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Assessing the Spatial Efficiency of Urban Development within the DPSIP Model

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Abstract. Based on the principle that urban land use changes in multi use negatively impact the natural envi-ronment, this paper attempts to design a systematic model named DPSIP(Driving Forces- Pressure- State- Impact- Policy & Pattern) for assessing spatial development efficiency based on the planning perspective and employing data envelopment analysis and GIS. This paper adopted Tainan as the study area and described nine important indicators to evaluate the relative effi-ciency of 233 lis in Tainan. The analytical results demonstrated that the average spatial efficiency was 89.44% which had clear spatial differentiation. Relevant policy implications for the case study are given.

Keywords: spatial efficiency, urban land development, natural environmental impact, DPSIP

1. Introduction

For most cities, the transformation of land use is required to meet the needs of life and economic development. Under the influence of various interacting factors, such as the economy, society, the environment, and culture, the natural environment may suffer the most direct and serious impacts (Lambin and Meyfroidt 2010), including reduced habitat diversity or quality (Whitford et al. 2001), the depletion of water resources (Haase and Nuissl, 2007), increased surface runoff(Tang et al. 2008), a rise in the earth's surface temperature (Pauleit et al., 2005), and increased carbon dioxide emissions (Whitfordet al. 2001). However, although it will cause an impact on the environment, such land transformation will also provide income, employment, and other economic benefits to the city and its residents, with a concommitant improvement in living conditions.

The major consideration of urban development efficiency has traditionally been economic. Since the issue of sustainable development has arisen, the consideration of urban development efficiency has begun to be more environmentally oriented. In 1990, Schaltegger and Sturm introduced the concept of “eco-efficiency,” which is the ratio of the increased value to the increased environmental impact. To combine sustainable development with the manufacturing process, in 1992, the World Business Council for Sustainable Development (WBCSD) further defined this concept as the ratio of the economic value to its associated impact on environmental indicators. Because environmental efficiency emphasizes the integration between the economic benefits and the environmental impact, it attempts to effectively combine business units on a micro-scale and on an individual level with urban or regional development planning and management on a much larger spatial scale, as well as with the macro-scale objective of sustainable development. Therefore, environmental efficiency has received increasing attention and application in different fields and industries. The studies of Huppes and Ishikawa (2005) and Hukkinen (2003) have indicated that environmental efficiency is one of the most important concepts of environmental policy and is an important idea in the evaluation of the overall sustainability of the environment. Above all, the main goal of environmental efficiency is to improve both the technology of production and environmental quality on a

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micro-scale, which is then converted into the achievement of sustainable development on a macro-scale (Seppala et al. 2005; Li et al. 2010).

There have been many studies on efficiency as it relates to the environment (Hua et al. 2007). However, these studies have mostly focused on the environmental efficiency for manufacturers, which is non-spatial and involves only limited consideration of the overall environmental efficiency. In addition, these previous studies have focused predominantly on the efficiency analysis as it is related to production operations. To date, no research has taken the interior space of a city as the subject of the study. Therefore, the current knowledge is still quite limited about how to integrate and estimate the impact of urban development on the natural environment, which would lead to a further assessment of the corresponding development efficiency of each spatial unit in a city under the threat of urbanization or urban sprawl. The consideration of these factors may result in controlling the space differences and factors related to the corresponding planning or policy.

The study presented here developed an assessment framework and methodology for efficient environmental transformation in urban land development with integration and spatiality based on the characteristics of the diverse impacts to the natural environment during urban development from the viewpoint of urban planning and a background of global environmental change. Based on both theory and case studies, this report reveals the essence of spatial efficiency in the process of urban land development and develops the definition of measurable and comparable efficiency. Furthermore, starting from the major policies of urban development, which have been widely used internationally, methods were designed for the measurement of environmental efficiency and the factors affecting it to understand the possible correlations. Therefore, this study will act as a reference for efficiency improvement and strategies for the movement towards sustainable development.

2. Materials and Methods

2.1. Study Area

Tainan City was selected as the area for empirical research in this study; the scope and geographic location are shown in Fig. 1.

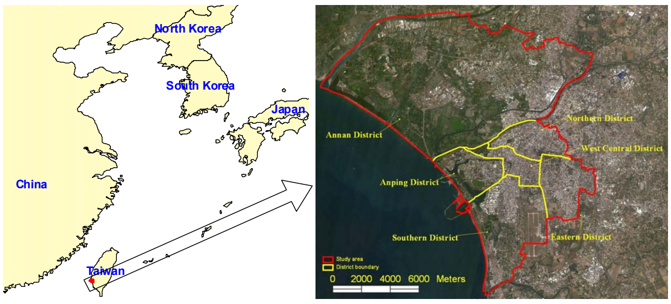

Fig. 1: Location of the research site

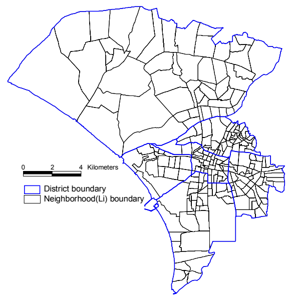

Fig. 2: The relative locations of analysis units.

For selecting the spatial analysis units in this study, 4 basic principles were developed, including the significance of a standard measurement for efficiency assessment and the practical applicability of urban planning, which reflected the development characteristics of the area for empirical research and met the restrictions of the number of units for evaluation and decision making. A total of 233 neighborhoods in Tainan City were considered as the smallest unit of analysis. The relative locations of each neighborhood are shown in the following Fig. 2.

2.2. DPSIP Model

The DPSIR (Driving Forces- Pressure- State- