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Exploring the Spatial Pattern of Environmental Change Efficiency of Coastal Shrinking Cities in Taiwan

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ABSTRACT

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The declining population has become a special phenomenon for many cities all over the world. Among 352 townships in Taiwan, 63.92% of them have been facing the situation of shrinking population from 2006 to 2016; furthermore, the proportion of this has been increasing over the years. Taiwan is facing problems of negative growth in total population, aging structure of population, rising of dependency ratio, aging society and so on. This study applied environmental change efficiency index and identified 10 important indicators to evaluate the relative efficiency and sustainability of coastal shrinking cities in Taiwan. The inputs were oriented toward natural environmental resources and the ecological environment, including surface temperature, surface runoff, habitat quality, water consumption and power consumption. The outputs were chosen to reflect the benefits and goals of economic and social development, included population, production, income, the service quality of infrastructure, and employees. The results indicate that the average environmental change efficiency is 70.71%, which has clear spatial differentiation and it would be helpful to develop strategies for coastal shrinking cities.

ADDITIONAL INDEX WORDS: *Coastal management, island, shrinking cities, environmental change efficiency.*

INTRODUCTION

According to the 2017 Revision of World Population Prospects, the global population is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100 (United Nations, 2017). The total population of Taiwan was 19,258,053 in 1985 and 23,293,524 in 2014 and is expected to reach 24,150,708 in 2030. On the other hand, the 2014 Revision of World Urbanization Prospects indicated that the population living in urban areas is projected to increase by 2.46 billion, an increase from 3.88 billion (54%) in 2014 to 6.34 billion (66%) in 2050, at which point approximately 64% of the population of the developing world and 86% of the developed world will be urbanized.

Even though the total population has been increasing for many cities, declining population has become a special phenomenon for many other cities all over the world. Shrinking cities are widespread throughout the world despite the rapidly increasing global urban population. Oswalt (2005) considered that shrinking cities are not merely a statistic of population, but that they also contain the aspects of economy, space, and society. The shrinking city is regarded as a variant and complicated phenomenon. Declining industry, industry transformation, and investment outflow are the reasons for urban decay, which cause a great loss of employment opportunities and population migrations. In 2013, Haase *et al.*(2013) provided a conceptual model of urban shrinkage. In the model, urban shrinkage evolves when the place-specific interplay of economic transformation, suburbanization and demographic change leads to population decline.

From the viewpoint of spatial location, there is coastal population growth in many of the world's deltas and it has been estimated that 23% of the world's population lives within 100 km of the coast. In many countries, coastal regions are important sites of human population aggregation because of the natural resources and locations that they provide. In recent years, studies related to coastal areas have increased. Many current studies address the functions, strategies for coastal management, and suitable uses of coastal land. The changes of using coastal land are affected by the results of the interaction between many factors, such as economics, society, natural environment, human behaviors, and so on. In the past, studies were mainly focused on continental land instead of coastal land. With the increasing important of coastal land, the research has begun to emphasize environmental planning research of the function of coastal land, the description of coastal land management, and the suitable analysis of land uses. Additionally, due to climate change, the coastal areas are projected to suffer the most significant impacts include flooding, ecosystem change, wetland loss, coastal erosion, saltwater intrusion, and rising water tables (Fu *et al.*, 2017; Nicholls, 2011).

Taiwan is located in the continent of Asia (E120°0'00"~ E122°2'42", N21°50'40"~ N25°19'45") (see Figure 1), covering an area of 35,980 square km and a coastline of 1,139 km. The population of Taiwan was 18,193,955 in 1981 and 23,288,844 in

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2016. The population average of 352 townships is 66,161, the maximum is 552,285 and the minimum is 1,896. Among 352 townships in Taiwan, 63.92% of them have been facing the situation of shrinking population from 2006 to 2016; furthermore, the proportion of it has been increasing over the years. This study applied environmental change efficiency index and integrated the data envelopment analysis (DEA), geographic information system (GIS) and local indicators of spatial association (LISA) methods to evaluate the relative efficiency and sustainability of the spatial pattern of coastal shrinking cities in Taiwan.

