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Assessment of Vulnerability and Risk of Taijiang Coastal Areas to Climatic Changes

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***Abstract*—**This study aims to assess the vulnerability and risk of the coastal areas of Taijiang to abnormal oceanographic phenomena. In addition, this study aims to investigate and collect data regarding the disaster losses, land utilization, and other social, economic, and environmental issues in these coastal areas to construct a coastal vulnerability and risk map based on the obtained climate-change risk assessment results. Considering the indexes of the three coastal vulnerability dimensions, namely, man-made facilities, environmental geography, and social economy, this study adopted the equal weighting process and Analytic Hierarchy Process to analyze the vulnerability of these coastal areas to disasters caused by climatic changes. Among the areas with high coastal vulnerability to climatic changes, three towns had the highest coastal vulnerability and four had the highest relative vulnerability. Areas with lower disaster risks were found to be increasingly vulnerable to disasters caused by climatic changes as time progresses.

***Keywords*—**Climate change, coastal disaster, risk, vulnerability

I. Introduction

RECENTLY, with the effects of global warming and marine climate change, sea-level rise, frequent typhoons, and other climatic problems have adversely affected our homes and living environments. Taiwan is located in the middle of the typhoon path in the western Pacific Ocean. It faces the Taiwan Strait on the west, reaches the Pacific Ocean on the east, and borders the Bashi Channel on the south. During summers and autumns, Taiwan is usually hit by typhoons or violent storms resulting from tropical low pressure. For the past century, Taiwan has been hit by typhoons 3.75 times on average per year. In addition, based on the record of typhoons hitting Taiwanese waters, the frequency of the typhoons in the Western Pacific has increased in the last 40 years. The strong winds, heavy rains, and big waves accompanying typhoons or low pressure are the main causes of sea-level rise in coastal areas. According to the typhoon data for the last decade from the Central Weather Bureau, the annual lowest pressure decreased, whereas the maximum wind speed near the typhoon center increased. Moreover, studies on the continuous sea-level rise due to climatic changes indicate that the global sea levels rise by 3.32 mm per year. Meanwhile, the sea levels in Keelung and Kaohsiung increase annually by 3.81 and 3.6 mm, respectively.

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The abnormal sea levels resulting from storm tides seriously damage the coastal areas of Taiwan. Storm tides and big waves cause coastal erosion due to the impact of the water on the coastal soil. Storm tides and big waves also rise over levee crests and cause salt-water encroachment and floods in the coastal areas, hence damaging crops and fish farms. These typhoon effects greatly impact the development of marine environments in Taiwan. Therefore, an accurate understanding of the marine and meteorological characteristics of coastal areas is necessary to mitigate effects and improve disaster prevention practices and disaster relief operations.

II. Theories and Methods

A. Coastal vulnerability index (CVI)

The CVI proposed by the United Nations Environment Programme (UNEP) [1] refers to the impact of sea-level rise on a particular area. These effects include overflow, coastal erosion, storm tides, and seawater intrusion, among others. CVI includes the following parts:

- Population Density in Coastal Areas is defined as the population in coastal areas divided by the area of coastal land.
- Probability of Natural Disaster Incidents refers to the frequency of natural disasters in the last century, including violent storms (typhoons and cyclones) and storm tides (tsunamis and high tides).
- Percentage of Vegetation Cover is defined as the vegetation area divided by the coastal land area.
- Geographic Exposure is used to evaluate the proportion of used land in a country (less than 50 m) and the proportion of the coastline length to the national border.
- Human Development Index includes three dimensions: health life (average life expectancy), knowledge (adult literacy rate/rough enrollment rate), and standard of living (Gross Domestic Product).

In addition, the United States Geological Survey (USGS) adopted the coastal vulnerability assessment proposed by Thieler and Hammar–Klose [2] to analyze the impact of sea-level rise on the United States coastlines. However, USGS reduced the number of parameters by adopting only six variables including physiognomy, coastline change, coastal slope, relative change of sea level, height of significant wave, and tidal area.

In this study, the coastal vulnerability to disasters is determined by the vulnerability of a coastal system to potential disasters such as floods or sea-level rise resulting from climatic changes. Özyurt [3] stated that the CVI must be developed based on different objectives, processes, and temporal and spatial scales using the current local data. Therefore, basing on the studies of Doukakis [4], Hong et al. [5], Kavi Kumar and Tholkappian [6], and UNEP [1], this study analyzed the existing domestic circumstances and data to develop a suitable CVI, as shown in the level diagram in Fig. 1. Coastal vulnerability has three dimensions: man-made facilities, environmental geography, and social economy. Each dimension uses 13 proper indexes in the construction and quantification.

