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Vulnerability Assessment of Climate Change on Sea Level Rise Impacts on Some Economic Sectors in Binh Dinh Province, Vietnam

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Abstract

Assessing the vulnerability for some economic sectors of Binh Dinh province plays a very important role. The study has applied the vulnerability method according to Iyengar and Sudarshan to assess vulnerability for 03 different sectors: 1) Agriculture, forestry and fisheries; 2) Industry and construction and 3) Service. Calculation results of vulnerability classification for different sector groups according to the E, S, AC, and V_i indicators are used to develop a hierarchy of vulnerability classification for different sector groups. The calculation results indicate that only Phu My district has a high vulnerability index for agriculture, forestry and fisheries with the value of $V_i = 0.6$; For the service sector, only Quy Nhon City has a high vulnerability index with the value of $V_i = 0.63$. The vulnerability index calculated for sector groups for the remaining regions is low to moderate. The result of the vulnerability classification maps due to sea level rise will help planners and managers make plans, plans and solutions to mitigate risks caused by natural disasters.

Keywords

Vulnerability, Sea Level Rise, Economic Sectors, Binh Dinh Province

1. Introduction

There is a multitude of definitions and interpretations of the term vulnerability [1]. The only general consensus that seems to exist is that vulnerability is bound to a specific location and context [2]. The Intergovernmental Panel on Climate Change (IPCC) identifies three components of climate change vulnerability: exposure, sensitivity and adaptive capacity [3]. More specifically, climate vulnerability is defined by the IPCC as arising when some ecosystem service, such as food production, is 1) exposed to changing climatic conditions; 2) limited in its ability to adapt to these conditions; and 3) sensitive to these changes. Researchers and scholars such as Folke (2006) [4] and Smit and Wandel (2006) [5] developed these ideas and emphasized that in addition to exposure, sensitivity and adaptive capacity, vulnerability is also a function of a system's resilience, that is, its ability to absorb shock as well as its ability to recover after being exposed to stress [6]. Vulnerability and adaptive capacity are multidimensional, complex and no directly observed phenomena [7] making their evaluation difficult; however, studies have addressed this problem using different approaches. They have focused, for example, on the vulnerability to a particular stressor, such as rising sea levels [8] [9] [10] as well as on assessing the impacts of climate change [11] [12] [13] [14]. Sea level rise is one of the most serious threats of climate change that is currently impacting coastal areas. Potential impacts cover both socio-economic and biogeophysical sectors as the results of increasing flood frequency, inundation, coastal erosion, rising of water table, and saltwater intrusion [15]. The damages from those impacts can be categorized into direct and indirect [16]. The actual degree of damages from sea level rise to a specific coast depends on the adaptability of the affected socio-economic and ecological systems of that coast, as well as its potential for harm by a hazardous event [2].

Vulnerability has been applied to a sector of interest, such as agriculture [17] [18] [19] [20] [21]. Climate change vulnerability assessments of ecosystems [22] [23] [24] [25] [26] have followed an outcome/endpoint interpretation of vulnerability [27]. Evaluating climate change vulnerability, we believe it is required to assess the sector of interest and the potential impacts at the national level, first. The national level is suitable for generating and managing information, as it is used by governments to shape policy. After the national context has been analyzed, attention can be directed locally, mainly because the initial analysis identified the sub-national regions where the most vulnerable people are and the variables that drive their vulnerability. If the regions and socio-economic or environmental variables are identified first, they may serve as a starting point for understanding and addressing drivers of local vulnerability [28] [29] [30]. To assess vulnerability to climate change of different districts of study areas, Iyengar and Sudarshan (1982) [31] methodology was employed for the development of Composite Index of Vulnerability to Climate Change from multivariate data and it was used to rank the districts in terms of their economic performance [32] [33] [34] [35]. The objectives of the paper are to: 1) Apply the vulnerability method by Iyengar and Sudarshan to assess vulnerability for three economic sector groups; 2) Establish the vulnerability maps caused by sea level rise for three economic sector groups; 3) Evaluate the vulnerability areas for each sector.

2. Materials and Methods

2.1. Description of Study Site

Binh Dinh is a coastal province in Central Vietnam. The territory of the province stretches 110 km in the North-South direction, the natural area: 6,025 km^2, the territorial area: 36,000 km^2. It is bordered on the north by Quang Ngai Province, on the south by Phu Yen Province, on the west by Gia Lai Province, on the east by the East Sea with a coastline of 134 km long, the easternmost point is Nhon Chau commune (Cu Lao Xanh) in Qui Nhon City (Figure 1). Binh Dinh is assessed as having a strategic position of great importance in socio-economic development of the central key economic region, considered one of the gateway to the sea of the Central Highlands and southern provinces. Laos, northeastern Cambodia. Binh Dinh has a lot of rivers, rivers are not big, high, short, low sediment. There are four big rivers: Lai Giang, Kon, La Tinh and Ha Thanh.

