MAPPING COASTAL VULNERABILITY USING ICVI (INTEGRATED COASTAL VULNERABILITY INDEX) IN NAM DINH COAST, VIETNAM

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SUMMARY

Based on coastal topographical and geomorphologic features, natural and socioeconomic conditions, 3 groups of indices were selected to assess the coastal vulnerability, including: (i) geographical indices; (ii) eco-environmental indices; and (iii) socio-economic indices. Through surveying in field trip and based on available reports, this study analyzed data and constructed coastal vulnerability maps in Nam Dinh coast. The results showed that the total length of the studied shorelines is 65.62 kilometers, including 17.42 km of coastline with low level of vulnerability (26.55%); 16.73 km with moderate level of vulnerability (25.5%); 14.63 km of coastline with high level of vulnerability (22.3%); and 16.84 km of coastline with a very high level of vulnerability (25.65%). Based on the results, this study proposed 3 main solutions to adapt climate change impacts for vulnerable areas, containing (i) protection; (ii) accommodation; and (iii) retreat.

Keywords: Adaptation, climate change, coastal vulnerability, index, Nam Dinh coast.

I. INTRODUCTION

Nowadays, evidence of climate change impacts as global warming and sea-level rise is one of the greatest challenges for human on a global scale. With 3,260 km of shorelines in length, Vietnam's coastal zone provides the diverse natural resources and auspicious conditions for socioeconomic development, such as fisheries, aquaculture, agriculture, tourism, transportation, urbanization. There are many low-lying coastal land areas, in there, over 80% of Mekong River Delta' area and over 30% of Red - Thai Binh river' area have an elevation under 2.5 m (Tuan et al., 2012). Thus, these coastal areas are seriously influenced by drought and saltwater intrusion in dry season and inundation in rainy season every year, and climate change has made it worse.

Nam Dinh is one of these low-lying land regions with its coastline, which is about 72 km long. Here one will also find Xuan Thuy National Park. In recent years, along with economic development there are negative impacts of climate change and sea-level rise on these areas. They lead to decreasing of mangrove forest area, increasing saltwater intrusion or flood tide etc. These factors have raised the vulnerable level for natural resources, environment, structures and coastal people's lives. From that point it causes adverse effects to production activities of coastal people. Nam Dinh is one of the coastal provinces where are easy to be vulnerable due to climate change impacts, however, there is still less research and project assessing coastal vulnerability in this area. In this paper, mapping coastal vulnerability using ICVI (Integrated Coastal Vulnerability Index) and GIS is conducted in Nam Dinh coast as a case study in Vietnam. Findings of assessment of coastal vulnerability will provide the basis for further studies in order to forecast and propose adaptation and mitigation solutions for coastal areas in Vietnam, in general and in the studied area in particular.

II. RESEARCH METHODOLOGY

Selection of coastal vulnerability assessment indices:

This study extended the original formulation of the ICVI by taking into account variables representing the socio-economic

systems and eco-environmental characteristics.

(1) Group of Geographical indices

Coastal geomorphology index is adapted from Pendleton et al. (2010).

Coastal Elevation index is adapted from Kumar et al. (2010).

Relative sea-level index rise is adapted from Abuodha and Woodrofle (2006).

Coastal slope index is adapted from Davies (2012).

Average tidal range index is adapted from Ozyurt (2010).

Mean wave height index is adapted from Thieler and Hammar-Klose (1999).

Table 1. Assessing coastal vulnerability according to Geographical indices

Variables	Ranking of coastal vulnerability index (CVI)				
	1	2	3	4	5
Coastal Geomorphology (a)	Coastal cliff is parent rock	Coastal cliff is sediment	Dike; Sea-wall	Mangroves; No coastal cliff	No coastal cliff nor mangroves
Coastal elevation (m) (b)	-	> 10.0	5.0 ÷ 10.0	1.0 ÷ 5.0	< 1.0
Relative sea-level rise (mm/year) (c)	< 0.0	0.0 ÷ 0.9	1.0 ÷ 2.0	2.1 ÷ 3.0	> 3.1
Coastal slope (degree) (d)	> 20.0	11.0 ÷ 20.0	7.0 ÷ 11.0	3.0 ÷ 7.0	0.0 ÷ 3.0
Average tidal range (m) (e)	> 2.1	1.6 ÷ 2.0	1.1 ÷ 1.5	0.6 ÷ 1.0	0.0 ÷ 0.5
Mean wave height (m) (f)	0.0 ÷ 0.5	0.6 ÷ 1.0	1.1 ÷ 1.5	1.6 ÷ 2.0	> 2.1

Sources: Adapted from Pendleton et al. (2010), Kumar et al. (2010), Abuodha and Woodrofle (2006), Davies (2012), Ozyurt (2010), Thieler and Hammar- Klose (1999).