- Seawall length relative ratio: the ratio of the seawall to coastline length in a certain area. The degree of protection of the coastal area is strong and its relative vulnerability is low if this index is high.
- Seawall height relative ratio: the ratio of the average height of a certain area to the corresponding average wave height. The degree of protection of the coastal area is strong and its relative vulnerability is low if this index is high.
- Tide gate relative ratio: the ratio of the number of tide gates to the number of river mouths or sewers in the area. The degree of protection of the coastal area is strong and its relative vulnerability is low if this index is high.
- Elevation: the average elevation in a certain area calculated using digital elevation model (DEM) data. DEM data adopt 20mx20m resolution. The degree of protection of the coastal area is strong and its relative vulnerability is low if this index is high.
- Slope: the slope in a certain area calculated using DEM data. The degree of protection of the coastal area is strong and its relative vulnerability is low if this index is high.
- Variability of tidal level: the variability of the tidal level that can be calculated from the mean high tide less the mean low tide during a specific period. The degree of protection of the coastal area is weak and its relative vulnerability is high if this index is high.
- Land subsidence rate: the subsidence rate of elevation in a period based on long-term monitoring data. This study used the subsidence rates from 2001 to 2009 for the calculation and analysis. The degree of protection of the coastal area is weak and its relative vulnerability is high if this index is high.
- Rate of coastal erosion: the rate of coastline change or standard deviation of many coastline changes in a period of time (variation intensity). The degree of protection of the coastal area is weak and its relative vulnerability is high if this index is high.
- Land utilization: generally classified as ports, industrial areas, agricultural areas, and national parks, among others. The vulnerability depends on the type of land use. The vulnerability of an agricultural area is lower than that of an industrial area.
- Population density: the ratio of the population to the area of a region. The degree of protection of the coastal area is weak and its relative vulnerability is high if this index is high.
- Education level relative ratio: the ratio of the number of literate to illiterate people in a certain area. The degree of protection of the coastal area is strong and its relative vulnerability is low if this index is high.
- Providing ratio: number of people with ages from 0 to 15 and over 65 in relation to the number of people with ages from 15 to 64. The degree of protection of the coastal area is weak and its relative vulnerability is high if this index is high.
- Enterprise compensation: the enterprise compensation of a certain area for the whole year expressed as enterprise compensation = profits + bad debt loss and transfer expenditures + other non-revenue expenditure – income on investment and income from sales of assets in other non-operating income. The degree of protection of the coastal area is weak and its relative vulnerability is high if this index is high.

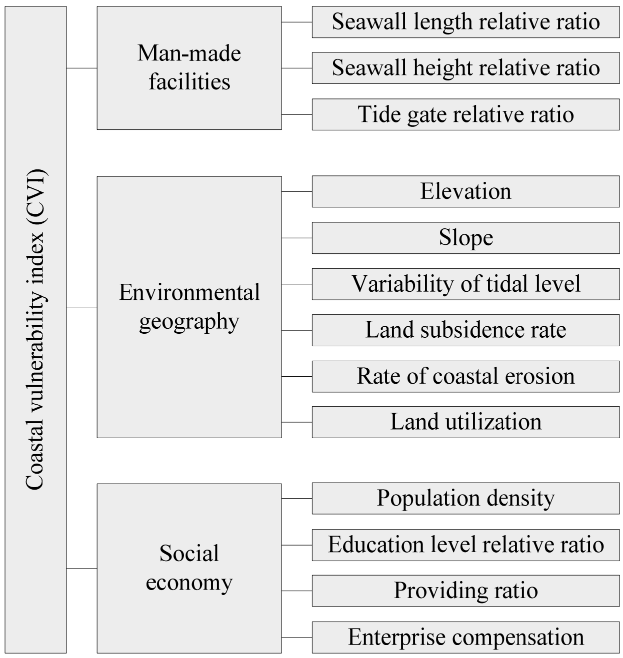


Fig. 1 Level diagram of coastal vulnerability

B. Vulnerability Assessment Methods

In this study, each index is classified according to a five-level scale. Based on the relativity of the index value, the vulnerability strength can be described as follows: Rank 1 is defined as not vulnerable, Rank 2 is defined as slightly vulnerable, Rank 3 is defined as average, Rank 4 is defined as vulnerable, and Rank 5 is defined as strongly vulnerable.

The *j*th ($j=1,2,\cdots$) index of the ith ($i=1,2,3$) dimension is $I_{(i,j)}$, which can be converted into Rank $R_{(i,j)}$ based on the definition. The maximum of $R_{(i,j)}$ is defined as max{ $R_{(i,j)}$ }, and the minimum of $R_{(i,j)}$ is defined as min{$R_{(i,j)}$}. Therefore, each index is determined by normalization

$$R^*_{(i,j)} = \frac{R_{(i,j)} - \min\{R_{(i,j)}\}}{\max\{R_{(i,j)}\} - \min\{R_{(i,j)}\}} \quad (1)$$

where $R^*_{(i,j)}$ is a standardized or normalized value from zero to one. After calculating and analyzing the impact of each index on vulnerability using the Analytical Hierarchy Process (AHP) method to obtain the weight of each index $w_{(i,j)}$, the impact F_i of the ith dimension of disaster vulnerability is defined as

$$F_i = \sum_{j=1}^{J_i} w_{(i,j)} \times R^*_{(i,j)} \quad (2)$$

where J_i refers to the total index of the ith dimension. After the impact of each dimension on vulnerability has been calculated, analyzed, or performed using AHP to obtain the weight of each index $p_{(i)}$, the overall impact (aggregative index) V on all dimensions of disaster vulnerability is

$$V = \sum_{i=1}^{3} p_{(i)} \times F_{(i)} \quad (3)$$

C.AHP Calculation

AHP calculation is used to classify issues into simple hierarchy levels. The evaluation method is used to determine the priority levels or contributions of each element (factor) in a level, which are integrated into the overall priority level for all programs (factors). The AHP calculation has the following steps [7]:

