C	Mountain	10–15	Granite	HGa	70–100	c	0.28–0.45
7	Corrosion on limestone	7A	Mountain	15–20	Limestone	HLi	> 100	d	0.28–0.45
		7B	Mountain	15–20	Limestone	HLi	> 100	e	0.15–0.22
		7C	Mountain	15–20	Limestone	HLi	> 100	d	0.28–0.45
8	Gravity slopes on limestone	8A	Gravity slopes	15–20	Limestone	Fe	30–50	d	0.28–0.45
		8B	Gravity slopes	15–20	Limestone	Fe	30–50	e	0.078–0.15
		8C	Gravity slopes	> 20	Limestone	Fe	10–30	e	0.15–0.22
9	Rock mountain	9	Slope mountain	> 20	Limestone	HLi	< 10	f	-0.35–0.078

The “high” level of erosion sensitivity consists of gravity sides with high ground and bushes as vegetation. Remarkably, the type 6B was assessed to be highly sensitive to erosion though this type has low slopes and thick soil horizons. This is due to the cover of bushes that is unable to resist erosion. The area of this sensitivity level is relatively large with 25.78% accounted. In comparison with previous studies regarding soil erosion [39], it appears that the area of the “high” level is increasing dramatically. This result reflects the alteration of landscapes at mountainous regions in time because of artificial impacts, especially the ones that cause forests to decrease in terms of areas [8]. As a result, challenges in exploiting and sustainably utilizing mountainous landscapes emerge.

The “very high” level of erosion sensitivity, which was characterized as the ninth type landscape, is extant in an area of 440.45 hectares corresponding to 5.47%. This type of landscapes distributes on gravity sides with great slopes. Virtually, empty fields and limestone mountains are the occupants of the “very high” level areas. This also means human activities are unsuitable there.

Conclusively, compared to the determination of erosion in accordance with the Universal Soil Loss Equation (USLE) (Wischmeir and Smith 1978), the approach of a

spatial analysis model in assessing landscape erosion sensitivity is completely different. The resultant appraisals derived from the USLE are dependent distinctly on the erosion index of each erosion factor, whereas the spatial analysis offers the landscape erosion sensitivity levels based on the aggregation of erosion factors following each landscape unit. The model also inherits traditional evaluation methods such as the arithmetic mean method [3], the utilization of landscape equilibrium indexes [9, 11], and the combination of GIS spatially analytical technology [43]. The obtained results regarding erosion assessments at Ngu Chi Son commune are accurately homogeneous to the realistic status of landscape erosion. Nevertheless, in order to assess mountainous landscape erosion on a large scale, it is required to construct an algorithm evaluating every single landscape factor based on different levels of criteria. Nowadays, GIS software versions with open source codes are capable of meeting this requirement. This is also a new prospect for studies regarding the assessment of mountainous landscapes.