(2) Group of Eco-environmental indices

Mangroves width index is adapted from Raji et al. (2013), Palmer et al. (2011).

Coastal vegetation structures index is adapted from Sousa et al. (2012).

Coastal protection structures index is adapted from Ozyurt et al. (2010).

Table 2. Assessing coastal vulnerability according to eco-environmental indices

Variables	Ranking of coastal vulnerability index (CVI)				
	1	2	3	4	5
Mangroves width (m) (g)	-	> 140	100 ÷ 140	70 ÷ 100	< 70
Coastal vegetation structure (h)	-	Dense vegetation cover with many types of vegetation	Cover almost all coastal area: grasses, shrub and other plants…	Thin vegetation, nearly absent	Absence
Coastal protection structures (%) (i)	> 50	30 ÷ 50	20 ÷ 30	5 ÷ 20	< 5

Sources: Adapted from Ozyurt et al. (2010), Sousa etal. (2012), Raji et al. (2013).

(3) Group of Social indices

Distance of residential area to Coast index is adapted from Raji et al. (2013), Palmer et al. (2011).

Population density index is adapted from Jana and Hegde (2016).

Land use pattern index is adapted from Ozyurt et al. (2010).

Table 3. Assessing coastal vulnerability according to social indices

Variables	Ranking of coastal vulnerability index (CVI)				
	1	2	3	4	5
Distance of residential area to Coast (m) (j)	> 1,000	700 ÷ 1,000	400 ÷ 700	100 ÷ 400	< 100
Population density (people/km^2) (k)	< 5,000	5,000 ÷ 10,000	10,000 ÷ 15,000	15,001 ÷ 20,000	> 20,000
Land-use pattern (l)	National park	Natural mangroves, grass, shrubs	Residential area	Industrial land	Farmland

Sources: Adapted from Ozyurt et al. (2010), Jana and Hegde (2016), Raji et al. (2013), Palmer et al. (2011).

Each parameter is assessed and given score according to the rank from 1 to 5, which are proportionate to different vulnerable degrees: very low (1), low (2), moderate (3), high (4), and very high (5).

Based on the developed assessment model, this study assessed coastal vulnerability for each variable within 65.62 km of the Nam Dinh shoreline.

Calculation of ICVI (Integrated Coastal Vulnerability Index):

After class scores are obtained, the ICVI is calculated as the square root of the product of the ranked variables divided by the total number of variables. This formula was used in the study of Kumar et al. (2010) with adaptation.

$$ICVI = \sqrt{\frac{a\ b\ c\ d\ e\ f\ g\ h\ i\ j\ k\ l}{12}}$$

Where: a is Coastal Geomorphology; b is Coastal elevation; c is Relative sea-level rise; d is Coastal Slope; e is Average tidal range; f is Mean wave height; g is Mangroves width; h is Coastal vegetation structure; i is Coastal protection structures; j is Distance of residential area to Coast; k is Population; l is Land-use pattern.

Classification of vulnerable degrees: After calculating, each group of indices is divided into four ranks: low (1), moderate (2), high (3), and very high (4). Percentiles (25th, 50th, 75th) are used to determine the limits of scores in ranking based on the quartile ranges and data visual inspection.

Construction of coastal vulnerability maps: After the categorization, maps of coastal vulnerability are constructed based on the data ranks and tabulations of each vulnerability variables combining with coordinate points in latitude and longitude taken by GPS in the field survey. From that, classifying vulnerable degrees for the studied coast was carried out. ArcGIS 10.1 software was used to construct maps by using spatial analyst tools, including Spatial Analyst Tools and Data Management Tools.

