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Vulnerability assessment of protected area to forest landscape restoration and climate change mitigation: A case study from Vietnam

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ABSTRACT

Vietnam has been committed to reduce Green House Gas (GHG) emissions and to Reduction of Deforestation and forest Degradation (REDD). Nature reserve areas are effectively managed and protected contributing to reduce emissions. The vulnerability assessment is a necessary step to reflect the exposure, sensitivity and adaptive from flora in Than Sa – Phuong Hoang nature reserve that significantly contributes to decision-making processes of the sustainable forest management (SFM). The result showed tha tillegal logging activity was the main reason accounted for 74% of all reasons caused the exposure. *E. tonkinense* species was the most sensitive species of flora, followed by *F. brillettii, M. pasquieri, C. balansae* and *P. eriifolius*, and least sensitivity species belonged to *F.recisa* species. The highest criterion adaptive capacity was poverty rate among sub-region in the study area. Weighting all criteria in vulnerability assessment were assessed based on the Analytic hierarchy process (AHP) approach and meet the consistency, areas of highest vulnerability accounted for 3.4% of the total study area, high vulnerability accounted for 21.5% of the total area. Vulnerable areas were identified to provide a helpful evidence for the managers and staff of the nature reserve to make decision, set up activities in response to minimize impacts of negative effects and make plan scenarios for more effective management of forests and biodiversity. A combination between Geographical Information System (GIS) and AHP can perform spatial distribution vulnerability levels and be transferred and applied to other areas, however criteria applying has to be adapted to the circumstances in each new region.

Key words: *Vulnerability, Analytic hierarchy process, Exposure, Sensitivity, Adaptive*

Introduction

The vulnerability is commonly defined as a function of exposure, sensitivity and adaptive capacity to hazards (Paavola, 2008, Ghimire *et al*., 2010; Nghiem 2017), or considered as a function of exposure to a stressor, effect (also termed sensitivity or potential impact) and recovery potential (also termed resilience or adaptive capacity) (Turner *et al*., 2003; Opiyo *et al*., 2014). Within the context of conservation, vulnerability is defined as the likelihood of biodiversity loss to current or impending threatening processes (Wilson *et al*., 2005). Hence, under the management perspective of a protected area, identifying vulnerable area is an important task in supporting decision making on forest protection, biodiversity maintenance and sustainable management (FAO, 2013; Khoi and Murayama, 2010).

Measuring vulnerability enables to evaluate risks of hazards, acquired abilities to against damage. Developing tools to measure vulnerability needs link between the theoretical concepts of vulnerabil-

ity and day-to-day decision-making (Bogardi, 2006). Analyzing vulnerability is commonly based on both qualitative and quantitative approaches (Manangan *et al*., 2015). Quantitative approaches are formed through analyzing existed data such as reports, statistic data, and spatial datasets. While, qualitative approaches for examining vulnerability are implemented by a special questionnaire focused on experts and stakeholders to obtain judgments (Nghiem, 2017). Both approaches can help to answer important questions such as vulnerability of what, where and why events happen.

Vulnerability of protected area or habitat vulnerability is the possibility of habitat changes in relation to some stress factors should be accounted for (De Lange *et al*., 2010). Therefore, vulnerability assessment of protected area should include local knowledge, expert opinion and detailed data collection and technical analyses show how natural systems cope with stress. However, there has not been any research before conducted to study on vulnerability assessment in Than Sa Phuong Hoang nature reserve. Furthermore, selection of criteria to perform understanding of the exposure of both natural and human activities that influence protected area is not yet mentioned to support decision-making systems and project scenarios for the future of the protected area. Besides, criteria serve vulnerability assessment are various from one location to another location.

Up to date, for sustainable management of protected areas in Vietnam, little is known about how assess vulnerability of forest use management in response to adverse disaster and human disturbances. The study focuses on the valuation of adverse nature impacts and human disturbances that may affect the potential vulnerability in a protected area through assessments of exposure, sensitivity and adaptive capacity, which suggests a decision support tool for forest landscape restoration and climate change mitigation. Specifically, the study addresses the following questions: (1) How can vulnerability of a protected area be assessed? (2) Which criteria are essential in order to undertake the vulnerability assessment? (3) Can the developed vulnerability assessment model apply for other protected areas?

The results of the study provide valuable information about criteria and a holistic approach for identifying priority areas for forest conservation management in the protected area and the results are basic to improve the efficient management of the remaining forest areas and to support sustainable forest management and biodiversity conservation.

