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Decentralization of criticality for watershed protection and sustainable agricultural production orientation in Lai Giang River Basin, South Central Coast, Vietnam

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Abstract Watershed vulnerability assessment is a crucial task reflecting the risk of land degradation due to erosion of a river basin. This study assessed criticality by applying GIS to assess soil erosion potential and for solutions to reduce soil erosion in the most vulnerable. The potential erosion level is applied, RUSLE's loss equation with four parameters of rainfall (R), slope (S), slope length (L), and soil properties (K) according to the formula: Y = K*R*S*L assuming no land cover. The research results revealed that the Lai Giang River basin has a very high potential for soil erosion with no land cover. After combining with land cover in the basin through index land cover (C) and index farming activities (P), soil loss is gradually lower. This study shows the positive effects of land cover in reducing soil erosion. We tried to come up with possible solutions on the area required for protection forest development to limit the possibility of soil erosion, that is, the area of protective forest land that needs to achieve 58.000 ha. The improved use of RUSLE integration with GIS and remote sensing is more efficient and less expensive in estimating vulnerability to land protection priorities in river basins.

Keywords: potential erosion, Lai Giang river basin, watershed protection, sustainable agricultural, GIS

1. Introduction

The decentralization of the critical level of land for the orientation of land allocation for protection and watershed protection is an urgent requirement of many countries in the world (MRC 2005). The watershed is where many essential functions of the river basin are performed (water supply function, regulation function, soil protection function, ...). The decline of those functions will seriously affect most living and productive activities in the basin. Watershed protection research is a general analysis of natural conditions in the basin to point out the most critical places regarding water source protection and land protection (Huyen 2015). It describes a landscape's potential soil erosion risks based on its physical or environmental characteristics (Centre for Development and Environment CDE 1997). Potential soil erosion is an essential criterion for critical watershed assessment and a significant concern globally due to its adverse impact on agricultural productivity, natural ecosystems, and agroecosystems, threatening the agricultural production of the people (Chalise et al 2019). Some authors suggest that most of the Earth's topsoil has been lost to soil erosion in the last 150 years (Devatha 2015) and that most of it occurs in the watershed. Estimating soil erosion potential and mapping critical levels at the watershed level is crucial for land resource managers and decision-makers. This is especially true in Vietnam's river basins, where agriculture is the mainstay of the basin's economy (accounting for 70% of economic activity). The severe problem of the Lai Giang River basin is due to the heavy year-round rainfall and a high potential for soil erosion, which is the main form of land degradation, continuously affecting the sustainability of agricultural production in the area (Huyen 2015). Soil erosion in the watershed is one of the many factors affecting the livelihoods of the entire basin by losing land, reducing productivity, and exacerbating poverty (Quang 2005). Various methods have been developed to estimate soil erosion potential in a watershed. The most widely used are the universal soil loss equation (USLE), revised soil loss equation (RULSE) and physical process models (MMF, AGNPS, SWAT), and physics-based dynamic models (CREAMS, EUROSEM, KINEROS, EPIC, WEEP). These studies have used geographic information systems (GIS) and remote sensing techniques to assess soil erosion in different parts of the world, integrated with these and other models or stand-alone applications. The USLE equation, developed by Wischmeier and Smith in 1965, then modified to RUSLE in 1997 by Renard et al., is an empirical model that has been used effectively to estimate soil erosion in areas lacking water measurement (Wischmeier and Smith 1978; Renard KG 1997; Weier and Herring 2000; Tošić et al 2012; Amit 2017; Pham et al 2018; Negese et al 2021; Arias-Muñoz et al 2022; Nasir et al 2023), based on rainfall, soil type, topography, cropping

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systems, and management practices), soil erosion potential (K), topography (LS), cover and management (C), and practice support (P). The RUSLE method, combined with GIS, has been used in numerous modern works and research studies to predict and make erosion risk map in many countries worldwide in recent periods (Quang 2005; Prasannakumar et al 2012, Alexandridis et al 2015; Milentijević et al 2021), which led to very satisfactory results. Previous studies in Vietnam have used the combined application of GIS and remote sensing with the RUSLE model to predict soil erosion in river basins in Vietnam, such as the Be river (Long 2020) and Dong Nai river (Ba et al 2003) , and other areas such as Quang Tri province Hung Trinh Le (Hung and Thu 2017), upland basins northern Vietnam (Vezina et al 2006).

