ASSESSING THE ECOSYSTEM VULNERABILITY AND ITS IMPLICATIONS ON BIODIVERSITY CONSERVATION IN PU MAT NATIONAL PARK, NGHEAN PROVINCE, VIETNAM

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Abstract. The purpose of this paper is to assess ecosystem vulnerability using three ecological criteria divided into 11 indexes. These criteria are ecological pattern, ecological function, and ecological pressure, all of which played an important role in preserving the primary function for biodiversity in Pu Mat National Park, Nghe An province, Vietnam. Integrating the fuzzy analytic hierarchy process (FAHP) and geographical information systems (GIS) is the main method used in an attempt to obtain insights into the status and assess ecosystem vulnerability on the effectiveness of related policies. The outcomes of this step will be aggregated and compared to habitat vulnerability evaluated ecosystem changes from 2010 to 2020, and ecosystem diversity indicators calculated using a combination of FAHP, GIS, and Fragtats 4.2. Our method adds another option for a more comprehensive assessment of ecosystem vulnerability, and it should be tested at larger spatial scales to provide references for regional or ecosystem conservation work as well as biodiversity conservation generally.
Keywords: *risk, ecosystem, FuzzyAHP, GIS, Fragtats, Pu Mat (Vietnam)*

Introduction

Vulnerability involves a range of notions and elements, such as sensitivity to injury and a lack of ability to cope and adapt (IPCC, 2014). An index is used as a measure for describing vulnerability, and it is frequently used to combine and aggregate many single indicators or sub-indices in different ways (Füssel, 2007; Garschagen and Romero-Lankao, 2015; Shinny Thakur, 2021).

Ecosystem vulnerability is caused by ecological processes and the development of economic and social effects on natural and man-made ecosystems. In recent years, eco-environmental vulnerability trend evaluation has advanced significantly, and it may provide useful baseline information for environmental restoration (Wang et al., 2008). Many approaches, such as the comprehensive assessment method (Li et al., 2005), the indices weight method (IWM) (Li et al., 2001), and the analytical hierarchy process (AHP), have been created by researchers for such studies (Li et al., 2005; Wang et al., 2008).

Understanding land use patterns and soil erosion patterns, as well as formulating measures for resource management, especially ecosystem management, necessitates studies on eco-environmental vulnerability. Using a spatial principal component analysis

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(SPCA) model, an environmental numerical model was created. Twelve components make up the model, including land use, soil erosion, topography, climate, and vegetation. The main causes of the eco-environmental changes over ten years in this case were identified as population growth, vegetation degradation, and governmental policies for eco-environmental protection (Wang et al., 2008).

Not only temperature and precipitation affect ecosystems but by the combined effects of the two, thus their method may not fully characterize the degree of exposure of ecosystems to climate change. Therefore, the exposure to future climate was characterized using a moisture index (MI) that integrates the effects of temperature and precipitation (Xu et al., 2020).

Pu Mat National Park has a great diversity of vegetation spread over several height belts (Leonid, 2007). With 2,494 different plant species found in Vietnam's flora system, Pu Mat National Park has the most of all the national parks in the nation's national park system. She is an important component in the Vietnamese flora system's plant species composition. Nearly all of Vietnam's plant phylums, or roughly 23.7% of the country's total species, were found at Pu Mat National Park (Nghe An Provincial people committee, 2007).

Currently, AHP and GIS are common methods for assessing the quality of the eco-environment (Wang et al., 1994; Kurttila et al., 2000; Solnes, 2003; He et al., 2004). The analytical hierarchy process (AHP), developed in the 1970s by Satty (1977), is a systematic engineering method that synthesizes the integration of qualitative and quantitative data (Li et al., 2007). Given that the AHP approach can quantify qualitative analyses from subjective judgments, it has been used in the quantitative investigation of many different fields, including nature, society, and the economy. Despite having a nearly 70-year history, only in the last 20 years has GIS been utilized for managing natural resources and performing eco-environment assessments (Li et al., 2007). It can also consider time as a dimension while researching the dynamic changes in the quality of the natural ecosystem.

Materials and methodology

Study area

Pu Mat National Park is part of the Western Nghean Biosphere Reserve and is located in three districts of Anh Son, Con Cuong Tuong Duong in Nghean province, approximately 130 kilometres from Vinh City. Pu Mat National Park has high biodiversity, with 2494 plant species belonging to 160 families and nearly 1,000 animal species. Rare and wild genetic resources are protected at Pu Mat National Park.

The park, formerly known as the Pu Mat National Reserve, covers 194.804 ha in total, divided into 94.804 ha of core zone and 100,000 ha of the buffer zone (See *Figure 1*).

Material

The following were the input data used in assessing vulnerability and data related to it (habitat vulnerability, ecosystem changes, and ecology diversity indicators): 1) Digital land use map for the years 2010 and 2020 provided by the Resource and Environment Department, Nghean Province, Vietnam; 2) A forest status map at a scale of 1:50.000 for three districts in the research area was provided by The Science Department, Pu Mat National Park. 3) Downloaded Digital Elevation Model (DEM) of the research area from

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the USGS website. 4) Year Book in 2021 in three districts of the research area provided by the Statistics Department in three districts in the research area. 5) Water resources and Soil resources are provided by The Agricultural Department, Nghean province 6) Downloaded the Road system from https://export.hotosm.org/ (like the road system in Google Earth); 7) Other input data are interpolated by analysis tools in ArcGIS 10.5 with weight calculation.

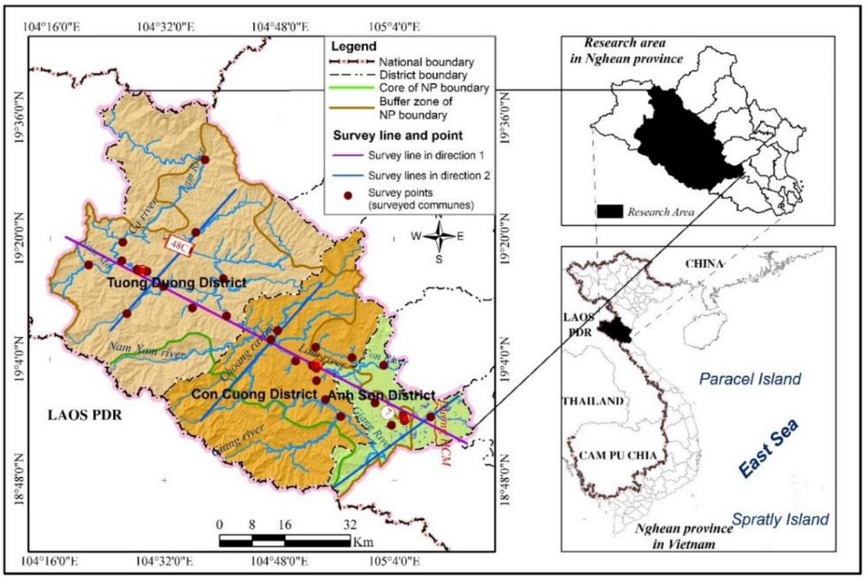

***Figure 1.** Map of the Research area*

Survey and investigation: The authors undertook two survey trips, fieldwork, and interviews to assess socioeconomic and risk factors for the environment in 2022 with 300 attendees in the following approaches: First direction: Travels along the Lam River and Highway 7 from northwest to southeast. The majority of the communes in the Pu Mat National Park's core and buffer zone are traversed in Direction 2 from Northwest to Northeast in each district within the research area. Two investigations and surveys were carried out that are consistent with the survey line and survey point illustrated in *Figure 1*.