- Statement of assessment problems: The problem is the basis and focus of the study and the objective of the final assessment stage. Therefore, it should be clearly defined so that the discussion does not deviate from the topic.
- Identification of all factors influencing the decision: Based on previous studies, relative theories, and experience or by means of group brainstorming and the Delphi method, the factors that may influence the decision are listed and separated according to their relative or independent degree.
- Establishment of relationship levels: The relationship levels can be established from top to bottom, generating each level gradually, or from bottom to top starting from the program to objective level. The number of levels depends on the requirements of the actual problem.
- Establishment of paired comparison matrix: The AHP performs a paired comparison of all programs or factors, thus obtaining a Positive Reciprocal Matrix. Thereafter, the eigenvector of this matrix is calculated to obtain the prioritized vector of this level. The relative priority of the final program is obtained by adding all of the prioritized vectors in all levels (namely, factor weights).
- Calculation of the eigenvector, maximal eigenvector, and priority value vector: The priority value vector (weight) must be derived from the paired comparison matrix obtained by the AHP.
- Consistency test: The consistency test evaluates the consistency of the decision maker before and after making judgments and is used in the paired comparison matrix.
- Calculation of overall level weight: After calculating the weights of all level factors, the overall level weight can then be calculated. If the overall level structure passes the consistency test, then the alternative scheme of the final objective can be determined according to the weight number of every alternative scheme.
- Gathering of decision information: When the whole issue is made, the level structuring mentioned in above is used to obtain the relative priority value of each factor for all levels and to pass through the consistency test, the results are provided to the decision makers for their reference in determining relative reliability.

D.Disaster risk assessment

Disaster risk assessment requires integrated consideration, including the overall vulnerability and hazard analysis. Other than the reality aspect, the economic, social, and environmental aspects should also be considered in the discussion. The UN Disaster Relief Organization (UNDRO) proposed an operational definition of disaster risk R in a report [8]:

$$R = H \text{ (Hazard)} \times V \text{ (Vulnerability)}. \quad (4)$$

This equation shows the possible combinations of disaster risk R, disaster potential H, and vulnerability V. Disaster risk refers to the variation degree which may cause disasters. Generally, if disaster strength is strong and frequency is high, then the damages and losses caused by disasters are more severe. The exposure of affected bodies involves all people and properties, such as personnel, livestock, buildings, and crops, among others, that may be threatened by the risk factor. If the exposure of personnel and properties to the risk factor and the value of stricken properties in an area are high, then the potential loss will be significant. Vulnerability refers to the ease with which potential risk factors cause damage or loss to the properties in the given areas. The higher the vulnerability, the larger the losses and the higher the disaster risk [9]. Adaptability refers to the ability of the government and individuals to adopt a series of measures for preventing and reducing risk. The higher adaptability, then the risk is lower.

Based on the basic concepts of disaster risk assessment proposed by the National Science and Technology Center for Disaster Reduction (NCDR), vulnerability is a factor of the social, environmental, physical, and economic aspects, whereas hazard is a factor of the geophysical, meteorological, hydrological, biological, environmental, and technological aspects. When hazard combines with vulnerability, risk will happen. Fig. 2 shows the coastal vulnerability assessment, which includes the anthropogenic factor. The degree of protection of a coastal facility affects its vulnerability, environmental factors have a certain degree of influence on sea-level rise. The land subsidence in the southwestern coast is also an important factor influencing vulnerability.

The social and economic aspects include population density and human development parameters (health life, knowledge, and standard of living). Potential disaster refers to floods and overflows and other disasters caused by risk factors, including typhoons and storm tides. After the primary study of the coastal risk assessment index factor, as shown in Fig. 3, all index factors are combined using the Geographic Information System (GIS) to evaluate their risk degrees. The evaluation is similar to the vulnerability assessment.

This study aims to analyze the coastal disaster potential under climatic change. Simulations were used to illustrate astronomic tides, storm tides, and typhoon waves and to achieve offshore waves, wave rise, and overtopping situations. A questionnaire was used to obtain the important index factors and the weights of all index factors using the AHP mode. Finally, the disaster potential ranks were determined and used as basis for determining the coastal vulnerability and risk map.

