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Project Paper

Assessment of Vietnam Coastal Wetland Vulnerability for Sustainable Use (Case Study in Xuanthuy Ramsar Site, Vietnam)

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Abstract

For sustainable use of coastal wetland ecosystems, vulnerability of the Xuan Thuy Ramsar site in the northern coast of Vietnam, an internationally important area for feeding and roosting of migratory water birds, is assessed. The assessment tools include 1) a geographical information system database, which describes physical, socio-economic, and environmental conditions; 2) spatial multi-criteria decision analysis, and 3) evaluating criteria by a pair-wise comparison method. Consequently, coastal vulnerability criteria were determined following three periods of a year with different density of migrating birds: the highest density period – from September to March of the following year; the average density period – April and from August to October; the lowest density period – the remaining time in year. For each period, 5 levels of vulnerability (from 1-lowest to 5-highest level) were determined. High vulnerability level is concentrated in a great area, belonging to the ecological restored area and the south of communes Giao Thien, Giao Xuan; Low vulnerability level is distributed in communes of the buffer zone. Correspondingly to each vulnerability level, recommendations are given for the risk management, resource use, environment protection and human activities.

Key words: wetland, vulnerability, Ramsar site, hazard, sustainable use

Introduction

With more than 3200 km of shoreline, Vietnam's coastal zone provides a diverse range of natural resources (wetlands, geotopes, minerals, etc.) and favorable conditions for social and economic development (fisheries, aquaculture, agriculture, tourism, transportation, urbanization, etc.). However, the ecosystems there are highly vulnerable, due to several coastal hazards such as typhoons, storm surge, erosion, earthquakes, environmental pollution, global climate change and sea level rise and irregular exploitation and human activities which intensify these natural impacts such as mangrove logging for shrimp farming and fuelwood, wastes disposal, etc. These vulnerability causing factors are great obstacles to the country's purposes of sustainable use of coastal wetland resources.

In order to diminish damages from unexpected events, vulnerability has been researched since 1990s on several different thematics, including economic and environmental vulnerabilities [18, 9], human and community vulnerability [17], vulnerabilities from natural hazards [4, 3], coastal vulnerability [8], and human insecurity [5]. In recent years, due to the increase of hazards in the linkage with global climate change, the thematic of vulnerability from impacts of global climate changes and sea level rise is more concentrated [1, 22]. Vulnerability criteria and protocols of vulnerability assessment and mapping is proposed by NOAA [17], SOPAC [9, 18] and Bankoff et al [3], are involved with 3 groups of criteria: risk, vulnerable objects and coping capacity in an applicable manner with mapping software. Whereas spatial variation in values of these three components is widely assessed based on the vulnerability map, the temporal variation is assessed in only few researches, with focus on some specific subjects, such as seasonal variations of natural hazards [3] or annual variations of exposed population [4, 5]. These researches also emphasis vulnerability analysis as a mean of strengthening policy formulation and policy practice, in aspects of hazard mitigation, environment protection, conservation and sustainable use of natural resources, etc. In Vietnam, vulnerability was only assessed for the geological risks [10, 16], showing that, for sustainable development of coastal areas, the planning for wetland use should be based on vulnerability assessment.

In this study, the vulnerability assessment approach is applied for the dataset (update until 2007) of Xuan Thuy Ramsar site, in the northern coast of Vietnam, an internationally important area for feeding and roosting of migratory water birds, in order to identify current stressors and wetland resources, and how stressors and wetland resources can change temporally and across the landscape under future scenario of global changes and intensification of coastal natural hazards.

Methodology

Study site

The Xuan Thuy Ramsar site, belonging to the Giao Thuy district, Nam Dinh province, is a typical estuarine wetland area in the north of Vietnam (figure 1). The total area of the site is >15.000 ha with 7.100 ha allocated for the core zone and 8.000 ha as a buffer zone [11]. The Xuan Thuy site was defined as a region with highest biodiversity and productivity, but also the most sensitive of ecosystems, characterized by diversified, plentiful flora and dense habitats of several fauna species. In total of 219 bird species, 50 species of migratory bird are determined there, with species in the World Red book such as *Platalea minor, Larus ichthyaetus, Tringa orchropus, Egretta eulophotes* [11].

Density of migratory birds in this area varies following three periods of a year: the period with the highest density (up to 30 – 40 thousands of individuals observed) – from September to March of the following year; the period with average density (up to 20 thousands of individuals observed) – April and from August to October; the period with the lowest density (few individuals observed) – the remain time in year [11].

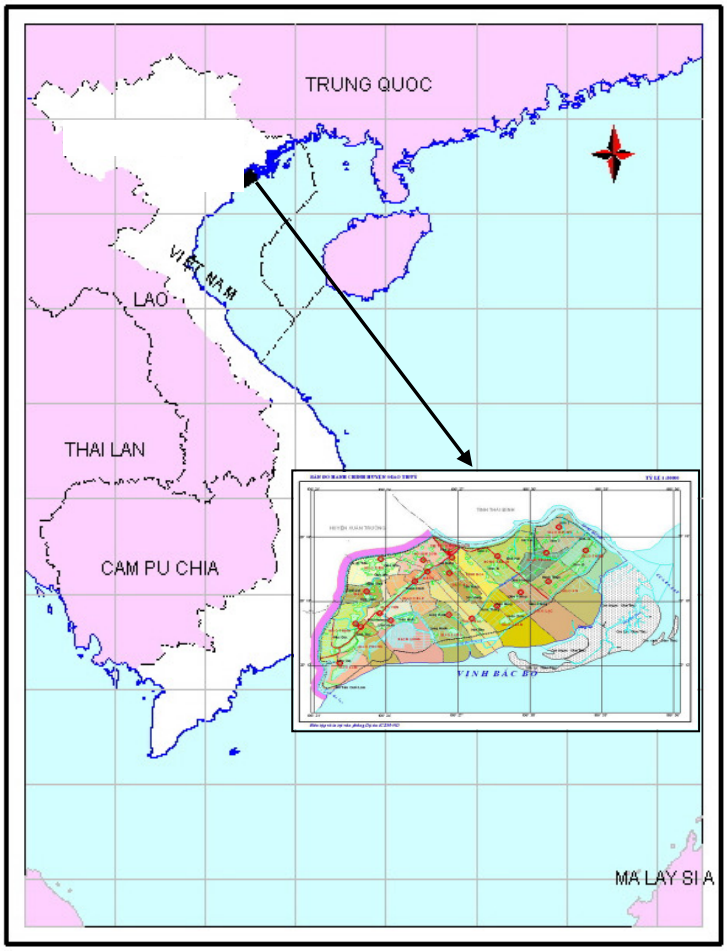

Figure 1: Location of the study area, Xuan Thuy Ramsar site.

In this area, the determined hazards include erosion, channel siltation, storm and flooding, salt contamination, environment pollution, sea level rise [14, 15]. Erosion was determined to occur intensively at Lu Island (eroded few hundred meters along the back part), the coastal zone of Giao An commune and Giao Phong commune and up to 4 km along the coastline of the Giao Xuan commune (with rates of 8mm/year). Therewith, channel siltation occurred at both heads of Lu, Ngan and Mo Islands. During the period from 1938 to present, the Ba Lat estuary has had its main channel changed four times [15]. Storms occur most frequently from July-September, with an average of five major storm events per year, leading to floods with a great loss of property. In 27th Sep. 2005, the seventh storm of the year occurred with the spring tide on had raised the tide level up to 2, 65 m (highest ever recorded in the last 40 years) and brought sea water over the Bach Long dike, leading to structural failure of several segments of dike and a subsequent loss of tens hectares of rice fields [14]. The environment is high polluted by wastes from the local residents and the industries and cities over the whole catchments. In aquatic environment, concentrations of Cu, Pb, Zn and Hg are 1.2 to 6.9 times higher than the allowed limitations (in comparison to the Vietnamese standard TCVN 5943-1995) [13, 14]. In sediments, concentrations of peticides and herbicides such as lindan (33.2 ppm), aldine (4.5 ppm) and endrine (8.98 ppm) are higher than the allowed limitations, also [11, 13, 14]. According to World Bank (2007) [7], Vietnam is of the 3 countries under the highest influences by global climate change and sea level rise. In addition mean sea level height has been estimated to increase by as much as 1 m, directly influencing all low land areas less than 10 m height. Because the average altitude of the study area is only 0.5 – 0.9 m, destruction of coastal ecosystems and habitats, etc. In Lu Island alone, more than 2 ha of casuarinas forest died because of the rise in sea level.