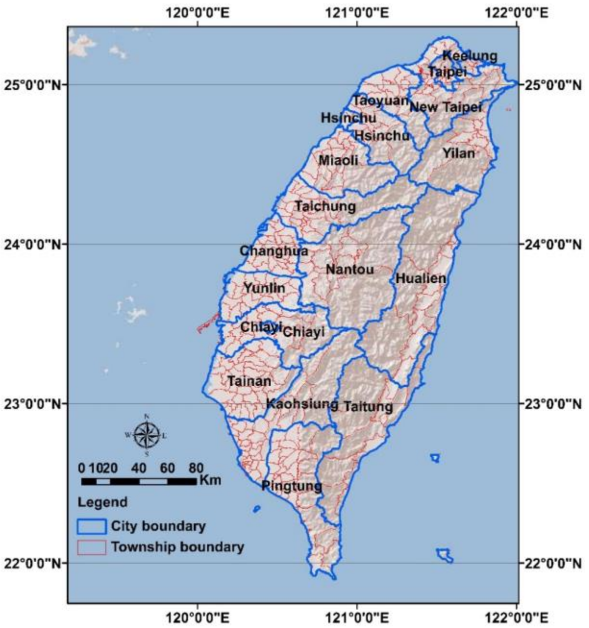

Figure 1. Location and spatial unit of study area.

METHODS

Data Envelopment Analysis

There are two main methods of environmental efficiency evaluation. The first one is stochastic frontier analysis method, which is a parametric approach. The second is a nonparametric method, which is known as DEA (Chen and Jia, 2017). DEA as a non-parametric method was first proposed by Charnes, Cooper, and Rhodes (1979). It can be used to evaluate the relative efficiency of a set of homogeneous decision-making units.

One characteristic of DEA is that no prior knowledge of the production function between the input and output attribute data is required; similarly, no relative weight needs to be set for the attribute data (Bevilacqua and Braglia, 2002; Huang *et al.*, 2014; Lauwers, 2009; Yin *et al.*, 2014). Therefore, DEA is useful for comprehensively assessing indicators of different dimensions; it is widely used in economic science, agricultural economics, public economics, financial economics, and economic policy. DEA is considered an appropriate analysis method for many studies related to environmental efficiency (Chen and Jia, 2017; Kuo and Tsou, 2015; Liu *et al.*, 2017; Peng *et al.*, 2017; Wu *et al.*, 2016; Yang *et al.*, 2015).

Application of Environmental Change Efficiency

In 2015, Kuo and Tsou (2015) provided the environmental change efficiency to the sustainability of urban development. It was considered as a comprehensive evaluation index for the efficiency of urban development and environmental impacts. This index constitutes a new resource for achieving urban sustainability.

The definition of environmental change efficiency is expressed as follows:

$$\text{Environmental change efficiency} = \frac{I_1(\textit{positive impacts})}{I_2(\textit{negative impacts})} = \frac{\sum_{j=1}^{n} O_j}{\sum_{i=1}^{m} I_i} \quad (1)$$

I_1 = Positive impacts resulting from the accumulation of state changes in the society and economy; the sum of outputs

I_2 = Negative impacts resulting from the accumulation of state changes in related natural environmental resources and the ecological environment; the sum of inputs

In this study, an indicator is defined as a measurable and detectable variable that reflects the causes and effects of land use change and can be easily understood and used in both planning and decision making. An initial list of input and output indicators was developed based on earlier studies (Pauleit, Ennos, and Golding, 2005; Sanjuan *et al.*, 2011; Whitford, Ennos, and Handley, 2001; Yu *et al.*, 2013; Zhao *et al.*, 2011). After the potential indicators had been evaluated, the most suitable indicators were chosen for demonstration. Finally, the final five input indicators and five output indicators were selected based on the availability of data and the practicality for use at the township level.

The inputs were primarily oriented toward natural environmental resources, including factors such as surface temperature (Hoppe, 2002; Pauleit, Ennos, and Golding, 2005; Svensson and Eliasson, 2002), surface runoff (Lin *et al.*, 2007; Tang, Wang, and Yao, 2008; Whitford, Ennos, and Handley, 2001; Fox *et al.*, 2012; Zhang *et al.*, 2012), habitat quality (Hirzel *et al.*, 2002; Kattwinkel, Biedermann, and Kleyer, 2011; Kohsaka, 2010; Sandstrom, Angelstam, and Khakee, 2006; Whitford, Ennos, and Handley, 2001), power and water consumption (Haase and Nuissl, 2007; Interlandi and Crockett, 2003; Lin *et al.*, 2007). The outputs were chosen to reflect the benefits and goals of economic and social development (Lee and Huang, 2007; Sanjuan *et al.*, 2011; Singh *et al.*, 2009; Yu *et al.*, 2013; Zhao *et al.*, 2011). The outputs included population, production, income, the service quality of infrastructure, and employee.

Local Spatial Autocorrelation Analysis

In this study, LISA was applied to investigate whether there are correlations between the spatial location and scores of the environmental change efficiency. This method yields the spatially aggregated distribution of attribute data (Anselin, 1995). The univariate LISA analysis of efficiency score in a township *(i)* is associated with efficiency score in its surrounding townships *(j)*. The univariate LISA (Equation. (2)) was applied to calculate the efficiency score for each of the townships examined in this study.

$$I_i = z_i \sum_j w_{ij} z_j \quad (2)$$

where, Z_i and Z_j are standardized scores of attribute values for *I* and *j* townships, which according to W_{ij} (row standardized weight matrix) (Poudyal *et al.*, 2016).