Fig. 5 Landscape erosion sensitivity map of Ngu Chi Son commune

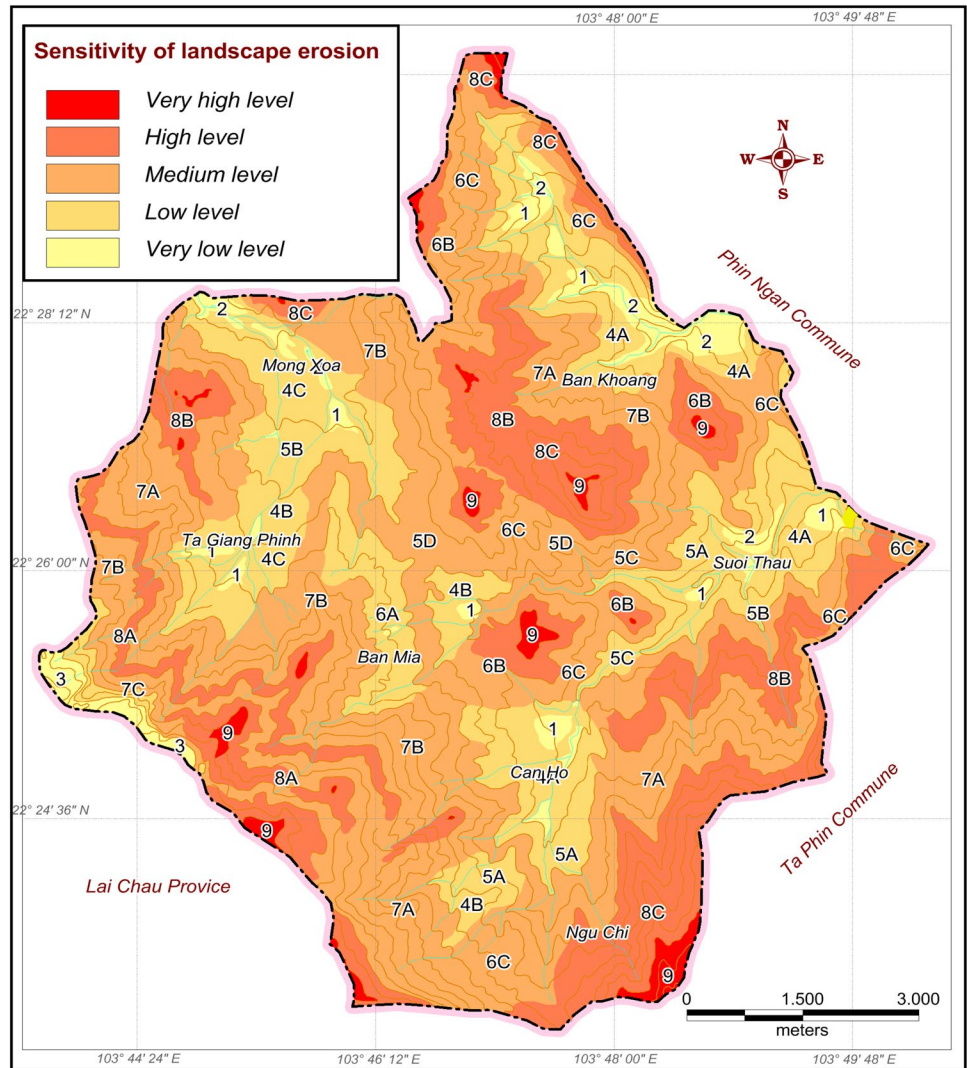


Fig. 6 Landscape types erosion sensitivity chart of Ngu Chi Son commune



Table 3 Classification results of sensitivity levels of Ngu Chi Son's landscapes

Erosion sensitivity levels	Area (hectares)	Rate (%)	Landscape type
Very low	744,82	9,25	(1); (2); (3)
Low	1.885,00	23,41	(4A); (4B); (4C); (5A); (5B); (6A); (7C)
Medium	2.906,01	36,09	(5C); (5D); (6C); (7A); (7B); (8A)
High	2.075,84	25,78	(6B); (8B); (8C)
Very high	440,45	5,47	(9)
Total	8052,125	100,0	20

3.2 Proposed orientations for the reasonable utilization of resources and protecting the environment at the researched area

Based on the assessment results regarding landscape erosion sensitivity, these are the orientations recommended by the authors in order to regulate properly the utilization of natural resources and protecting the environment.

3.2.1 For landscape areas at the “very low” or “low” levels of sensitivity according to the assessments:

The cultivation of agricultural plants such as rice, vegetables, flowers, and fruit trees should be promoted in these areas as they are relatively flat. It is also possible to develop residential sites though measures preventing flash floods are essentially considerable. Concurrently, the Deluvi colluvium landscapes are believed to suit short-term plants, pharmaceutical herbs, flowers, and vegetables as well. In addition, for the primeval forest landscapes located at northern Hoang Lien national park, rigorous protective measures are crucial for preserving the natural ecology there.

3.2.2 For landscape areas at the “medium” level of sensitivity according to the assessments

The occupation of these areas was recorded to be the largest with thick soil horizons. However, the average slope of these areas was significantly high and as a result suitable for afforestation following lines and the aggregation of forestry and agriculture as well. Cultivation techniques in accordance with contour lines are believed to take



Low level of landscape erosion



Medium level of landscape erosion



High level of landscape erosion



Very high level of landscape erosion

Fig. 7 Some pictures of landscape erosion level of Ngu Chi Son commune

advantage of this landscape's potentials while still maintaining environmental sustainability. On the other hand, in order to reduce the landslide of soil and rocks along the sides of mountains and hills, preventing negative consequences for residents, it is necessary to proceed planting forests and cultivating terraces.