III. RESULTS

3.1. Coastal vulnerability assessments

(1) Group of Geographical indices

a) Coastal Geomorphology: The entire studied coast is protected by sea dike and breakwaters. In some areas such as Thinh Long town (Hai Hau district), dike system is downgraded and eroded because of some recent storms. However, the local government has planned to restore and upgrade dike system in these areas. Thus, the entire coast is assessed at score 3 as moderate vulnerability.

b) Coastal Elevation (m): Data in Google Earth and DEM extracted through ArcGIS show that most parts of the studied coast have an elevation ranging from 5 m to 10 m; other parts are above 10 m of elevation, so the assessments for these areas are 2 and 3 scores, respectively. Very few parts in Giao Hai, Bach Long communes (Giao Thuy district) and Rang Dong commune (Nghia Hung district) are

assessed at 4 and 5 scores because the elevation in these areas is less than 5 m and some other parts are less than 1 m.

c) Relative sea-level rise (mm/year): Based on the report from Vietnam Institute of Marine Geology and Geophysics, it increases 2.15 mm of sea-level each year in Nam Dinh. Therefore, this index is assessed at 4 score as high vulnerability.

d) Coastal slope (degrees): Similar to elevation, coastal slope is assessed according to the information from Google Earth and DEM, most parts of the coast have slope ranging from 0 to 7 degrees, so the assessment ranking is 4 or 5 scores. Besides, there are some alternate parts having coastal slope ranging from 7 to 20 degrees, thus these areas are assessed at 1 or 2 or 3 scores.

e) Average tidal range (m): Nam Dinh People's Committee (2016) reported that the average tidal range thereis about 1.6 ÷ 1.7 m, thus the assessment ranking for the whole coast is 2 as low vulnerability.

f) Mean wave height (m): Based on the monitoring data from Hon Dau station, average wave height is about 1.8 ÷ 2 m in winter and 1.2 ÷ 1.4 m in summer. Thus the mean wave height is about 1.6 m and the entire coast is assessed at 4 score as high vulnerability.

(2) Group of eco-environmental indices

Through surveying in fieldtrip combining with Google Earth, the Eco-environmental indices are assessed as follows:

g) Mangroves width (m): In Xuan Thuy National Park which contains Giao Thien, Giao Hong, Giao An and Giao Lac communes, mangrove width is more than 600 m, some sections have mangrove width ranging from 200 ÷ 600 m. Mangrove in the Northeast of Hai Dong commune and Rang Dong, Nam Dien is also dense. Thus these areas are assessed at 1 and 2 scores as very low and low vulnerability. Some sections in Giao Xuan, Hai Loc, Hai Dong, Hai Ly, Rang Dong and Nam Dien are assessed at moderate vulnerability at 3 scores with thinner mangrove belt. There are no mangroves in some areas such as Giao Hai, Giao Long, Bach Long, Giao Phong communes, Quat Lam town, most of Hai Hau coastline and some sections in Rang Dong and Nam Dien. Some sections in these areas have very little mangrove. Thus, these areas are assessed at score 4 and 5. It means high and very high vulnerability.

h) Coastal vegetation structures: Most of Giao Thuy district (Giao Thien, Giao An, Giao Lac and Giao Xuan communes) is assessed at 2 scores as low vulnerability because the coastal vegetation structure is mangrove forest and Casuarina. Two communes Rang Dong and Nam Dien also have mangrove so the assessment ranking is the same. Some areas such as Giao Hai, Giao Long, Bach Long, Giao Phong communes, Quat Lam town, most of Hai Hau coastline and some sections in Rang Dong and Nam Dien have no vegetation, so the assessment ranking is 4 or 5.

i) Coastal protection structures (%): Most of the shoreline is protected by sea dike, however areas have both dike and vegetation (mangrove and Casuarina) are protected better than other areas. Therefore, some communes located in Xuan Thuy National Park (Giao Thien, Giao An, Giao Lac, Giao Xuan, Giao Hong) and Rang Dong, Nam Dien are assessed that the areas protected over 50%. Thus, the assessment ranking is 1 score. Other areas, which are only protected by sea dike and have thin vegetation, are assessed at 2 or 3 scores. Some parts are assessed at 4 or 5 scores because these areas have no vegetation or the dike system is downgraded (almost Hai Hau coast).