Methodology

Flowchart of Methodology is showed on *Figure 2*.

a. Vulnerability of ecosystems

Below the equator, the vulnerability of ecosystems is assessed using 11 factors as variables:

$$V_j = \sum_{i=1}^{n} W_i \, x \, r_{ij} \qquad \text{(Eq.1)}$$

where Vj is the vulnerability at level j, W_i represents the weight of index i, r_{ij} is the degree of membership of index I to level j, and n is the number of indices.

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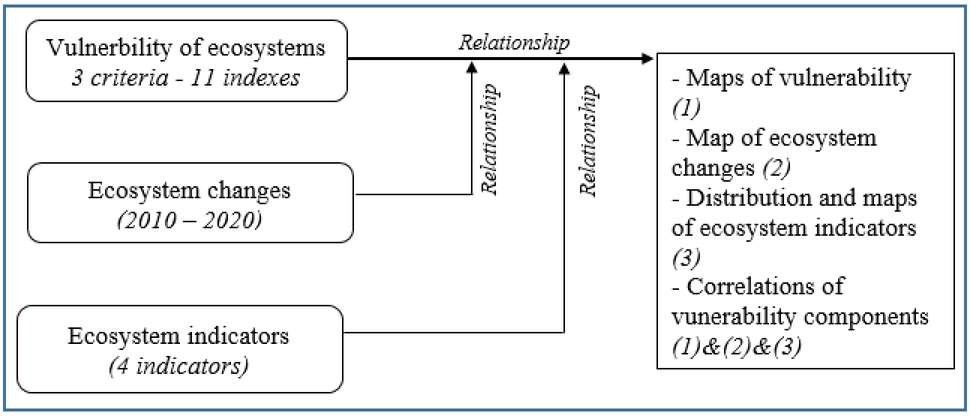

Figure 2. *Flowchart of Methodology*

The formula for calculating r_{ij} is as follows:

$$when\ j = 1, \quad r_{ij} = \{1, I_{ki} > P_{i1} \frac{F_{ki} - P_{i2}}{P_{i1-P_{i2}}}, P_{i2}\ 0,\ I_{ki} < P_{i2} \le I_{ki} \le P_{i1} \qquad \text{(Eq.2a)}$$

$$When\ =2,3,\ldots,\ m\text{-}1, \quad r_{ij} = \{\frac{P_{ij-1} - I_{ki}}{P_{ij-1} - P_{ij}}, P_{ki} \le P_{ki} \le P_{i1-1} \frac{F_{ki} - P_{ij+1}}{P_{ki} - P_{ij+1}}, P_{ij+1} \le I_{ki} \le P_{ij};\ 0,\ I_{ki} > P_{ij-1}, I_{ki} \le P_{ij+1} \qquad \text{(Eq.2b)}$$

$$when\ j = m, \quad r_{ij} = \{0, I_{ki} > P_{im-1} \frac{P_{im-1} - I_{ki}}{P_{im-1} - P_{im}}, P_{im}\ 0,\ F_{ki} < P_{im} \le I_{ki} \le P_{im-1} \qquad \text{(Eq.2c)}$$

where rij represents degree of membership of index i to level j, I_{ki} is the practical attribute value of index i, P_{ij} (i =1, 2,...,n, j = 1, 2,...,m) is standard attribute value of positive index i at level m.

The degree of membership of negative indices was calculated in the same manner. In this study, I_1 is positive index, while $I_2 – I_{11}$ are negative.

Assessment indices and weight assignment

The assessment index system in this study was divided into 11 factors grouped into three levels, based on earlier studies (Li et al., 2006, 2009; Li and Huang, 2009; Su et al., 2010), as well as incorporating expert perspectives and practical limits of the case study.

All of these criteria were chosen based on the following principles: integrity, geographic accuracy, dynamic response, and data accessibility (Zhao et al., 2006; Gu et al., 2015). A total of thirteen factors were chosen and indicated by $I1 - I11$ in order: Vegetation coverage, Elevation, Slope gradient, Degree of fragmentation, Water conservation index, Soil conservation index, Population density, Road density, Proportion of ≥ 20° cultivated land, Proportion of < 20° cultivated land, Proportion of built up.

The assessment standards in this study were classified into five levels ranging from 1 to 5, which corresponded to vulnerability levels of slight, light, medium, heavy, and

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extreme, respectively (*Table 1*). For a more comprehensive evaluation, all variables should first be standardized into a uniform rating scale.

Table 1. *Standardized rates of assessment indicators*

Criterion	Indicator		1	2	3	4	5
Ecological pattern	Vegetation coverage/%	I1	>80	60 – 80	40 – 60	20 – 40	< 20
	Elevation/m	I2	<500	500 – 700	700 – 1,200	1,200 – 1,700	> 1,700
	Slope gradient/(°)	I3	< 8	8 – 15	15 – 25	25 – 35	> 35
	Degree of fragmentation (PLAND)	I4	< 1.0	1.0 - 2.5	2.5 – 4.0	4.0 – 5.5	> 5.5
Ecological function	Water conservation index (Standardized)	I5	1 – 1.5	1.5 – 2.0	2.0 – 3.5	2.5 – 3.0	3.0 – 3.5
	Soil conservation index + Erosion /ton/ha/year	I6	< 2	2 - 5	5 - 10	10 - 15	> 15
Ecological pressure	Population density /(person.km^{-2})	I7	< 20	20 – 50	50 – 200	200 – 500	> 500
	Road density/(km/km^{-2})	I8	< 0.2	0.2 – 0.4	0.4 – 0.6	0.6 – 0.8	> 0.8
	Proportion of ≥ 20° cultivated land/%	I9	< 2	2 - 5	5 - 10	10 - 15	> 15
	Proportion of < 20° cultivated land/%	I10	< 2	2 - 4	4 - 6	6 - 8	> 8
	Proportion of built up/%	I11	< 0.5	0.5– 1.5	1.5 – 3.0	3.0 – 4.5	> 4.5

Vegetation coverage is determined by the NDVI derived from Landsat 8 images (bands 4 and 5). This landsats 8 (30 m x 30 m) is taken in 2022 which was downloaded from USGS systems. The following equation is used to estimate NDVI:

$$NDVI = \frac{NIR - RED}{NIR + RED} = \frac{B5 - B4}{B5 + B4} \quad \text{(Eq.3)}$$

in which, B4: band 4 of Landsat 8; B5: band 5 of Landsat 8 in the research area. The NDVI results are reclassified into four ranges (> 0; 0 - 0.15, 0.15 - 0.3, > 0.3) that correlate to four LULC types (Water Body, Land, Shrubs, and Healthy Vegetation) (*Table 2*).

Tabe 2. *NDVI ranges for LULC types*

NDVI ranges	LULC types
< 0	Water Body,
0 – 0.15	Land,
0.15 - 0.3	Shrubs
> 0.3	Healthy Vegetation

The NDVI indicator defines "healthy vegetation" criteria as ranging within the range of > 0.3.

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Elevation and Slope are interpolated from the Digital Elevation Modem DEM data of the research area which was downloaded from USGS systems.

Degree of fragmentation (PLAND) describes in percentage terms the composition of a given ecosystem type.

$$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100) \quad \text{(Eq.4)}$$

(Unit: Percent)
Range: $0 < PLAND \leq 100$
P_i = proportion of the ecosystem type occupied by patch type (class) i.
a_{ij} = area (m^2) of patch ij.
A = total ecosystem area (m^2).

The water conservation index (WCI) is a widely used and significant indicator of ecosystem health that measures the ability to store precipitation and modify runoff. It is calculated as:

$$WCI = \sum_{i=1}^{n} H_i w_i \quad \text{(Eq.5)}$$

where, H_i is the value of component i, w_i is the weight of component i, i = 1,2,3. The components, weights and standardized measurements are shown in *Table 3*.