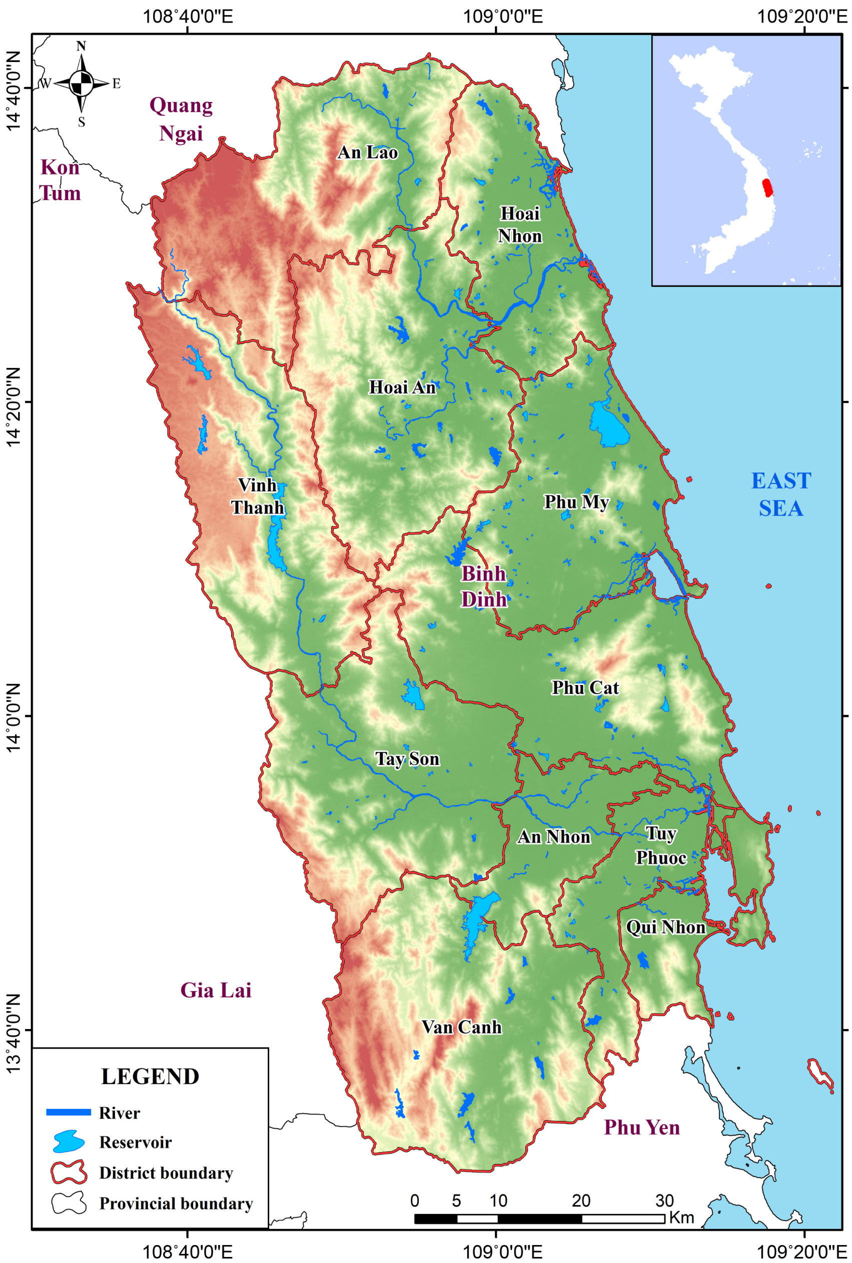

Figure 1. Map of study area.

Binh Dinh has humid tropical and monsoon tropical properties. Average annual air temperature: in the mountainous areas of 20.1˚C - 26.1˚C; in the coastal area is 27˚C. Average humidity in the year: in mountainous areas is 22.5% - 27.9% and relative humidity is 79% - 92%; In coastal areas, the average absolute humidity is 27.9% and 79% relative humidity. The average annual rainfall is 1751 mm, the maximum is 2658 mm, the minimum is 1131 mm. The rainy season starts from September to December; the dry season lasts from January to August. The structure of geology, topography and climate makes Binh Dinh without large plains but with fertile fields, diversified in agricultural, forestry and fishery products, etc. Many mineral resources and hydroelectric potential.

2.2. Data Collection

Data used in this study as follows disaster data such as number of landfall storms, number of floods, duration of droughts collected from Viet Nam Institute of Meteorology, Hydrology and Climate Change (IMHEN); Data on changes in rainfall, changes in humidity, temperature changes are taken from the Climate Change and Sea Level Rise, 2016 of the Ministry of Natural Resources and Environment; The socio-economic statistical yearbook of Binh Dinh Province in 2016 was collected to identify sub-indicators related to vulnerability to economic sectors (**Tables 3-5**).

In addition, in this study, interviews with officials and people were conducted, in particular: 20 interviewed officials were distributed equally to districts and sectors with work related to climate change; 50 votes were interviewed in districts across the province (**Tables 3-5**).

2.3. Vulnerability Assessment Methods

Previously, the definition of IPCC refers to vulnerability as a function of vulnerability exposure, sensitivity and adaptive capacity [36] [37]. This definition is used in documents in Vietnam, in which many authors identify vulnerability as a function of exposure levels to hazards, sensitivity and adaptive capacity basis for analysis.

However, in this article, the social context is clearly emphasized and vulnerability is determined independently of natural phenomena. Vulnerability assessment focuses on human capacity to resist and promptly recover damages and losses, so socio-economic factors are reviewed and analyzed [38] [39]. The study was conducted based on the index method and the concept of vulnerability by IPCC (2007) [37] including 3 factors: exposure (E), sensitivity (S) and adaptative capacity (AC), specifically as follows:

$$V = f\left(E, S, AC\right) \tag{1}$$

where V is the vulnerability index; E is the exposure indicator; S is sensitive indicators; AC are adaptive capacity indicators.

Besides selecting the vulnerability assessment method, the selection of directives is also important, determining the rationality, efficiency and accuracy of vulnerability assessment. Based on the availability of data sources, relevance to local conditions and circumstances as well as following the socio-economic development strategies of the study area to select the indicator set. The directives are based on domestic and foreign inheritance, combined with direct interview and expert consultation.

2.3.1. Method to Select x

The index method is widely applied, popular in studies of vulnerability assessment. The indicators are selected in a variety of natural, economic and social aspects to fully reflect the factors to ensure comprehensive and reliable evaluation results, specifically steps define the indicators (Figure 2).

2.3.2. Analysis and Assessment of Vulnerability Levels

The first is to select the study area of different regions. In each region, a set of indicators is selected for each component of the vulnerability capacity. Indicators are selected based on data availability, personal assessment or previous research. Since vulnerability changes over time, it should be noted that all directives need to be related to the selected year. If vulnerability needs to be assessed over the years, it is necessary to collect data on indicators in each region in each year.

2.3.3. Data Arrangement

For each component of vulnerability, the collected data are then arranged in the

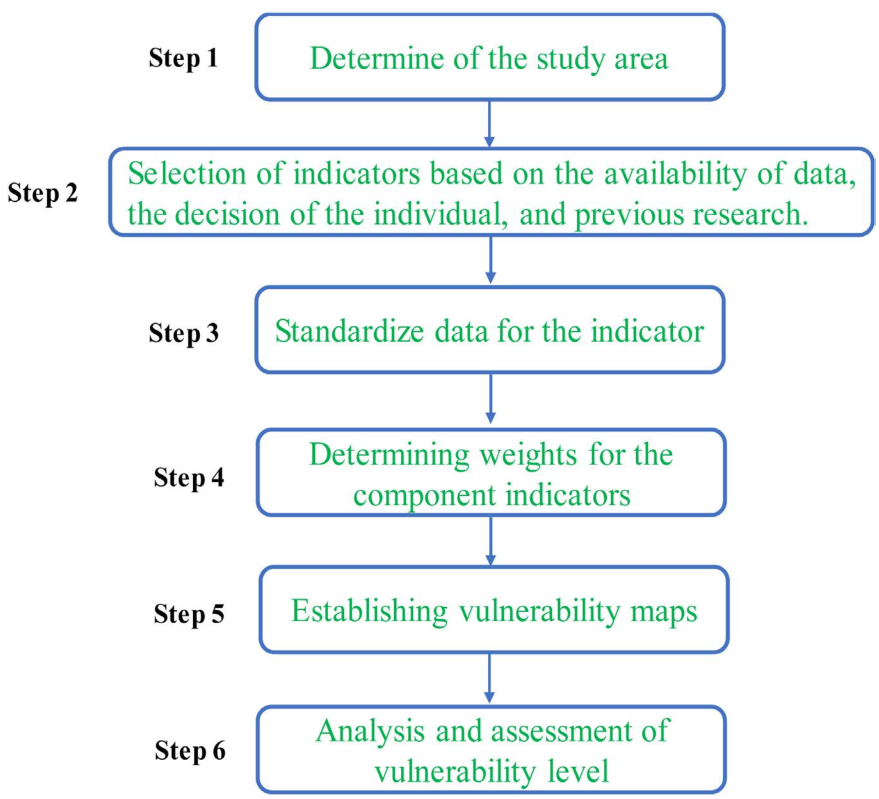

Figure 2. Steps defined the indicator in this study.