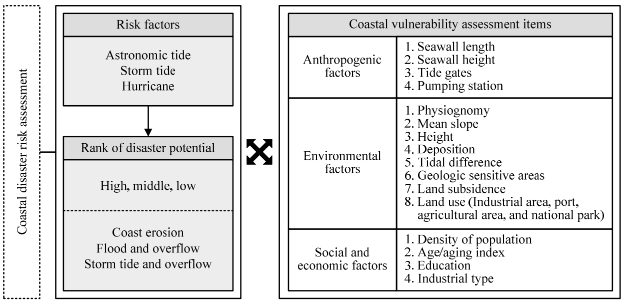


Fig. 2 Conceptual graph of coastal disaster risk assessment

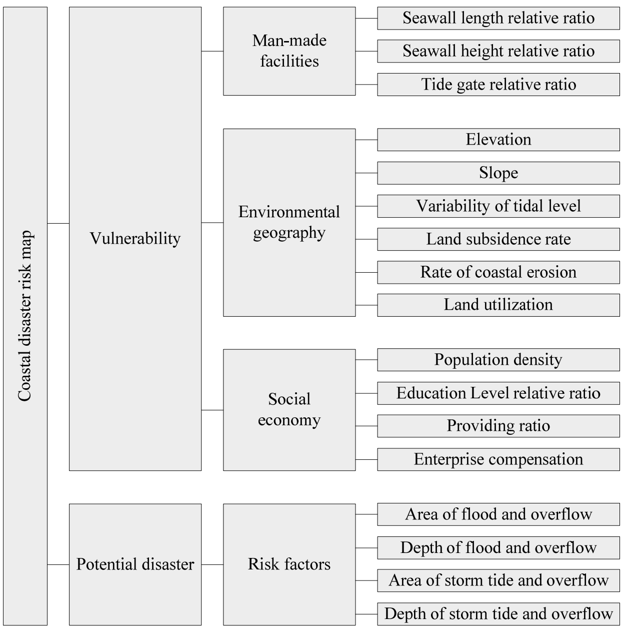


Fig. 3 Diagram of the levels of coastal disaster risk assessment indexes

III. Background of Study Area, Results and Discussion

A. Background of Study Area

The study area for this research covers the Taijiang coastal areas. Located at the southwest portion of Taiwan, Taijiang was an inland sea with an area of 1050 km^2 before it eventually turned into a land mass. Therefore, this area is called the Taijiang inland sea and has many rivers within its border. Taijiang was a political, military, educational, and cultural center in the early years. Taijiang Neihai is bordered by Daofeng Neihai on the north. Based on the study and actual needs, Daofeng Neihai was included in the calculation and analysis. The variation intensity of the land and sea borders was calculated based on the Taiwan Coastline Map that has been used for almost 280 years [10]. In Fig. 4, the Sea-Land Variation Intensity Map of Taiwan clearly shows that the southwestern areas of Taiwan, which once included Taijiang Neihai, experienced the greatest change. The map shows complicated staggering changes in both sea and land.

Based on the description of Taijiang area and the topographic changes, the coastal areas of Taijiang are almost located in Chiayi County and the coastal villages of Tainan County. Chiayi County covers the Dongshi Village and Budai Town. Tainan County covers Beimen, Jiangjun, and Qigu Villages. Tainan City covers the Annan, Anping, and South Districts. Fig. 5 shows the eight administration regions within the study area.

Fig. 4 Variation intensity graph of sea and land borders in Taiwan island

Fig. 5 Administration regions within the study area

B. Calculation and analysis of vulnerability

This study considers the village as the basic unit for the grid size. The whole study area is at least 25,716 m^2. Supposing that this area represented as a square grid, the village area can be represented as a 160 m ×160 m grid. Therefore, a 200 m × 200 m grid size was used in the calculation and analysis. Table I presents the list of the data analysis format of the vulnerability indexes of coastal areas. The size can be divided into three levels. The first level refers to the township boundary, which has a large area. The second level refers to the village boundary, which has a smaller area. The third level refers to a finer grid boundary.

TABLE I
DATA ANALYSIS FORMAT OF VULNERABILITY INDEXES OF COASTAL AREAS

Dimension	Index	Level of obtained materials			Original data structure	Unit
		Town	Village	Grid		
Man-made facilities	Relative ratio of seawall length	✓	-	-	Polyline	dimensionless
	Relative ratio of seawall height	✓	✓	-	Point; Polyline	dimensionless
	Relative ratio of tide gate	✓	✓	-	Point; Polyline	number/meter
Environmental geography	Height	-	-	✓	Point	meter
	Slope	-	-	✓	Point	degree
	Tidal difference	✓	-	-	Point	cm
	Speed of land subsiding	-	-	✓	Polygon	cm
	Rate of coast erosion	-	-	✓	Point	Nil
	Type of land use	-	-	✓	Polygon	Nil
Social economy	Density of population	✓	✓	-	Polygon	Num. of people/km^2
	Relative ratio of education level	✓	✓	-	Polygon	dimensionless
	Supporting ratio	✓	✓	-	Polygon	dimensionless
	Enterprise compensate	✓	-	-	Polygon	NT$

The original data level obtained by index calculation is different and the data format lacks some data. Therefore, some materials have to be approximated in the calculation and analysis. The weight values were determined via two methods, namely, equal weighting process and AHP using expert and scholar questionnaires.