Nevertheless, in order to evaluate the erosion level for the critical watershed hierarchy, it is necessary to conduct a study on potential soil erosion through the assessment of natural factors causing erosion (R, K, L, S) with the assumption that no vegetation cover does not exist (Quang 2005) many of these studies calculated soil erosion. Tošić et al (2012) calculation of the intensity of erosion processes is also estimated by the potential erosion method (Tošić et al 2012), and this method is widely used in Keyna states (Angima et al 2003). Because hazards such as heavy rains and runoff on bare land cause severe erosion leading to soil degradation, especially in mountainous areas (Prasannakumar et al 2012)· I.A. Kronev (1971), developed the potential erosion method and applied RUSLE with adjusted and improved variables to match the natural characteristics in research in Russia's midland and mountainous regions. The authors Do Hung Thanh, and Nguyen Thi Kim Chuong (1992) applied in the study of accelerated erosion for the Northwest Mountains, Thanh D.V. (2011), for Bac Giang province, and Van L.T, 2000 for Binh Dinh (Van 2011) with exponential functions corrected and tested in practice with the formula: Y= K*S*L*R. Integration of vegetation indexes (C) and production and soil protection coefficients (P) shows the actual level of soil erosion at the time of the study, comparing with the potential erosion area is a suggestion practical for determining the area of watershed protection land for the basin (Van 2011).

This study was carried out in the Lai Giang River basin using the integration of Geographic information system (GIS) and remote sensing techniques with the aim of (1) estimating the basin's potential erosion level for determining the river's vulnerability basin without vegetation; (2) Integrating vegetation cover and land tillage coefficient for identifying and prioritizing areas of high vulnerability for planning and implementing conservation measures by identifying protected forest areas and land use capacity in agricultural and forestry development.

2. Materials and Methods

2.1. Study area

Lai Giang river basin is a large Binh Dinh province basin in the South Central Coast of Vietnam, with geographical coordinates from 14°10' to 14°45' North latitude and 108° 44' to 109° 10' East longitude (Figure 1). Covering an area of 1,683.27 km^2. The terrain is complex and inclined from West to East. Hills and mountains account for over 83%, mainly low hills; the average height is 500 m (the lowest is 40 m, and the highest is 1,012 m). Especially in the west and northwest of the river basin, the topography is over 600 m, and the average slope is 23%, but along the mountain slopes, the average slope is 60-80%. The Lai Giang river basin has much potential for developing the agro-forestry economy. The area of agricultural land is about 132,305.02 hectares (accounting for 78.6% of the total natural area in 2022, in which the land for forestry is about 63.5% and the land for agricultural production is about 15.1%).

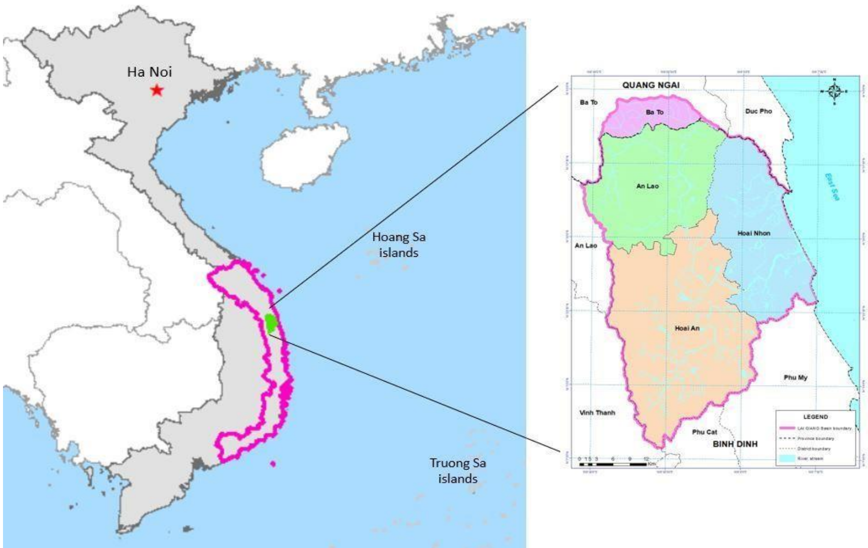

Figure 1 Location map of the study area.

The landscape of the watershed is diverse. The basin's topography is characterized by hills and mountains occupying a large area, and the valleys are deeply divided in letters. The soil in the Lai Giang basin is quite diverse, with eight main soil groups with quite complex characteristics and properties, giving Lai Giang basin many advantages for socio-economic development, especially economic development. Agriculture and Forestry.

2.2. Data types and sources

Topography, climate, soil properties and vegetation cover, and other management practices influence the critical level of soil erosion. Therefore, assessing the critical level of watershed requires data regarding these factors. The data needed for the study were collected from a variety of sources.