form of a rectangular matrix with rows representing regions and columns representing indicators. Let there be M regions/districts and let us say we have collected K indicators. Let X_{ij} be the value of the indicator j corresponding to region i. Then the table will have M rows and K columns as shown in Table 1.

It should be noted that this type of arrangement of data is usually done in statistical analysis of survey data.

2.3.4. Normalisation of Indicators Using Functional Relationship

Obviously the indicators will be in different units and scales. The methodology used in UNDP's Human Development Index (HDI) [40] is followed to normalize them. That is, in order to obtain figures which are free from the units and also to standardize their values, first they are normalized so that they all lie between 0 and 1. Before doing this, it is important to identify the functional relationship between the indicators and vulnerability. Two types of functional relationship are possible: vulnerability increases with increase (decrease) in the value of the indicator. Assume that higher the value of the indicator more is the vulnerability. The variables have ↑ functional relationship with vulnerability and the normalization is done using the formula as

$$x_{ij} = \frac{X_{ij} - \min_i \{X_{ij}\}}{\max_i \{X_{ij}\} - \min_i \{X_{ij}\}} \tag{2}$$

It is clear that all these scores will lie between 0 and 1. Value 1 will correspond to that region with maximum value and 0 will correspond to the region with minimum value.

On the other hand, consider adult literacy rate. A high value of this variable implies more literates in the region and so they will have more awareness to cope with climate change. The vulnerability will be lower and adult literacy rate has ↓ functional relationship with vulnerability. For this case the normalized score is computed using the formula

$$y_{ij} = \frac{\max_i \{X_{ij}\} - X_{ij}}{\max_i \{X_{ij}\} - \min_i \{X_{ij}\}} \tag{3}$$

Table 1. Arrangement data of regional indicators.

Region/District	Indicator					
	1	2	…	j	…	K
1	X_{11}	X_{12}	…	X_{1j}	…	X_{1K}
2	X_{21}	X_{22}	…	X_{2j}	…	X_{2K}
…	…	…	…	…	…	…
i	X_{i1}	X_{i2}	…	X_{ij}	…	X_{iK}
…	…	…	…	…	…	…
M	X_{M1}	X_{M2}	…	X_{Mj}	…	X_{MK}

It can be easily checked that $x_{ij} + y_{ij} = 1$ so that y_{ij} can be calculated as $y_{ij} = 1 - x_{ij}$. While constructing the vulnerability index, sufficient care must be applied to take into account the direction of functional relationship of each variable to vulnerability. After computing the normalized scores, the index is constructed by giving either equal weights to all indicators/components or unequal weights.

2.3.5. Iyengar and Sudarshan's Method

Iyengar and Sudarshan (1982) [31] developed a method to work-out a composite index from multivariate data and it was used to rank the districts in terms of their economic performance. This methodology is statistically sound and well suited for the development of composite index of vulnerability to climate change also. A brief discussion of the methodology is given below.

It is assumed that there are M regions/districts, K indicators of vulnerability and x_{ij}, i 1, 2, ⋯, M; j 1, 2, ⋯, K are the normalized scores. The level or stage of development of ith zone, y_i, is assumed to be a linear sum of x_{ij} as

$$\overline{y_i} = \sum_{j=1}^{K} w_j \times x_{ij} \tag{4}$$

where w's ($0 < w < 1$ and $\sum_{j=1}^{K} w_j = 1$) are the weights. In Iyengar and Sudarshan's method the weights are assumed to vary inversely as the variance over the regions in the respective indicators of vulnerability. That is, the weight w_j is determined by

$$w_j = \frac{c}{\sqrt{\operatorname{var}_i\left(x_{ij}\right)}} \tag{5}$$

where c is a normalizing constant such that

$$c = \left[\sum_{j=1}^{K} \frac{1}{\sqrt{\operatorname{var}_i\left(x_{ij}\right)}}\right]^{-1} \tag{6}$$

After calculating the values of the three main components E_i, S_i, AC_i, calculating the weight for each component according to Equation (5), w_E, w_S, w_{AC} are the weights of the active components such as sensitivity and adaptative capacity.
where

$$w_E + w_S + w_A = 1 \tag{7}$$

The vulnerability index for each district corresponding to each component is calculated by the equation as

$$V_i = E_i \times w_E + S_i \times w_S + A_i \times w_A \tag{8}$$

where V_i is the vulnerability index calculated for the region i.

To decentralize the vulnerability of the regions, it is necessary to determine the probability distribution of V_i. Iyengar and Sudarshan (1982) have assumed that V_i's probability density function is suitable with Beta function, is a skew distribution function, receives values from 0 - 1. The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and distort inter regional comparisons. The vulnerability index so computed lies between 0 and 1, with 1 indicating maximum vulnerability and 0 indicating no vulnerability at all.

For classificatory purposes, a simple ranking of the regions based on the indices V_i's, y_i would be enough. However for a meaningful characterization of the different stages of vulnerability, suitable fractile classification from an assumed probability distribution is needed. A probability distribution which is suitable for this purpose is the Beta distribution, which is generally skewed and takes values in the interval (0, 1) as followed by Iyengar and Sudarshan (1982) has been applied. This distribution has the probability density given by

$$f(z)=\frac{z^{a-1}(1-z)^{b-1}}{\beta(a,b)},\quad 0<z<1 \text{ and } a,b>0 \tag{9}$$

where $\beta(a,b)$ is the beta function defined by

$$\beta(a,b)=\int_0^1 x^{a-1}(1-x)^{b-1}\,\mathrm{d}x \tag{10}$$

The two parameters *a* and *b* of the distribution can be estimated either by using the method described in Iyengar and Sudharshan (1982) or by using software packages. The Beta distribution is skewed (**Figure 3**). Let (0, z_1), (z_1, z_2), (z_2, z_3), (z_3, z_4) and (z_4, 1) be the linear intervals such that each interval has the same probability weight of 20 percent [31] [32]. These fractile intervals can be used to characterize the various stages of vulnerability.