(3) Group of Social indices

j) Distance of residential area to Coast: Most of the communes in Giao Thuy and Rang Dong (Nghia Hung) are protected by a large

area of mangrove forest, so the residential areas are far from the coast, these areas are assessed at 1 or 2 or 3 scores. In other areas such as Quat Lam, Thinh Long communes (Hai Hau district), the residential areas are near the coast, thus the assessment ranking in these areas is 4 or 5.

k) Population density: This index is assessed at 1 score in the entire coast because three districts have a population density less than 5,000 people/km^2. In particular, Giao Thuy district has 816 people/km^2, Hai Hau has 1,118 people/km^2, and Nghia Hung has 703 people/km^2 (Statistics Office of Nam Dinh, 2013).

l) Land use pattern: Communes located in Xuan Thuy National Park were assessed at 1 score. Some areas having thin mangrove or shrub or Casurina such as Rang Dong (Nghia Hung district) or some alternate sections in Hai Hau district are assessed at 2 scores. Quat Lam, Thinh Long communes (Hai Hau district) are residential areas so the assessment ranking is 3. Other areas which have aquaculture ponds (Giao Phong, Hai Dong, Hai Ly, Hai Chinh and Rang Dong commune) and paddy fields (Thinh Long town) are assessed at 5 scores.

Table 4. Summary of Integrated Coastal vulnerability indices (ICVI) in the studied coast

Groups of indices	ICVI		
	Min	Average	Max
Geographical indices	5.66	13.66	20.00
Eco-environmental indices	0.82	4.41	6.45
Social indices	0.58	1.42	2.58
Integrated Indices	8.00	200.48	707.11

The calculated ICVI values range from 8.00 to 707.11 and the mean ICVI value is 200.48. The 25th, 50th, and 75th percentiles are 53.67, 189.74 and 309.84, respectively. Based on the calculated results, ICVI is divided into 4 levels of vulnerability corresponding with intervals 25% (Low vulnerability), 50% (Moderate vulnerability), 75% (High vulnerability) and 100% (Very high vulnerability). Specifically, ICVI values below 53.67 are assigned to the low risk category. Values from 53.67 to 189.74 are considered moderate risk. High risk values lie between 189.74 and 309.84. ICVI values above 309.84 are classified as very high risk (Figure 1).

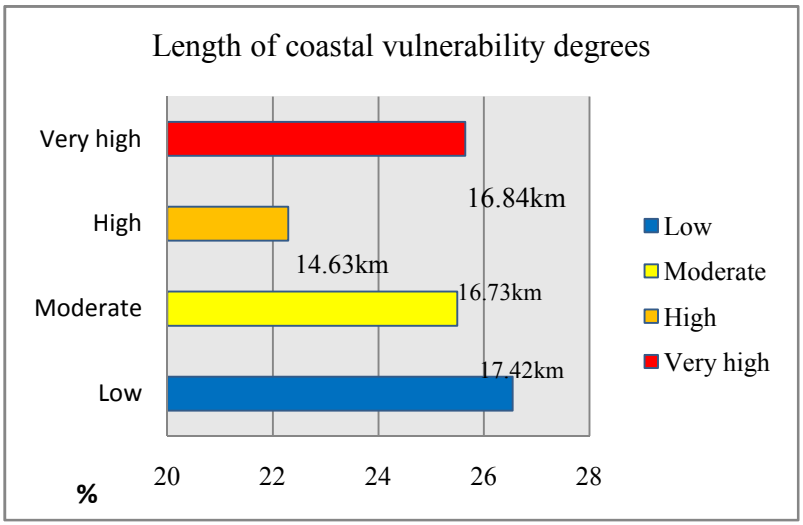

Figure 1. Length of coastal vulnerability degrees

Figure 1 shows a total of 65.62 km of shoreline is ranked in the studied area. Of this total, 25.65 percent of the mapped shoreline is classified as being at very high risk due to future sea-level rise. 22.30 percent is classified as high risk, 25.5 percent as moderate risk, and 26.55 percent as low risk.