Fig. 6 shows the vulnerability analysis results after the combination of the three dimensions (man-made facilities / environmental geography / social economy), simulations of the existing circumstances / scenarios, and equal weighting process / AHP. The analysis results of the existing circumstances using equal weighting showed that vulnerability of man-made facilities was highest in Budai Town, Chiayi County, and Anping District, Tainan City, had the highest vulnerabilities. In environmental geography, vulnerability was highest in Dongshi Village and Budai Town, Chiayi County, followed by Qigu Village, Tainan. In the social economy dimension, vulnerability was highest in Anping District, Tainan City, which has the highest population density. The analysis results of the existing circumstances using AHP showed the highest vulnerability of man-made facilities in Anping District, Tainan City. In environmental geography, vulnerability was highest in Dongshi Village and Budai Town, Chiayi County, followed by Qigu Village, Tainan County. In social economy, the vulnerability was highest in Anping District, Tainan City, which has the highest population density. The analysis results of the simulation using equal weighting showed that the vulnerability of man-made facilities was highest in Budai Town, Chiayi County, and Anping District, Tainan City, followed by Qigu Village. In environmental geography, the vulnerability was highest in Dongshi Village and Budai Town, Chiayi County, followed by Qigu Village, Tainan County, and then Annan District, Tainan City. In the social economy dimension, the vulnerability was highest in Anping District, Tainan City, which has the highest population density. The analysis results of the simulations using AHP showed that the vulnerability of man-made facilities was highest in Anping District, Tainan City. In environmental geography, vulnerability was highest in Dongshi Village and Budai Town, Chiayi County, followed by Qigu Village, Tainan County, and then Annan District, Tainan City. The simulations also showed that some areas of Annan District tended to subside.

In the social economy dimension, vulnerability was highest in Anping District, Tainan City, which has the highest population density. Fig. 7 shows the analysis results of the overall vulnerability in the study areas by integrating the three dimensions. Fig. 7(a) shows the vulnerability analysis results after considering the existing circumstances using equal weighting. These figures show that the vulnerabilities of Budai Town (Rank 4 and 5), Chiayi County, and Anping District (Rank 5), Tainan City, were the highest. This result is attributed to the small number of tide gates and the high land subsidence rate in Budai Town, Chiayi County. The seawall length and population density in Anping District, Tainan City, are high, and the land use is categorized as mainly for urban development. Fig. 7(b) shows the analysis results of vulnerability after considering the existing circumstances using AHP. In this figure, the highest vulnerabilities were observed in Dongshi Village (Rank 4) and Budai Town (Rank 5), Chiayi County, Qigu Village (Rank 4), Tainan County, and Anping District, Tainan City. Fig. 7(c) shows the analysis results of vulnerability by using simulations and equal weighting. The highest vulnerabilities were observed in Budai Town (partly Rank 4), Chiayi County, and Annan (partly Rank 4) and Anping Districts (Rank 4 and 5), Tainan City. Fig. 7(d) shows the analysis results of vulnerability using simulations and AHP. The highest vulnerabilities were observed in Budai Town (Rank 4), Chiayi County, Qigu Village (Rank 4), Tainan County, and Annan (Rank 4 and 5) and Anping Districts (Rank 5), Tainan City. According to the simulation analysis, vulnerability is higher in Qigu Village, Tainan County, because of the increased coastal erosion and land subsidence rate in the area. The vulnerability of some regions in Annan District reached Rank 5 because of the increased land subsidence at the borders of Annan District and Yongkang City. Based on the gathered information, all index items are classified into different ranks. The area of the index items is equally divided into five ranks or general methods. For example, according to the definition from the Water Resources Agency, floods with depths of less than 30 cm belong to Rank 1, whereas those with depths of more than 50 cm belong to Rank 2, which indicates the occurrence of a flood disaster. Floods with depths of 50 cm to 100 cm belong to Rank 3, those with 100 cm to 150 cm depths belong to Rank 4, and finally, those with depths of more than 150cm belong to Rank 5, which is the highest rank.