Values of I_i larger than 0.5 indicate that the efficiency score in spatial unit I is higher than average, whereas values of I_i below 0.5 indicate that the efficiency score in spatial unit I is lower than average. These results can be used as the basis for designating hotspot zones. Based on the LISA spatial autocorrelation statistics, the spatial patterns of the indictors are categorized into the following zones: high-high, low-low, high-low, low-high, and no significant spatial autocorrelation. A spatial statistics module that uses a combination of GIS and spatial statistical methods is used to present the LISA results on a basic map of the study area.

RESULTS

Input and Output Indicators

Data were primarily collected from the Landsat Thematic Mapper Satellite Image, 2011; the Land Use Investigation of Taiwan, 2008; the Taiwan Water Corporation, 2011; the Taiwan Power Corporation, 2011; the Department of Household Registration, the Ministry of the Interior, 2011; the Industry, Commerce and Service Census, 2011; the Financial Data Center, the Ministry of Finance, 2011.

Table 1. *Definition and descriptive statistics of input and output indicators for the DEA efficiency analysis.*

Indicators	Definition	Units	Mean	Std. dev.	Range
Input					
Surface temperature	Global average surface temperature	℃	26.154	3.227	17.270
Surface runoff	Total volume of overland flow draining off the land	m^3/s	849.321	823.735	7,666.260
Habitat quality	Area-weighted mean patch fractal dimension value of habitats	None	1.363	0.033	0.204
Water consumption	Total water use	Degree	5,811,991.810	8,783,981.899	53,572,606.000
Power consumption	Total power use	Degree	116,759,793.550	154,874,461.062	995,336,889.000
Output					
Population	Total population	Persons	65,380.020	81,653.054	553,501.000
Service quality of infrastructure	Area of infrastructure	m^2/ha	352.664	205.331	1,111.670
Production	Total production of industry and commerce	Thousand NTD	83,400,951.860	175,424,776.565	1,285,606,245.000
Income	Total household income	Thousand NTD	14,032,658.570	24,424,810.922	190,188,200.000
Employee	Total employees	Persons	22,682.820	40,098.561	326,019.000

The definition and descriptive statistics of input and output indicators for the DEA efficiency analysis is presented as Table1.

Scores of Environmental Change Efficiency

A total of 352 townships (see Figure 1) in Taiwan were considered as the decision-making units (DMUs) of analysis. In order to compare the relation between efficiency and types of cities, the cities are divided into 126 coastal cities which belong to the coastal zone planning and management districts in Taiwan. Additionally, according to the population grow rate between 2006–2016, the cities with a negative growth rate of population are defined as shrinking cities.

Table 2 presents the results of the DEA analysis for environmental change efficiency. The average efficiency score of the 352 townships was 0.7071, with a maximum efficiency score of 1.00 and a minimum of 0.3326. A total of 46 townships had an efficiency score of 1.00. The relative locations are shown in Figure 2. Comparing the location and development situation, the ratio of efficient DMUs to all DMUs was 21.43% in non-coastal and non-shrinking cities, and 16.28% in the coastal area with none shrinking. There are only four townships (Shoufeng Township in Hualien County, Qianjin District in Kaohsiung, Taitung City in Taitung County and South District in Tainan City) in the coastal area with shrinking situation.

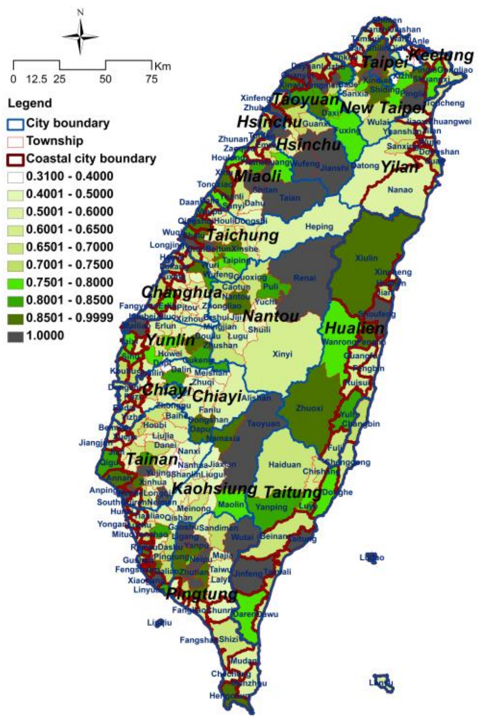

Figure 2. Spatial patterns of the environmental change efficiency score.

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