THE ENVIRONMENTAL SIMULATION ADJUSTMENT OF ISLAND LAND USE ON VULNERABILITY CONCEPT

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Abstract - Nowadays the global climate and environment changes, resulting the land use planning based on disaster prevention is one of the important issues in the future especially for island country. In the past relevant research, the impact of vulnerability data were collected at one point in time, and also a lack of discussion on space impact influence. However, the different land use zoning had spatial structure differences that was not easy to control the complex relationship of environmental impact in effect and was unable to understand the vulnerability in different land characteristics, and to discussion on development trend. Based on the above reasons, this study takes Penghu as the research area in Taiwan. Appling the UNEP (2005) Vulnerability analysis method to investigate environmental sensitivity, vulnerability and adaptation of island coastal area development. Finally, based on cellular automata theory to simulate space distribution situation of future developing land. The results could be the spatial strategies references for coastal land use, disaster prevention and island city development in the future.

Keywords - Island, Vulnerability, Cellular Automata, Markov-Chain Model

I. INTRODUCTION

According to EVI Report (South Pacific Applied Geosciences Commission, SOPAC, 2004), Indicators for the EVI were selected to characterise the risks and resilience / vulnerability of the complex interactive and hierarchical natural systems that support countries. The results present Taiwan belongs to the highly vulnerable area. There are 165 islands scatter around Taiwan. Penghu is the most densely populated offshore islands of Taiwan. The superior natural and geographical advantages of Penghu islands highlight the significance of this region. With the current tourism economic boom in Penghu, this region has great potential to accelerate economy and construction of public infrastructure. However, nowadays the global climate and environment changes, resulting the land use planning based on disaster prevention is one of the important issues in the future. Especially for island country is more important, the island is a space closure system, belongs to the high risk area, that the disaster caused by the outside effect is not enough to adjust ability. Therefore, in the planning and development of land, it should be considered the characteristics of the coastal environment of the island, to give the sustainable development strategy for coastal land suitability.

In the past relevant research of island area, the impact of vulnerability and land use were less discussed, but also a lack of discussion on space impact influence. Considering that climate change impacts and disasters on island area are very dependent on regional geographical features, climate and socio-economic conditions, impact studies should be performed at the local or, at most, at the regional level [1], but don't consider spatial dependencies based on relationship with surrounding places [2][3][4][5]. However, the different land use zoning had spatial structure differences that was not easy to control the complex relationship of environmental impact in effect [6], and was unable to understand the environmental vulnerability in different land characteristics arising from different systemic effects and characteristics. Therefore, it is necessary to grasp the environmental vulnerability in space distribution and correlation to make adapted strategies to adjust and govern.

Hence, the main aim of this paper first is to try to identify the vulnerability, and evaluate the vulnerability of Penghu. Second, exploring the influence relationship between island coastal area development and coastal vulnerability by Spatial Autocorrelation. Second, it cut into 20M × 20M grid cells. Appling the UNEP (2005) Vulnerability analysis method to investigate environmental sensitivity, vulnerability and adaptation of island coastal area development. Finally, based on cellular automata theory, combining the vulnerability assessment and Markov-CA-based model, simulating space distribution situation of future developing land. The results could be the spatial strategies references for land use, disaster prevention and island city development in the future.

II. METHODS

The application of the methodology allows the identification and prioritization of key vulnerable receptors in the island area, and through the Markov-CA model to simulate the land use change.

A. Description of the study area

The study area selected is the Penghu County, locates on the Taiwan Strait between China and Taiwan in Asia. It is the only island county of Taiwan. The Penghu archipelagoes scatter all over the ocean and extending around 60Km north to south, 40Km west to east. The total measure of the area of the 90 islands is

around 127.96km2. The coastline of Penghu is crooked and lasts for 448,974 long. Except for the common cape bays, we can also see wave-erosion platform, wave-erosion cliff, wave-erosion cavity, sandy coast and rocky coast landforms along the coast area.

Table 1: Datasets used for the application of the regional vulnerability assessment methodology to the case study area.