Human activities are an important cause that threaten ecosystem in the area. Local people can earn VND25, 000 - VND30, 000 per day from selling crabs, shrimps or oysters [6]. Cutting of mangrove for firewood is great threat to the mangrove forest ecosystem in the area. Other activities such as living activities, industry, aquaculture, cultivation, transportation, etc. release wastes, pollutants and also create

risks to coastal ecosystems, environmental quality. So vulnerability of Xuan Thuy wetland has been having increasing tendency, obstructed sustainable resource use in the area.

Methods

The methods used in this research were inherited from methods and criteria for assessment of coastal vulnerability index (CVI) of America [8, 17], for environmental vulnerability index (EVI) of SOPAC [9, 18], assessment protocol of NOAA [17] with calibration to Vietnam situation [10, 16]. Following, vulnerability of the Xuan Thuy wetland is defined as a function of three components:

$$V_{ij} = f\,(aRx_iy_j,\ bPx_iy_j,\ cCx_iy_j)$$

1) Rx_iy_j: the total risk from natural hazards (i.e. erosion, channel siltation, storm, sea level rise, environmental pollution; etc.)

2) Px_iy_j: Density and distribution of vulnerable objects (i.e. population, properties, resources, ecosystems);

3) Cx_iy_j: Coping ability (including objects with natural coping capacity such as mangrove forest, intertidal muddy sand or sandy mud flats, consolidated geological formations or with social coping capacity such as intellectual level, infrastructure and programs, actions to protect natural resources and environment, mitigate hazards, etc.)

x_iy_j is geographical location of each pixel in the coastal vulnerability map, in this studied area, dimension of a pixel is 1 km x 1 km

a,b,c: are weight of the components.

Calculation of Rx_iy_j is based on the following formula:

$$Rx_iy_j = \sum_{t=1}^{n} k_t \times G_t$$

In which, $G_t = (F_t + A_t) \times M_t$ [3]; n is number of the hazards (and hazard intensifying factors) in the studied cell, k_t is the weight of the hazard number t, determined by, G_t is grade of the single hazard number t, F is frequency of the hazard number t, A is the affected area of the hazard number t, M is intensity of the hazard number t, R is the total risk of all hazards available in the cell.

Values of F, A, M are spatial interpolated based on GIS tools (density, distance, classification) and value of G_t is calculated for all pixels in the map.

Based on their significance, criteria of the three vulnerability components were weighted, graded and grade - based ranked (from 1 to 5 for the lowest to highest level, respectively) for levels of risk (or pressures) (i.e. hazards and potential factors causing or intensifying hazards), density and coping capacity of the vulnerable objects. The weighting method followed the Assessment Matrix [20] and was conducted based on Expert Choice software [19, 20].

The protocol to establish vulnerability map of wetland ecosystem in Xuan Thuy Ramsar is shown in figure 2.

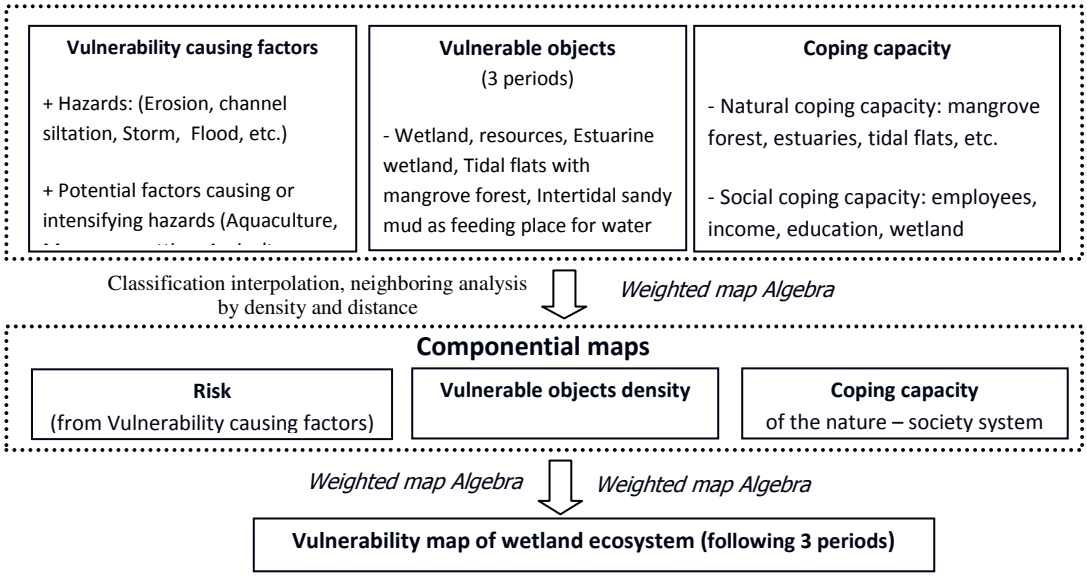

Figure 2: Protocol to create Vulnerability map of wetland ecosystem in Xuan Thuy Ramsar site in GIS

Results and Discussion

For vulnerability assessment of the Xuan Thuy Ramsar site, the three following criteria were considered:

a. The level of risk as a driving force for vulnerability

The level of risk in the Xuan Thuy Ramsar site was defined to include hazards (e.g. erosion, channel siltation, sea level rise, environment pollution, etc.) [11, 14, 15] and potential factors causing or intensifying hazards (e.g. human activities [6] like aquaculture, cutting mangroves, agriculture, tourism, transportation etc.). The grading results shows that, hazards such as erosion and environmental pollution have the highest grade (0,181) whereas earthquake risk has rather low grade (0,042).

Correspondingly, in the established map of total risk in scale of 1:60.000 (figure 3), three regions with very risk level from low to high can be distinguished as follows:

Regions with high risk include some parts of Lu and Xanh areas, which belong to the strictly protected zone, (area of 543.8 ha, accounting for 4.1% total area of Xuan Thuy Ramsar site), Giao Thien commune (2.4%), Giao An commune (2.3%) and the ecological restoration zone at the southern part of Lu island (1.6%). Regions with high risk were determined to be distributed around Ngan Island, along Tra and Vop rivers, bordering the strictly protected zone and Giao Thien, Giao An communes, southwest of Lu Island and the southeastern part of Xuan Thuy site, neighbouring the Ba Lat estuary.

Regions with low risk locate at the south of Lu and Xanh islands, around the internal flat of Giao An commune.
Regions with very low risk remain at the buffer zone, belonging to Giao Hai, Giao Thien, Giao An, Giao Lac, Giao Xuan communes and the northern part of Lu Island.

It is clear that the regions with high risk are closer to hazard causing subjects (e.g. river and tidal creeks as pollutant transporters, tourism or settlement site as sources of pollutants, geological faults as cause of earthquake…), sensitive to hazards (e.g. unconsolidated geologic background,…), or have high density of hazards. These tendencies are similar to the Phan Thiet – Ho Tram coast, as mentioned by Nhuan et al (2005) [16].

b. Vulnerable objects

Vulnerable objects include: bio-resources (e.g. native birds, migratory birds, etc.) and wetland types (e.g. the permanent submarine water area <6 m water depth in neap tide, estuarine wetland, tidal mudflat with mangrove forest, agricultural and aquacultural areas, etc.)

The most prominent features of the study area is the presence of some seasonally migratory bird species, which have great value for bio-conservation, feeding, breeding and living on tidal flats, estuarine water area, estuarine islands, etc [11]. Therefore, the wetlands, with functions as feeding, breeding and living places for migratory birds, are highly graded, relatively to the other vulnerable objects in the studied area. Corresponding to three periods with different densities of migratory birds, three-zoning maps of vulnerable object density were created (figure 4, 5, 6).