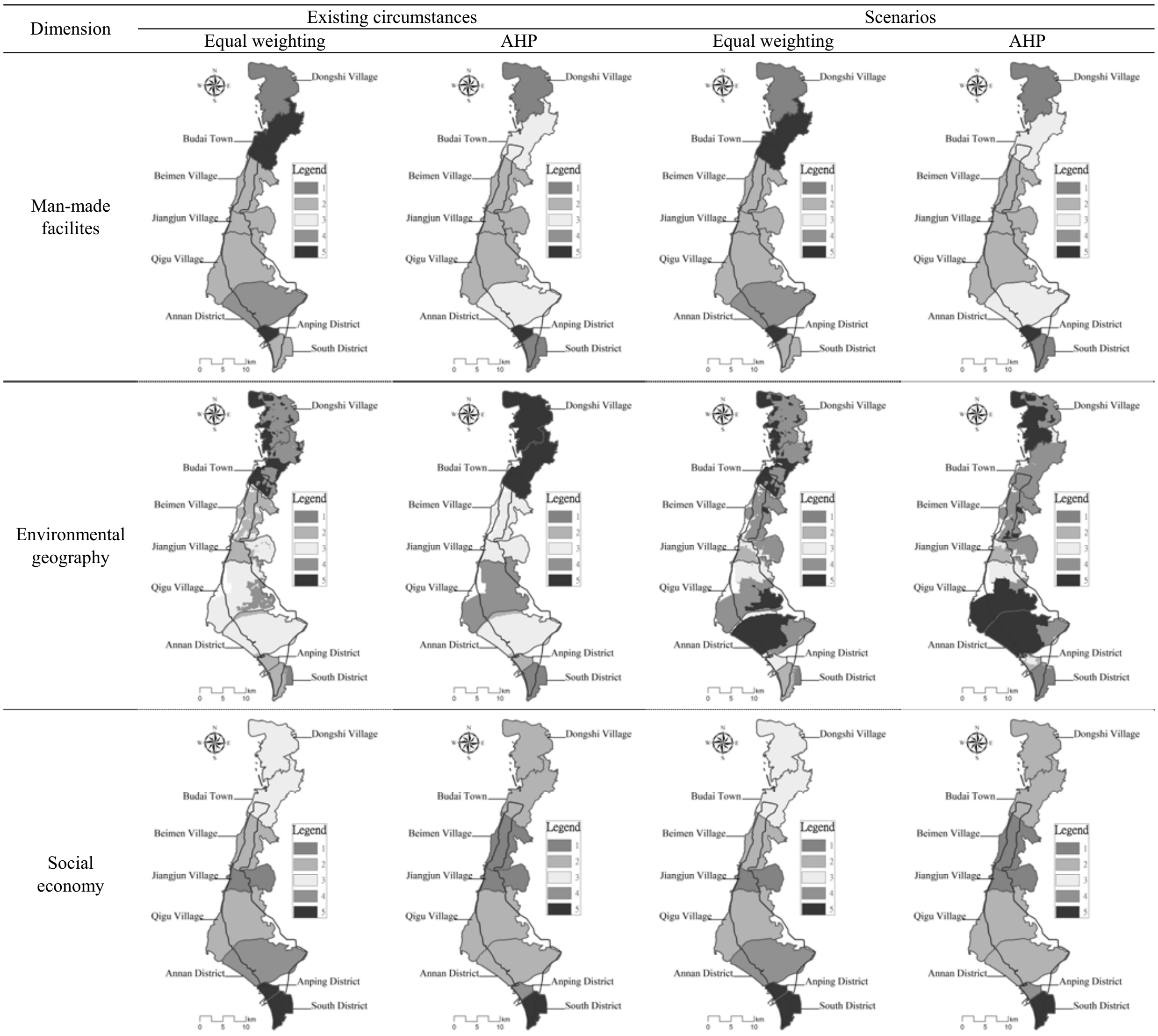
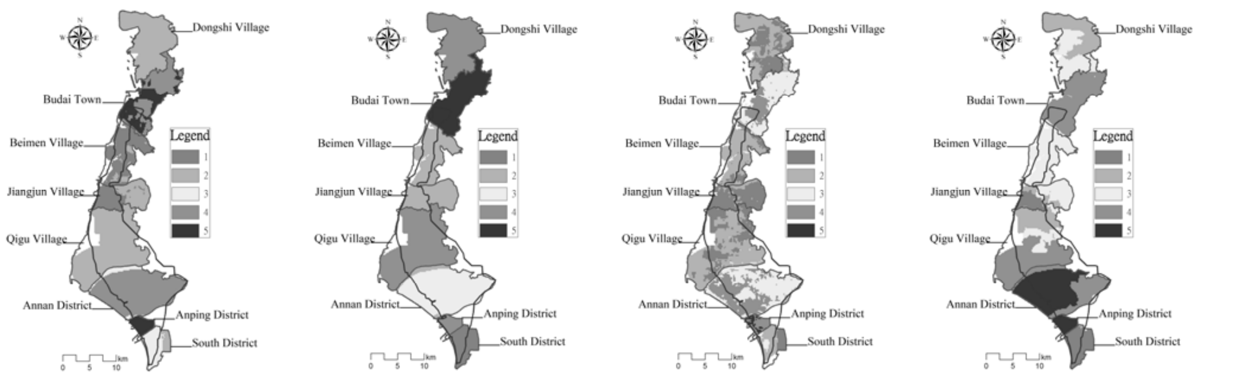


Fig. 6 Vulnerabilities of the Chiayi and Tainan coastal areas according to the three dimensions



(a) Existing circumstances and equal weighting
(b) Existing circumstances and AHP
(c) Scenario simulations and equal weighting
(d) Scenario simulations and AHP

Fig. 7 Vulnerabilities of the Chiayi and Tainan coastal areas

C. Calculation and analysis of risk map

In coastal disaster risk analysis, vulnerability analysis is continued and indexes are divided according to equal weighting and AHP. As shown in Table II, the risk factors of disaster potential include the area and depth of flood and overflow and storm tide and overflow. The value of this index is based on the analysis of the results of the Evaluation Program of Impact of Climatic Change on Flood and Drought Disaster Prevention and Relief (1/2) executed by the National Cheng Kung University (NCKU) Research and Development Foundation (2010) and entrusted by the Water Resources Agency, as shown in Table III. The area of flood and overflow is the most important disaster potential risk factors with a weighted value of 0.384, followed by the depth of flood and overflow with a weighted value of 0.271. Meanwhile, for the factors of coastal disaster risk, the weight of vulnerability is higher than that of disaster potential. Their weighted values are 0.596 and 0.404, respectively.