Vulnerability indicator	Description	Unit	Correlation	References
Population density	The population density is derived by dividing the population count by the land area. It represents population per 10,000 m^2.	Peo./ 10,000m^2	Positive	SOPAC(2004) ; Cutter(2003)
Coastal geomorphology	Geomorphologic structure of the coastal zone. It refers to muddy, sandy or rocky coast typology. Scores are ranked according to the relative resistance of a given landform to erosion.	-	Positive	
Rainfall intensity	Average the amount of rainfall received during a year.	mm/y	Positive	Lei (2012).
Mean elevation	It represents the surface of selected island unit (pixel) within a specific class of elevation Xi (e.g. 0.15m_Xi _ 0.3 m).	m	Negative	Lei (2012).
Land use	It selects agricultural land, industrial land, commercial land, residential land, and Port land, etc. as an analysis item. The land use value larger that the vulnerability higher.	%	Positive	Lei (2012).
Distance from the shoreline	It represents the distance from the shoreline.	m	Negative	Lei (2012).
Green areas	The percentage of vegetation. Higher vegetation is lower vulnerability.	%	Negative	
Organizations of accessibility and roads	The percentage of roads area.	%	Positive	Abeyratne (1999)
Efficient water use	It represents the annual average water consumption.	ton	Positive	Baharuddin et al. (2013)
Tourism arrivals	It represents annual tourists per 10,000 m2.	Peo./ 10,000m^2	Positive	Alonso and Liu (2012) ; McKee (2013)

In 2015, almost 100,000 people resided permanently in Penghu with an average growth rate projected to reach up to 1.89% over the past 10 years while the influx of tourists can double during the summer months. Unfortunately, development has been expanded without any integrated vision or long-term planning taking into account the carrying capacity of Penghu main island. Highly developed sections of the main island coupled with the high-energy, swell-dominated nature of the near shore makes it increasingly vulnerable to coastal erosion, storm surges and extreme weather events.

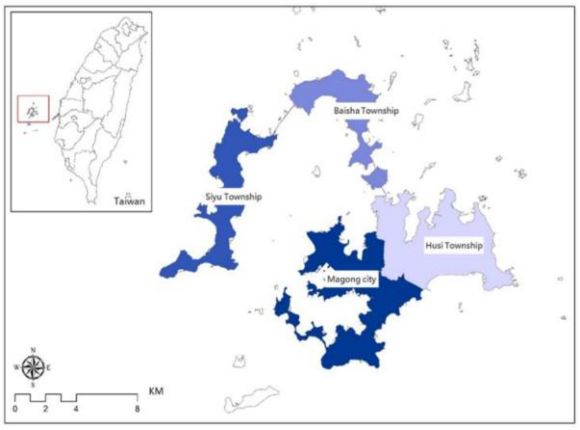

Fig.1. The case study area

B. Construction of vulnerability maps

Table 2: Each vulnerability class for the Penghu island

Vulnerability indicator	unit	score				
		1	2	3	4	5
Population density	Peo. /10,000m2	0	0.000001 - 0.000441	0.000442 - 0.001550	0.001551 - 0.004553	0.004554 - 0.030287
Coastal geomorphology	-	Inland	Reef	Coral Reef	Gravel	Sandy, Wetlands
Rainfall intensity	mm/y	582.06 - 719.23	719.23 - 856.38	856.38 - 993.54	993.54 - 1,130.69	1,130.69 - 1,267.85
Mean elevation	m	0.00000- 7.34340	7.34340- 12.5987	12.59865- 20.06986	20.06986- 33.17068	33.17068- 55.00000
Land use	%	0.00000	0.00000- 0.03747	0.03747- 0.12937	0.12937- 0.32370	0.32370- 1.00000
Distance from the shoreline	m	- 4.6310 - 0.62250	0.62251 - 0.79030	0.79031 - 0.89380	0.89381 - 0.96660	0.96661 - 1.00000
Green areas	%	0.00000 - 0.13420	0.13421 - 0.35580	0.35581 - 0.60320	0.60321 - 0.85269	0.85270 - 1.00000
Organizations of accessibility and roads	%	0.00000 - 0.52689	0.52690 - 0.70939	0.70940 - 0.84530	0.84531 - 0.94999	0.95000 - 1.00000
Efficient water use	ton	0.00000 - 0.52689	0.52690 - 0.70939	0.70940 - 0.84530	0.84531 - 0.94999	0.95000 - 1.00000
Tourism arrivals	Peo. /10,000m2	0.0000 - 0.0595	0.0596 - 0.2104	0.2105 - 0.4162	0.4163 - 0.6487	0.6488 - 1.0000
Overall Penghu vulnerability	-	Very Low	Low	Medium	High	Very High
		0.00000 - 0.28589	0.28590 - 0.36438	0.36439 - 0.45201	0.45202 - 0.60300	0.60301 - 1.00000