The first period (from November to March of the following year) (Figure 4): is characterized by having the highest densities of vulnerable objects, corresponding with the peak period of migratory birds (e.g. Black-

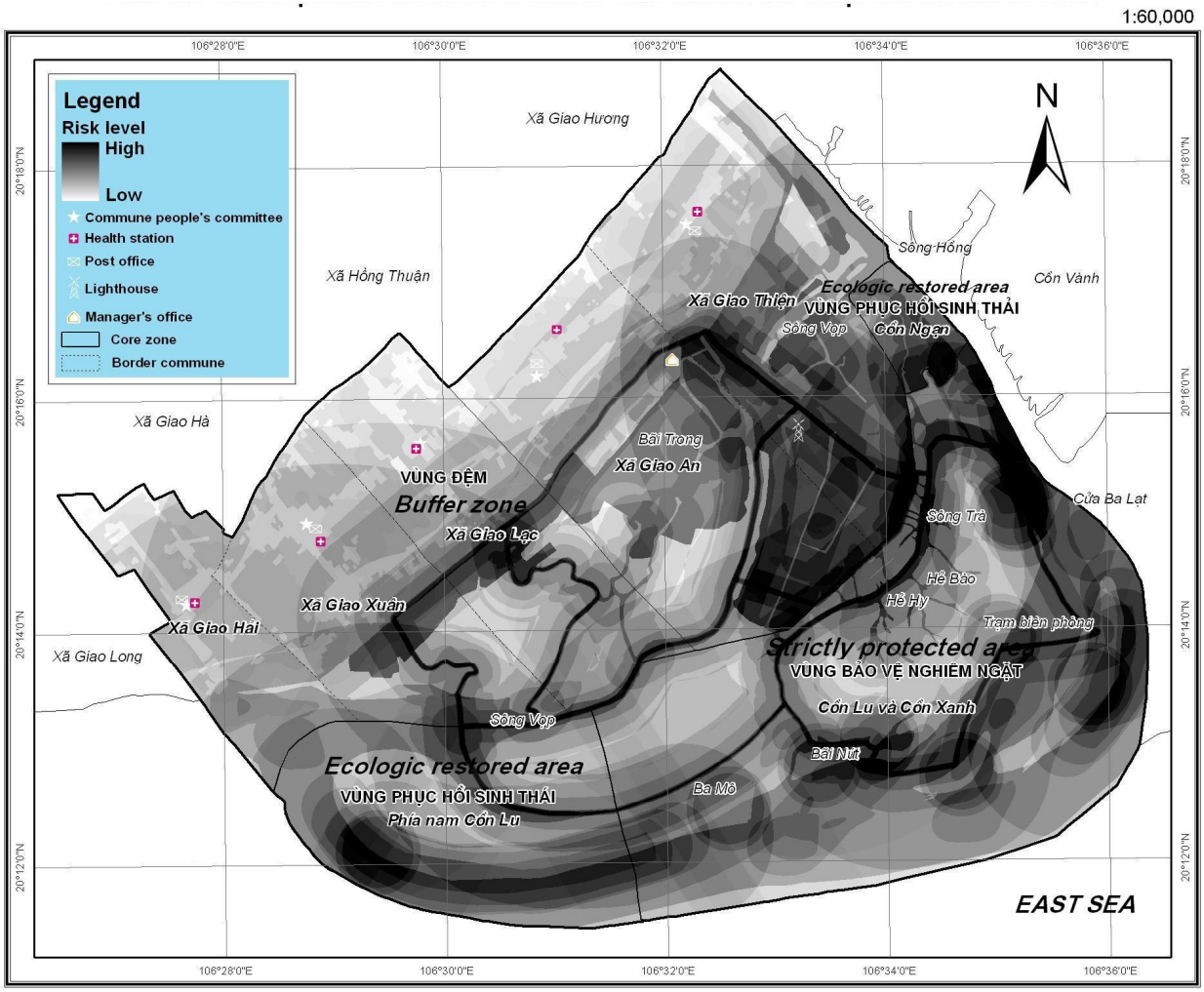

Figure 3: Zoning map of risk, scale 1:60.000

faced Spoon - Bill Platalea minor, Spoon - billed Sandpiper *Eurynorhynchus pygmeus, Saunder`s Gull Larus saudersi, Black-tailed Godwit Limosa limosa*, etc.), and other native fauna species as well. Regions with the highest densities of vulnerable objects were located mainly at the strictly protected area and the ecological restored area.

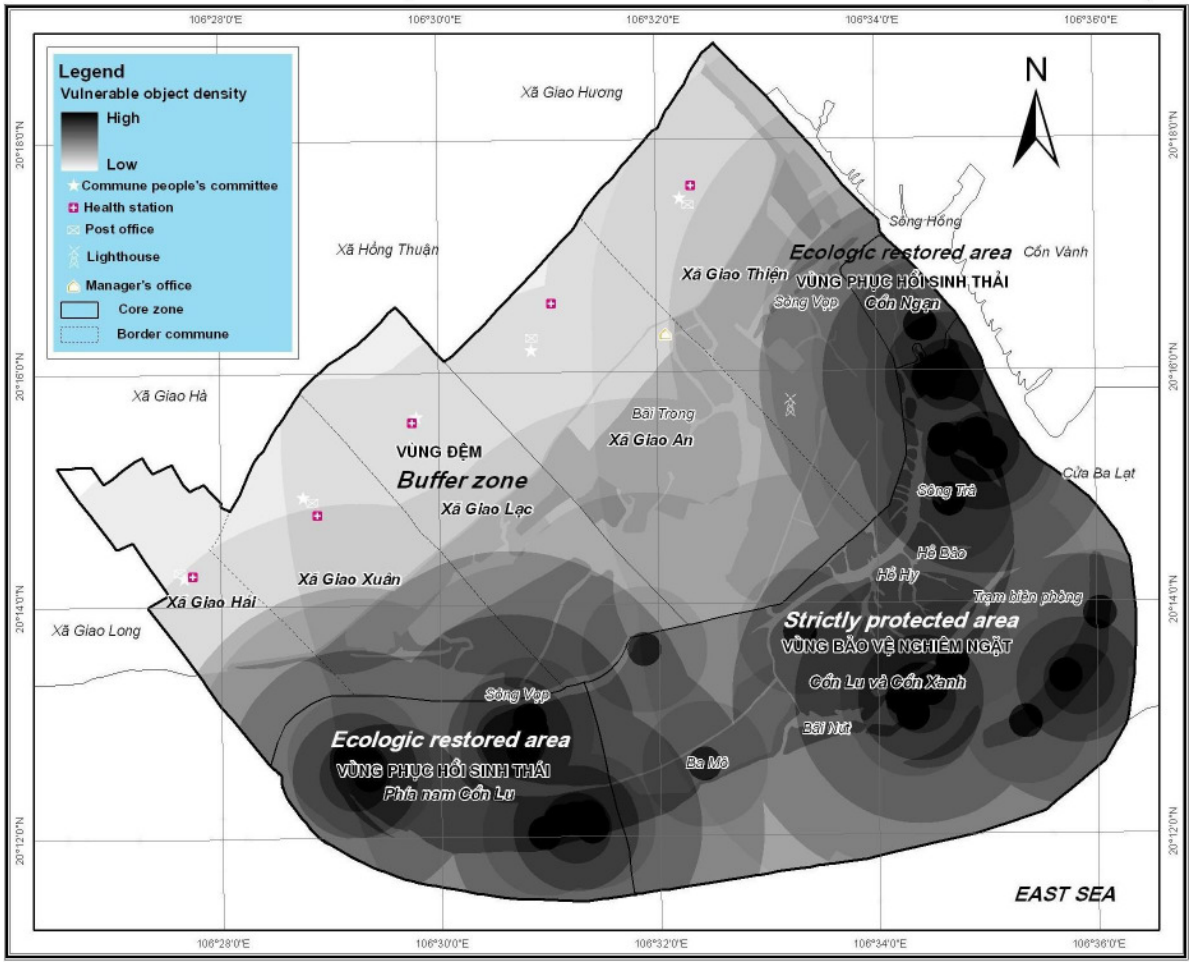

Figure 4: Map of vulnerable object density in the first period

The second period (in April and from August to October), figure 5: has lower densities of vulnerable objects, partially linked with the migration of water birds. The vulnerable objects remained included some common migratory water birds such as Black - faced Spoon - Bill Platalea minor, Spoon - billed Sandpiper *Eurynorhynchus pygmeus*, together with some native fauna, flora and wetland types.