However, it is not necessary to decentralize V_i index by Beta distribution function, but can be approximated by many calculated distribution functions such as Kritxki-Menkel, Gamma function, or according to average line moving through the experience frequency points. The study has used a classification of vulnerability method as following uniform distribution function (**Table 2**).

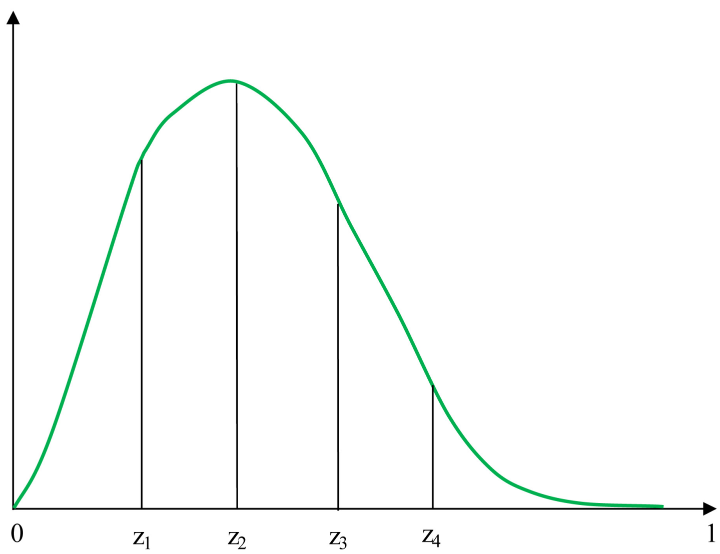

Figure 3. Beta distribution.

Table 2. Classification of vulnerability status.

Value	Color	Classification
$0 < V_i \le 0.2$		Very low
$0.2 < V_i \le 0.4$		Low
$0.4 < V_i \le 0.6$		Average
$0.6 < V_i \le 0.8$		High
$0.8 < V_i \le 1.0$		Very high

2.3.6. Map and GIS Methods

Map and GIS methods are used to integrate information layers and to analyze spatial factors such as area affected by sea level rise, flooded area due to sea level rise, and establishment vulnerability maps. In this study, ArcGIS 10.1 was used to calculate and express spatial elements.

3. Results and Discussion

3.1. The Identification of Vulnerability Indexes for Key Sectors

In Vietnam, economic sectors are divided into three groups including agriculture, forestry and fisheries, industry and construction, and service. These are groups of industries to make up Vietnam's economic system. In the paper, the popular distribution is used to develop a set of vulnerability indexes for each industry group. Based on the availability of data sources, the conditions of Binh Dinh with the characteristics of the research, the indexes are identified. These indexes are developed based on the vulnerability approach by IPCC (2007) [37], whose characteristics of each sector and availability of data. In addition, the expert method is used to consult the effectiveness of the indicator set with three choices as relevant, irrelevant and supplementary content answers. Accordingly, the study sent questionnaires to 20 independent experts at different agencies, 80% of experts said that the indicators were relevant; 5% of them were irrelevant and 15% need additional instructions. Although there is no absolute agreement on the suitability of this indicator, most experts believe that this indicator set is appropriate. The results of the set of indexes to assess vulnerability for sectors groups are shown in Tables 3-5. The indicators used to assess the vulnerability of climate change for the agriculture, forestry and fisheries, are shown in Table 3.

For industry and construction, the indexes applied to assess vulnerability due to climate change as shown in Table 4.

For the service sector, the indexes applied to assess vulnerability due to climate change are shown in Table 5.

3.2. Impact of Inundation by Sea Level Rise to Economic Sectors

Based on climate change and sea level rise scenario announced by the Ministry of Natural Resources and Environment in 2016 [41], this study uses ArcGIS 10.1

Table 3. Indicators to assess the vulnerability caused by climate change for agriculture, forestry and fisheries.

Groups of Index	Main Index	Sub-index	Data sources
Exposure degree (E)	Extreme disasters (E1)	Number of floods affecting the area/year (a)	IMHEN
		Number of storms affecting the area/year (b)	IMHEN
		Average duration of drought (c)	IMHEN
	Changes in climate variables (compared to the base year) (E2)	Temperature change (RCP 8.5) (a)	Climate Change Scenario for VN, 2016
		Rainfall change (RCP 8.5) (b)	Climate Change Scenario for VN, 2016
		Moisture change (c)	Climate Change Scenario for VN, 2016
Sensitivity (S)	Land area (S1)	Agriculture (a)	Statistical Yearbook
		Forestry (b)	Statistical Yearbook
		Aquaculture (c)	Statistical Yearbook
	Flooded areas based on sea level rise (S2)	Agriculture (a)	GIS analysis
		Forestry (b)	GIS analysis
		Aquaculture (c)	GIS analysis
	Production value/year (S3)	Agriculture (a)	Statistical Yearbook
		Forestry (b)	Statistical Yearbook
		Aquaculture (c)	Statistical Yearbook
	Average fluctuation in the area (S4)		Survey
Adaptative Capacity (AC)	Education (AC1)	School numbers (a)	Statistical Yearbook
		Percentages of high school graduates (b)	Statistical Yearbook
	Infrastructure (AC3)	Farm numbers (a)	Survey
		Number of meteorological and hydrological observation stations in the area (b)	Survey
	Government (AC4)	Number of staff assigned to the field of natural resources and environment (a)	Survey
		Awareness of managers about climate change and the impacts of climate change on the agricultural sector (b)	Survey
	Program/plan to support people in agricultural activities to cope with climate change (AC5)	Energy saving policy (a)	Survey
		No burning forest, deforestation limitation (b)	Survey
		No burning upland fields (c)	Survey
		Planting forests, greening bare land and bare hills (d)	Survey
		Use water economically and efficiently (e)	Survey
	Community awareness about climate change (AC6)		Survey
	Measures to adapt to climate change (AC7)	Plant structure transformation (a)	Survey
		Livestock's structure change (b)	Survey
		New farming techniques (c)	Survey

Table 4. Vulnerability indexes caused by climate change for industry and construction.