Vegetation data: The study's vegetation data includes the current land use map in 2022 and the Landsat 8 Operational Land Imager (OLI) satellite image with a spatial resolution of 30 m in 2022, at cloud cover <20% from the US Geological Survey website, with spectral band characteristics:

Table 1 Features of Lansat 8 image spectrum channel (cloud cover <20%).

Band	Description	Wavelength width (μm)	Resolution
1	Coastal aerosol	0.433–0.453	30 m
2	Blue	0.450–0.515	30 m
3	Green	0.525–0.600	30 m
4	Red	0.630–0.680	30 m
5	Near Infrared (NIR)	0.845–0.885	30 m
6	SWIR 1	1.560–1.660	30 m
7	SWIR2	2.100–2.300	30 m
8	Panchromatic	0.500–0.680	15 m
9	Cirrus	1.360–1.390	30 m

Terrain: DEM (figure 2a) data is the significant input for the calculation of the LS factor derived from the digital elevation of the Space Shuttle Radar Terrain Mission (SRTM) model (DEM). SRTM version 4 at 30 m resolution is a global free DEM data widely used in many disaster management and environmental research applications. At the same time, the topographic map is provided by the Department of Natural Resources and Environment with a scale of 1:50.000.

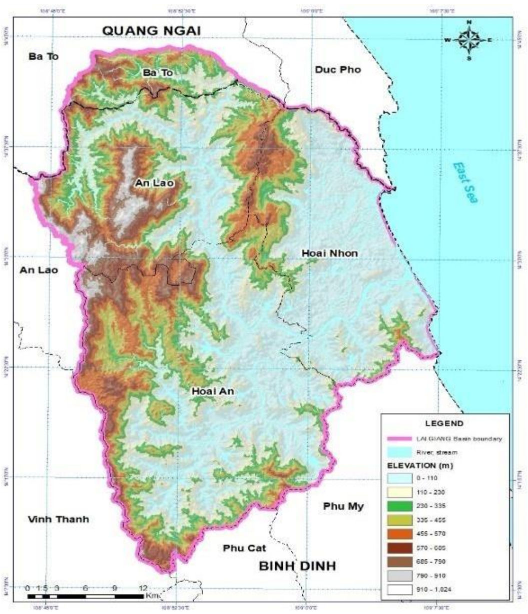

Figure 2a SRTM DEM Model.

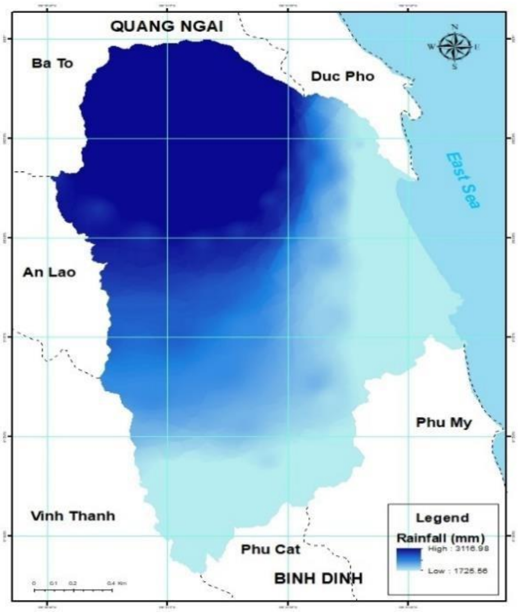

Figure 2b Average annual rainfall (the period 2002 – 2022).

Rainfall: Average annual rainfall data of some meteorological stations in the basin and the whole province and surrounding areas within 20 years, including (2002 - 2022) Hoa Nhon, Quy Nhon, and An Hoa stations. At the same time, data is collected from rainfall from weather stations in Vietnam extracted from the Disaster and Household Welfare Report, version 1.0, published five years ago by the World Bank. The map of average annual rainfall is shown in figure 2b**;** the average annual rainfall of the basin ranges from 17254.6 to 3111.7 mm; the highest is in the northwest of the basin.

Soil data: The soil map of the Lai Giang river basin is extracted from the 2005 soil map of Binh Dinh province provided by the Binh Dinh Department of Agriculture and Rural Development and provided by the Institute of Agrochemical Soil with a scale of 1/50.000.

2.3. Methodology

The primary method to assess the critical level of soil erosion in the Lai Giang River basin is based on the RUSLE equation (Long 2020) integrated with open-source GIS techniques (using GRASS GIS and QGIS software) according to the program **(**figure 3). The software (QGIS) is used to prepare, normalize the input data, calculate, transform, integrate the map coefficients in the model, and make statistics of erosion data and decentralization of critical level. In addition, the calculation of the C coefficient in the RUSLE model uses the Normalized Difference Vegetation Index (NDVI) obtained from the Landsat 8 satellite images. Through these Landsat 8 images, calculating the C coefficient in the USLE model becomes easier.