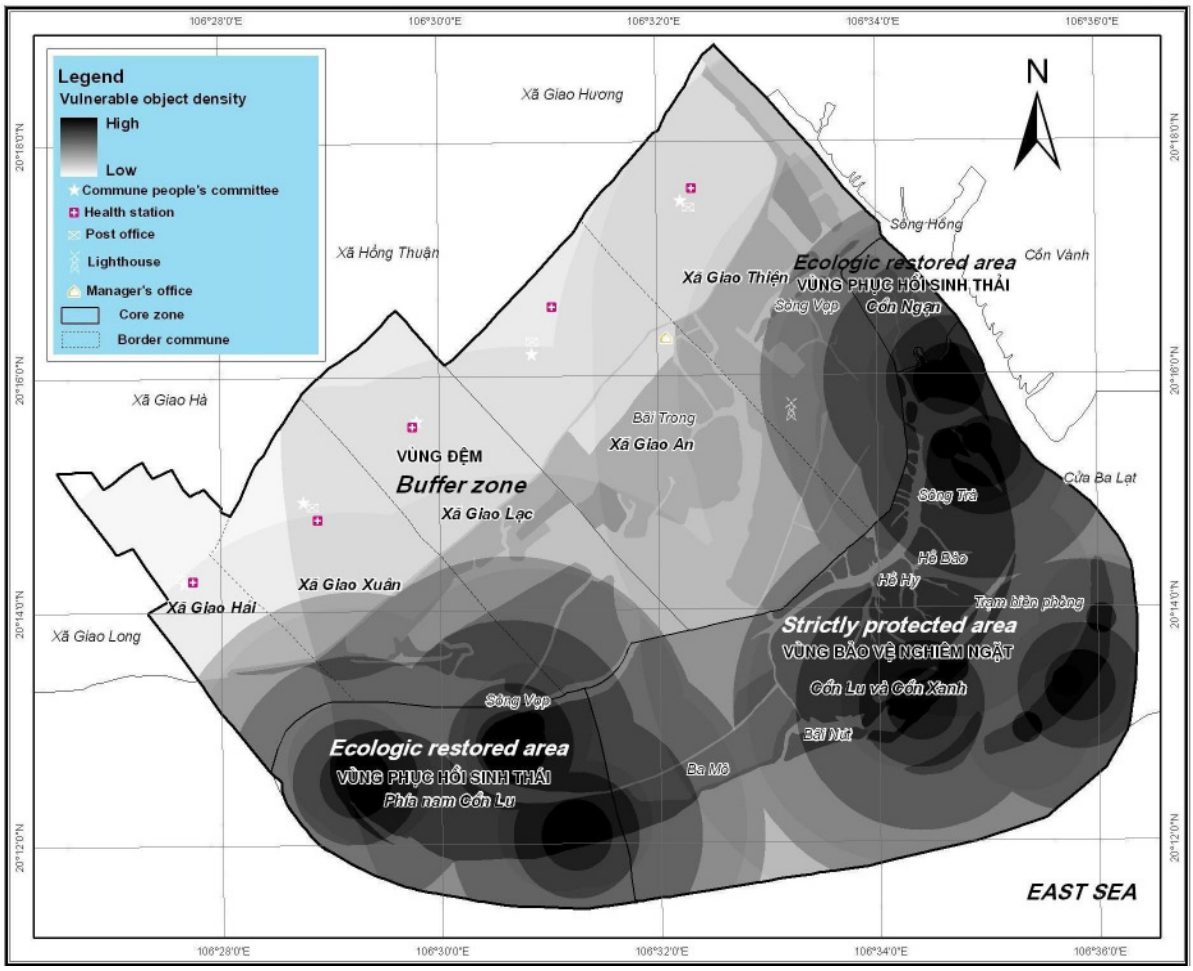

Figure 5: Map of vulnerable object density in the second period

The third period (from May to July) (Figure 6): has the lowest density of vulnerable objects due to the completed migration of water birds. Because of the lack of migratory water birds, the vulnerable objects consist mainly of other native fauna, flora and wetland types.

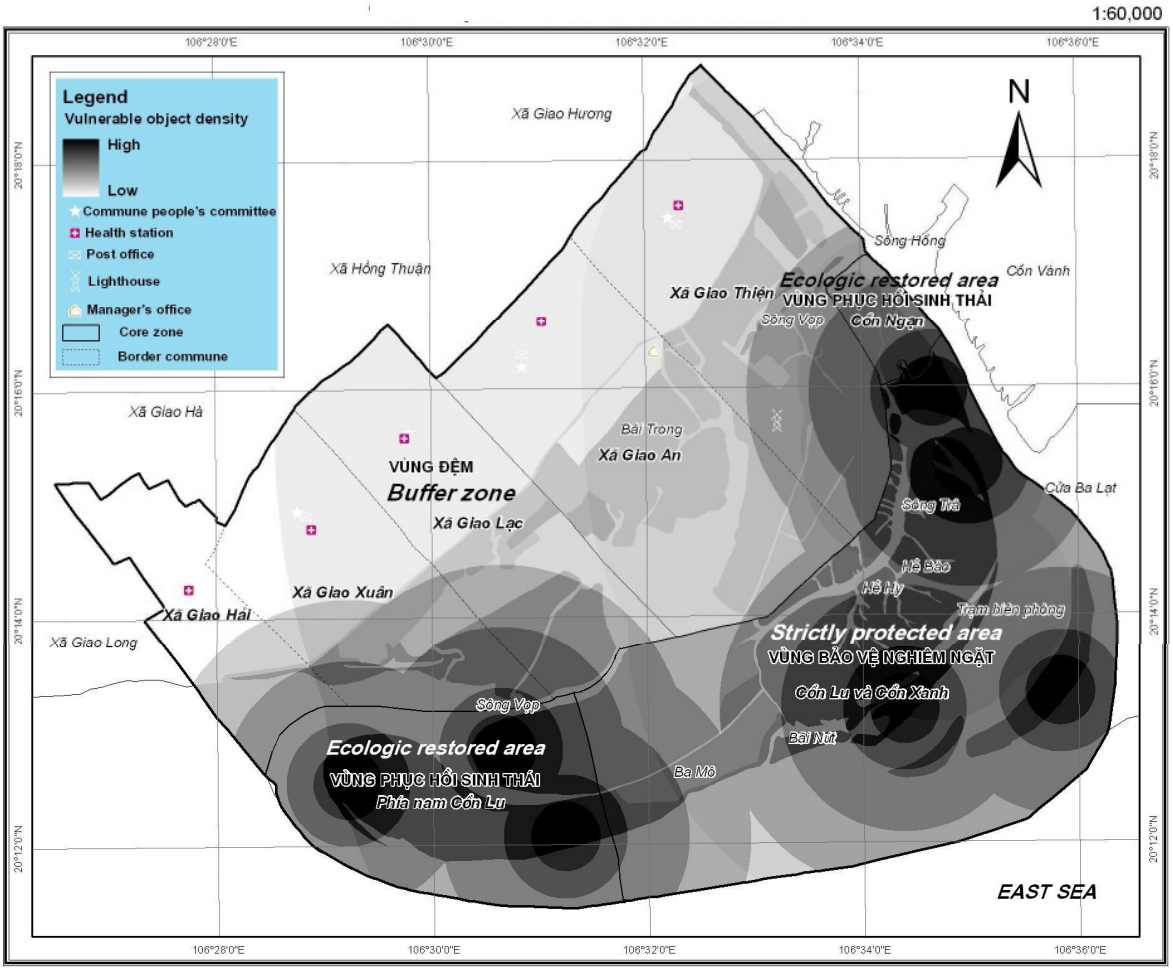

Figure 6: Map of vulnerable object densities in the third period

In general, the strictly protected areas and the ecological restored areas have the highest density of vulnerable objects (birds, wetland types such as mangrove forest, tidal mudflat, tidal creeks, etc.). In the first and second periods, density of vulnerable objects in these areas is much higher, linked the higher density of migratory water birds.

c. Coping capacity of Xuan Thuy Ramsar site

The coping capacity of the Xuan Thuy Ramsar site against hazards and potential factors causing or intensifying hazards was determined to deal with social potential (e.g. employees, income, education, wetland conservation activities, transport system, dyke and dam systems, etc) (table 1) and natural potential (geological ground, protective forest, mangrove forest, etc). Of these mentioned criteria, measures and activities for wetland conservation [*6*] were assessed to be the most important component of coping capacity in the Xuan Thuy Ramsar site.