Table 3. *Standardized rates of components of WCI*

Components	**Weights**	**Rating**				
		Slight	**Light**	**Medium**	**Heavy**	**Extreme**
		1	2	3	4	5
Vegetation coverage/%	0.4	80–100	60–80	40–60	20–40	0–20
Vegetation types	0.4	Water Body	Forest, thicket	Grassland	Cultivated land	Others
Impervious area	0.2	3		Bare land	Rock mountain	Built-up

The soil conservation index is displayed through soil erosion intensity which indicates the soil conservation ability of the ecosystem. Soil erosion modulus was calculated by using the revised universal soil loss equation (RUSLE) (Jiang et al., 2012).

$$A = \underline{R} * \underline{K} * \underline{LS} * \underline{C} * \underline{P} \quad \text{(Eq.6)}$$

where
A = estimated average soil loss in tons per acre per year
R = rainfall-runoff erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover-management factor
P = support practice factor.

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The corresponding intensities in terms of soil erosion modulus are described in *Table 4*.

Table 4. *Soil erosion modulus and intensity relationships*

Soil erosion intensity	Potential	Light	Moderate	Heavy	Extreme
Soil erosion modulus/(t/ha.yr)	< 2	2-5	5-10	10-15	> 15

Table 5 shows the derived weights of indices. In this paper, the FAHP method was used in this study to determine the weights of indices. FAHP's detailed description can be found in Li et al. (2009); Su et al. (2010) and Gu et al. (2015).

Table 5. *The derived weights of indices*

Criterion	Weight 1	Indicator		Weight 2
Pattern of ecosystems	0.4706	Vegetation coverage/%	I1	0.0939
		Elevation/m	I2	0.0663
		Slope gradient/(°)	I3	0.0535
		Degree of fragmentation (PLAND)	I4	0.0716
Function of ecosystem	0.1852	Water conservation index (Standardized)	I5	0.0909
		Soil conservation index *+Erosion (ton/ha/year)*	I6	0.0943
Pressure of ecosystem	0.5294	Population density/(person.km–2)	I7	0.1252
		Road density/($km.km^{-2}$)	I8	0.0767
		Proportion of ≥ 20° cultivated land/%	I9	0.1032
		Proportion of < 20° cultivated land/%	I10	0.0867
		Proportion of built up/%	I11	0.1375

b. Ecosystem changes

Based on the distribution of ecosystems for the two time periods 2010 and 2020, ecosystem fluctuations are estimated. Forest status maps and forest inventory maps, as well as the current land use map for the relevant period, combine and generalize these two component maps. The tools in ArcGIS are used to generate the fluctuation matrix utilizing map overlay technology. Thus, in addition to the opportunity for change, it is also visible that the area and the changing trend of different types of ecosystems for one another between 2010 and 2020.

c. Methodology for ecosystem indicators

The Methodology for ecosystem indicators is showed on *Table 6*.

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Table 6. *Indicators go with their parameters and meaning*

Indicator		Parameters	Meaning
3. Percentage of Landscape (PLAND)	$\text{PLAND} = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$ *(Unit: Percent)* *Range: 0 < PLAND ≤ 100*	P_i = proportion of the landscape occupied by patch type (class) i. a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).	Percentage of Landscape (PLAND), describes in percentage terms the composition of a given landscape ecology
4. Shape (SHAPE)	$SHAPE = \frac{p_Y}{\min p_y}$ *(Unit: None)* *Range: SHAPE ≥ 1, without limit.*	p_{ij} = perimeter of patch ij in terms of number of cell surfaces. min p_{ij} = minimum perimeter of patch ij in terms of number of cell surfaces (see below).	Shape (SHAPE_AM) is a measure of the geometric complexity of the landscape elements of a given land cover categor
5. Landscape Shape Index (LSI)	$LSI = \frac{E}{\min E}$ *Unit: None* *Range: LSI ≥ 1, without limit.*	E = total length of edge in landscape in terms of number of cell surfaces; includes all landscape boundary and background edge segments. min E = minimum total length of edge in landscape in terms of number of cell surfaces.	LSI has a direct interpretation, in contrast to total edge, for example, that is only meaningful relative to the size of the landscape. LSI can also be interpreted as a measure of patch aggregation or disaggregation, similar to the class-level interpretation.
6. Aggregation index (AI)	$\text{AI} = \left[\frac{g_{ii}}{\max \rightarrow g_{ii}}\right](100)$ *Unit: Percent* *Range: 0 ≤ AI ≤ 100*	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the *single-count* method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type (class) i (see below) based on the *single-count* method.	Aggregation index (AI), as the previous one indicates the tendency of the types of coverage to aggregate

(Source: Fragstat metrics research at Umass)

Results and discussion

Components distribution of the vulnerability of the ecosystem

a. Elevation

The elevation of the research area, which ranges from 7 meters to 2122 meters above sea level, is 457 meters on average. The highest elevations were found in the western and northeastern parts of the study area, resulting in a range of typical mountains between 1200 and 2122 meters. The research area's western and northeastern regions also have lower elevation areas, including 830383. 90 hectares of mountains with 700–1200 meters count 16.14 percent the research area and 86141.37 hectares of hills with 500–700 meters (count 16.17 percent the research area). The majority of the area, or 63.36 percent of the entire research area, is located in the central section of the Con River, which consists of

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204316.20 hectares of hills with a height of 200–500 meters (which account for 39.60 percent of the study area) and 121857.43 hectares of plains with a height of 0 – 200 meters (count 23.67 percent of the research area). However, as a result of the investigation and the expert interaction, the elevation component in association with the vegetation cover in the study area's specific location creates the character of the national park's core region and buffer region. It was also used to determine the slope and aspect to assess the safety of site selection for the development of residential areas and agricultural areas (*Figure 3a*).

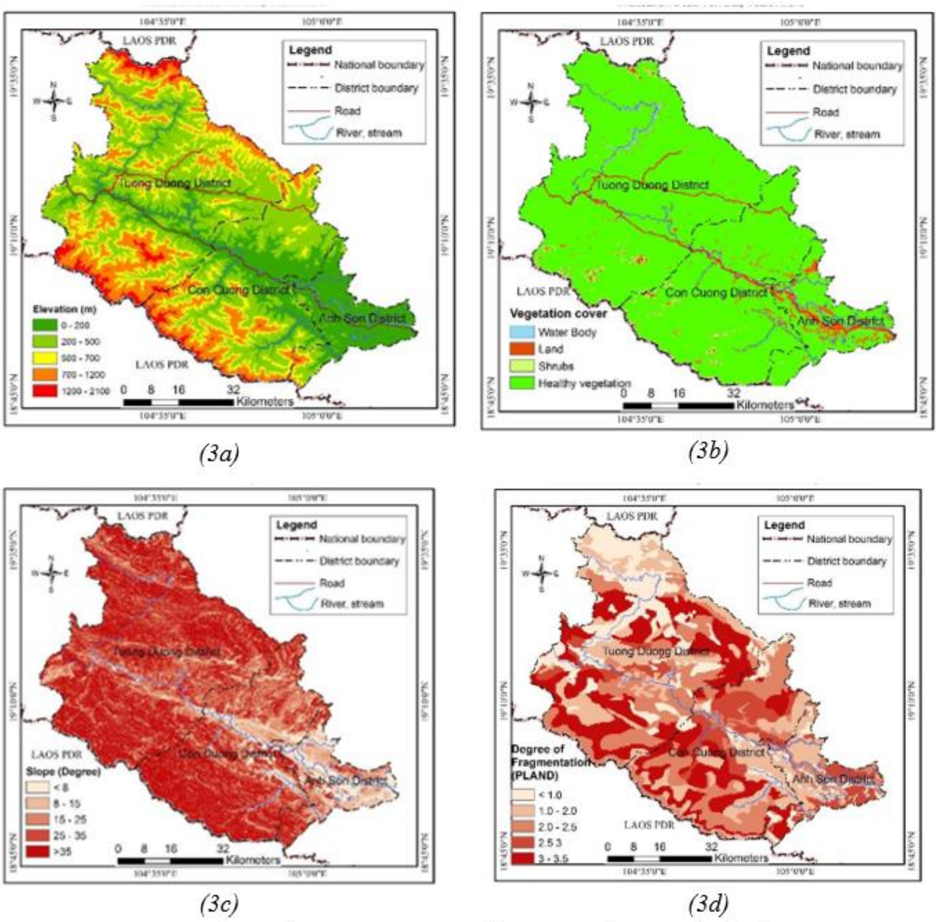

Figure 3. *Ecological component map of the research area - (3a): Elevation; (3b): Vegetation cover; (3c): Slope; (3d): Fragmentation (PLAND)*