Materials and Methods

Study area

The research was conducted in ThanSa – Phuong Hoang nature reserve area (Figure 1). The protected area is situated in the northwest part of Thai Nguyen province, Vietnam with an area of 45423 ha. Theprotected area contains a wide variety of plant and animal diversity with 1096 species and 160 families of flora, 295 species and 93 families of fauna. In this protected area, there are 11 endangered species listed in the Red Data Book of Viet Nam (2007) and the IUCN Red List of Threatened Plants (2019). However, the protected area is suffering different pressures and threats come from hazards and disturbances such as forest fire, soil erosion by forest cover change, illegal anthorpogenic activities like logging, hunting, mining, cattle ranching, and conversion of forest land (Nguyen, 2014).

Data collection

To assess vulnability of ThanSa – Phuong Hoang nature reserve areaunder natural impacts and adverse human activities, the research approach is carried out through four stages:

Step 1. Collecting data: reports and statistic data, and spatial data available from Thai Nguyen department of forest ranger and department of environment and resource.

Step 2. Collection household information: questionnaire for the local households about households' economic condition, turnover from forestry and forest based activities, use of resources from the protected area, illegal activities. Based on the list of households, about 5% of a total of households (222 households) were selected randomly, households are representative of ethnic groups who mainly live in the protected area. Semi-structured face to face interviews were conducted from 2020 to 2021.

Step 3. Forest survey: The survey was undertaken according to forest transect lines to locate illegal activities, distribution of rare and endangered plants listed in IUCN and Vietnam Red book, 2007). The transect inventory lines were laid out on a systematic lines of 1 by 1 km

Step 4. Expert interview: The study also conduted in-depth interviews with how many Forest experts and researchers who have at least 10 years' experi-

ence in conservation and forest biology, director and vice directors of of the Than Sa Phuong Hoang nature resreve, director of forest ranger department in Vo Nhai District, official scientific experts, conservation experts from Thai Nguyen University of Agriculture and forestry, Vietnam. Before interviewing, all selected experts were explained clearly about the protected area condition through quantitative and qualitative data from the survey in stage1, stage 2 and stage3, which facilitates to deeply understand particular research problems from the perspective of the protected area. Experts involved in making judgments based on AHP approach.

Data analysis

All data from forest survey was unified, verified, stored in Excel files, maps of point distribution developed by using ArcGIS 10.3 inluding point distribution of illegal activities: illegal Logging, illegal grazing, illegal conversion of natural forest areas into plantation and agriculture land areas; point distribution of 6 rare and endangered plants listed in IUCN and Red book. All data from interviewed households was unified, verified and processed by statistical methods using SPSS 22 software.

Vulnerability assessment of Than Sa Phuong Hoang protected area is defined mathematically as a function of three components: Vulnerability = f (Exposure, Sensitivity, Adaptive capacity)

Exposure - the main negative effects on the protected area, through household interview and forest survey, three different criteria were selected inluding soil erosion, illegal logging and illegal grazing. Soil Erosion Risk Assessment was evaluated by utilizing the USLE model and ArcGIS 10.3 to determine the soil erosion rates.

The USLE, proposed by Wischmeier and Smith (1978), is described by the following equation (1):

$A = R * K * LS * C * P$ (1)

Where:

A is the average annual soil loss (tons ha^{-1} $year^{-1}$),

R is the rainfall erosivity (MJmm ha^{-1} h year)

K is the soil erodibility factor (tons ha^{-1} R $unit^{-1}$)

LS is the topographic factor (dimensionless),

C is the cropping management factors

P is the practice support factor

R defined as (Merritt, 2003): $R = 0.548257*M - 59.9$ (2)

M is the yearly precipitation (mm)

Pham *et al*. (2018) suggested K values for soil type in Central Vietnam

The LS-factor was computed using the ArcGIS raster calculator tool suggested by Mitasova and Mitas (1999) and shown in Equation (3):

$$LS = \left(\frac{FA * cell\ size}{22.13}\right)^{m} * \left(\frac{\sin(slope\ angle) * 0.01745}{0.0896}\right) \quad .. (3)$$

Where:

LS: the slope-length and steepness factor (no unit)