Table 1: Features on coping capacity of communes in buffer zone of the Xuan Thuy Ramsar site

Criteria	Giao Thien	Giao An	Giao Lac	Giao Xuan	Giao Hai
Polulation (person)	10.494	10.150	9.876	9.693	6.910
Density (people/km^2)	1.023	1.180	1.331	1.291	1.207
Population in labour age (people)	4.571	4.702	4.947	4.061	4.481
Number of rich/ poor family	134/289	252/251	110/356	60/283	54/139
Total pupils of elementary, secondary and high schools	1.885	2.500	2.012	2.061	1.179
Rocky, bitumen road	30	45	29	45	14

Source: [6]

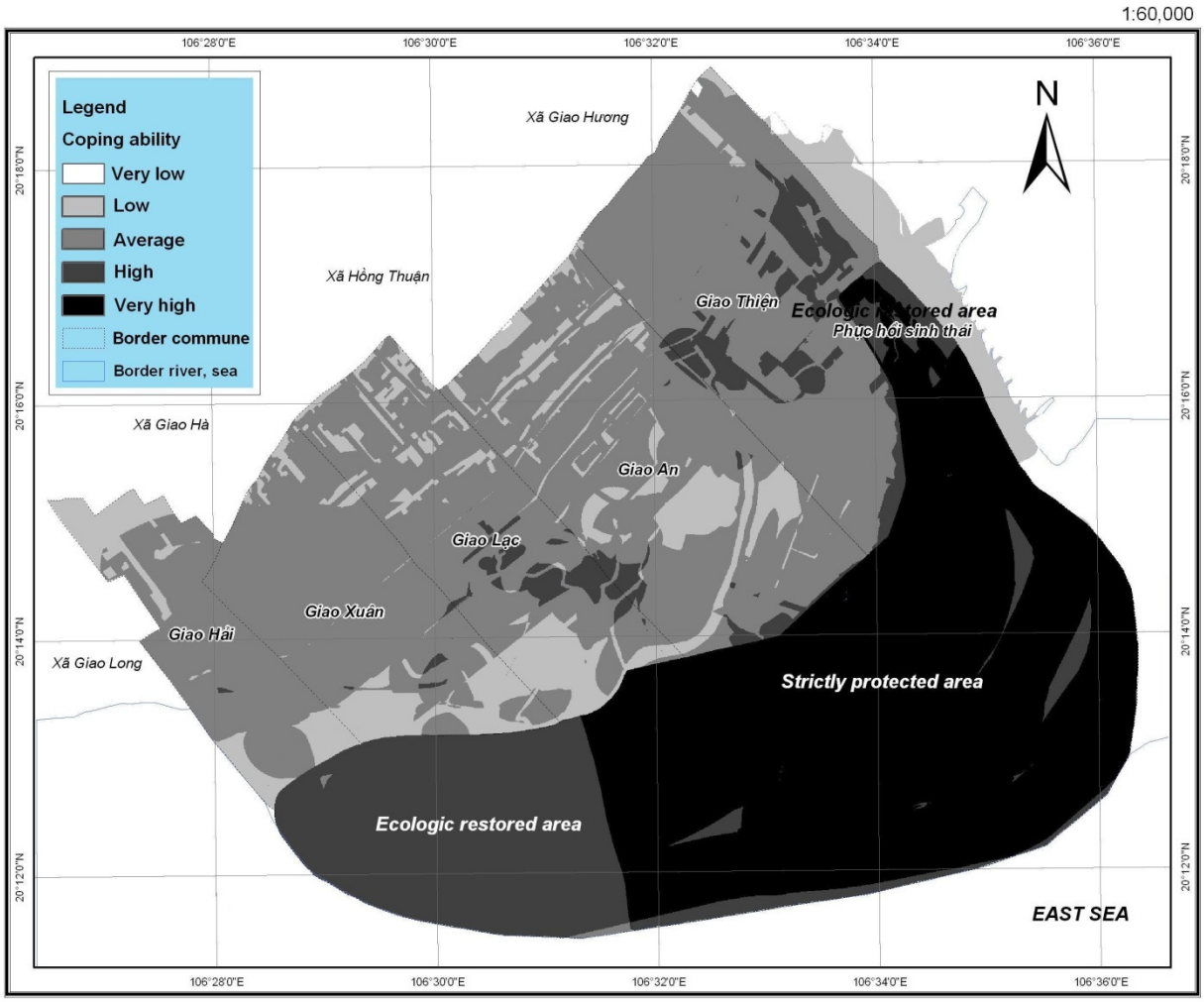

Figure 7: Zoning map of coping capacity of the Xuan Thuy Ramsar site

Results from the assessment allowed a creation of a map of coping capacity of the Xuan Thuy Ramsar site (figure 7). Regions with the highest coping capacity were the strictly protected zone, thanks to the effective protection activities there. Lower coping capacity is registered for the ecological restored zone and communes in the buffer zone.

Discussion

Vulnerability of the Xuan Thuy Ramsar Site was summarized based on three components: Risk; Density, distribution of vulnerable objects; and coping capacity with the risks. Following the protocol in figure 2, the wetland vulnerability maps of Xuan Thuy in are created following three period with different vulnerable objects (figure 8, 9, 10).