TABLE II
DATA ANALYSIS FORMAT OF RISK INDEX IN COASTAL AREAS

Construction	Index	Level of obtained materials			Original data structure	Unit
		Town	Village	Grid		
Risk factors	Area of flood and overflow	-	-	✓	Polygon	m^2
	Depth of flood and overflow	-	-	✓	Polygon	cm
	Area of storm tide and overflow	-	-	✓	Polygon	m^2
	Depth of storm tide and overflow	-	-	✓	Polygon	cm

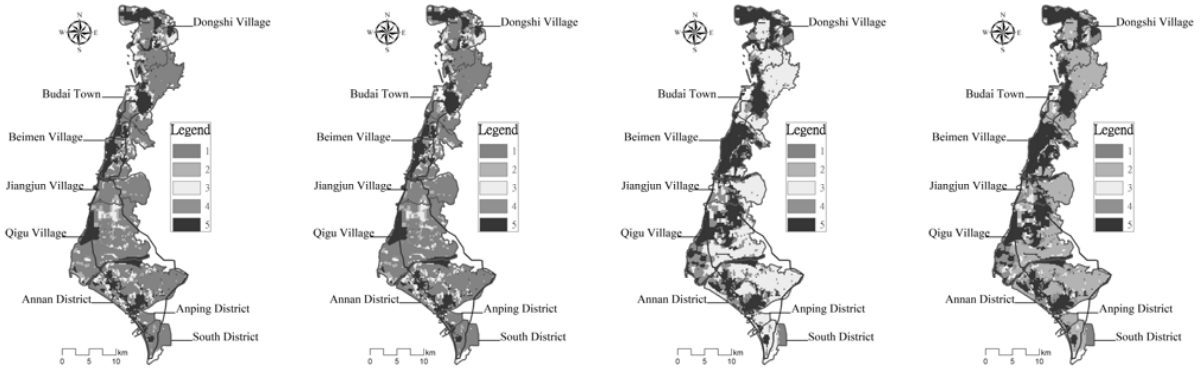
TABLE III
AHP WEIGHTING ASSESSMENT ANALYSIS RESULTS FOR COASTAL DISASTER RISK INDEX

Level		Dimension		Index	
Name	Weight	Name	Weight	Name	Weight
Vulnerability	0.596	Man-made facilities	0.195	Relative ratio of seawall length	0.257
				Relative ratio of seawall height	0.499
				Relative ratio of Tide gate	0.244
		Environmental geography	0.327	Height	0.139
				Slope	0.098
				Tidal area	0.086
				Rate of coastal erosion	0.359
				Rate of land subsidence	0.226
				Land utilization	0.093
		Social economy	0.075	Density of population	0.415
				Relative ratio of education level	0.223
				Supporting ratio	0.166
				Enterprise compensation	0.196
Disaster potential	0.404	Risk factors	0.404	Area of flood and overflow	0.384
				Depth of flood and overflow	0.271
				Area of storm tide and overflow	0.159
				Depth of storm tide and overflow	0.186

All index factors are analyzed using equal weighting and AHP. After the combination, the existing circumstances of disaster potential and scenario materials were obtained, as shown in Fig. 8. The analysis results of the existing circumstances using equal weighting and AHP in Fig. 8(a) and 8(b), respectively, did not have significant differences. Meanwhile, the analysis results of simulations using equal weighting and AHP in Fig. 8(c) and 8(d), respectively, were significantly different. The equal weighting analysis results showed that the disaster potential of coastal areas under climatic changes evidently increased. The disaster potentials of the areas within the research area were ranked higher than Rank 3, indicating increased disaster potential. In the AHP analysis, the disaster potential also increased, reaching ranks higher than Rank 2. However, the values were considerably smaller.

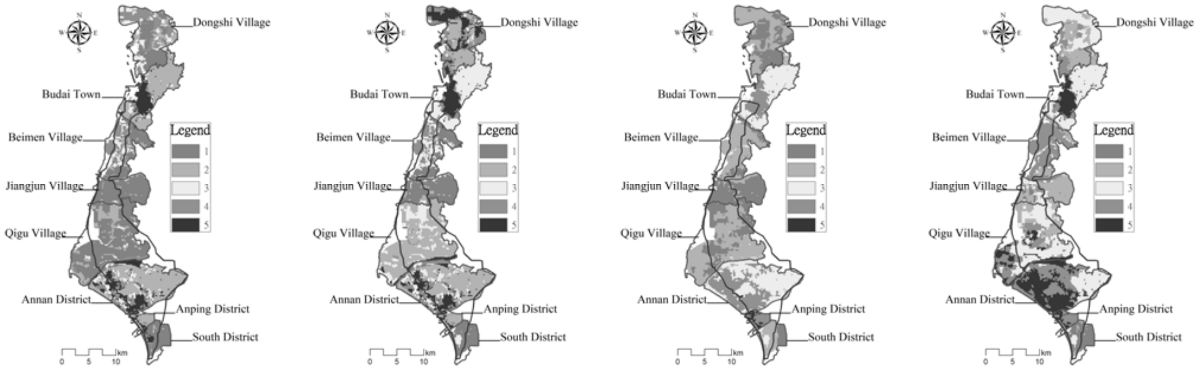
Finally, the coastal disaster risk map was obtained by combining the vulnerability and disaster potential analysis results, as shown in Fig. 9, using existing data and scenario simulations. Fig. 9(a) and 9(b) show that the areas with higher coastal disaster risks were located on the Chiayi coastal areas, as well as Beimeng Village and Annan District, Tainan City. Meanwhile, the simulation results in Fig. 9(c) and 9(d) were similar, but their risk degrees increased. The figures also show that climatic changes significantly increase coastal disaster risk.

For further analysis on the effects of climatic changes, the differences between the scenario simulations and existing circumstances were analyzed. The results are shown in Table IV. Using equal weighting analysis, existing circumstances showed that 69.1% of the whole research area belongs to Ranks 1 and 2, whereas the scenario simulations indicate that the areas belonging to Ranks 1 and 2 only accounted for 28.91%. The areas with original disaster risk belonging to Ranks 3 and 4 increased from 21.4% to 36.32% because of the effects of climatic changes. The difference in the results was calculated by subtracting the existing circumstance level from the scenario simulation level, as presented in Fig. 10. The figure shows that the difference between the current and predicted (for year 2039) levels can be classified as Rank 2, with an area of 9.96 km^2.



(a) Existing circumstances and equal weighting
(b) Existing circumstances and AHP
(c) Scenarios and equal weighting
(d) Scenarios and AHP

Fig. 8 Analysis results of coastal disaster potential



(a) Existing circumstances and equal weighting
(b) Existing circumstances and AHP
(c) Scenarios and equal weighting
(d) Scenarios and AHP

Fig. 9 Analysis results of coastal disaster risk maps

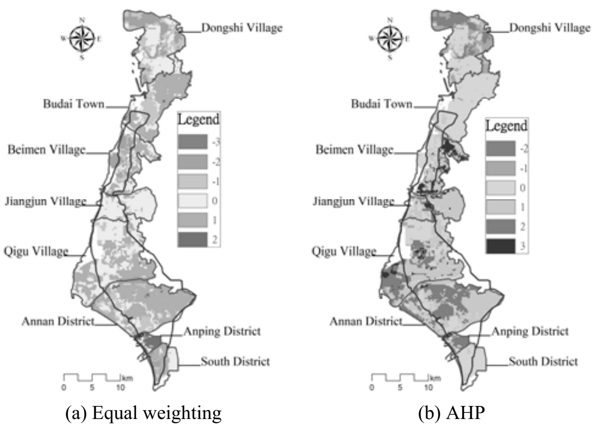
TABLE IV
ANALYSIS OF THE AREA (SQUARE KILOMETERS) DIFFERENCE FOR COASTAL DISASTER RISK BASED ON THE EXISTING CIRCUMSTANCES AND SIMULATIONS IN THE OBJECTIVE YEAR (2039)

Items	Rank				
	1	2	3	4	5
Existing circumstances:					
Equal weighting	204.28	158.6	50.00	68.44	44.12
AHP	82.12	187.56	116.92	72.12	66.72
Scenarios:					
Equal weighting	132.88	196.32	115.76	76.88	3.08
AHP	22.08	95.96	171.92	149.44	85.52

This difference could be classified as Rank 3 if AHP was used, with an area of 17.8 km^2 mainly located in the towns of Beimeng and Jiangjun, Qigu County. These results show that the areas with lower original disaster risks tend to experience more disaster risks under future climatic changes. More attention should be given in the development of these areas in the future.

IV. Conclusion

1. Based on the index factors of the three dimensions, namely, man-made facilities, environmental geography, and social economy, this study adopted the equal and AHP weighting modes in the analysis of the vulnerability of a certain area to disasters under climatic changes. Three coastal regions currently have the highest vulnerability to disasters (Ranks 4 and 5), whereas four are predicted to have the highest relative vulnerability in the future.
2. The flood and overflow area is the most important among all index weights of disaster potential risk factors, followed by the depth of flood and overflow. The influence of coastal disaster risk on vulnerability is more significant than that of disaster potential. This study obtained a coastal disaster risk map by combining the analysis results of coastal vulnerability and disaster potential. The map shows that three regions currently have the highest coastal disaster risk. Considering future coastal disasters due to climatic changes, the above three regions also have the highest disaster risk as their risk levels significantly increase.
3. The coastal disaster risk variation analysis was performed based on scenario simulations and existing circumstances. The difference between the weight results of the existing circumstances and simulations in 2039 could be classified as Rank 2 with an area of 9.96 km^2. If AHP is used, the difference could be classified as Rank 3, with an area of 17.8 km^2. These results show that in the areas with lower original disaster risk, the disaster potential will increase considering future climatic changes. Hence, more attention should be given in the development of these areas.



(a) Equal weighting (b) AHP

Fig. 10 Difference risk maps of coastal disasters in existing circumstances and simulations

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