b. Vegetation coverage

Vegetation coverage was calculated using Landsat 8 and NDVI, with bands 4 and 5 following the *Equation (3)*. The research area is divided into four classes based on NDVI results: healthy vegetation (79.14 percent), shrubs (19.18 percent), land (0.7 percent), and water body (0.98 percent). To determine vegetation coverage, these are paired with the distribution of elevation levels. According to the findings, the area has more than 75 percent, vegetation convergence and is located on a high mountain with a steep slope. The area, on the other hand, has a 65-75 percent vegetation cover and is located in the remaining area (*Figure 3b*).

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c. Slope

The slope angle in the research area varies from 0 to 71.4 degree with an average of 22.08 (std. 10.41). According to the slope map (*Figure 3c*), the bulk of the study area (62.64%) has a mild slope of more than 25 degrees, with the western and northeastern regions of the study area having slopes of 37.85% and 24.79%, respectively, and more than 35 degrees. There is 18.66 percent of the research area has a slope between 15 and 25 degrees. 11.95 percent of the land has a slope between 8 and 15 degrees, while 6.75 percent has a slope of less than 8 degrees.

d. PLAND

A relative metric that can be used to compare landscapes of different sizes is PLAND, as opposed to total landscape ecology area. PLAND is unaffected by the spatial distribution or configuration of habitat fragmentation. Per landscape unit, the PLAND in the research region varies, ranging from 0.01 to 6.4. This indicates that all of the linked landscape type's landscape units are sparse and modest (*Figure 3d*).

e. Water conservation index

As a consequence, WCI ranges from 1 to 5, which is divided into 5 classes of 1-1.5; 1. 5 - 2.5; 2.5-3.0; 3.0 - 3,5 and >3.5, using *Equation (5)* to determine for 3 components (Vegetation coverage, Vegetation type, and Impervious area) in *Table 3*. It demonstrates the biggest value of WCI, 5189 hectares, which is situated in the valley along the Ca River and accounts for just 1.01 percent of the research area. The class of 3,5 is then 31454.16 hectares (count 6.11 percent of the research area), and the class of 2,5–3 is then 40694.68 hectares (count 7.9- percent of the research area). These two classes are present in low-lying areas (low hills and valleys). 14.640 for the classes of 1.5 to 2.5 (*Figure 4a*).

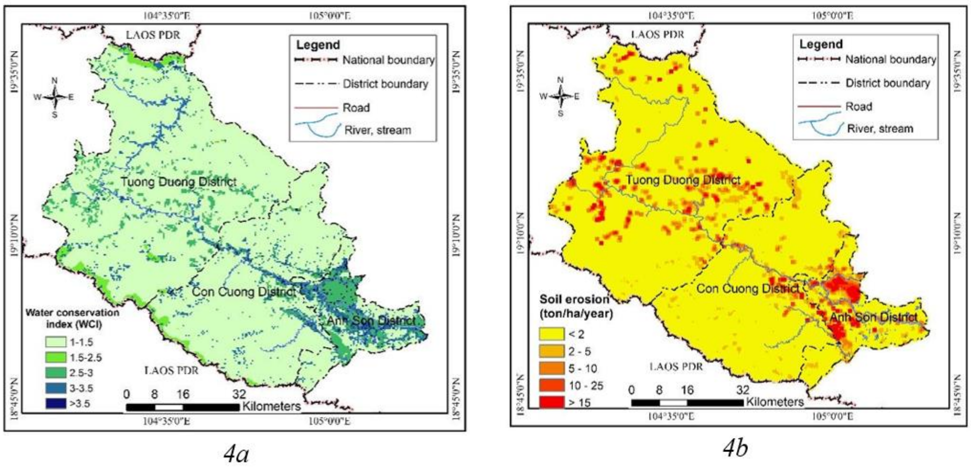

Figure 4. *The function of ecosystem map of the research area 4a: Water conservation index; 4b: Soil conservation index (Soil erosion)*

f. Soil conservation index

The soil conservation index is reflected by the five classes of soil erosion (2 - 5, 5 - 10, 10 - 15, and > 15 ton/ha/year) where 3.88 percent of the research area is for class 10 -15, and it is situated in hills along the Ca River. There is also 4.14 percent of research areas

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for classes 5 – 10 and 7.25 percent for classes 2 -5, all of which are dispersed throughout the valley and hills along the Ca River (*Figure 4b*).

g. Population density

Population density can be used as a direct proxy for population size, which is of course what many ecologists are fascinated by. This is especially true in applied ecology. The research area's highest population density (>500 people/km^2) is found in the Pu Mat NP buffer zone, which is in the Anh Son and Con Cuong districts (*Figure 5a*).

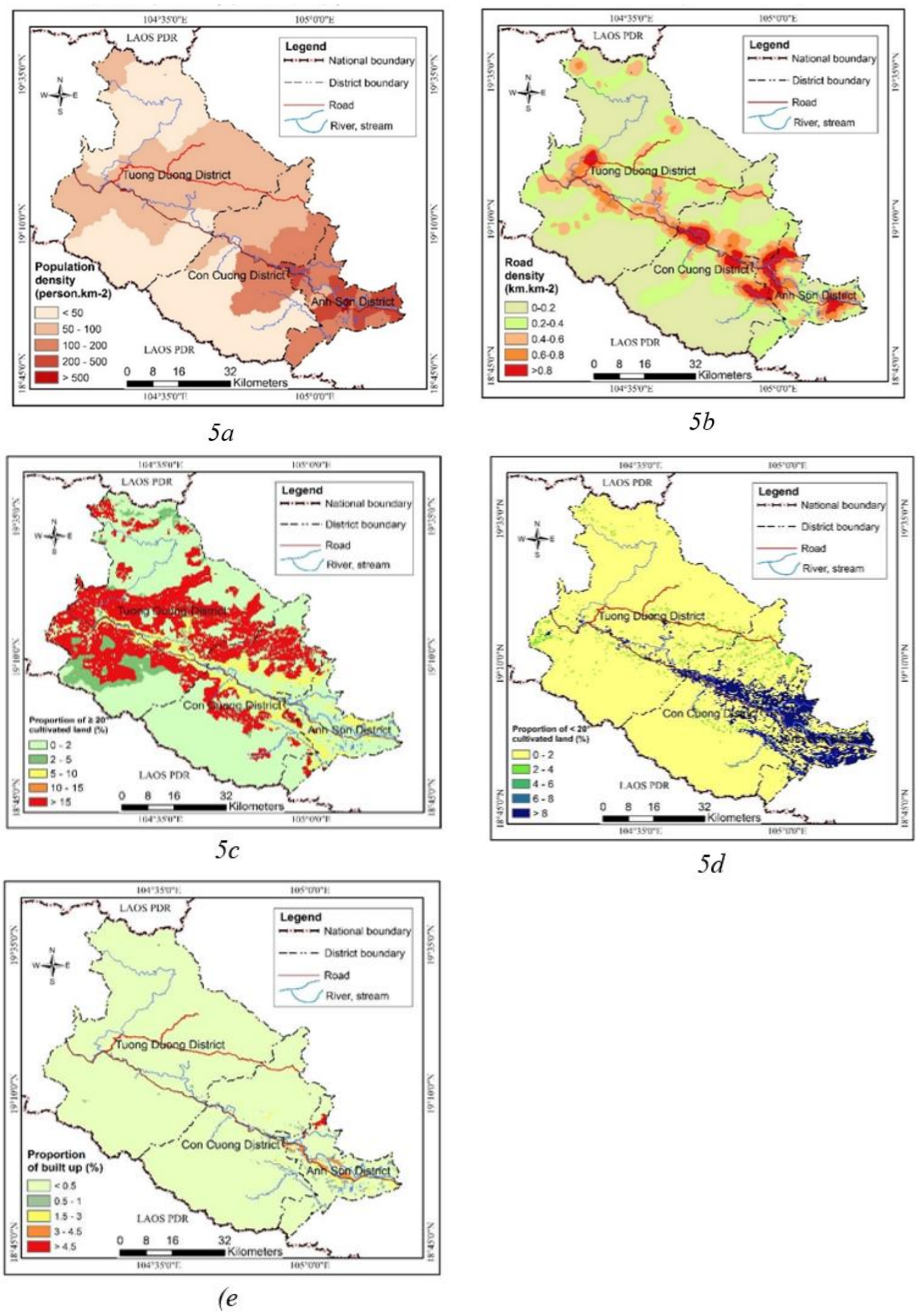

Figure 5. *The pressure of ecosystem map of the research area* ***-*** *5a: Population density; 5b: Road density; 5c: Proportion of ≥ 20° cultivated land; 5d: Proportion of < 20° cultivated land (PLAND); 5e: Proportion of built up*

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Road density

In Pu Mat NP areas, we investigated the connection between road density and the distribution of different ecological types. Understanding these consequences enables transportation policy and planning to choose environmentally preferable options. The road network has both positive and negative ecological effects. We determined the main road density for the study area, which is depicted in *Figure 4a* and looked up the association between it and the distribution of the various habitat types. The highest road density is found in the valley and plain along the Ca River, where it is approximately 0.8 km/km^2. Otherwise, the road density decreases gradually to between 0.4 and 0.6 in hills and 0.2 km/km^2 in mountainous areas (*Figure 5b*).

Proportion of ≥ 20° cultivated land

A significant percentage of sloping land has been converted to farming because there isn't much flat land and there isn't much agricultural land in the research area. It began to form on the hills around the Ca River. These locations include a forest of production and an ecosystem of industrial plants (*Figure 5c*).

Proportion of < 20° cultivated land

In mountainous places such as the research area, cultivated lands which slope < 20° are playing an important role which ensures food security and improving the living standard for local people (*Figure 5d*).

Proportion of built up

In the Con Cuong and Anh Son districts, where there are valleys or low hills and a lot of flat land, the proportion of built-up areas is concentrated along National Highway 7 and Highway 48C (*Figure 5e*).

Vulnerability to ecosystem

Based on analysing, and accessing the conditions which are effective on vulnerability for ecosystems divided into 11 indicators following the different weights, the map of vulnerability for ecosystems in the research is built with five levels of vulnerability: Very low – Low – Average – High – Very high.

The parameters that describe the correlation between the vulnerability levels and ecosystem distribution in each ecosystem are calculated by combining the map of vulnerability for ecosystems and the map of ecosystem distribution in the research area.

The mean value of vulnerability for ecosystems in the research area ranges from 1.70 to 3.76. Which, the largest' value is located in ecosystems 4; 3 and 2 at the value of more than 3. Then the smaller value is located in ecosystems 5 and 1; ecosystems 6; 7 and 8 with values of 2.76 to 1.70 (*Figure 6, Table 7*).

Ecosystem changes

The ecosystem of Pu Mat National Park is diversified in both type and distribution, with seven different ecosystems including an evergreen broadleaf forest, mixed bamboo and wood ecosystem, planted forest ecosystem, glade ecosystem, shrubs, agricultural ecosystem, and aquatic ecosystem (*Figure 7, Table 8*).

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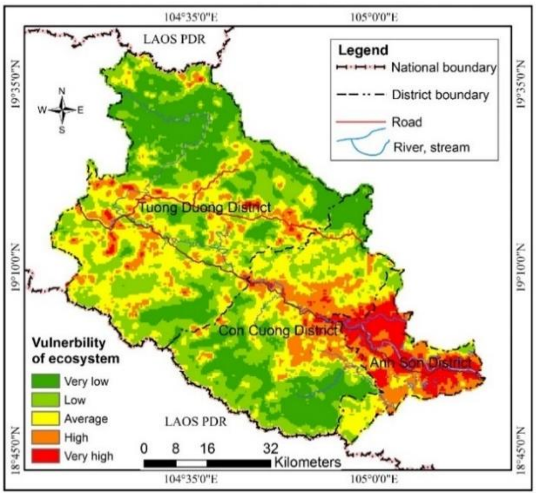

***Figure 6.** Map of vulnerability for ecosystems in Pu Mat National Park, Nghean, Vietnam*

***Table 7.** The values of ecosystem vulnerability in the research area*

ECOSYSTEM	AREA (hectares)	STD	VARIETY	MAJORITY	MINORITY	MEAN
Ecosystem 1	280676.39	1.19	5	2	5	2.89
Ecosystem 2	126186.78	1.16	5	4	1	3.64
Ecosystem 3	19871.18	1.15	5	5	1	3.76
Ecosystem 4	18607.23	1.00	5	4	1	3.68
Ecosystem 5	32782.64	0.98	5	3	1	2.97
Ecosystem 6	4575.81	0.98	5	2	5	2.76
Ecosystem 7	26702.90	1.29	5	2	5	2.62
Ecosystem 8	5391.78	1.03	4	1	3	1.70

Note: The vulnerability levels are 1: Very low, 2: Low, 3: Average, 4: High, and 5: Very high. - Ecosystem names for the following include: (1) humid tropical evergreen broadleaf closed forest; (2) tropical secondary mixed timber and bamboo forest; (3) bamboo or mixed bamboo; (4) planted forest; (5) secondary scrub (with timber trees); (6) secondary grassland; (7) agricultural plant; and (8) green tree in the residential area

***Table 8.** The change matrix of ecosystems in the period of 2010-2020*

2010 \ 2020	1	2	3	4	5	6	7	Total
1	212739.61	2174.66	2559.74	31050.22	603.16	5605.82	601.81	***255335.02***
2	9219.14	5218.91	1178.04	1081.16	9.65	252.12	0.87	***16959.89***
3	3170.08	706.68	19434.12	4647.46	18.91	2764.24	66.44	***30807.93***
4	482.85	84.63	112.22	3119.39	11.56	1421.07	276.25	***5507.97***
5	27842.32	419.53	4558.02	95829.32	3085.27	36340.13	2561.58	***170636.17***
6	2376.90	65.74	641.49	9478.20	431.83	19008.88	321.25	***32324.29***
7	7.41	0.23	1.76	28.54	0.19	66.46	2824.18	***2928.77***
Total	***255838.31***	***8670.38***	***28485.39***	***145234.29***	***4160.57***	***65458.72***	***6652.38***	**514500.04**

Note: 1) The evergreen broadleaf forest environment, 2) The mixed bamboo and wood ecosystem, 3) The bamboo ecosystem, 4) The planted forest ecosystem, 5) The shrub ecosystem, 6) The agricultural ecosystem, and 7) The aquatic ecosystem

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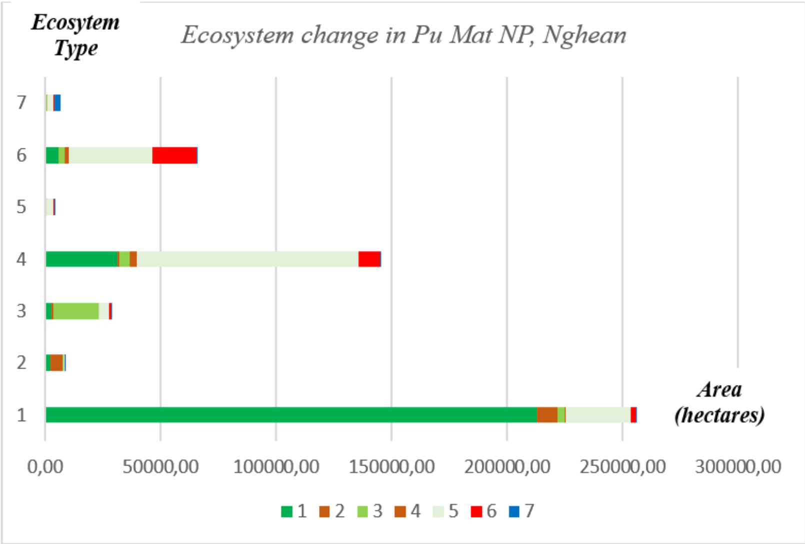

Figure 7. *Ecosystem change in Pu Mat NP, Nghean*

The area of the evergreen broadleaf forest ecosystem has not changed greatly, with 83.32% of it (or 212739.61 ha) remaining intact. 12.16 percent, or 2559.4 ha, transformed a mixed bamboo and woody environment. Additionally, the evergreen broadleaf forest ecosystem saw slight changes in ecosystems 2, 5, 6, and 7 between 2010 and 2020, despite a rate of only 1%.

The mixed bamboo and wood ecosystem has undergone a significant amount of change between 2010 and 2020, with only 30.77% (or 5218.91 ha) of its original area remaining. Up to 54.36% of the area, or 9219,141 ha, was converted into an ecosystem of evergreen broadleaf forests. The mixed bamboo and wood ecosystem was also transformed into ecosystems 3 and 4, with a rate of around 6.5%, and into ecosystems 5, 6, and 7, with a rate of just about 1.5%.

The bamboo ecosystem had significant fluctuations from 2010 to 2020, with only 63.08% of its original area (or 19434.12 hectares) remaining. Up to 15.09% of the land area (4647.46 ha) was converted to a planted forest ecosystem. The evergreen broadleaf forest ecosystem (10.29%, or 3170.08 ha), followed by the agroecosystem (8.97%, or 2764.24 ha), is the next significant area of change. Additionally, the mixed bamboo and wood environment is transformed into ecosystems 2 (2.29%, or 706.68 hectares), and ecosystems 5 and 7 with a minor amount of less than 1%.

At vertical axis of *Fig. 7*, 1-7 indicates is the names of ecosystem which showed in in lines 295-297. 1) The evergreen broadleaf forest environment, 2) The mixed bamboo and wood ecosystem, 3) The bamboo ecosystem, 4) The planted forest ecosystem, 5) The shrub ecosystem, 6) The agricultural ecosystem, and 7) The aquatic ecosystem.

The ecosystem of grasses and shrubs had significant fluctuations between 2010 and 2020 as a result of the conversion of land to plantations (56.16%, or 95829.32 ha), an evergreen broadleaf forest ecosystem (with 16.32%, or 27842.32 ha), and an agro-ecosystem (with 21.30 ha, corresponding to 2561.58 ha). Only 1.50 ha of this sort of ecosystem's area remained constant throughout the computation period. The difference between one ecosystem and the one above is too large since in the first half of 2010, space for this type of ecosystem was generated as a result of logging, temporary deforestation, or new planting, so is still considered to be a shrubland. In light of this, a significant

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change will occur by 2020 when the current ecosystem will take the place of the temporary one.

The agro-ecosystem experienced significant changes between 2010 and 2020, with just 58.81% of the total area remaining in the same state at the end of that time (corresponding to 19008.88 ha). With 29.32% of the area covered by planted forest, this ecosystem underwent significant alteration (corresponding to 9478.20 ha). The calculations' findings indicate that an evergreen broad-leaved forest ecosystem now makes up 7.35 percent of the area of agro-ecosystems. Due to the evidence, this change is the opposite of ecological succession. The categorization method and generalization rate of these objects vary depending on the input data (forest status, land use status).

Distribution of ecosystem indicators

a. Shape (SHAPE)

Shape is all *a*bout the geometry of patches, whether they are even and irregular or simple and compact (McGarigal et al., 2002). Using a fundamental shape index, a patch's perimeter to area ratio is determined. In this instance, a higher SHAPE index indicates increasingly erratic patches that less closely resemble circles or squares. The mean fractal dimension of a single ecosystem unit or the fractal dimension of the entire ecosystem is determined via a more complex shape index (*Figures 8 and 12*).

b. Landscape Shape Index (LSI)

LSI can be viewed as a measure of patch aggregation or disaggregation, much like the class-level interpretation. In particular, the patches get progressively disaggregated as LSI increases. Ecosystem units in the research region have LSI values that range from 1.3 to 9.2, which is a wide range. However, the single square (or almost square) area that makes up the ecosystem is evident from the fact that the median LSI value is just 3.3, or practically 1 (*Figures 9 and 13*).

c. Percentage of Landscape

(PLAND) In PLAND is a relative metric that can be used to contrast landscapes of differing sizes. There is no impact on PLAND from the spatial pattern or structure of habitat fragmentation. Each ecosystem unit in the research area has a different PLAND, ranging from 0.01 to 6.4. This means that all of the linked ecosystem type's ecosystem units are small and rare (*Figures 10 and 14*).

d. Aggregation Index (AI)

Using an Aggregation Index (AI), ecological spatial patterns are measured. An unaffected by landscape composition Aggregation Index (AI) for a certain class. According to AI, pixels in a class with the largest amount of aggregation (AI = 100) share the most conceivable edges. The class with the lowest amount of aggregation (AI = 0) has no pixels that share any edges (totally disaggregated). The ecosystem unit has been maximum aggregated into a practically single, compact patch in the study region, where AI index values range from 98 to 99 (*Figures 11 and 15*).

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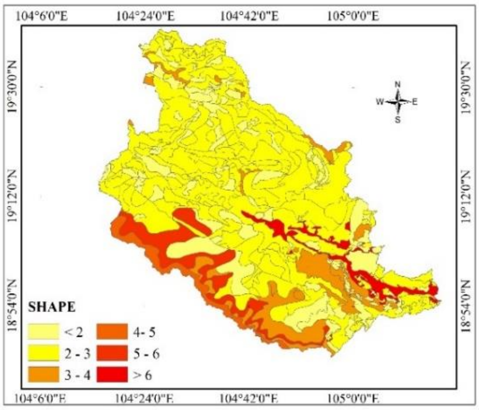