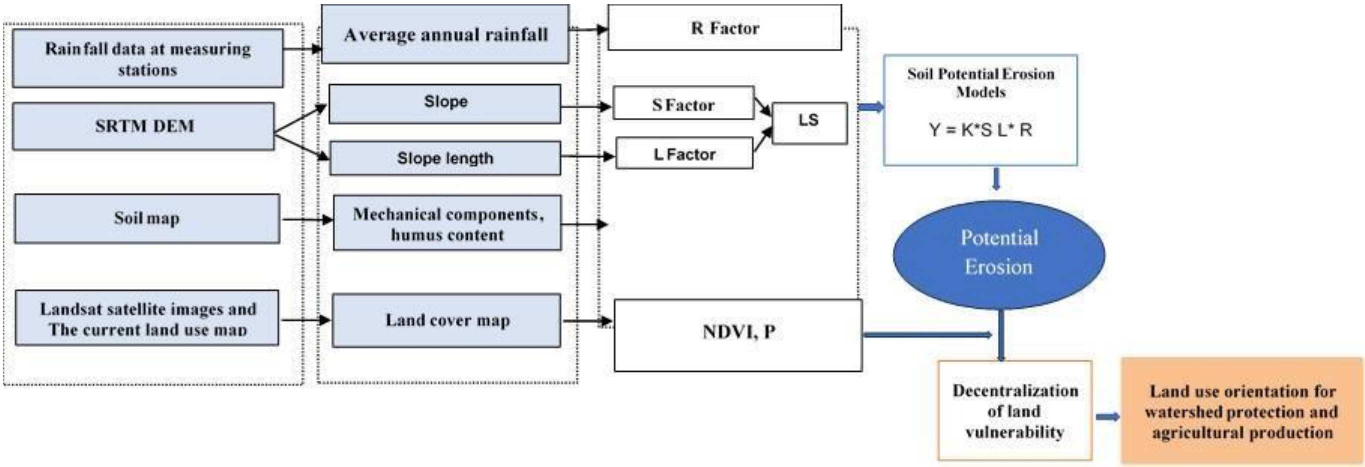

Figure 3 The watershed protection decentralization workflow.

Soil erosion factors

a. Coefficient (R)

The average annual rainfall of the Lai Giang basin is calculated from data from 3 terrestrial meteorological stations (Hoai Nhon, Quy Nhon, An Hoa station). Furthermore, interpolated by the inverse weighted distance (IDW) method in a GRASS GIS environment. The precipitation distribution map (figure 4) calculates the erosion caused by the R factor. In this study, we have applied the formula developed by Nguyen Trong Ha to the structural system. Preventing erosion caused by rain in areas in Vietnam (Ha 1996):

$$R = 0.548257 * P - 59.9 \quad (1)$$

R is the coefficient of erosion according to the average annual rainfall (J/m^2); P is the average annual rainfall (mm/year); The process of calculating the R coefficient is also done through the Map Calculator module in GRASS GIS as follows: r.mapcalc “Rfactor” = 0.548257 * Precipitation – 59.9.

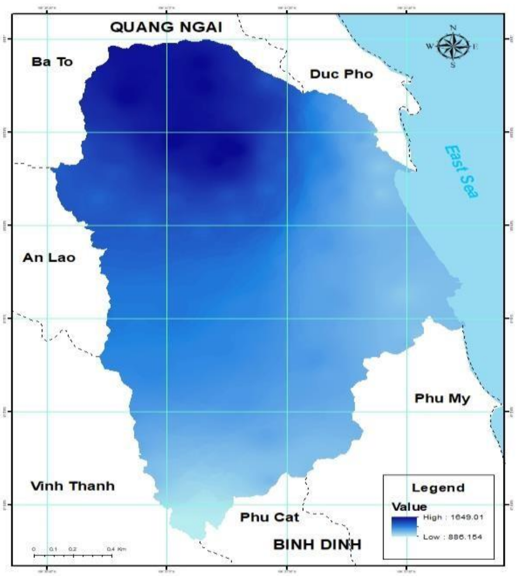

Figure 4a R Factor.