FA: is flow accumulation

m: slope length exponent

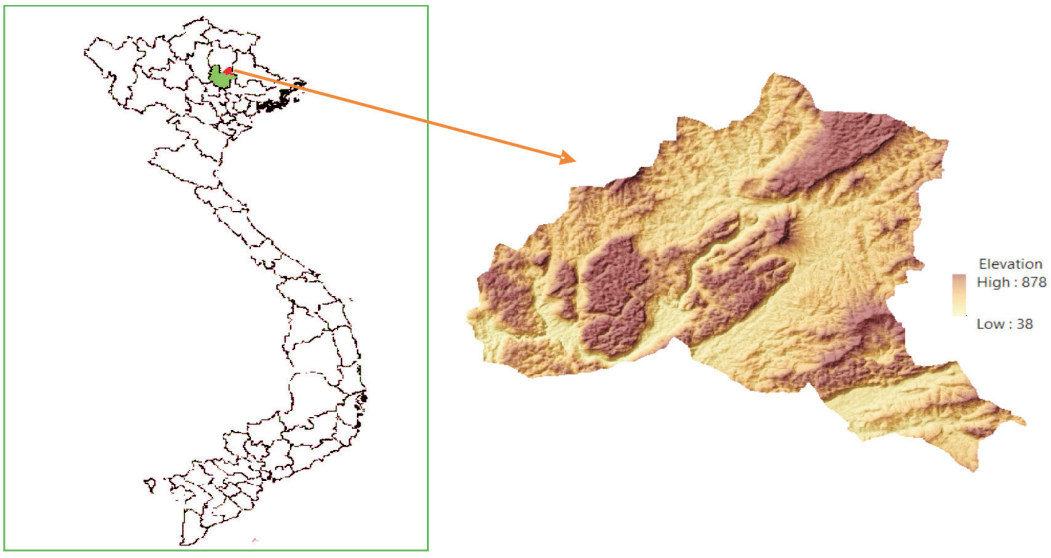

Fig 1. Map of ThanSa – Phuong Hoang nature reserve area

n: slope steepness exponent

Slope angle: Slope angle of DEM (°)

m and n were respectively assigned 0.5 and 1.3 as recommended by Mitasova and Mitas (1999) and Liu *et al*. (2000).

Land Cover and Management Factor (C): The C factor eflects the effect of cropping and management practices on the soil erosion rate decreases from 1 to 0 depending on vegetation cover and cropping management systems (Renard *et al*., 1997; Kheir *et al*. 2008, Desmet and Govers 1996). C equal to 1 indicates no cover present and the surface is treated as barren land, whereas C near zero (0) indicates very strong cover effects and well-protected soil. In this study, the C factor is defined as the following equation (4):

$$C = \frac{(1-NDVI)}{2} = \frac{\left(1-\frac{(NIR-RED}{(NIR+RED}\right)}{2} \quad .. (4)$$

Where:

NDVI: Normalized Difference Vegetation Index

NIR is the surface spectral reflectance in the near-infrared band of

RED is surface spectral reflectance in the red band

In order to meet requirements of images with the lowest cloud cover percentage and easily recognizing the difference between agriculture land and forests, the NDVI values is themean value ofthe time series of NDVIs in March and November, 2020 with information as in Table 1.

Support practice index (P): P factor expresses the impact of land use on the soil erosion. It is not easy to estimate P value because of intensive time and highcost (Morgan and Nearing, 2016). The P factor value ranges between 0 and 1, where 0 indicates the highest effectiveness of the conservation practice and 1 indicates that there are no measures implemented. In this research, the P factor is calculated by the cultivation and slope (Kim and Julien, 2006; Pham *et al*., 2018; Shin, 1999) based on land use map of year 2020 from Natural Resources and Environment Department of Thai Nguyen province and DEM database.

GPS points of illegal logging, grazing and conversion of natural forest areas into plantation and agriculture land areas collected were imported using ArcGIS Desktop 10.3.

Sensitivity – density and distribution of vulnerable plant species

Raster maps from point data of *Fernandoa brillettii* Dop, *Excentrodendron tonkinense* A.Chev, *Madhuca pasquieri* (Dubard) H. J . Lam, *Cinnamomum balansae* H.Lec, *Podocarpus neriifolius* D. Don *and Fibraurea recisa* Pierre distribution were developed by applying spatial interpolation and density in ArcGIS 10.3.

Adaptive capacity - natural adaptive capability and social adaptive capacity such as education, residential area, poverty, management effect.

Maps of adaptive capacity based on residential area was analyzed and developed by euclidean distance function, maps of adaptive capacity based on education and poverty were generated by local government's judgments, while management effect was shown based on distance to ranger stations and analysed by using density function in ArcGIS 10.3. In this study, an AHP approach is applied for analysing the uncertainties in expert judgments from pair-wise comparisons to determine weights of different criteria representing the current preferences of the decision makers.