3.2.3 For landscape areas at the "high" or "very high" levels of sensitivity according to the assessments

These areas are potential in terms of space and expandable for afforestation of combining forests and pharmaceutical plants. However, it is required to be especially wary of artificial vegetation and ecological conditions for plants on lower floors. Additionally, it is necessary to notice the methods that locate and nurture forests on stone mountains. The combination of fruit trees and pharmaceutical plants under forest canopies is also recommended. Particularly, although the landscapes of the "very high" level were distributing merely at empty grounds and a few stone mountains, the development of natural vegetation therein should be promoted with the cultivation of upstream forests to preserve freshwater and restrict the expansion of erosion.

4 Conclusion

Ngu Chi Son is a typical mountainous region in Vietnam. This place has relatively complicated natural conditions and no concrete orientations for exploiting the territory according to landscape units so far. This study on the application of spatial analytical models that assess the sensitivity of landscape erosion at Ngu Chi Son has indicated the erosion sensitivity levels based on landscape appraisals. Moreover, this is also a synthetic approach of research that integrated the GIS spatial analysis model, which resulted in a comprehensive prospect of landscape erosion. To be specific, the study results classified erosion sensitivity of Ngu Chi Son's landscapes into five levels. It was also detected that the high level and very high level accounted dramatically for 31.25% over the total area. With the data of other levels, the views provided by the overall result of this study prove fundamental for the future paths of mountainous development. They are also believed to improve the utilization of natural landscapes in terms of using purposes and, furthermore, to sustain natural resources and the environment for proper exploitation. Those are also the reasons why this study should be applied in other mountainous communes or even expanded the research scale to larger mountainous regions of Vietnam.

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Compliance with ethical standards

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

References

1. Isachenko AG (1973) Principles of landscape science and physical-geographic regionalization trans from Russian by R.J. Zatorski, edited by J.S. Massey. Carlton, Victoria, Australia: Melbourne University Press.
2. Pampaloni V, Ferro V (2020) Estimating Soil Loss of Given Return Period By USLE-M-Type Models. *Hydrological Processes*
3. Williams JR, Renard KG (1983) Dyke PT (1983) epic - a new method for assessing erosions effect on soil productivity. *J Soil Water Conserv* 38:381–383
4. Dale VH, Beyeler SC (2001) Challenges in the development and use of ecological indicators. *Ecol Ind* 1(1):3–10
5. Shi ZH, Cai CF, Ding SW, Wang TW, Chow TL (2004) Soil conservation planning at the small watershed level using RUSLE with GIS: a case study in the Three Gorge Area of China. *CATENA* 55(1):33–48
6. Meusburger K, Konz N, Schaub M, Alewell C (2010) Soil erosion modelled with USLE and PESERA using QuickBird derived vegetation parameters in an alpine catchment. *Int J Appl Earth Obs Geoinf* 12(3):208–215
7. Lin BS, Chen CK, Thomas K, Hsu CK, Ho HC (2019) Improvement of the k-factor of usle and soil erosion estimation in shihmen reservoir watershed. *Sustainability* 11(2):341–355
8. Borrelli P, Panagos P (2020) An indicator to reflect the mitigating effect of common agricultural policy on soil erosion. *Land Use Policy* 92(2):454–467
9. Turner MG, Gardner RH (1991) Quantitative Methods in Landscape Ecology. Springer-Verlag, New York
10. Marshall JA, Roering JJ, Bartlein PJ et al (2015) Frost for the trees: did climate increase erosion in unglaciated landscapes during the late pleistocene. *Science Advances* 1(10):81–99
11. Thomas MF (2001) Landscape sensitivity in time and space - an introduction. *Catena* 42(2–4):83–98
12. Uuemaa E, Mander Ü, Marja R (2013) Trends in the use of landscape spatial metrics as landscape indicators: a review. *Ecol Ind* 28(1):100–106
13. Mogan RPC (2005) Soil Erosion and Conservation. Blackwell Publishing, USA
14. Barton C, Ullah I, Heimsath A (2015) How to make a barranco: modeling erosion and land-use in mediterranean landscapes. *Land* 4(3):578–606
15. Beer AR, Turowski JM, Kirchner JW, (2017) Spatial patterns of erosion in a bedrock gorge. *J Geophys Res Earth Surf* 122(1):191–214
16. Thomas L, Saaty, (2008) Decision making with the analytic hierarchy process. *Int J Serv Sci* 1(1):167–175
17. Kil SH, Lee D, Kim JH, Li MH, Newman G (2016) Utilizing the analytic hierarchy process to establish weighted values for evaluating the stability of slope revegetation based on hydroseeding applications in South Korea. *Sustainability* 8(1):47–58