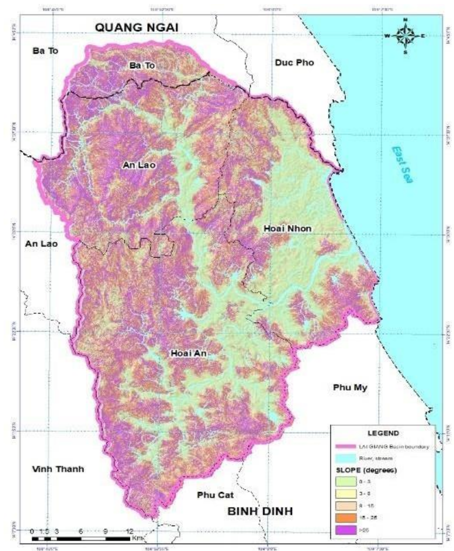

Figure 4b S Factor.

Figure 4c L Factor.

Figure 4d LS Factor.

b. Coefficient (K)

Based on the soil properties from the soil map of the Lai Giang River basin, the K coefficient has been determined for the soil classes in the basin, as shown in Table 2. The results of the K coefficient are updated in the soil flow map. Area using the Edit Attribute Table tool in Quantum GIS software. This K-map was imported into GRASS software and converted to raster format with the exact 30m resolution as other data layers.

Table 2 Coefficient (K) of soil (Nguyen Trong Ha, 1996).

Symbol	Name	K factor
P	Fluvisol	0.46
Fa	Gold soil	0.27
Fk	Reddish brown soil on basic igneous rock	0.27
Fs	Yellow red soil on clay and metamorphic rocks	0.32
Fq	Light yellow soil on sandstone	0.39
Ha	Red yellow humus soil on acid magmatic rocks	0.25
D	Valley soil	0.61
Ba	Discolored gray soil on acid magmatic rocks	0.22
Xa	Gray soil on acid magmatic rock	0.21
E	Rocky eroded soil	0.9
M	Salty soil	0.035
C	Sandy soil	0.34

c. LS Factor

The slope length and slope (LS) coefficients were generated directly from the SRTM DEM model (30 m spatial resolution) of the watershed (figure 3**).** We calculated the slope and flow accumulation from the DEM data, the two critical parameters in generating the LS coefficient. Both slope and cumulative runoff parameters were generated using a topographic analysis tool in GRASS GIS software with the formula (Mitasova, Hofierka et al 1996)

$$LS = (t + 1)\left(\frac{A}{Lo}\right)^{t}\left(\frac{sinß*0.01745}{bo}\right)^{n} \qquad (2)$$

Where LS is the slope length - steepness coefficient; A represents the flow accumulation of the study basin; sin ß is the slope of a given terrain in degrees; and bo (slope), Lo (slope length), t, n (constant) at the "standard" measurement site for soil loss (where bo is 9%; Lo is 22.13 m; t=0.6 and n=1.3). The LS coefficients are calculated according to formula (2) using the cartographic calculator module in GRASS GIS.

d. Coefficient (C)

The Normalized Difference Vegetation Index (NDVI) was calculated to determine coefficient C, which refers to soil cover. The NDVI is a popular and widely used remote sensing index representing an area's resistance to land surface (Prasannakumar, Vijith et al 2012). In this study, NDVI data (figure 5a). were obtained from Landsat 8 OLI images. The NDVI index is typically calculated according to the formula (Quang 2005). The NDVI index calculation tool is Map Calculator on GRASS software. The input data are digital numerical values in Table 1 on the Google Earth Engine environment (https://earthengine.google.com) The study used the formula method developed by De Jong (Renard KG 1997) to calculate the erosion coefficient according to coefficient C, according to formula 3.

$$C = 0{,}431 - 0{,}805 \times NDVI \quad (3)$$

Figure 5a NDVI value.

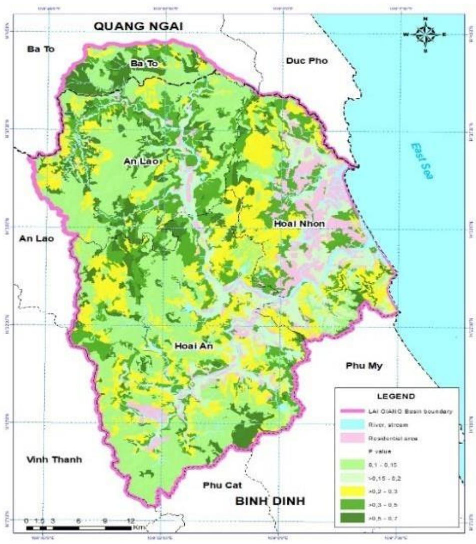

Figure 5b P factor.

e. P factor

The cultivation coefficient (P) is defined as the effect of land use or farming system on soil erosion. This factor expresses the impact of specific conservation practices in the soil, such as contouring, cropping, terraces, and subsurface drainage. These practices influence erosion by changing the flow pattern, grade, or direction of surface runoff and reducing the amount and speed of runoff. The P value for the study area ranges from 0.1 to 1, and the P-coefficient map obtained from the land use status map is shown in Figure 5b.