In AHP methodology, pairwise comparisons show forestry experts' preferences by comparing two factors at a time steps (Vaidya and Kumar, 2006). Using pairwise matrix to evaluate and assign the importance of each factor with scale ranges from 1 to 9. According to Saaty and Vargas (2012), preferences are expressed by numerical values of 1, 3, 5, 7 and 9, respectively, with 2, 4, 6 and 8 as intermediate values between adjacent scale values. For example, 1 implies "least valued than" and 9 implies "absolutely more important than" in the pairwise comparison matrix. Eigenvalue ëmax of the reciprocal ratio matrix, eigenvector, consistency ratio (CR) based on consistency index (CI) and random index (RI) and the normalized value for each criteria/alternative

Table 1. Acquisition of Sentinel 2 images

Sentinel 2 images	Date acquired	Cloud cover (%)
20200309T032551_20200309T033758_T48QWK 20200309T032551_20200309T033758_T48QXK	09.03.2020	< 10
20201109T032949_20201109T033934_T48QWK 20201109T032949_20201109T033934_T48QXK	09.11.2020	< 5

Checking the satisfactory of consistency ratio (CR) in order to make decisions based on the normalized values for criteria and determine the final overall rating.

Aggregation Individual Judgment (AIJ) is considered a unique mode to combine individual judgments into group judgment (Saaty and Peniwati 2008). AIJ matrices are calculated as the following equation (5):

$$A = \sqrt[m]{x_1.x_2 \ldots . x_m} \quad .. (5)$$

where:

xi are judgments of individual i, i={1,…,m}

A: Aggregation individual judgment by geometric mean

To ensure that the decision makers' judgments of are consistent, the consistency ratio (CR) and consistency index (CI) were applied, which are defined as the following equation (6) and (7):

$$CR = CI/RI \quad .. (6)$$

$$CI = (\lambda max – n)/ (n-1) \quad .. (7)$$

where:

λ_{max} is the maximum eigenvalue of the normalized comparison matrix, $\lambda max \geq n$.

RI is a Random Index for the number of factors compared in a matrix, appropriate consistency index, corresponds index of consistency for random judgment (Saaty and Vargas, 2012).

n = number of criteria being compared

CI estimates the level of consistency with respect to the entire comparison process.

CRs less than or equal to 0.1 (10%) indicate consistent assessments of decision-makers, for CRs > 0.1 the individual criteria have to be re-examined. Each input raster layer was weighted according to its proportional influence given the constraint that the sum of the percentage influence weights for all the raster map.

Finally, the result of AHP was integrated into a GIS to combine all of the criteria layers from potential risk and impacts, the sensitivity of vulnerable species and adaptive capacity.

Results

Household interview

Data from the undertaken 222 surveyed households in the seven communes representing different socio-economic status in the nature reserve shows that the average age of interviewees was 42 years. 70% of respondents were in the working age from 28 to 60 years and 30% of them were older than 60 years. Generally, most of households composed of three members which represents for the average household size in the study area.

Education level is different among communes. The percentage of respondents with primary school and middle school education in Phu Thuong and Than Sa was significantly higher than Vu Chan, Nghinh Tuong, Thuong Nung and Sang Moc. The largest group of household incomes ranged between VND 80 million and VND 95 million per year, which is equivalent to 65% of respondents in study area. The lowest imcome belonged to Vu Chan, Nghinh Tuong, Sang Moc with an average of 57 million per year. 70% households noticed that their incomes increased slightly compared to previous years, and the remaining households had no change.

35% of the respondents indicated that forest plantations contributed more than 30% of the total household incomes. 69% of respondents anwered that forest resource problems in study area were well managed. Approximately 100% of respondents were awareness of the benefits of forests to communities such as hydrological services, soil protection, and carbon sequestration. The life of many households depends on forest resources, although there are only 10% of the surveyed households in the study area answered that they knew the occurrence of illegal activities and only 2% conducted illegal activities, there are higher perecentage of households implemented illegal activities on the protected area through the forest survey.

Soil erosion risk mapping

Mean annual rainfall data collected from 14 stations within 15 years (2005 – 2020) was used to calculate the R factor by using the function developed by (Merritt 2003). The mean annual rainfall ranged from 1538 to 1791 mmyear^{-1}, and consequently the calculated rainfall erosivity ranged from 783 to 922 (MJmm ha^{-1} h year).

Soil types were extracted from soil type map of Thai Nguyen Province which was provided by the Vietnam National Institute of Agricultural Planning and Projection (NIAPP) in 2005 using the scale 1/ 100000. Previous studies (Siem and Phien, 1999; Pham *et al.*, 2018) suggested K values for soil type in Vietnam. The soil types Fs (K value: 0.32), FLd (K value: 0.44) and limestone soils (K value: 0.1) occu-

pied 27558.7 ha, 2308.5 ha and 15536.7 ha respectively.