The vulnerability maps represent the main outcome in this paper. Vulnerability are calculated as the sum of the indexes for each significant island area unit. For this paper was considered a unit equal to a 20m X 20m grid cell. According to the classes proposed by UNEP(2005), with some adjustment adapted to the local context of Penghu, this paper proposed 10 variables for the Vulnerability indicators, include population density, coastal geomorphology, rainfall intensity, mean elevation, land use, distance from the shoreline, green areas, organizations of accessibility

and roads, efficient water use and tourism arrivals. Variables and related rankings are presented in Table 1. Appling the UNEP (2005) Vulnerability analysis method to investigate environmental sensitivity, vulnerability and adaptation of island coastal area development. The assignation of scores to vulnerability classes was performed using a 1-5 scale. For each analyzed impact, this scoring method allowed the definition of relative rankings within the subset of vulnerability classes associated with each vulnerability factor. This means that the maximum score 5 was always assigned to the most important (i.e. higher) vulnerability class. In the same way the minimum score 1 was assigned to the vulnerability class that was considered the least important (i.e. the lowest vulnerability class).

C. Aggregation of vulnerability indexes

According to the conceptual vulnerability framework adopted in this paper, vulnerability is a multi-dimensional concept, encompassing physical, social, economic, and environmental factors (Table 1). Appling the UNEP (2005) Vulnerability analysis method to integrate different Vulnerability indicators and then to estimate the final vulnerability index. This paper was used according to the following equation:

$$CVI = f[a + (1 - b) + c + d + (1 - e) + (1 - f) + g + h + i + j] \quad (1)$$

Where CVI is integration value of vulnerability index; a is Mean elevation, b is Rainfall intensity, c is Coastal geomorphology, d is Distance from the shoreline, e is Green areas, f is Organizations of accessibility and roads, g is Efficient water use, h is Population density, i is Tourism arrivals, j is Land use.

In order to convert all the vulnerability indexes in the same standard scale ranging from 0 to 1 and facilitate the comparative analysis of vulnerability values in the case study area, a normalization procedure should be performed. For the application of the regional vulnerability assessment on Penghu, all the vulnerability values obtained from Eq.(1) were converted in the range between 0 and 1 according to the following linear equation:

$$V = \frac{V_i - V_{min}}{V_{max} - V_{min}} \quad (2)$$

Where V is normalized vulnerability index; V_i is initial vulnerability index; V_{min} is minimum vulnerability value; V_{max} is maximum vulnerability value. If the index and vulnerability is negative correlation, it adopt the equation of 1 normalized value to convert the relationship between the index and vulnerability into positive correlation, according to the following equation:

$$y' = 1 - \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (3)$$

D. The simulation based CA-Markov model

In this paper, calibration data over the period 1995-2006 was used to extract transition probability matrix. Then two types of criteria (factors and constraints) were developed to determine which lands are suitable for future development. Three types of validation analysis was performed using Kappa Agreement Index (KIA) (Fig.2).

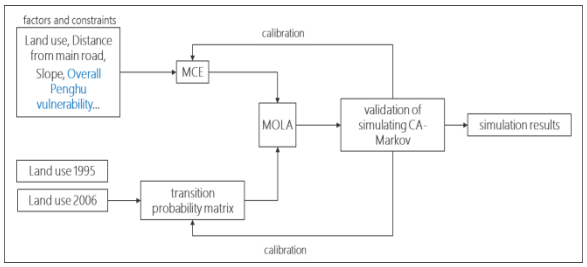

Fig.2. Stepwise of CA-Markov model.

III. RESULTS

A. The vulnerability of overall Penghu island

Vulnerability graded showed in Fig.3. and Table 2., according to these indicators to calculate the overall vulnerability index (CVI value) to quantify divided into five levels which corresponding to the vulnerability degree were very low, low, medium, high and very high.

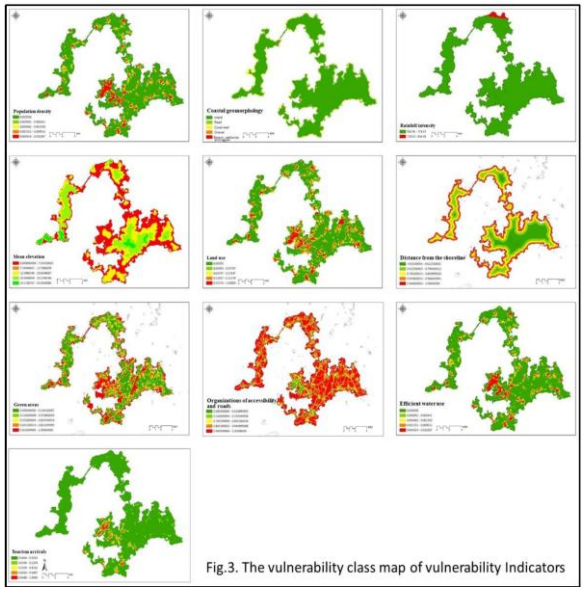

Fig.3. The vulnerability class map of vulnerability Indicators

From the result, the vulnerability of beach and coastal areas around the Penghu Island, and the densely inhabited areas were high which distributed in Magong City, Huxi Township, and Baisha Township while the vulnerability of inland area and where land-use value lower were low which distributed in Xiyu Township.