3. Results

3.1. Potential for soil erosion (without vegetative cover) in Lai Giang river Basin

Potential erosion is the erosion process that does not consider the impact of vegetation cover and human production. Therefore, the potential erosion map has been established by integrating the coefficient maps R, K, and LS. At the same time, the total natural territory of the Lai Giang River basin is 168,327.0 hectares; the authors have removed the area of residential land, construction land, river, stream, pond, and other non-agricultural lands. Other industries (30,238.0 hectare, accounting for 17.96% of the total natural area of the basin) by overlaying the 2022 land use status map to exclude. Only 138,089.0 hectare of the basin area is included in the assessment, with mainly agricultural and forestry economic activities. The calculation procedure using the calculation tool is as follows:

r.mapcalc"Potential_Erosion"=Rfactor*Kfactor*Lsfactor

According to Vietnamese standard TCVN 5299-1995, potential levels of soil erosion in Lai Giang river basin can be classified in Table 3.

Table 3 Statistics of potential soil erosion in potential area of the Lai Giang river basin

No.	Level	Potential erosion (tons/ha/year)	Area (ha)	Percentage %
1	I	0 - <50	31,692.8	23.0
2	II	50 - 100	19,053.3	13.8
3	III	100 - 200	20,605.4	14.9
4	IV	200 - 400	16,911.2	12.2
5	V	400 - 800	15,596.1	11.3
6	VI	800 - 1600	12,869.5	9.3
7	VII	1,600 – 3,200	11,835.5	8.6
8	VIII	>3,200	9,525.2	6.9
		Total	**1,380,89**	**100%**

The results of Table 3 show that the whole basin has a level of erosion potential, level I accounting for 23.0%, and most of the remaining levels account for 6-15 %. Erosion I and II mainly occur in plains, low hills, and valleys with slopes < 8º in the Hoai Nhon district and some communes in lowland Hoai An and An Lao. Levels VI, VII, and VII occur a lot on slopes of 15º or more, high hilly terrain (150 - 300 m) and mountains > 300 m, and high rainfall upstream of An Lao and Kim Son rivers (figure 6).

Figure 6 Potential soil erosion.

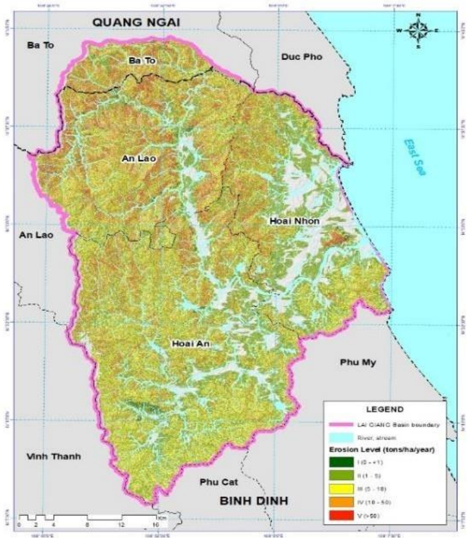

Figure 7 Soil erosion with vegetation cover.

3.2. Soil erosion with vegetation cover

In this study, the erosion risk map (with vegetation cover) was considered as current erosion considering the influence of vegetation and farming practices. Therefore, the potential erosion map has been established by integrating the coefficient maps R, K, LS, C, and P. The formula for calculating the current amount of soil erosion carried out is:

r.mapcalc "Erosion" = Rfactor * LSfactor * Kfactor* Cfactor

According to Vietnamese standard TCVN 5291-1995 on soil erosion risk, the classification for current erosion models in the Lai Giang river basin is shown in Table 4.

Table 4 Current Soil Erosion in Lai Giang river basin.

No.	Level	Erosion (tons/ha/year)	Area (ha)	Percentage %
1	I	0-10	79,765.9	57.9
1a	I1	0- 0,5	29,912	21.7
1b	I2	> 0,5-1	26,589	19.3
1c	I3	> 1-5	3,323.9	2.5
1d	I4	> 5-10	19,941	14.4
2	II	> 10-50	37,487.1	27.1
3	II	>50- 200	15,473.9	11.2
4	IV	> 200	5,362.1	3.8
		Total	**138,089**	**100**

The results of Table 4 show that soil erosion of the Lai Giang River basin tends to change markedly compared to potential erosion. The extent of erosion has changed compared to the potential erosion map. The erosion rate below 50 tons/ha/year has increased significantly, and the erosion rate >50 tons/ha/year has decreased. Simultaneously, updating the classification according to Vietnamese standards (TCVN 5299:2009), actual soil erosion in the Lai Giang river basin is divided into five levels; the results are shown in Table 5.