The LS factor illustrates the effects of topography on soil erosion. The L and S factors were extracted from the Digital Elevation model and computed using the ArcGIS raster calculator tool suggested by Mitasova and Mitas (1999). The LS-factor ranged from 0 to more than 30, which means that the slope is very steepand slope lengths are short. This can result in soil erosion more serious in the study site (Table 2).

Table 2. Topographic factor

LS factor	Area (ha)
$0 \leq$ LS ≤ 1	14692.4
$1 <$ LS ≤ 10	9108.5
$10 <$ LS ≤ 20	12921.6
$20 <$ LS ≤ 30	5449.3
LS > 30	3232.2
Water	19.1
Total	45423.0

The mean value NDVI map was calculated based on Google Earth Engine and ArcGIS 10.3. The results have shown that NDVI value ranged from –0.50 to 0.92, the C factor ranged from 0.04 to 0.75.

In this research P factor based on land cover map of year 2020 analyzed from Sentinel-2 satellite (date acquired by 09/11/2020, cloud cover < 5%). Land cover map was developed based on Google Earth Engine and random forest function. The land cover map 2020 with an overall accuracy and Kappa of 84.6% and 0.77 respectively. The land cover 2020 was classified into four classes including Agriculture land, forest, bare land and water body. The P

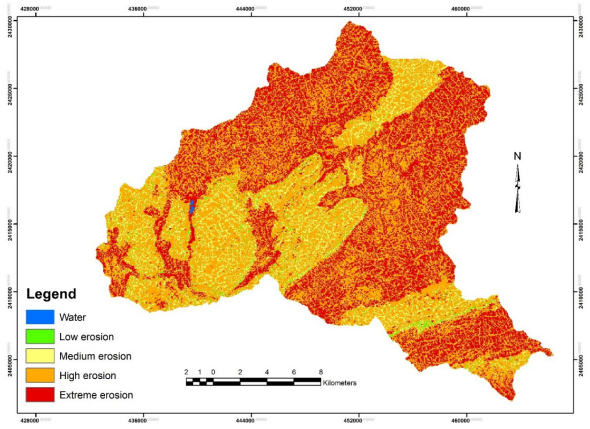

Fig 2. Annual average soil loss rate map

factor is suggested by previous studies resulted in a value range from 0.21 to 1.00 (Kim and Julien, 2006, Pham *et al*., 2018, Shin, 1999).

The soil loss predictions in the research area range from low erosion, medium erosion, high erosion to extreme erosion levels were accounted for 1.3%, 9.1%, 57.5% and 32.2% of the natural area respectively (Figure 2). This reflects the significance variability of mountainous area erosion in the study area. Soil erosion threatens lifes of plant species. Most of the eroded soil is from the area with low vegetation cover

Exposure

Three main different criteria including soil erosion, illegal logging and conversion from forest into agriculture land were selected and measured following the 9 expert interviews. Based on the AHP technique, each criterion was compared to each other in order to create the pair-wise comparison matrix. The method of aggregation individual judgments was used with the geometric mean approach to perform ranking. From the result of calculated geometric mean, the aggregation of the nine judgments was calculated to obtain the eigenvector and give the results of weighting calculation based on revised power (Table 3).

The result showed that the consistency index (CI) for paired criteria concerning the impact of different factors on the exposure was 0.050 (5%) and the consistency ratio (CR) was 0.096, which was acceptable as it is smaller than the 10% threshold proposed by Saaty and Vargas (2012). After assigning weights for each criterion, Illegal logging was identified as the most important criterion, followed by soil erosion and Illegal grazing. Figure 3 illustrates overlaying of the three criteria components with the respective calculated weightings, the raster calculator tool in an ArcGIS environment was utilized to combine raster inputs with different weights of criterion. The colour in changes from green – which represents low exposure areas, gradually to light green – which represents medium exposure areas, to yellow – which represents high exposure areas, and finally turn to red – which presents the areas of highest exposure.