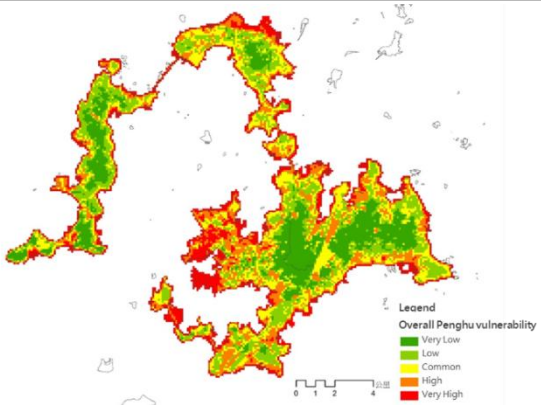

Fig.4. Vulnerability map for Penghu.

B. The simulation of land use change using the CA-Markov model

The Markov Chain model was used to calculate the transition probabilities matrix, as presented in Table 3.

Table 3. Transition probability matrix for land use change modeling under the 2006-2026 period.

Category	Water bodies	Traffic	Other	Idle land	Forest	Agricul-ture	Business	Commu-nity	Industry
Water bodies	0.6825	0.0428	0.0255	0.1285	0.0830	0.0342	0.0000	0.0022	0.0013
Traffic	0.0140	0.5041	0.0490	0.1144	0.2252	0.0187	0.0035	0.0665	0.0047
Other	0.0185	0.0316	0.4080	0.1193	0.3566	0.0442	0.0040	0.0092	0.0086
Idle land	0.0187	0.0492	0.0852	0.1927	0.5690	0.0236	0.0049	0.0506	0.0062
Forest	0.0182	0.0165	0.0529	0.1388	0.7504	0.0215	0.0000	0.0017	0.0000
Agricul-ture	0.0067	0.0141	0.0536	0.2435	0.5729	0.0789	0.0026	0.0236	0.0041
Business	0.0000	0.0556	0.0000	0.2778	0.0000	0.0000	0.0556	0.6111	0.0000
Commu-nity	0.0000	0.0929	0.0124	0.0836	0.0433	0.0372	0.0124	0.7121	0.0062
Industry	0.0000	0.0000	0.1000	0.2000	0.2000	0.0000	0.0500	0.3000	0.1500

According to transition probability matrix, the biggest change occurred on business land. Due to in recent years Penghu focused on tourism development, therefore business land changed to residential area for tourism accommodation. The other land changed to idle land or forest land were also higher probability, we knew that the island land use needs may be concentrate to the development(Fig.5.). From this study's results, simulated land use and land cover change between the years 2006 to 2028. In this paper reported that CA-Markov was validated successfully, with Kstandard of 81.52%, respectively.

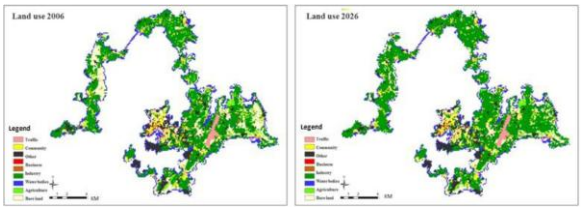

Fig.5. Comparison between the simulation result.

CONCLUSION

This study considered whether the vulnerable relationship displayed between the island environment and social conditions or not. To assess vulnerability completely of the island city, through reviewing the present relevant study and considering the characteristics of island to propose the assessment indicators of vulnerability what containing the natural environment and social elements. Through reviewing the present relevant study and considering the characteristics of island to propose 10 assessment indicators of vulnerability. And as the analysis results of Penghu island, high vulnerability areas were distributed in Magong downtown area, coastal areas, and the population concentrated regions. If the effects of climate change continued in the future, the disasters in these areas would be the most serious, the impact of storm surge would destroy the local infrastructure, and the victim population per unit area under the disaster impact would also be greater than in other regions.

Island area growth is a complex phenomenon and many factors influence it. Island planning laws and regulations have influence on land development, especially in terms of urban expansion and protection of natural areas. The decision support system can be used for evaluating different planning options by using the performance indicators, which can be defined on the basis of the relevant planning agenda. Future improvements of the methodology can be obtained by eliciting more potential receptors and extending their subset of vulnerability factors. The results could be the spatial strategies references for Penghu's land use, disaster prevention and island city development in the future.

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