Table 5 Current status of erosion in the Lai Giang river basin according to TCVN 5299:2009).

No.	Level	Erosion (tons/ha/year)	Area (ha)	Percentage %
1	I	0-1	56,501	40.9
2	II	1-5	3,324	2.4
3	III	5-10	19,941	14.4
4	IV	10-50	37,487	27.2
5	V	> 50	20,836	15.1
	Total		**138,089**	**100**

3.3. *Decentralization of watershed criticality*

Based on the statistical results in Tables 4 and 5 and the regulation on a division of watershed protection levels in the Forestry Manual of Vietnam (Sam 2006), critical level of the river basin Lai Giang is divided into four levels. Statistical results in Table 6 and Figure 8.

Table 6 The critical level of watershed of the Lai Giang river basin.

No.	Level	Amount of soil loss (tons/ha/year)	Area (ha)	Percentage %
1	None	0-1	56,501	40.9
2	Low	>1-10	23,265	16.8
3	Medium	>10-50	37,487	27.2
4	High	>50- 200	20,836	15.1
		Total	**138,089**	**100**

Statistical results in Table 6 are essential for determining the critical forest area for watershed protection and agricultural production activities in the Lai Giang River basin.

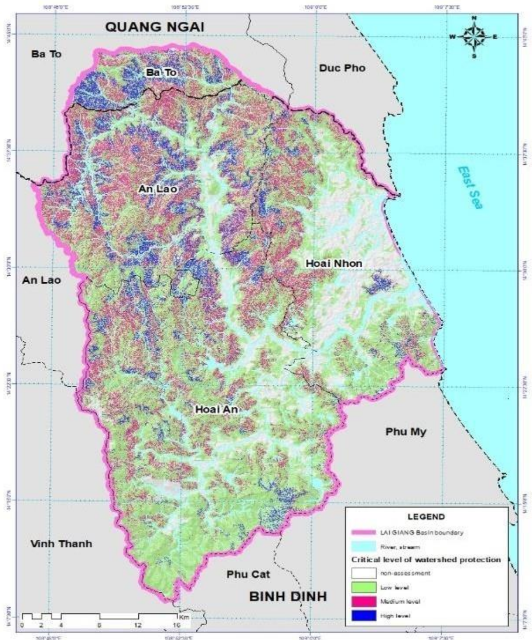

Figure 8 Level critical protection of river basins.

Figure 9 Demand for watershed protection and agricultural production.

4. Discussion

4.1. *Discussion on soil erosion assessment and watershed critical hierarchy in the Lai Giang River basin*

Human and natural causes drive soil erosion. It is a severe cause of land degradation and puts enormous pressure on a river basin's productivity and environmental stability. Understanding and estimating the extent of erosion is an important issue to identify critical levels and propose preventive measures, especially watershed protection forests. There have been many models to assess soil erosion at different spatial scales. However, RUSLE is an effective method, and it is accepted worldwide because of its reliability in calculating loss studies land. This model is enormously influential in estimating soil erosion in areas with limited data, such as the Lai Giang River basin in the South Central Coast, Vietnam (Huyen 2015). Lai Giang River basin is prone to soil erosion due to the high average annual rainfall and steep terrain. Quantitative results of potential erosion in the Lai Giang river basin from the main parameters of soil loss estimates in the RUSLE model (R, K, LS) confirmed the vulnerability to soil erosion of the river basin. Lai Giang area is very high (the amount of land lost from > 50 tons accounts for 70% of the area) and is concentrated mainly in the watershed areas. Severe and severe erosion is about 15% of the basin area and is mainly related to the slope coefficient-slope length and high rainfall. The results of potential erosion are an essential scientific basis for determining the critical capacity of the watershed of the river basin when there is no cover.

At the same time, vegetation cover factors (C) and land use control practices are influential in erosion prevention. The current erosion study results in the Lai Giang River basin confirm this. After adding vegetative cover, the amount of soil loss shifted towards a sharp decrease. In most places with a rich forest cover, with extensive coverage, the risk of soil erosion is significantly reduced (Figure 7). This indicates a very high role of vegetation in soil erosion prevention. Therefore, applying GIS combined with remote sensing, the RUSLE model, shows that it is reliable compared with previous studies. Quantitative results of land loss in the Lai Giang River basin are effective for critical decentralization (with five levels identified). It is the scientific basis for determining which land areas should be prioritized in watershed protection for appropriate land and water protection measures (Ermias 2009). A watershed priority approach based on land loss rate and watershed vulnerability is practical. The present study revealed that almost 50% of the area required various watershed protection measures for sustainable land use.