Sensitivity

An understanding of spatial sensitivity of species in protedted areas is essential. Sensitive species of Than Sa Phuong Hoang nature reserve were selected based on the endangered states of flora listed

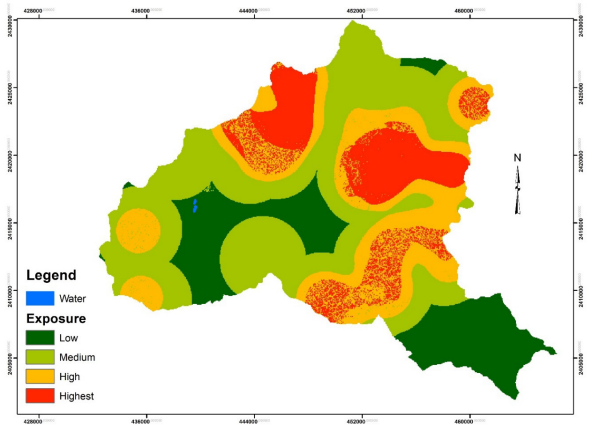

Fig 3. Hotspot areas of exposure map

in the Vietnam Red List threatened species and IUCN, and subsequently weighted based on the nine interviewed experts.

From Table 4, the results indicated that the consistency index (CI) for paired criteria concerning the roles of different species on the sensitivity was 0.0183 (1.83%) and the consistency ratio (CR) was 0.015, the consistency was accepted in judgments. *E.tonkinense* was the most sensitivities species of flora in Than Sa Phuong Hoang nature reserve, followed by *F. brillettii, M. pasquieri, C.balansae* and *P. eriifolius*, and least sensitivity species belonging *F.recisa*. Based on maps of species distribution, overall sensitivity of five different species of flora with weightings for each of species was developed. The colour in the Figure 4 changes from light green – which represents areas of low sensitivity, to yellow which represents areas of medium sensitivity, to red which represents areas of high sensitivity. The Figure 4 also illustrated that the highest level of sensitivity of flora is seen mostly in Vu Chan, Nghinh Tuong and Sang Moc communes. These regions are considered the potential suitable areas to grow and develop *E.tonkinense, F.brillettii, M.pasquieri, C.balansae* and *P. eriifolius species.*

Adaptive capacity

Since local people inhabit surrounding and in the protected area, most of the patrol routes was established by rangers and local communities. During the patrolling routes, commune guards were supporters to patrol protected areas, which results in preventing illegal activities more effectively. Activities of forest rangers may get less support of the local com-

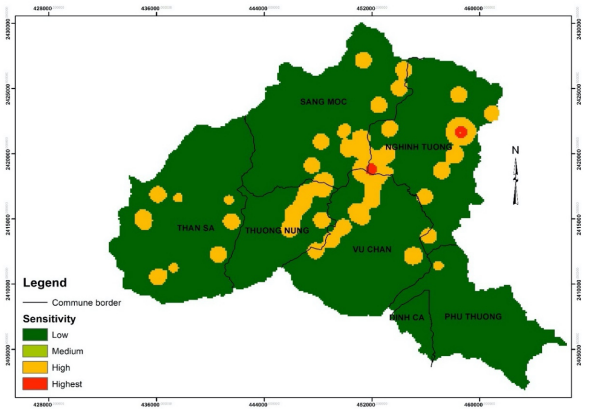

Fig 4. Overall sensitivity of six different species map

Table 3. Aij for pair-wise comparison matrix of nice experts for exposure

Criteria	Illegal logging	Erosion	Illegal grazing	Weight(Revised power)
Illegal logging	1	5.6	6.1	0.74
Erosion	0.2	1	1.2	0.14
Illegal grazing	0.2	0.8	1	0.12
Consistency Test (CR<=10%)	λmax = 3.099; CI = 0.050; RI = 0.52; CR =CI/RI = 0.096			

Table 4. Aij for pair-wise comparison matrix of nice experts for sensitivity

Species	*E.tonkinense*	*F.brillettii*	*M.pasquieri*	*C.balansae*	*P.eriifolius*	*F.recisa*	Weight (Revised power)
E. tonkinense	1.0	1.2	2.2	2.4	3.9	4.3	0.30
F. brillettii	0.8	1.0	2.0	2.2	3.6	4.2	0.27
M. pasquieri	0.5	0.5	1.0	1.3	3.0	3.8	0.17
C. balansae	0.4	0.5	0.8	1.0	2.3	3.2	0.14
P. eriifolius	0.3	0.3	0.3	0.4	1.0	2.1	0.07
F. recisa	0.2	0.2	0.3	0.3	0.5	1.0	0.05
Consistency Test(CR<=10%)	λmax = 6.0915;		CI = 0.0183;		RI = 1.24;	CR =CI/RI = 0.015	

munity if the people live far away from the residential areas. The assumption is taken that the further the distance to a residential area, the lower adaptive capacity. The management effect was assessed based on distance to ranger stations. The better the management is, the higher adaptive capacity is. When local people are well educated, they have high awareness of important role of environment and conservation and reduce negative impacts on the protected area. According to Decision No. 3326/QD-UNBD issued on 08/11/2021 by president of the People's Committee of Vo Nhai district about household poverty classification based on poverty line in 2021. The result of pair-wise comparison matrix for adaptive capacity was calculated and shown in Table 5.