3.2. Construction of coastal vulnerability maps

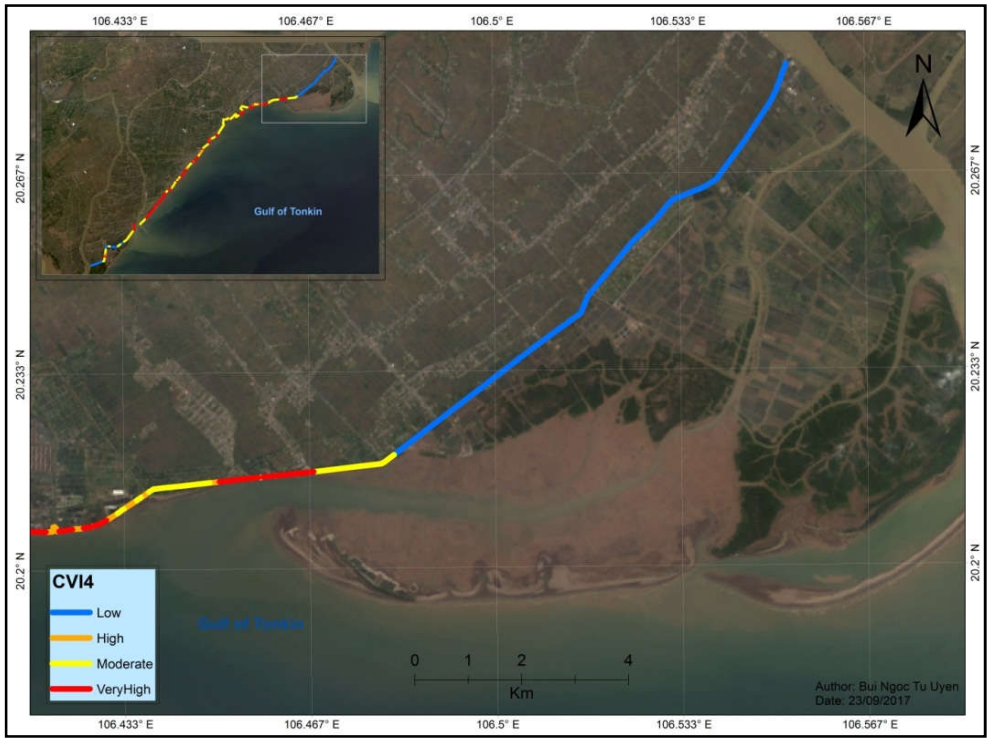

Figure 2. Coastal vulnerability from Giao Thien to Giao Xuan communes

Figure 3. Coastal vulnerability from Giao Hai to Hai Dong communes

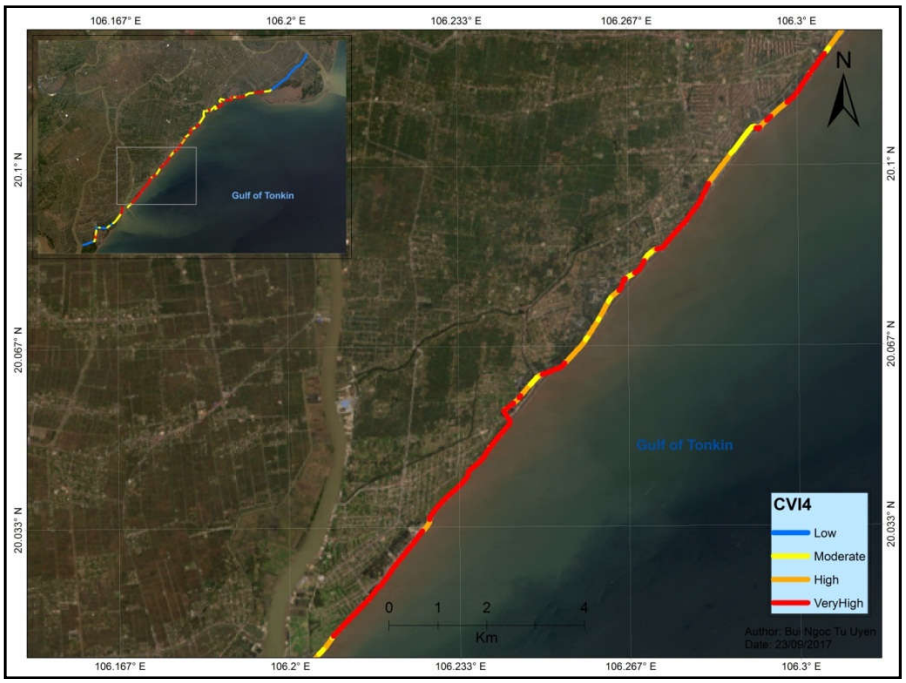

Figure 4. Coastal vulnerability from Hai Ly to Thinh Long communes

Figure 5. Coastal vulnerability from Nghia Phuc to Nam Dien communes

In Giao Thuy district, Giao Thien, Giao An, Giao Lac, and most of the shoreline in Giao Xuan communes are at low vulnerability with ICVI ranging from 8.00 to 53.67. These areas are protected by a large area of mangrove forest of Xuan Thuy National Park. However, in these communes, aquaculture ponds have been expanding both behind and in front of sea dike. These activities will increase coastal vulnerability under impacts of climate change and sea-level rise in the near future. Some sections in Giao Hai, Giao Long, and most of the shoreline in Bach Long, Giao Phong, and shoreline in Quat Lam beach (Giao Lam) are at high with ICVI ranging from 189.74 to 309.84 and very high vulnerability with ICVI ranging

from 309.84 to 707.11. These areas are not protected by mangrove forest, besides aquaculture ponds have been developing. Especially, in Quat Lam beach, tourism activities and houses, hotels built too close to the shoreline have caused many negative impacts on the shoreline and sea dike. Some sections of sea dike have been downgraded due to sea wave and storms. Thus, this area is one of the highest vulnerable areas in Giao Thuy district. Other sections are at moderate vulnerability with ICVI ranging from 53.67 to 189.74.

In general, Hai Hau district is the highest vulnerable area under climate change impacts in comparison with the whole coast of Nam Dinh. Specifically, nearly a half of Hai Dong shoreline and most of the shoreline in Hai Ly, Hai Chinh, Hai Trieu, Hai Hoa and Thinh long are at high and very high vulnerability. In these areas, residents live near the coast, vegetation is very thin (or nearly absent). In Thinh Long beach, livelihood activities of the residents occur too near the coast (hotels, houses, or paddy fields are close the shoreline). In other communes such as Hai Chinh, Hai Trieu, Hai Hoa, aquaculture ponds have been expanding near the sea dike. These activities contribute to increase coastal vulnerability under impacts of climate change. Remaining sections are at moderate vulnerability.