18. Haidara I, Tahri M, Maanan M, Hakdaoui M (2019) Efficiency of fuzzy analytic hierarchy process to detect soil erosion vulnerability. *Geoderma* 25(2):113853
19. DiBiase RA, Whipple KX, Heimsath AM, Ouimet WB (2010) Landscape form and millennial erosion rates in the San Gabriel Mountains CA. *Earth Planet Sci Lett* 289(1–2):134–144
20. Ouyang W, Skidmore AK, Hao F, Wang T (2010) Soil erosion dynamics response to landscape pattern. *Sci Total Environ* 408(6):1358–1366
21. Ganti V, Hagke C, Scherler D, Lamb MP, Fischer WW, Avouac JP (2016) Time scale bias in erosion rates of glaciated landscapes. *Sci Adv* 2(10):e1600204–e1600204
22. Riley KE, Rittenour TM, Pederson JL, Belmont P (2019) Erosion rates and patterns in a transient landscape, Grand Staircase, southern Utah, USA. *Geology* 47(9):811–814
23. Bou Kheir R, Abdallah C, Khawlie M (2008) Assessing soil erosion in Mediterranean karst landscapes of Lebanon using remote sensing and GIS. *Eng Geol* 99(3–4):239–254
24. D'Arcy M, Whittaker AC (2014) Geomorphic constraints on landscape sensitivity to climate in tectonically active areas. *Geomorphology* 204:366–381
25. Roda Boluda DC, Whittaker AC (2017) Structural and geomorphological constraints on active normal faulting and landscape evolution in Calabria. *Italy Journal of the Geological Society* 174(4):701–720
26. Barnhart KR, Tucker GE, Doty S, Shobe CM, Glade RC, Rossi MW, Hill MC (2020) Inverting topography for landscape evolution model process representation part 3 determining parameter ranges for select mature geomorphic transport laws and connecting changes in fluvial erodibility to changes in climate. *J Geophys Res Earth Surf.* <https://doi.org/10.1029/2019JF005287>
27. Ayad YM (2005) Remote sensing and GIS in modeling visual landscape change: a case study of the northwestern arid coast of Egypt. *Landsc Urban Plan* 73(4):307–325
28. Bou KR, Abdallah C, Khawlie M (2008) Assessing soil erosion in Mediterranean karst landscapes of Lebanon using remote sensing and GIS. *Eng Geol* 99(3–4):239–254
29. Tamene L, Adimassu Z, Aynekulu E, Yaekob T (2017) Estimating landscape susceptibility to soil erosion using a GIS-based approach in Northern Ethiopia. *Int Soil Water Conserv Res* 5(3):221–230
30. Bahadur KC (2009) Improving landsat and IRS Image classification: evaluation of unsupervised and supervised classification through band ratios and dem in a mountainous landscape in Nepal. *Remote Sens* 1(4):1257–1272
31. Andreani L, Stanek K, Gloaguen R, Krentz O, Domínguez-González L (2014) DEM-based analysis of interactions between tectonics and landscapes in the ore mountains and eger rift (East Germany and NW Czech Republic). *Remote Sens* 6(9):7971–8001
32. Alexakis DD, Hadjimitsis DG, Agapiou A (2013) Integrated use of remote sensing, GIS and precipitation data for the assessment of soil erosion rate in the catchment area of “Yialias” in Cyprus. *Atmos Res* 131:108–124
33. Cunliffe AM, Brazier RE, Anderson K (2016) Ultra-fine grain landscape-scale quantification of dryland vegetation structure with drone-acquired structure-from-motion photogrammetry. *Remote Sens Environ* 183:129–143