After building the four different component maps, the overlay of all four criteria maps was implemented. The highest criterion adaptive capacity belonged to poverty rate among subregion in the study area, followed by management effect and education, the lowest criterion adaptive capacity was residential area distribution compared to forests. CR < 0.1 of the matrix meets the requirements.

Figure 5 indicates the adaptive capacity to potential risks in Than Sa Phuong Hoang nature reserve. The colour in the Figure changes from green – which represents the lowest adaptive capacity, to light green – which represents low adaptive capacity, to orange – which represents medium adaptive capacity, and gradually changes to orange – which represents high adaptive capacity, and finally to red – which represents the highest adaptive capacity.

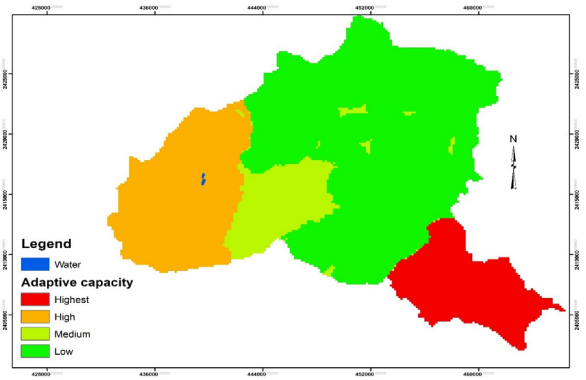

Fig 5. Adaptive capacity of Than Sa Phuong Hoang nature reserve

Vulnerability assessment

A vulnerability assessment model is considered as a function of exposure, sensitivity and adaptive capacity. Table 6 shows in detail the distribution areas of four vulnerability levels in Than Sa Phuong Hoang Nature reserve. The results showed that the consistency ratio (CR) was 0.026, which was acceptable as it is smaller than the 10% threshold.

The colours in the Figure 6 change from green – which represents the low vulnerability to light green – which represents medium vulnerability, to orange – which represents high vulnerability, and to red – which represents the highest vulnerability. The area with the highest vulnerability accounted for 3.4% of the total study area, the high vulnerability was seen to account for 21.5% of the total area and the low and medium vulnerability level occupied 75.1% of the total study area.

Table 5. Aij for pair-wise comparison matrix of nice experts for Adaptive capacity

Criterion	Poverty	Management effect	Education	Residential areas	Weight (Revised power)
Poverty	1	1.50	3.30	4.40	0.438
Management effect	0.67	1	2.90	3.90	0.336
Education	0.30	0.34	1	2.50	0.14
Residential areas	0.23	0.26	0.40	1	0.08
Consistency Test (CR<=10%)	λmax = 4.059;	CI = 0.02;	RI = 0.89;	CR =CI/RI = 0.022	

Table 6. Aij for pair-wise comparison matrix of nice experts for vulnerability

Criterion	Exposure	Sensitivity	Adaptive capacity	Weight(Revised power)
Exposure	1.00	3.02	4.37	0.63
Sensitivity	0.33	1.00	2.29	0.24
Adaptive capacity	0.23	0.44	1.00	0.13
Consistency Test(CR<=10%)	λmax = 3.03;	CI = 0.01;	RI = 0.52;	CR =CI/RI = 0.026

Notably, cells with high and highest vulnerability levels were mainly seen distributed in Sang Moc, Nghinh Tuong, Vu Chan communes, particularly in areas which are the intersections between bounderies of communes. It was also documented from the survey that most of illegal logging or forest loss and grazing activities happened in the period 2015 – 2020. In the fact, local government of each commune lacks the capacity to carry out demarcation sufficiently. Although boundaries are shown on maps, there are no signposts on the ground. Hence, the ability of local government to carry out their roles and responsibilities is limited.