In Nghia Hung district, nearly a half of the shoreline in Nghia Phuc and some sections in Nam Dien are at high and very high vulnerability. In Nghia Phuc, residents live near the coast; moreover this commune is not protected by mangrove forest. Coastal vulnerable sections in Nam Dien are in the intertidal zone, thus these areas are impacted by flood tide and sea-level rise. Most of the shoreline in Rang Dong and more than a half of the shoreline in Nam Dien are at low vulnerability due to dense ranges of mangrove. Other sections which have the same characteristics in Geographic, Eco-environment and Society are at moderate vulnerability.

3.3. Propose solutions to adapt climate change impacts on the studied coast

In the context of the present, adaptation and mitigation impacts of sea-level rise are very important in order to reduce coastal vulnerability and risks caused by climate change and sea-level rise. In general, there are many solutions to adapt climate change impacts depends on economic development and entity in each region. But based on the results, 3 main solutions are proposed:

a. Protection: It includes soft solutions and engineering solutions. Engineering solutions are popular solutions often used at present, such as constructing and upgrading breakwaters, drainages or sea dike, etc. This solution should be applied for some downgraded sea dikes and drainages in highly vulnerable areas like Bach Long, Quat Lam and Thinh Long communes. Soft solutions are called as "Ecological engineering solutions". It is ecosystem based approach (EbA) such as plant more mangroves to increase the area of mangrove forest or increasing accretion for the shoreline or reinforcing protection forest in the coast (Casuarina) etc. This solution is suitable for areas which have thin mangroves. For example, some sections at the end of Xuan Thuy National Park (Giao Xuan commune); some sections in Quat Lam town, Hai Loc, Hai Dong communes; especially in Thinh Long commune.

b. Accommodation: These solutions are transforming infrastructures, cultivation habits, or land use patterns etc. so as to reduce coastal vulnerability, and enhance the ability to adapt climate change and sea-level rise. Accommodation solutions should be applied to some areas such as Thinh Long. Specifically, paddy fields too close to the shoreline should be transformed to another purpose in order to

reduce saline intrusion risk. Floor of houses near the shoreline in Quat Lam and Thinh Long should be constructed much more higher to avoid inundation when storms or floods occur.

c. Retreat: If these solutions above cannot perform, final solutions should be retreat inland. It includes resettling and removing of houses or infrastructures from inundated areas to safe areas.