Figure 8. *Map of SHAPE indicator value distribution*

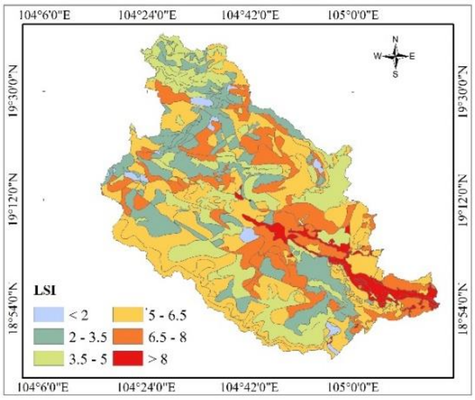

Figure 9. *Map of LSI indicator value distribution*

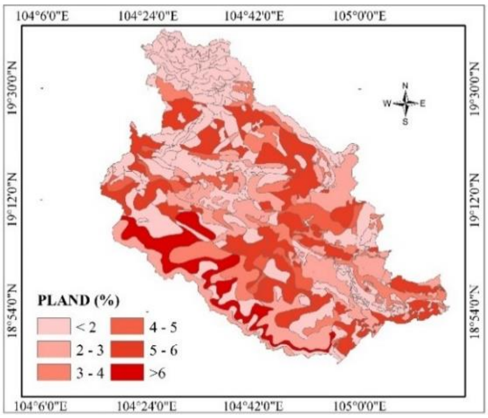

Figure 10. *Map of PLAND indicator value distribution*

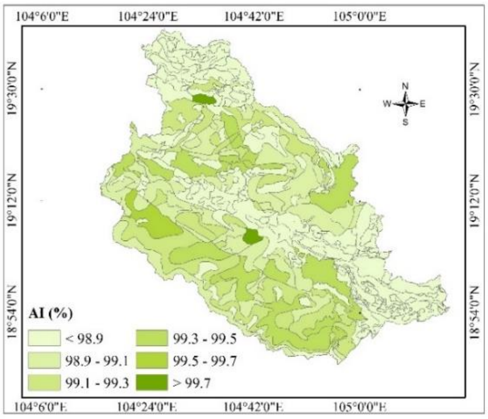

Figure 11. *Map of Aggregation Index (AI) value distribution*

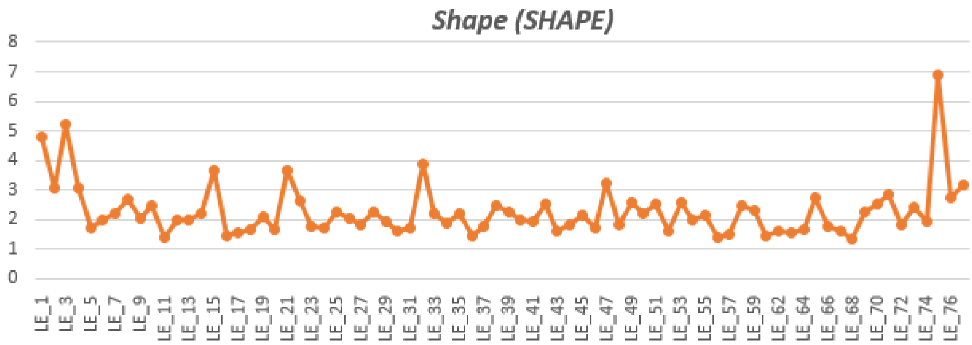

Figure 12. *Percentage of Shape (SHAPE) chart for ecosystem units*

Correlations of vulnerability components

Based on the values of 11 factors and the aggregate vulnerability value, the level of linear correlation between factors causing ecological damage is determined (from 11 composition maps and ecosystem vulnerability maps was established by AHP & GIS

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method of 11 factors affecting the ecosystem). These values relate to 200 set points to differentiate between the extent of damage to the composite ecosystem and the influence levels of various factors.

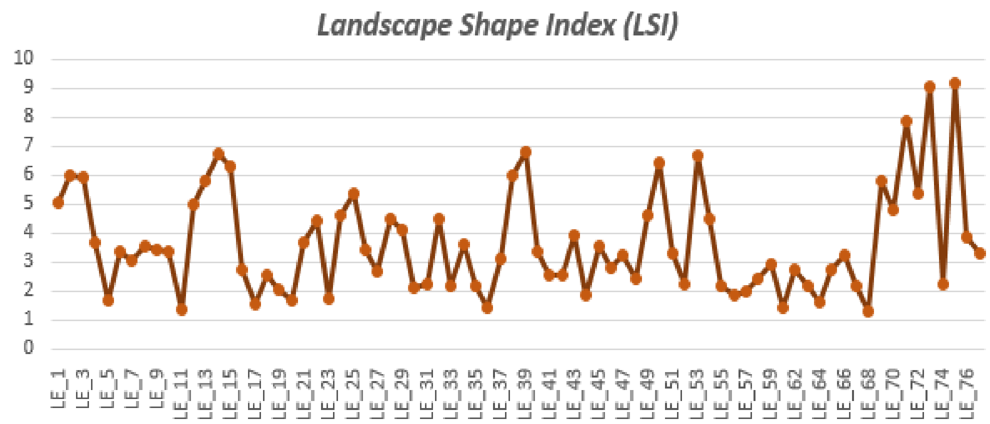

Figure 13. *Percentage of Landscape Shape Index (LSI) for ecosystem units*

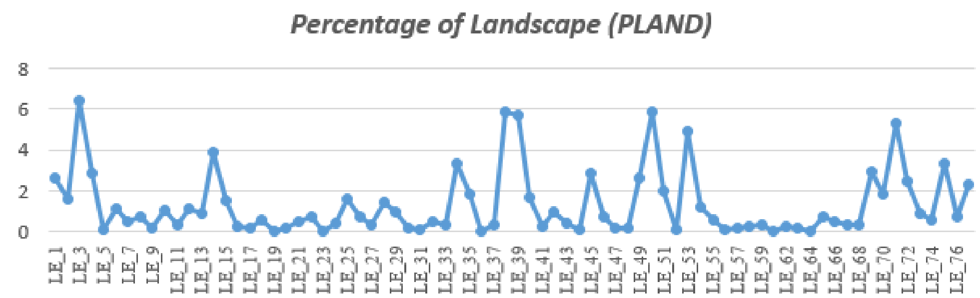

Figure 14. *Percentage of Landscape (PLAND) chart for ecosystem units*

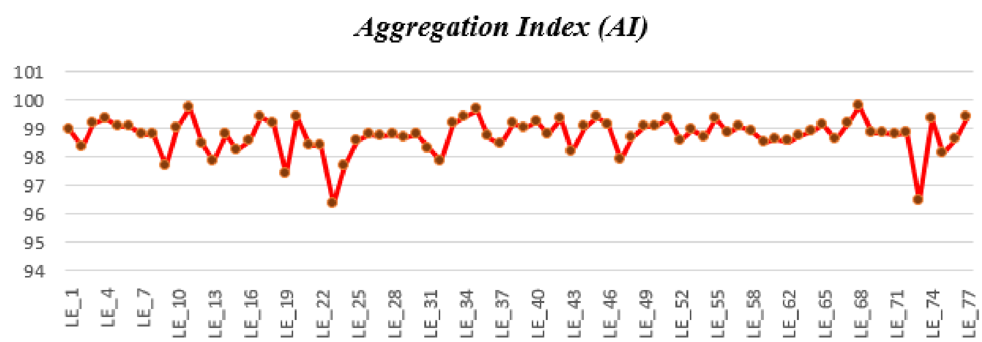

Figure 15. *Aggregation Index (AI) chart for ecosystem units*

Using SPSS software, the relationship between the degree of ecosystem vulnerability and the variables that make ecosystems vulnerable is examined from the viewpoint of the degree of ecosystem damage as an independent variable and 11 influencing factors as a variable. According to the analysis's findings, all 11 elements that have an ecological effect have a positive correlation (Sig coefficient 0.05), and four of them have a very

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significant positive linear association (with a coefficient of 0.05). Correlation coefficients (r) are as follows: water conservation index: r = 0.425; soil erosion: r = 0.508; population density: r = 0.567; and Proportion of < 20° cultivated land: r = 0.471. Road density (r = - 0.539) shows a strong negative linear correlation. Two other variables also have a weak negative linear correlation: Elevation: r = - 0.327; slope: r = - 0.332) (*Figure 16*).

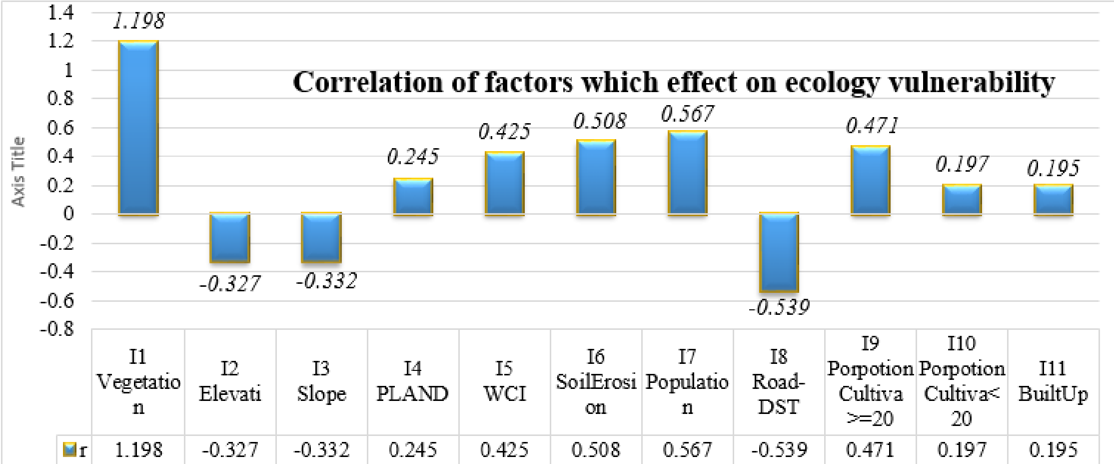

Figure 16. *Correlation of factors which effect on ecology vulnerability*

+ Water conservation index

Water conservation is a crucial ecosystem service that is described as the process and capacity of the ecosystem to maintain moisture in the system within specific temporal and geographical ranges and conditions (Chen, 2020). In the research area, Water conservation index has values for vegetation (sig 0.05; r = 5,50) and the percentage of built-up areas (sig 0.05; r = 0,422).

Soil conservation index (Soil erosion): The effect of soil erosion by water processes such as rain splash, overland flow/sheetwash, and rill formation is the removal of soil. The main effects are a loss of agricultural, productive land, degradation of soil structure, destruction of infrastructures, contamination of surface water, increased risk of flooding, etc. As a result, it impacts the research area's ecosystem. In the research area, the main factor affecting soil conservation coefficient, soil erosion, has a negative linear correlation with two factors (elevation and road density: r = -0.238 and -0.274, respectively) and a positive linear correlation with three factors (WCI: r = 0.335; population density: r = 0.216, and Proportion of < 20° cultivated land: r = 0.239).

Population density: Except for food production value, the value of each type of ecosystem service per unit area decreased as population density increased (Li et al., 2016). Population density in the research area has a strong negative linear correlation with Road density (r = 0.446), and a strong positive linear correlation with 2 factors (Elevation: r = 0.532; Slope: r = 0.490).

Road density: Because they destroy natural ecosystems and produce pollution, transportation operations have a significant negative influence on the environment. Roads disrupt natural habitats, divide ecosystems, and fundamentally change the environment. The construction of roads negatively affects species that need large regions of open land. Vehicles' extensive use of fossil fuels is what has the biggest environmental impact. Road

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density in the study area moderate shows a positive correlation with two factors (Elevation: r = 0.554; Slope: r = 0.441) and strongly negatively correlates with the proportion of ≥ 20° cultivated land (r = -0.520).

Discussion and conclusion

Discussion

- *The method used in this paper:* The primary method for accessing ecosystem vulnerability inherited by Gu et al. (2015) (indicators in *Table 1*) is based on an overview of research findings connected to vulnerability, as well as analysis and assessment of factors affecting ecosystem vulnerability. It affects ecosystem vulnerability as well as how the vulnerability is manifested in natural, social, and environmental aspects as well.

- *Contribution of components map and vulnerability maps for conservation work in Pu Mat NP in planning and investing for conservation or development:* The scope and area values of each indicator, as well as the overall vulnerability in the research's area, are displayed on the maps of vulnerability and its constituent parts. They are produced by interpolating for input maps built from DEM, satellite images, thematic maps, and statistics information that is gathered from the regional office in the research area. These results which show the scope and values of vulnerability, and its components help managers in making policies for planning biodiversity conservation and having measures to minimize damage in the right damaged place to ecosystem vulnerability in the research area.

In fact, a lot of biodiversity research possessing on, but it mostly focuses on carpet categorization and plant and animal classification. However, not much research has been done concerning the relationship between ecosystem vulnerability, ecosystem distribution, and the factors that contribute to such vulnerability. As a result, the system of component maps and vulnerability maps given by this paper can assist in establishing of specific biodiversity conservation strategies in the research area.

- *Accurately and Convenience:* The maps of vulnerability and its components illustrate the scope and area values of each indicator as well as the overall vulnerability in the research region. They are created by interpolating input maps made from DEM, satellite images, thematic maps, and statistical data collected from the regional office in the research area. The component maps and vulnerability results are credible because the input data was accurate. Additionally, using the GIS tools on the way to study allows for simple updating and modify new versions of component maps or the weight of every component to have a more precise vulnerability map. These findings, which emphasize the extent and significance of vulnerability and its components, help managers to establish strategies for planning the conservation of biodiversity and setting protective measures in place to lessen damage to vulnerable ecosystems in the research area.

- *The effect of the findings:* According to the findings of this paper, ecosystem vulnerability (assessed from 11 indicators), four ecosystem indicators, ecosystem change, and their linear relationships can be used to determine the planning areas to be protected for ecosystem conservation in particular and biodiversity conservation generally. On the other hand, maps of areas with considerable influence, as well as mitigation strategies for each dominant factor and the aggregate vulnerability, will be included. Managers can save time by using this to quickly locate vulnerable areas.

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Conclusion

The value of ecological vulnerability in Vietnam's Pu Mat National Park is calculated using the integration of GIS technology and the FAHP technique based on the analysis and synthesis assessment of 11 component data related to natural, social, and environmental hazards, taking into account the weights of the elements identified by the FAHP technique. According to the findings, the ecologically vulnerable areas are found in the valleys, plains, and hills around the Lam River, on highways, and in the buffer and transition zones of Pu Mat national park. This is where the great majority of research area residents live, along with the ecological economic model and agricultural production that rely on the research region. The study's findings provide an investigation and evaluation of the factors that have an impact on ecosystems, as well as a summary of how vulnerable ecosystems are at each level.

The direction that an ecosystem should be oriented can be determined with the use of this knowledge. The research area argues for responsible use, environmental protection, and maintenance of the livelihoods of those who depend on those ecosystems. Also, it was discovered from the analysis of ecological changes in the study area between 2010 and 2020 that these changes are concentrated in areas with high vulnerability values. Another outcome is that the indicators Percentage of Landscape (PLAND), Shape (SHAPE), Landscape Shape Index (LSI), and Aggregation index (AI), derived using GIS, Fragstats, can be used to evaluate the landscape for particular purposes like land use planning and function zoning. The outcomes of these landscape indices also demonstrate the differentiation across the entire research area. The degree of ecological change and negative impacts on the environment in the research area is also partially reflected in this variation.

According to the SPSS software's analysis of the linear correlation between 11 factors that cause ecosystem damages (using 200 sample points), 4 of the components have strong positive linear relationships, and 1 factor also has strong positive linear relationships. The two impacting elements have a modest negative linear correlation while there is a highly negative linear connection between them. The strategies for the protection of biodiversity in general and the conservation of ecosystem diversity in particular will be affected by this conclusion, along with the investigation and assessment of the influence of each element.

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