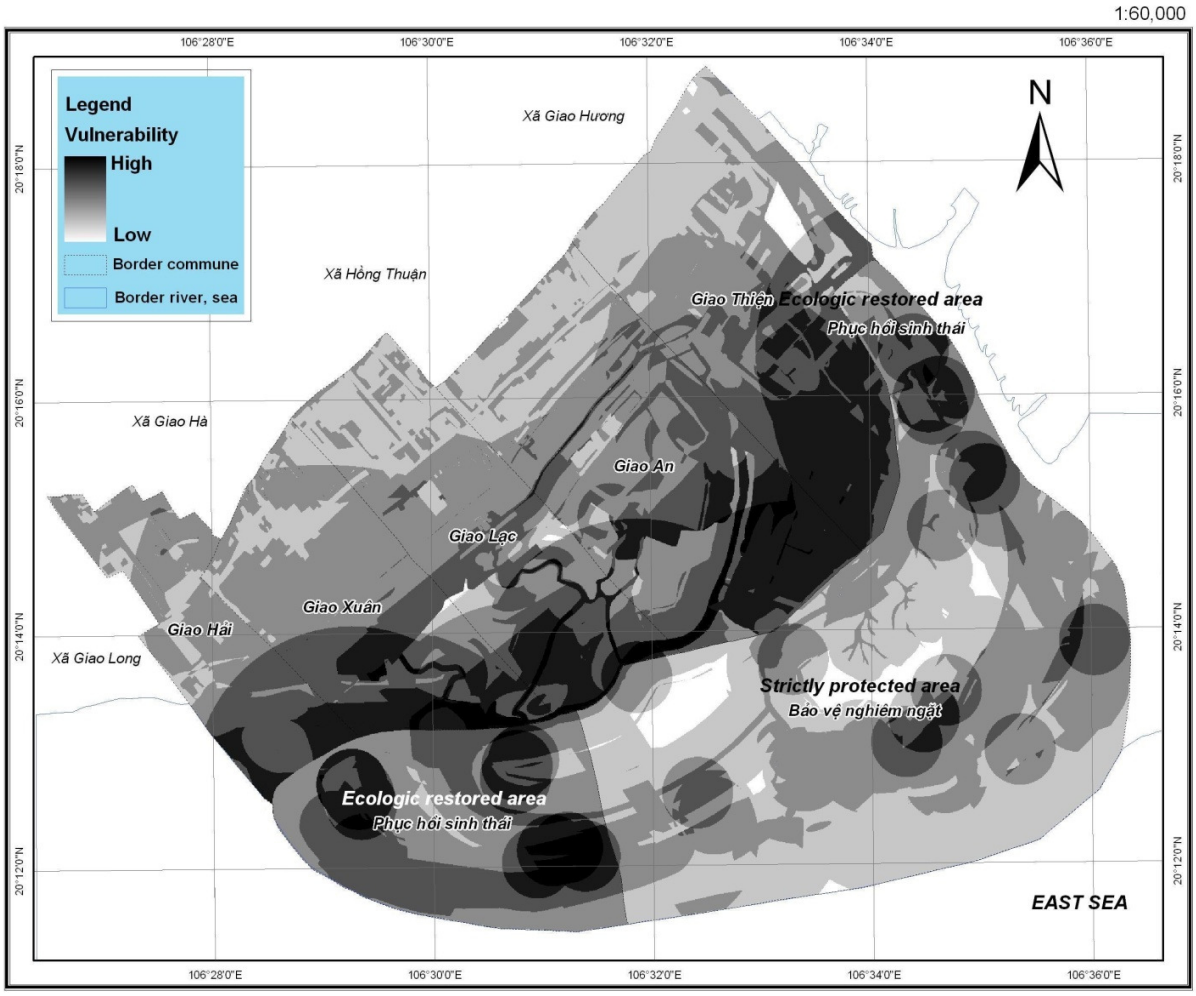

Figure 8: Map of Xuan Thuy wetland vulnerability from November to March of the following year, scale 1:60.000

The characteristics associated with the distribution of vulnerability differed according to space and time. Results from performing map algebra to the above three component maps created three coastal vulnerability maps of three periods in the year. The three maps are classified to 5 levels of vulnerability (from 1-lowest to 5-highest level). Finally, using methods of map algebra to the three vulnerability maps according to period, a vulnerability map in a year was established.

The first period (from November to March of the following year) (Figure 8): This is the most vulnerable period (least resilient). The highest level of vulnerability makes up 14.9% of the total area was concentrated in the South of communes: Giao Thien, Giao An, the buffer zone and a small part of strictly protected area (roosting areas for migratory water birds and areas of looking for food of birds). The lower level of vulnerability concentrated in ecological restored areas and the rest of the strictly protected area showed a diverse botanic-animal system. The lowest level of vulnerability (makes up approximately 2%) was centered in the North of communes of the buffer zone and a small path of strictly protected area.

The second period (in April and from August to October) (Figure 9): This period has lower vulnerability in comparison to the first period. The highest levels of vulnerability makes up 8.7%, concentrated in the South of communes: Giao Thien, Giao Xuan, the East South of commune Giao An. Ecological restored areas and strictly protected areas had lower levels of vulnerability. The North of communes of the buffer zone, a small part of Lu Island (a strictly protected area) had the lowest levels of vulnerability, making up 14.5%.

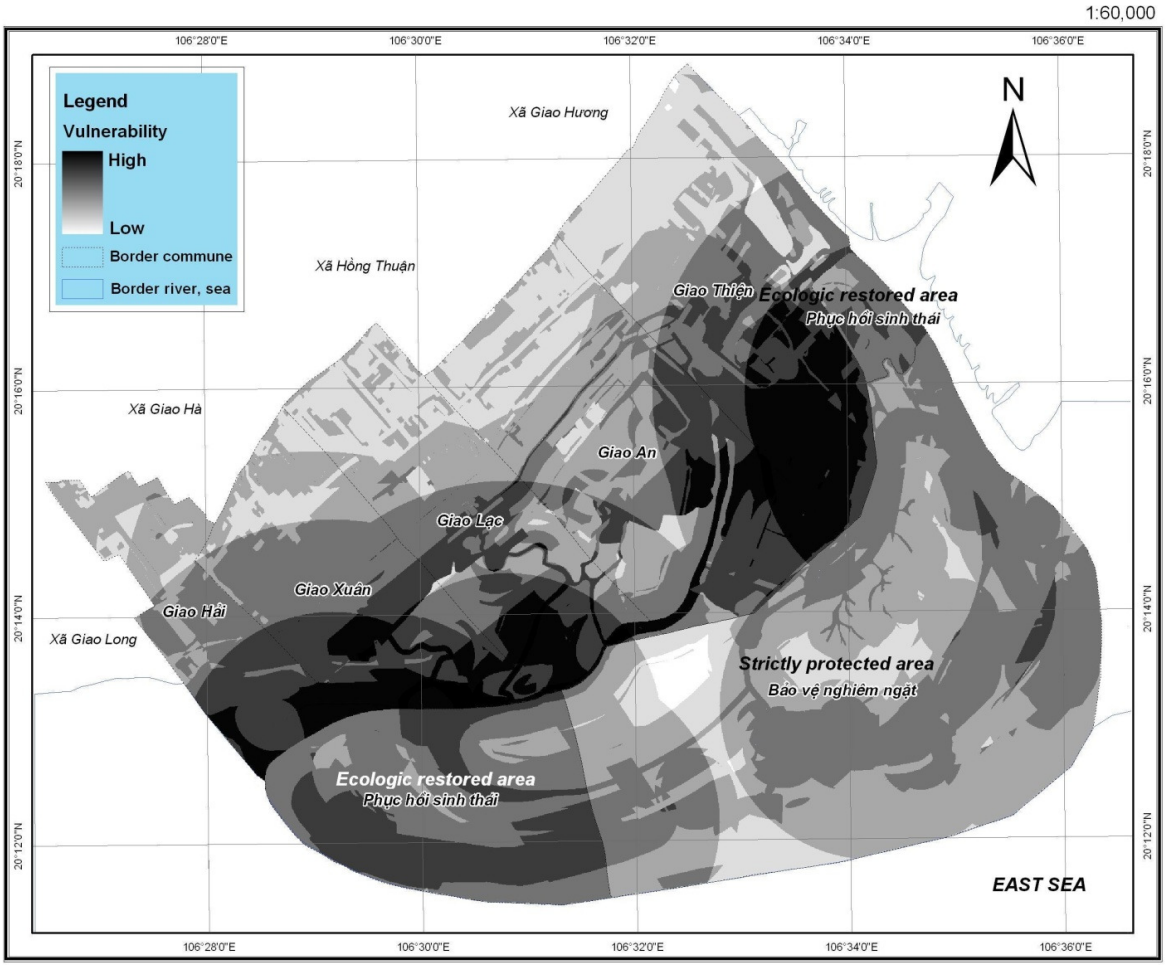

Figure 9: Map of Xuan Thuy wetland vulnerability in April and from August to October, scale 1:60.000

The third period (from May to July) (Figure 10): This period showed the lowest vulnerability. The areas with the highest levels of vulnerability makes up 5.7% of total area, concentrated in the South of communes: Giao Thien, Giao Xuan. Lower vulnerability was concentrated in the ecological restored area. The lowest level of vulnerability makes up 11.6%, concentrated in the North of commune Giao Hai.

Based on three vulnerability maps of three periods, a 1-yr vulnerability map of the Xuan Thuy Ramsar site was established (Figure 11). The highest levels of vulnerability made up 17%, concentrated in the ecological restored area and a part of the South of communes: Giao Thien, Giao Xuan where it borders along the ecological restored area and strictly protected area (these areas developed strong aquaculture and tourism, and are roosting and foraging sites for migratory water birds); coping ability to risk is at an average level. The lowest vulnerable level makes up 14.5% of the total area, concentrated in the South of communes: Giao Thien, Giao An, Giao Lac (these areas have poor wetland systems; the effect of risk is not high, and infrastructure is developed).