To apply these solutions above effectively, there should be some policies of the government in order to support local people to solve problems. For example, Resettlement Policy, Protection forest development policy etc. In addition, the government should have financial supports for coastal protection activities, media activities for raising awareness about impacts of climate change etc.; or investigation for projects about impacts of climate change on coastal areas, from there propose suitable adaptation and mitigation plans for each region.

IV. CONCLUSION

Based on coastal topographical and geomorphological features, natural and socioeconomic conditions, 3 groupsof indices were selected to assess the coastal vulnerability, including: (i) geographical indices; (ii) eco-environmental indices; and (iii) socio-economic indices. Through surveying in field trip and based on available reports, this study analyzed data and constructed coastal vulnerability maps in Nam Dinh Coast. The results showed that the total length of the studied shorelines is 65.62 km, including 17.42 km of coastline with low level of vulnerability (26.55%); 16.73 km with moderate level of vulnerability (25.5%); 14.63 km of coastline with high level of vulnerability (22.3%); and 16.84 km of coastline with a very high level of vulnerability (25.65%).

The areas being at the greatest vulnerability under climate change impacts are in Hai Hau district and Quat Lam town. In these areas, residents live near the coast, mangrove is very thin (or nearly absent) and livelihood activities of the residents occur too near the coast (hotels, houses, or paddy fields etc. are close to the shoreline). Conversely, the areas which are at low vulnerability are buffer zone communes of Xuan Thuy National Park (from Giao Thien to Giao Xuan) and Nam Dien commune due to the dense mangrove forests and low population density.

Based on the results, this study proposed 3 main solutions to adapt climate change impacts for vulnerable areas, containing (i) protection; (ii) accommodation; and (iii) retreat. In addition, other areas which are at low vulnerability now might not avoid climate change impacts in the future. Thus, adaptation and mitigation solutions under climate change impacts are very necessary in both high and low vulnerable areas.

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SỬ DỤNG CHỈ SỐ TỔN THƯƠNG (ICVI- INTEGRATED COASTAL VULNERABILITY INDEX) XÂY DỰNG BẢN ĐỒ NGUY CƠ TỔN THƯƠNG KHU VỰC BỜ BIỂN TỈNH NAM ĐỊNH

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TÓM TẮT

Quá trình khảo sát dọc tuyến ven biển Nam Định, dựa vào đặc điểm địa hình, điều kiện tự nhiên và kinh tế xã hội, nghiên cứu đã chọn 3 nhóm chỉ số để đánh giá mức độ nguy cơ tổn thương: (i) chỉ số về địa lý; (ii) chỉ số về môi trường sinh thái và (iii) chỉ số về xã hội. Qua quá trình khảo sát thực địa và dựa theo các báo cáo nghiên cứu trước đây, nghiên cứu đã phân tích số liệu và xây dựng bản đồ thể hiện nguy cơ tổn thương tại vùng biển Nam Định. Kết quả cho thấy tổng chiều dài đường bờ ven vùng biển nghiên cứu là 65,62 km, trong đó 17,42 km đường bờ ở mức tổn thương thấp (chiếm 26,55%); 16,63 km đường bờ ở mức trung bình (chiếm 25,5%); 14,63 km đường bờ ở mức tổn thương cao (chiếm 22,3%); và 16,84 km đường bờ ở mức tổn thương rất cao (chiếm 25,65%). Dựa theo kết quả nghiên cứu, nghiên cứu đề xuất 3 nhóm giải pháp chính nhằm ứng phó với ảnh hưởng của biến đổi khí hậu tại vùng biển nghiên cứu như sau: (i) Các biện pháp bảo vệ; (ii) Các biện pháp thích ứng and (iii) Các biện pháp di dời.

Từ khóa: Biến đổi khí hậu, biển Nam Định, thích ứng, tổn thương, vùng ven biển.

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