Groups of index	Main Index	Sub-index	Data sources
Exposure Degree (E)	Extreme disasters (E1)	Number of floods affecting area/year (a)	IMHEN
		Number of storms affecting the area/year (b)	IMHEN
		Average duration of drought (c)	IMHEN
	Changes in climate variables (compared to the base year) (E2)	Temperature change (RCP 8.5) (a)	Climate Change Scenario for VN, 2016
		Rainfall change (RCP 8.5) (b)	Climate Change Scenario for VN, 2016
		Moisture change (c)	Climate Change Scenario for VN, 2016
Sensitivity (S)	Flooded areas based on sea level rise (S1)	Industry (a)	GIS analysis
		Construction (b)	GIS analysis
	Number of businesses (S2)		Statistical Yearbook
	The number of non-agricultural, forestry and fishery establishments (S3)		Statistical Yearbook
	Number of employees in non-agricultural, forestry and fishery establishments (S4)		Statistical Yearbook
	The average urban population (S5)		Statistical Yearbook
Adaptative Capacity (AC)	Education (AC1)	School numbers (a)	Statistical Yearbook
		Percentage of high school graduates (b)	Survey
	Government (AC2)	Number of staff assigned to the field of natural resources and environment (a)	Survey
		Awareness of managers about climate change and the impacts of climate change on industry and construction (b)	Survey
		Program/plan to support people in industrial and construction activities to cope with climate change (c)	Survey
		Number of meteorological and hydrological observation stations in the area (d)	Survey
	Community awareness about climate change (AC3)		Survey
	Measures of people to reduce the cause of climate change (AC4)	Energy saving (a)	Survey
		Use water effectively (b)	Survey
		Reduce emissions (c)	Survey

Table 5. Vulnerability indexes caused by climate change for the service sector.

Groups of indexes	Main index	Sub-index	Data sources
Exposure Degree (E)	Extreme diasters (E1)	Number of floods affecting area/year (a)	IMHEN
		Number of storms affecting the area/year (b)	IMHEN
		Average duration of drought (c)	IMHEN
		Proportion of households with members injured or killed by storms, floods, droughts, tornadoes (d)	Climate Change Scenario for VN, 2016
	Changes in climate variables (compared to the base year) (E2)	Temperature change (RCP 8.5) (a)	Climate Change Scenario for VN, 2016
		Rainfall change (RCP 8.5) (b)	Climate Change Scenario for VN, 2016
		Moisture change (c)	
Sensitivity (S)	Population (S1)	The average urban population (a)	Statistical Yearbook
		Population density (b)	Statistical Yearbook
	Flooded areas based on sea level rise (S2)		GIS analysis
	Clean water and environmental sanitation (S3)	Rate of clean water to ensure people's living (a)	Survey
		The rise in disease rates (b)	Survey
Adaptative Capacity (AC)	Education (AC1)	School numbers (a)	Statistical Yearbook
		Percentage of high school graduates (b)	Statistical Yearbook
	Government (AC2)	Number of staff assigned to the field of natural resources and environment (a)	Survey
		Awareness of managers about climate change and the impacts of climate change on the service sector (b)	Survey
		Number of meteorological and hydrological stations monitoring in the area (c)	Survey
		Program/plan to support people in service activities to cope with climate change (d)	Survey
	Community awareness about climate change (AC3)		Survey
	Community awareness about the impact of climate change on tourism (AC4)	Reduce the number of tourists (a)	Survey
		Destroyed landscape, damaged facilities (b)	Survey
		Serious Environmental pollution (c)	Survey

to overlap the land use map to identify areas of land that are likely to be affected by flooding due to sea level rise with the base level is increased by 50 cm.

The results for the scenario of sea level rise of 50 cm show that the area of agricultural, forestry and fishery land are obviously affected (Figure 4). The area of agricultural land affected by sea level rise has considerable changes between districts. Tuy Phuoc district has the largest affected area of 380.5 ha, accounting for 3.66% of the district. In which, Hoai Nhon district has 64.38 ha, accounting for 0.28%. For the forestry sector, Quy Nhon City has the largest affected area of 5359 ha, accounting for 0.044%. In which, Phu My district has 0.528 ha accounting for 0.0026% (Table 6).

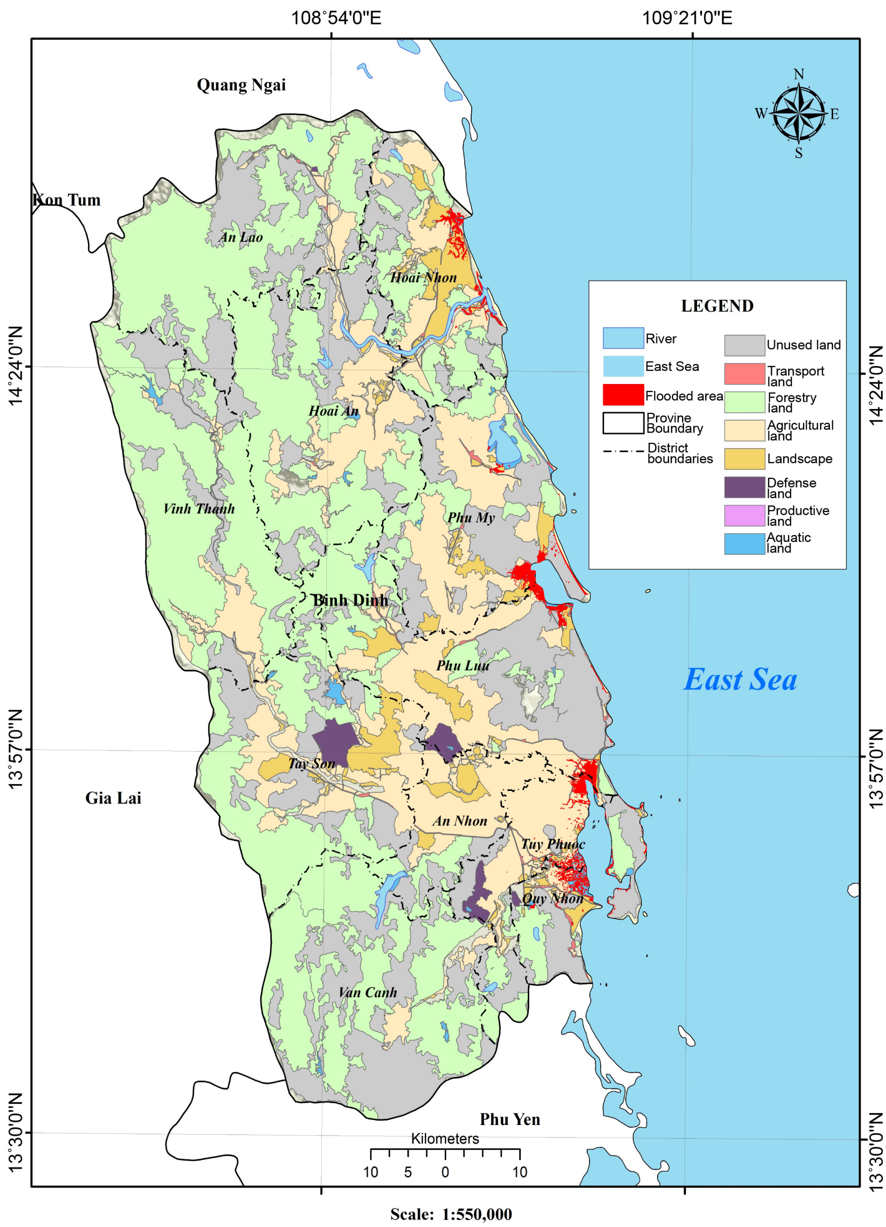

Figure 4. Sea level map of 50 cm according to climate change scenario in Binh Dinh province.