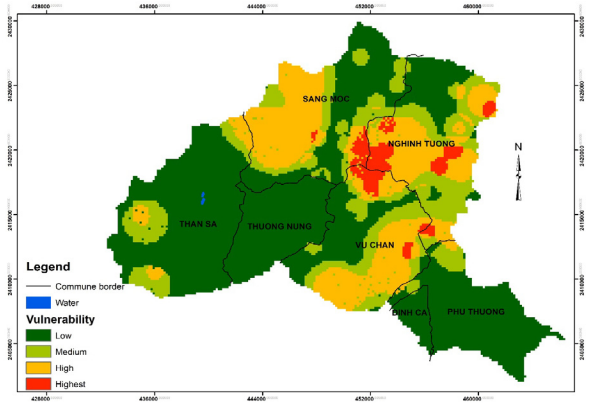

Fig 6. Vulnerability map of Than Sa Phuong Hoang nature reserve

Discussion

Vulnerability is resulted from intense disturbance by human economic and social activities (Hong *et al.* 2016). The spatial distribution of ecological vulnerability was obviously seen in the poverty areas in which local people depends on the forests for their livelihood, especially for ethnic minority groups. Economic benefit from the forest protection and management has not yet contributed to household livelihood income. Therefore, it is necessary to have specific solutions and policies to improve livelihoods for ethnic minorities in the study area. This study did not discuss the spatio-temporal changes in major environmental factors such as land cover.

Combination between AHP and GIS enables decision-makers to analyse and reflect complicate issues such as vulnerability. All criteria were selected by the help of expert knowledge. Weighting all critera in vulnerability assessment to meet consistency. The analysis process undergoes three phases consisting of pair-wise comparison, judgment and synthesis to assess the multi-criteria that related to habitat of plants and then the calculated average value is adopted. Vulnerability assessment of study area included local knowledge, expert opinion and detailed data collection and technical analyses showed how the protected area coped with potential risks. However, the AHP has been evaluated as a subjective weighting method based on expert opinions, judgment and ranking of criteria may differ from one expert to another (Chen *et al.*, 2011; Nefeslioglu *et al.*, 2013).

Combination between GIS and AHP can help to perform levels of vulnerability and be transferred and applied to other areas. Previous researches also indicated that criteria served vulnerability assessment were various from one location to another location (Liou *et al.*, 2017; Pennetta *et al.*, 2018; Xia *et al.*, 2021). Hence, criteria has to be adapted to the circumstances in each new region.

Identifying vulnerable area is crucial to forest conservation and sustainable management inprotected areas (Khoi and Murayama, 2010, Lapola *et al.*, 2020; Pennetta *et al.*, 2018). The results of the research help the board management of Than Sa Phuong Hoang nature reserve and stakeholders identify suitable areas to prioritize resources on the most vulnerable species and ecosystems and identify the most important hotspot locations for intervention. Managing vulnerability enables the manager and staffs of the protected area to predict and prevent instead of treating disturbance based on precautionary principles (Das and Gupta, 2021, Hong *et al.*, 2016; Rodríguez-Merino *et al.*, 2020; Xia *et al.*, 2021). Identifying vulnerability areas is also considered as a scientific basis and practice to enhance effective management of forested areas in contribution to implement forest landscape restoration and mitigate climate change and is helpful for the managers and staff to make decision and plan scenarios of management in coming time for Than Sa Phuong Hoang nature reserve. In the fact, because of lacking suitable policies and plans several endangered species are coping with completely disappear in the study area such as *Garcinia fagracoides* A. Chev, *Aquilaria crassna Pierre* ex Lecomte or *Parashorea chinensis* H. Wang.

Conclusion

Analyses of the exposure, sensitivity and adaptive

capacity are very important in the process of vulnerability assessment. In order to gain an understanding of the exposure of both natural and human activities and how they influence on Than Sa Phuong Hoang nature reserve, nine selected expert interviews were got involved to assess different importance role of each criteria based on the AHP approach and meet the consistency.

The result showed that illegal logging activity is the main reason accounted for 74% of all reasons caused exposure. *E.tonkinense* was the most sensitivities species of flora in Than Sa Phuong Hoang nature reserve, followed by *F.brillettii, M.pasquieri, C.balansae* and *P. eriifolius*, and least sensitivity species belonging *F.recisa*. The highest criterion adaptive capacity was poverty rate among sub-region in the study area and the lowest criterion adaptive capacity was residential area distribution compared to forests.

Weighting all criteria in vulnerability assessment were assessed, the area with the highest vulnerability accounted for 3.4% of the total study area, the high vulnerability accounted for 21.5% of the total area. The vulnerable areas were the most vulnerable flora *E.tonkinense* and other species occcuring. A combination between GIS and AHP can understand vulnerability levels and be transferred and applied to other areas, however criteria applying has to be adapted to the circumstances in each new region. The results suggest that vulnerable areas need to increase protection to prevent from human disturbance and managers of the Than Sa Phuong Hoang nature reserve can make plan scenarios for more effective management.

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