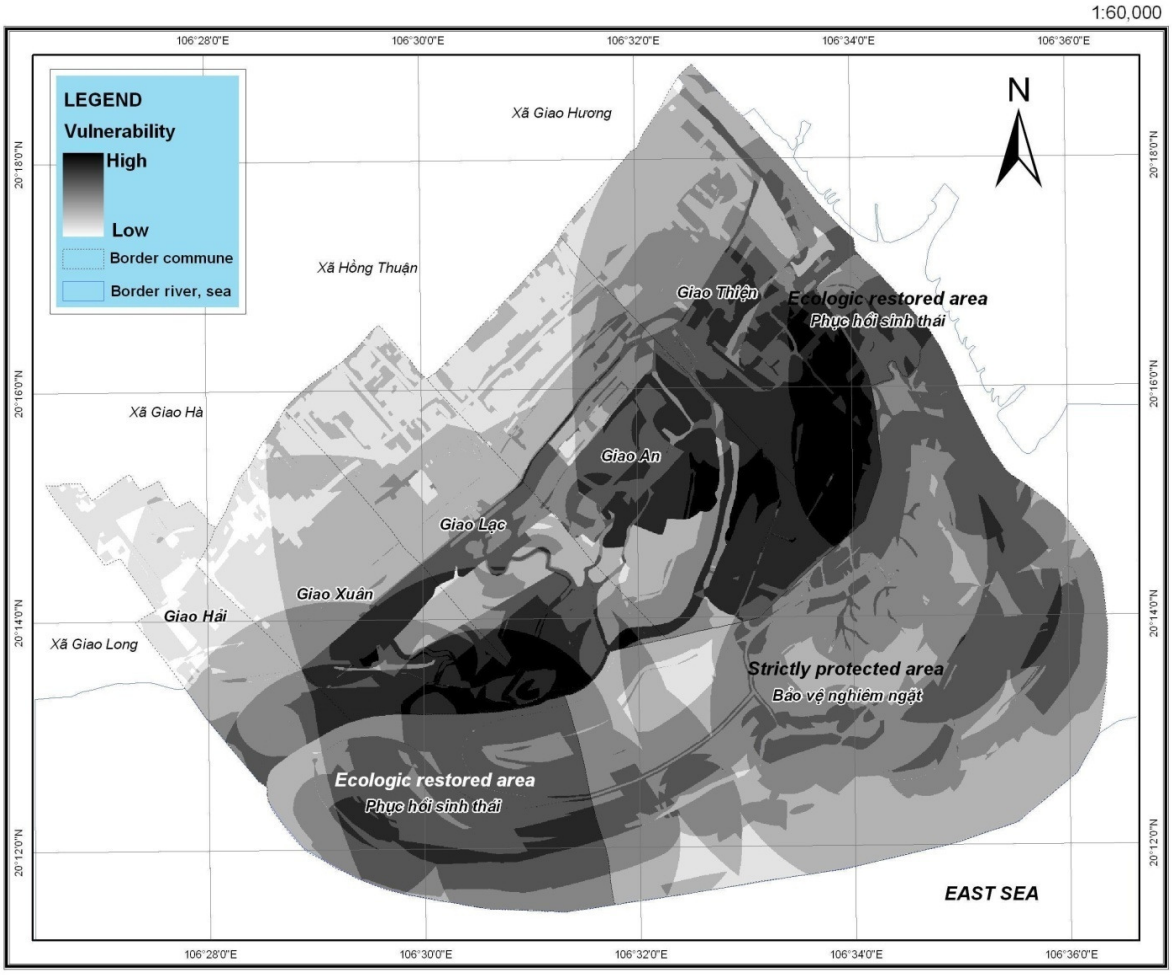

Figure 10: Map of Xuan Thuy wetland vulnerability from May to July, scale 1:60.000

The assessment of vulnerability of wetland ecosystem in Xuan Thuy Ramsar site shows that areas of high vulnerability is generally characterized by combination between high risk (from hazards and intensifying factors), medium to high density of wetland resources (specifically with migratory water birds) whereas the coping capacity of social – economic system is just medium. In controversy, the areas of low vulnerability not only have low risk from hazards but also locate far from social or economic center, inhabitant zone or position of high function – value resources.

Results of vulnerability assessment can be used as the fundament for sustainable use planning of wetland resources in the Xuan Thuy Ramsar site. Solutions to reduce vulnerability level should involve with three main tasks: hazard mitigation (to reduce risk), planning for sustainable wetland resource use (to mitigate damages and loss of vulnerable objects) and education, propagation on protection and conservation of wetland resources (to enhance coping capacity). The planning for sustainable wetland resource use should be based on vulnerability features of the assessed regions (Table 2). Based on characteristics of social-economic development, the types of symbolic wetlands and assessment vulnerability results, there are eco-models that need to be applied and carried out: develop public forestry and eco-tourism together (strictly protected area); eco-agriculture, eco-aquaculture and public forestry (ecological restored area); eco-agriculture and eco-aquaculture (communes of the buffer zone).

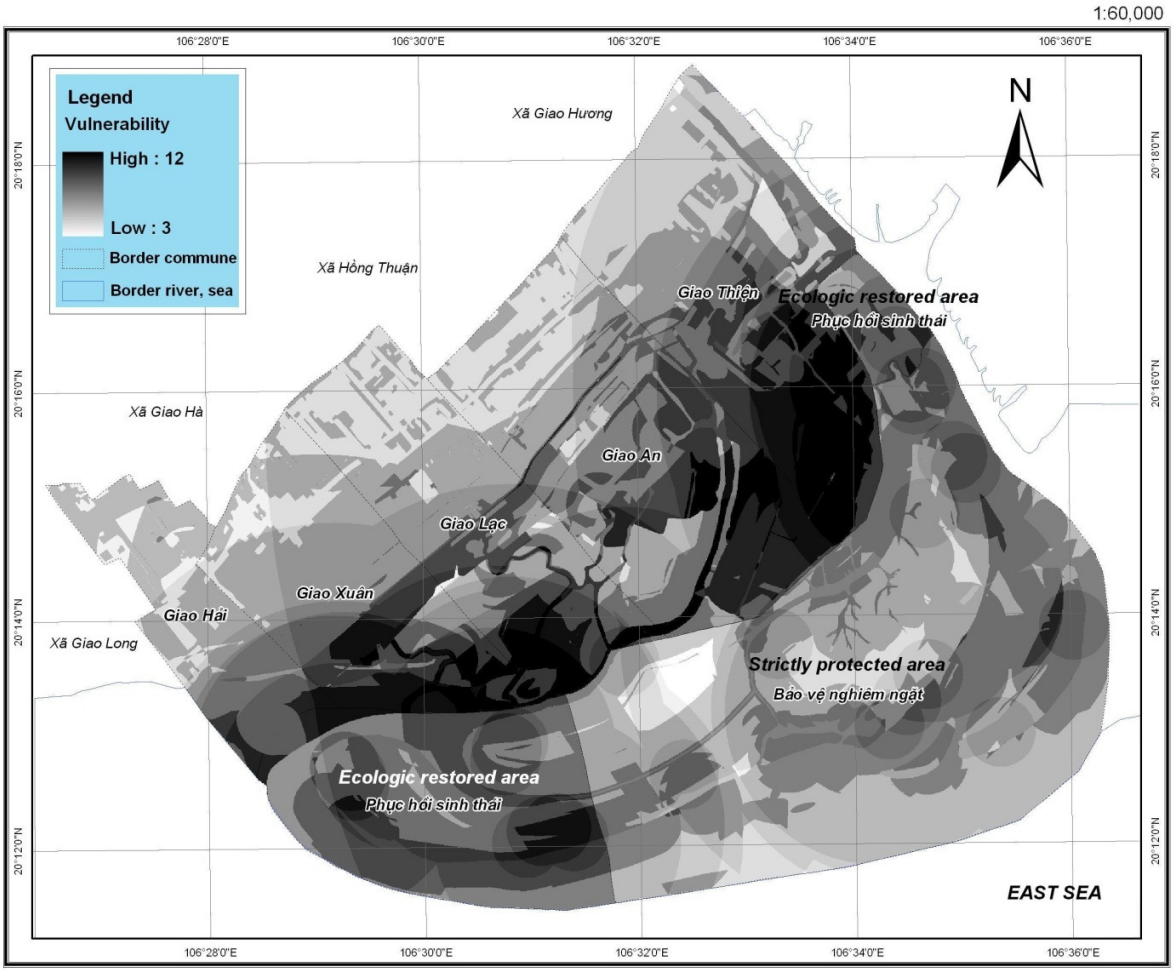

Figure 11: Map of Xuan Thuy wetland vulnerability in a year, scale 1:60.000

Besides, based on classifying vulnerability according to the periods, some solutions should be applied to increase coping capicity, restoring to decrease damage from risk and to protect and preserve the wetland resource. Concretely, the first period (from November to March of the following year) coincides with the peak of migratory water birds and the system is most easily impacted from environmental pollution and saltwater intrusion. Therefore, in this period, it is necessary for activities such as environmental monitoring, increasing management of the environmental resource at the local government, activities to educate and propagate, and raise knowledge in the community.

Conclusion and Recommendations

The factors defining vulnerability of wetland ecosystem in the Xuan Thuy Ramsar site are risk from vulnerability causing factors (with hazards such as erosion, channel siltation, storm and flooding, pollution of water and sediment, etc. and hazard intensifying activities such as aquaculture, agriculture and tourism), density of vulnerable objects (i.e. wetland ecosystem according three periods of a year with different density of migratory birds) and coping capacity (including objects with natural coping capacity such as mangrove forest, intertidal muddy sand or sandy mud flats, consolidated geological formations or with social coping capacity such as intellectual level, infrastructure and programs, actions to protect natural resources and environment, mitigate hazards, etc.).

Table 2: Actions for sustainable use of natural resources and environment in Xuan Thuy Ramsar site, based on vulnerability assessment

Zoning	Location	Characteristics	Actions for sustainable use of natural resources & environment
The areas with low and average vulnerable levels	Strictly protected areas	- Dangerous level from risk - Density, distribution of receptors of vulnerability are at high levels - Coping capacity of very high level	- To encourage development of sustainable ecological economic models, such as public forestry and eco-tourism. - To maintain high effects in management and protection of the area.
	Great area of communes of the buffer zone: Giao Thien, Giao An, Giao Hai, Giao Lac	- Low level of risk - Wetland resources and wildlife are not abundant - Coping capacity to risk is at an average level	- To encourage development of eco-agriculture and eco-aquaculture - To apply measures for management of natural resources and environment, propagation and education about functions and values of natural resources and environment, emphasis on hazard mitigation.
The areas with high vulnerable levels	A great part of area belonging to the ecological restored area and the South of communes Giao Thien, Giao Xuan	- Highest levels of risk - Diverse wetland system (sensitive mangrove ecosystem), as a roosting and foraging area for precious migratory water birds - Coping capacity of average level	- To allow development of only ecological economic models such as eco-agriculture, eco-aquaculture and public forestry. - To restrict effects of exploitation to wetland resources (tourism, aquaculture, agriculture, cut mangrove for firewood, etc)

The vulnerability map of wetland ecosystem in the Xuan Thuy Ramsar site in scale of 1:60.000 was established based on weighted map algebra with overlapping of three criteria classes: risk from vulnerability causing factors, density of vulnerable objects and coping capacity. The areas most vulnerable (a great part of area belonging to the ecological restored area and the South of communes Giao Thien, Giao Xuan) were those exhibiting highest levels of risk, high value vulnerable object (diverse wetland system with sensitive mangrove ecosystem, roosting and foraging area for precious migratory water birds), and coping capacity of humans to risks is at an average level. Conversely, the areas with average and low vulnerable levels of risk occurred in strictly protected areas (has a dangerous level from risk and density, distribution of receptors of vulnerability are at high levels, coping capacity is very high) and the great area of communes of the buffer zone: Giao Thien, Giao An, Giao Hai, Giao Lac (these areas are far from the coastline, they have a low level of risk, wetland resources and wildlife are not abundant, coping capacity to risk is at an average level).

Based on vulnerability levels, some solutions were proposed for the suitable use of wetland resources and to serve sustainable development of coastal zone: planning for suitable use of wetland resources based on assessment vulnerability (public forestry, eco-agriculture, eco-aquaculture, eco-tourism), increased coping capicity, restore to decrease damage from risk (manage resource and environment, educate, raise knowledge of community, environmental monitoring). Besides, in the period with the highest density of migratory bird (from November to March of the following year), activities such as environmental monitoring, wetland protection and management, education to enhance coping capacity should be emphasized.

References

1. Adger WN. 2006.Vulnerability. *Global Environmental Change*, 16 (3): 268-281.
2. Bankoff G, G Frerks, D Hilborst. 2004. Mapping vulnerability: disasters, development, and people. Earthscan Publications Ltd. Illustrated edition. 356 p.
3. Cutter SL. 1996. Vulnerability to environmental hazards. *Progress in Human Geography*, 20: 529 – 539.
4. Cutter SL, JT Mitchell, MS Scott. 2000. Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers*, 90(4): 713 – 737.
5. Cutter SL, C Finch. 2008. Temporal and spatial changes in social vulnerability to natural hazards. *PNAS* vol. 105 no. 7: 2301-2306.
6. Dao PTA, PN Hong, LX Tuan, TM Phuong, NH ThoH. 2007. Social economic features of the Xuan Thuy national park. *MERC – MCD*, Hanoi, Vietnam, 25p.
7. Dasgupta S, B Laplante, C Meisner, D Wheeler, J Yan. 2007. Impacts of sea level changes on the developing countries – A comparative analysis. The World Bank, USA.
8. Elizabeth AP, ER Thieler, SJ Williams. 2005. Coastal vulnerability assessment of Point Reyes National Seashore to sea-level rise. Open-file Report 2005-1059. U.S. Geological Survey, Coastal and Marine Geology Program, USA.
9. Kaly UL, C Pratt, J Mitchell. 2005. The Environmental Vulnerability Index (EVI). SOPAC Technical Report 384.
10. Hien LTT, MT Nhuan, TV Y. 2006. Vulnerability assessment for environmental planning and management (on example of Hai Phong city). *Journal of Earth Sciences*, No 1 (T.28): 1-10.
11. Hong PN, LX Tuan, PTA Dao. 2007. Biodiversity of the Xuan Thuy National Park. *MERC – MCD*, Hanoi, Vietnam, 41p.
12. Hong PDV, NV Cach, LT Binh, LX Dung. 2007. Management of the Xuan Thuy National Park. *MERC – MCD*, Hanoi, Vietnam, 25p.
13. Ngoc NTM, MT Nhuan, DV Luyen. 2004. Geochemical sedimentary evolution features of the processes of formation, development and degradation of mangrove forests in Namdinh coastal region, Vietnam. *VNU Journal of Science*, Nat., Sci., T.XX, No 3: 33 - 42.
14. Nhuan MT. 1997. The potential pollution of the sea water and sediments in Nga Son - Hai Phong shallow offshore area. Proceedings of the 7th Symposium on Geo-environment and Geo-technics, Tokyo: 63-70.
15. Nhuan MT. 1997. The Geohazards in the Nga Son - Hai Phong coastal zone. Proceedings of the 7th Symposium on Geo-environments and Geo-technics, Tokyo: 235-244.
16. Nhuan MT, NTH Hue, TD Quy, NT Tue. 2005. Vulnerability assessment of coastal zone from Phan Thiet – Ho Tram, Vietnam for sustainable development. *Scientific Journal of Hanoi National University*, No 4 (21): 6-16.
17. NOAA. 1999. Community vulnerability assessment tool CD – ROOM. NOAA Coastal Services Center .
18. Pratt CR, UL Kaly, J Mitchell. 2004. Manual: How to use the Environmental Vulnerability Index (EVI). SOPAC Technical Report 383.
19. Saaty TL. 1980. The analytic hierarchy process: planning, priority setting, resource allocation, McGraw-Hill, New York.
20. Saaty TL. 2003. Decision aiding: decision – making with the AHP: why is the principal eigenvector necessary, *European Journal of Operational Research*, No 145: 85-91.
21. Taubenböck H, J Post, A Roth, K Zosseder, G Strunz, S Dech. 2008. A conceptual vulnerability and risk framework as outline to identify capabilities of remote sensing. *Natural Hazards and Earth System Science*, 8 (3): 409-420.
22. Torresan S, A Critto, M Dalla Valle, N Harvey, A Marcomini. 2008. Assessing coastal vulnerability to climate change: Comparing segmentation at global and regional scales. *Sustainability Science*, 3 (1): 45-65.