Table 6. Statistics of land use area of affected sectors with sea level rise scenario of 50 cm in Binh Dinh province.

District	Agriculture			Forestry			Fishery			Industry			Construction			Transportation		
	Acreage (ha)	Flooded area (ha)	Rate (%)	Acreage (ha)	Flooded area (ha)	Rate (%)	Acreage (ha)	Flooded area (ha)	Rate (%)	Acreage (ha)	Flooded area (ha)	Rate (%)	Acreage (ha)	Flooded area (ha)	Rate (%)	Acreage (ha)	Flooded area (ha)	Rate (%)
Hoai Nhon	14.878	66.15	0.44	20.085	0.67	0.0033	331	119.5	36.10	-	-	-	1.552	134.2	8.65	529.5	7.613	1.44
Phu Cat	21.179	321.4	1.52	24.171	-	-	601	114.3	19.02	-	-	-	1.217	41.46	3.41	1.120	25.27	2.26
Phu My	23.064	64.38	0.28	20.311	0.53	0.0026	1.142	379.5	33.23	-	-	-	1.116	27.11	2.43	1.043	23.44	2.25
Quy Nhon City	3.868	92.68	2.40	12.093	5.4	0.044	531	170.8	32.17	-	-	-	1.053	13.49	1.28	750.2	6.37	0.85
Tuy Phuoc	10.403	380.5	3.66	2.182	-	-	1.085	32.66	3.01	-	-	-	1.006	7.503	0.75	358.3	1.20	0.34

It can be seen that the forestry areas of Phu Cat and Tuy Phuoc districts are not affected. Meanwhile, for the fishery sector, the area losted due to the most considerable affection of sea level rise is Phu My district with 379.5 ha, accounting for 33.23%, in which, Tuy Phuoc district is 32.66 ha, and accounting for 3.01%. Quy Nhon City has a large flooding rate of 32.17% (170.8 ha). Other districts such as Hoai Nhon and Phu Cat have flooded areas of 119.5 ha and 114.3 ha, respectively.

The statistical results show that the area for construction of coastal districts of Binh Dinh Province affected by sea level rise of 50 cm in about 7.5 ha - 134.2 ha. In which, Hoai Nhon district has flooded area of 134.2 ha/1552ha, accounting for 8.6% of the district's area; Phu Cat district has a flooded area of 41.46 ha/1217ha, accounting for 3.4% of the total area of the district; Phu My district has a flooded area of 27.11 ha/1116 ha, accounting for 2.4% of the total area of the district; Quy Nhon City has a flooded area of 13.49 ha/1053ha, accounting for 1.3% of the total area of the city. Tuy Phuoc district has an area of 7.5 ha/1006ha, accounting for 0.75% of the district.

In terms of the transport sector, the total flooded area in Binh Dinh Province is 63,891 ha, accounting for 1.68% of the total area used for transportation in the province, of which the area is flooded affecting transportation in Phu Cat district is the largest, with 25.27 ha accounting for 2.25% of the area. Followed by Phu My district, flooded area of 23.44 ha, accounting for 2.25% of the traffic area. Hoai Nhon covers an area of 7613 ha, accounting for 1.44% of the traffic area. The two districts with the smallest flooded area are Quy Nhon City and Tuy Phuoc district. The figures for that are 6367 and 1201 ha respectively, flooding rate accounts for 0.85% and 0.34% of the traffic area.

3.3. Results of Vulnerability Indexes for Sectors

Regarding the calculation of vulnerability indexes of Binh Dinh's economic sectors, the information after being aggregated and listed correspondingly to the standardized exposure, sensitivity and adaptability index calculated according to Research methods and results of standardization of impact indicators (E), sensitivity (S) and adaptative capacity (AC) for each industry. The study has selected 06 main sectors: agriculture, forestry, fisheries, industry, construction and services. In which, 06 sectors are divided into 03 groups: 1) agriculture, forestry and fishery; 2) Industry and construction; 3) Services to calculate and classify the vulnerability for different industry groups. After synthesis, the vulnerability indexes for economic sectors in Binh Dinh are presented in Tables 7-9. According to the survey for the adaptability to climate change in the local area, the education index in the province is relatively good. The total number of schools including schools from primary to high school is 447. In particular, Quy Nhon City has the largest number of 57 schools, the lowest is Van Canh with 16 schools. The percentage of high school graduates in affiliated districts and cities are 91% - 96.2%. In which, the highest percentage is Quy Nhon City with 96.2% and the lowest in Van Canh district with 91%. The process of interviewing local people shows that community awareness about climate change is positive. Accordingly, 77.55% of respondents are aware of local climate change phenomena. Of which 97.96% of respondents know how to adapt to climate change. Of which 93.87% of people have measures to change crop pattern, 46.93% have solutions to change the pattern of livestock, and 95.91% know how to apply new cultivation measures. Adaptive solutions of local officials as well as local people contribute to minimizing negative impacts of climate change, especially in the agriculture, forestry and fishery sectors.

1) Vulnerability indexes to agriculture, forestry and fishery

In Binh Dinh, the value of vulnerability index is almost average. In which, there are 10 districts with average rate, constituting 91%, a district with high value accounts for 9%, there are no districts with very low, low and very high

Table 7. Vulnerability indexes to agriculture, forestry and fisheries.

District	(E)	(S)	(AC)	V_i	Classification
Quy Nhon City	0.65	0.22	0.65	0.52	Medium
An Lao	0.65	0.11	0.62	0.47	Medium
Hoai Nhon	0.65	0.40	0.65	0.58	Medium
Hoai An	0.65	0.28	0.65	0.53	Medium
Phu My	0.65	0.50	0.65	0.60	High
Vinh Thanh	0.65	0.11	0.61	0.46	Medium
Tay Son	0.65	0.24	0.64	0.52	Medium
Phu Cat	0.65	0.43	0.65	0.59	Medium
An Nhon	0.65	0.17	0.65	0.50	Medium
Tuy Phuoc	0.65	0.35	0.64	0.55	Medium
Van Canh	0.65	0.19	0.61	0.49	Medium

Table 8. Vulnerability indexes for the industry and construction.