4.2. Demand for watershed protection and agricultural production in the Lai Giang River basin:

Based on the assessed critical level and orientation for regional agricultural development, the need for watershed protection and land for agricultural production is defined by the following four types of land use management: protection forest (including vital and critical protection forests), production forests, special-use forests, agricultural land, and another land. The requirements for each type of use are as follows:

- Protection forest land, defined for two types:

+ High-level critical protection of river basins: Requires high requirements for water and soil protection; in areas with very high vulnerability with high slopes, there is a risk of substantial and extreme soil erosion and the possibility of big flash floods

+ Medium critical protection of river basins: Where there is the slope, medium weak music level, and high requirement for land use and protection.

- *Special-use forest land:* Including national parks, nature reserves, biosphere reserves, landscape, cultural, and ecological conservation areas. This type of land is usually planned stably in both area and distribution according to the decision of the land management agencies.

- *Production forest land and agricultural land* are determined for the following types of use:

+ Production forestry: Land for production forest is distributed in places with relatively steep terrain in mountainous areas, often with slopes from 15^0-25^0 and even >25^0, with potential for erosion and critical level on average. The primary purpose is to plant production forests and to be able to trade in timber and other forest products and play the role of environmental protection.

+ Forestry - agroforestry: distributed in the high hills and midlands. Forest trees here are intercropped or banded with short- and long-term crops, fruit trees.

+ Agro – forestry: Requirement for agroforestry land with slope and terrain elevation lower than agroforestry land. Usually distributed on low hills - the transition between lowland plains and midland and mountainous areas, with medium vulnerability. The primary purpose is agricultural production (growing food crops, industrial crops, and fruit trees). The intercropping of perennial woody plants is mainly for agricultural protection. Agroforestry is also considered a land-use method with economic, environmental, and socio-cultural efficiency in community forestry development and rural economic development in mountainous areas.

+ Upland agriculture: Distributed in low-lying areas, valleys, and flat terrain in hills and mountains, with low or no critical level.

+ Lowland agriculture: Land for growing rice, crops, industrial crops, and fruit trees in the plains has low or low vital levels.

Research results identify watershed protection needs and agricultural production of the Lai Giang River basin with the area determined in Table 7 and Figure 9.

Table 7 Area demand for land protection and agricultural production.

No.	Main land use type	Area (hectares)	Percentage (%)
1	Protection forest land	58,000	34.6
3	Production forestry	32,198.3	19.1
4	+ Forestry – agroforestry	12,004.2	7.1
5	+ Agro – forestry	5,983.7	3.6
6	+ Upland agriculture	12,173	7.2
7	+ Lowland agriculture	15,970.7	9.5

Accordingly, the area demand for protection forests in the study area is 58,000 hectares, accounting for 34.6% of the assessed natural area. This indicates the need to establish vegetative cover to reduce soil erosion.

5. Conclusions

The application of QGIS combined with remote sensing is an effective research method in soil erosion prediction for determining the need for land protection in areas with mountainous and rugged terrain conditions to install monitoring and measurement stations like in Vietnam and other developing countries. This study applied the RUSLE erosion modeling method to calculate the amount of soil loss by integrating meteorological data (precipitation), geomorphological conditions (slope-side length), and soil properties. Using Landsat 8 satellite imagery to interpolate the C coefficient and the cultivation index P applied to Vietnam.

The study also built a map of potential erosion, current erosion, and a hierarchical map of critical levels in the Lai Giang River basin, clearly analyzing the spatial distribution and determining the need to ensure the area of forest protection (very critical and critical) and the ability to use the land for agro-forestry development in the basin (high and medium critical accounts for a relatively large area (about 42%), mainly in areas with steep slopes at the headwaters of the An Lao and Kim Son rivers in the Lai Giang basin). However, this study was limited in validating the results with field data, where field measurements of soil erosion require well-equipped technology, and labor-intensive support is still limited in developing countries like Vietnam.

In the future, with further studies, we will vigorously develop a soil erosion research model for determining the soil protection requirements in the watershed by combining the RUSLE equation with the integration with the measurement system. Field measurements and remote sensing images with the desire to be more accurate and more comprehensive for river basins in Vietnam. At the same time, climate change scenarios will be combined to forecast the risk of soil erosion in the future to have appropriate solutions to respond to and protect the soil for the study territory.

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Ethical considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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