34. Tarolli P, Straffellini E (2020) Agriculture in Hilly and Mountainous Landscapes: Threats, Monitoring and Sustainable Management. *Geogr Sustainability* 55(1):123–136
35. Zhang RH, Liu X, Gary C et al (2013) Assessment of soil erosion sensitivity and analysis of sensitivity factors in the Tongbai-Dabie mountainous area of China. *CATENA* 10:92–98
36. Nguyen CH, Pham QA (2005) Study on characteristics and landscape structure of Sa Pa - Ta Phin area, Sa Pa district. *J Sci, Hanoi Nat Univ, Vietnam, Ha Noi* 36(2):28–39
37. Pham HH, Nguyen QL (2016) Analysis of geomorphological conditions in Sapa serving socio-economic development. *J Soil Sci in Vietnam, Ha Noi* 24(2):108–116
38. Nguyen AT (2007) Analysis of ecological landscape structure of Sa Pa district for sustainable development of agriculture and forestry. PhD thesis, Hanoi National University, Vietnam
39. Pham TG, Degener J (2018) Kappas M (2018) integrated universal soil loss equation (USLE) and geographical information system (GIS) for soil erosion estimation in a sap basin: Central Vietnam. *Int Soil Water Conserv Res* 6:99–110
40. Pham QH, Bui CH (2017) Overview of landscape research in Vietnam. *J Earth Sci, Ha Noi* 52(3):15–28
41. Pham QT, Nguyen AT, Tran TA (2018) Prospects for development of fruit trees in mountainous areas landscapes and midland of Vietnam. *J Sci Technol, Hanoi Univ Educ* 22(4):51–60
42. Kurosawa K, Egashira K (2013) Sloping land agriculture and the agroecological conditions in the northern mountainous region of Vietnam: a case study in Sa Pa district. *Landscape Ecol* 57(2):223–230
43. Tran DL, Vi VT et al (2014) Research vegetation, flora and plant resources in high mountain ecosystems of Vietnam. Report the results of scientific research, Institute of Ecology and Biological Resources, Ha Noi
44. Goodchild MF, Haining RP (2003) GIS and spatial data analysis: Converging perspectives. *Pap Reg Sci* 83(1):363–385
45. Jia P, Cheng X, Xue H, Wang Y (2017) Applications of geographic information systems (GIS) data and methods in obesity-related research. *Obes Rev* 18(4):400–411
46. Shirowzhan S, Sepasgozar S (2019) Spatial analysis using temporal point clouds in advanced GIS: methods for ground elevation extraction in slant areas and building classifications. *ISPRS Int J Geo-Inf* 8(3):110–120
47. Wessel B, Huber M, Wohlfart C, Marschalk U, Kosmann D (2018) Accuracy assessment of the global TanDEM-X Digital Elevation Model with GPS data. *ISPRS J Photogramm Remote Sens* 139:171–182
48. Comber A, Zeng W (2019) Spatial interpolation using areal features: a review of methods and opportunities using new forms of data with coded illustrations. *Geogr Compass.* <https://doi.org/10.1111/gec3.12465>
49. Zhao K, Jin B, Fan H, Song W, Zhou S, Jiang Y (2019) High-performance overlay analysis of massive geographic polygons that considers shape complexity in a cloud environment. *ISPRS Int J Geo-Inf* 8:290–302
50. Asadzadeh S, Souza CR (2016) A review on spectral processing methods for geological remote sensing. *Int J Appl Earth Obs Geoinf* 47:69–90
51. Nguyen LD (2019) Analyze land characteristics in Sa Pa district. Lao Cai province, State level project, Vietnam Academy of Science and Technology

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