District	(E)	(S)	(AC)	V_i	Classification
Quy Nhon City	0.65	0.37	0.56	0.52	Medium
An Lao	0.65	0.01	0.46	0.36	Low
Hoai Nhon	0.65	0.39	0.55	0.52	Medium
Hoai An	0.65	0.07	0.48	0.39	Low
Phu My	0.65	0.22	0.52	0.45	Medium
Vinh Thanh	0.65	0.02	0.42	0.34	Low
Tay Son	0.65	0.12	0.48	0.41	Medium
Phu Cat	0.65	0.21	0.53	0.45	Medium
An Nhon	0.65	0.23	0.53	0.46	Medium
Tuy Phuoc	0.65	0.17	0.50	0.43	Medium
Van Canh	0.65	0.01	0.43	0.35	Low

Table 9. Vulnerability indexes to the service sector.

District	(E)	(S)	(AC)	V_i	Classification
Quy Nhon City	0.65	0.6	0.7	0.63	High
An Lao	0.65	0.2	0.6	0.49	Medium
Hoai Nhon	0.65	0.4	0.7	0.58	Medium
Hoai An	0.65	0.2	0.6	0.50	Medium
Phu My	0.65	0.4	0.6	0.58	Medium
Vinh Thanh	0.65	0.2	0.5	0.47	Medium
Tay Son	0.65	0.5	0.6	0.57	Medium
Phu Cat	0.65	0.2	0.6	0.53	Medium
An Nhon	0.65	0.4	0.6	0.56	Medium
Tuy Phuoc	0.65	0.4	0.6	0.55	Medium
Van Canh	0.65	0.2	0.5	0.47	Medium

levels (Table 7).

The district has a high vulnerability index is Phu My district, this is a coastal plain district of the province. The economic sector of the district is agriculture. Cultivation is the main economic sector with crops are mainly rice and crops, agricultural crops are mainly short-term crops. According to statistics in 2016, the locality has the largest area of agriculture and fisheries in the province with an area of 23,064 ha of agriculture and 1142 ha of aquatic products. However, with the climate and topography of the locality, the district has been suffering from many types of natural disasters such as storms, floods and droughts. In Phu My district, the area which lacks of rural water is the largest with 1145 ha, adversely affecting the production (Figure 5).

The average vulnerability index shows that the local areas are still vulnerable to climate change impacts. The study area in the central region of Vietnam, with

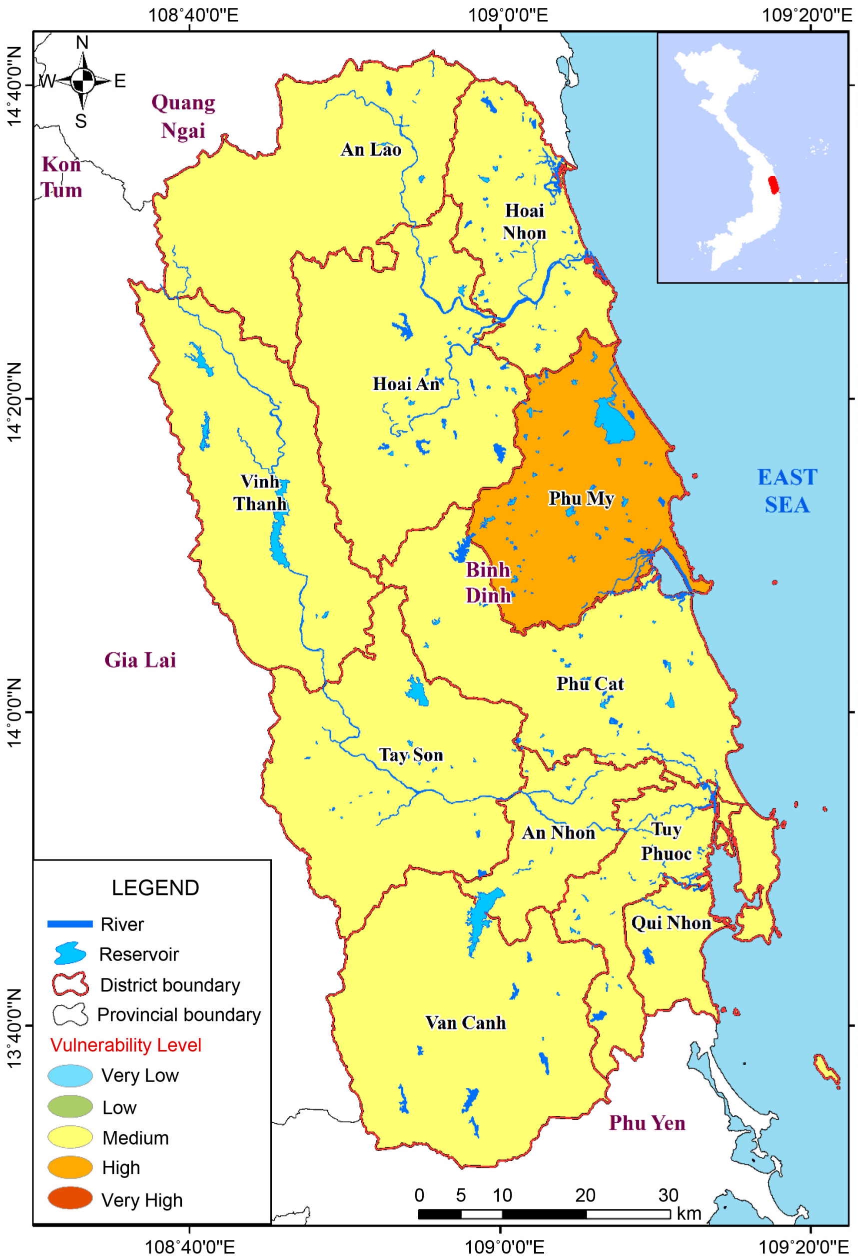

Figure 5. The map of vulnerability caused by sea level rise to industry and construction.

the characteristics is heat wave, with west wind in the dry season, high temperature makes evaporation lasting, and the terrain is also steep, and the river basins are too short so the rivers are unable to store of water in the rainy season, which causes drought. In arid areas, the annual rainfall averages only 500 - 700 mm, hot weather creates a semi-desert land that is difficult to develop production. In addition, the area suffers from annual natural disasters such as storms and floods. The average number of storms hitting Binh Dinh Province is 0.51 times, with 3 floods per year.

2) Vulnerability indexes to industry and construction

Besides the constant development of industry and construction, many local areas also face many difficulties due to climate change and sea level rise. According to the 2016 sea level rise scenario, if the sea level increases to 100 cm, the area of industrial and construction flooded by the area is 607 ha, in which coastal plain districts suffer the most. Hoai Nhon district has the largest flooded area of 295 ha. Phu My district is 154 ha, Phu Cat is 123 ha, Quy Nhon City is 17.53 ha. The districts of An Lao, Hoai An, Vinh Thanh and Van Canh are not affected by sea level rise (**Table 8**).

In Binh Dinh, it can be seen that the vulnerability index is almost low and average. In which, there are 4 low-level districts accounting for 36% and 7 districts with an average level of 64%. Districts with low vulnerability are all mountainous districts including An Lao, Hoai An, Vinh Thanh and Van Canh districts. The economy of these areas is mainly agricultural and forestry production.

Districts with average level of vulnerability are mainly coastal plain districts which are planned for construction and development of large industrial zones. In particular, Tay Son, An Nhon, Tuy Phuoc and Quy Nhon City are now speeding up the construction of Nhon Hoi economic zone to serve as the driving force for economic development of the province and the Central key economic region (**Figure 6**).

3) Vulnerability indexes to service sector

Recently, Binh Dinh has always focused on developing service and tourism sectors. However, in the context of climate change, natural disasters take place in the area with increased frequency and serious levels. The results of calculating the average number of storms hitting Binh Dinh province are 0.51, and 3 floods taken place per year. The average duration of drought months is 7 months per year. Under the 2016 sea level rise scenario, when the sea level rises to 100 cm, the area of flooded service sector is 157.24 ha. In which the area with the largest flooded area is Hoa Nhon district with 24.3 ha (**Table 9**).

The vulnerable index is high level in one district while the remaining 10 districts have a average vulnerability index. In which, the area with high index is Quy Nhon city (**Figure 7**). The result is also consistent with the fact that it is an economic center but it is located in the coastal area often affected by natural disasters and directly affected by climate change and sea level rise.

4. Conclusions

Based on a combination of different studies on vulnerability assessment and data availability, this study has developed a set of indexes for vulnerability assessment for a number of economic sectors in Binh Dinh Province with 36 indexes of level 1 and 60 indexes of level 2. Indexes are selected with criteria related to assessing vulnerability to economic sectors. Assessing vulnerability in the paper is based on three major assessments including exposure, sensitivity and adaptability. The indexes for each of these factors are aggregated based on Iyengar-Sudarshan analysis. On that basis, these three factors are aggregated to determine the vulnerability of industries. Vulnerability is high for the industry and construction

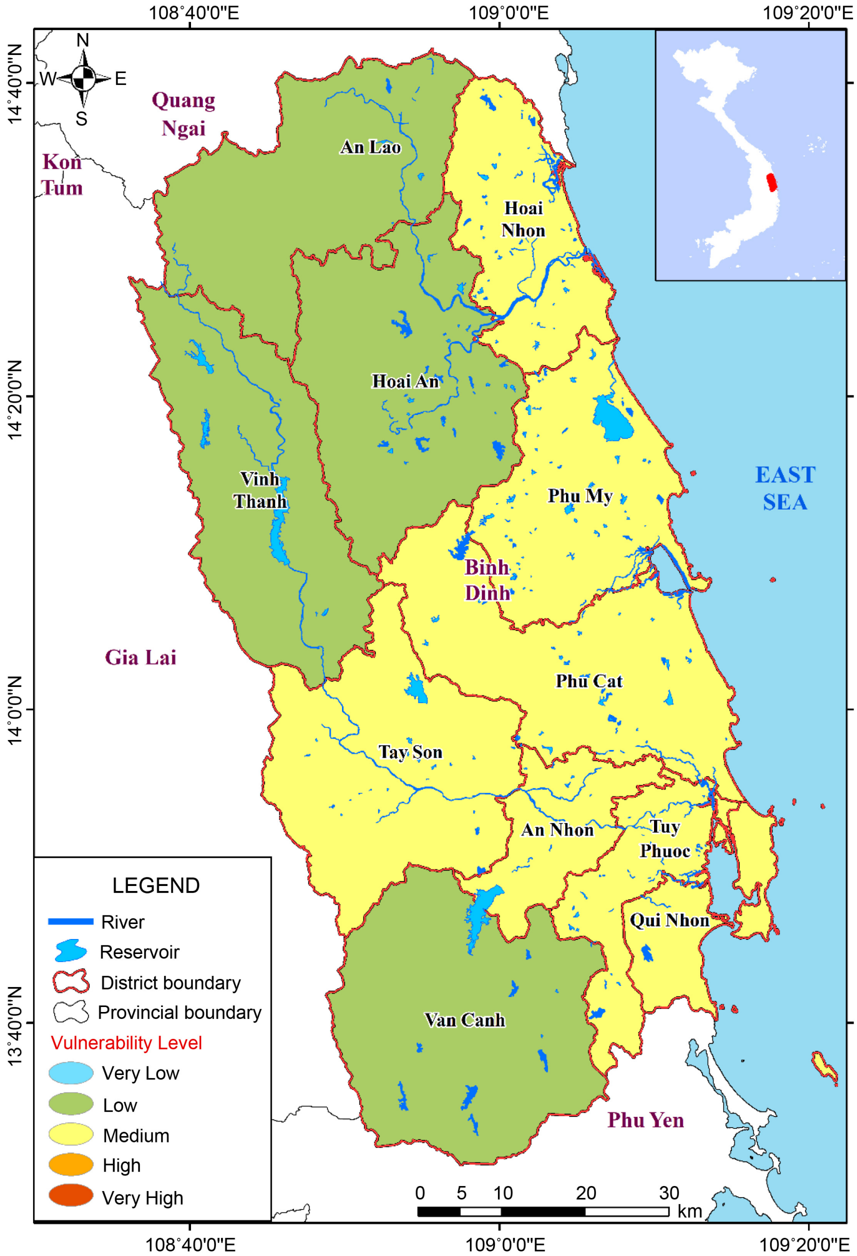

Figure 6. Map of vulnerability caused by sea rise level to industry and construction.

group in Phu My district, the service sector in Quy Nhon City, which are also two key economic areas in the province.

Research results are an important scientific basis for the local to develop policies and plans to respond to climate change for each industry group. In particular, for high-risk areas, there should be more proactive economic restructuring policies. The results of this study are studied at the district level, along with some information limitations, so it is necessary to have more detailed survey data to further clarify the vulnerability problems for economic groups in Binh Dinh Province. Particularly, research is needed for a few typical commune levels in highly vulnerable districts to implement pilot models before replicating models

Figure 7. Map of vulnerability caused by sea rise level to service sector.

for the whole province.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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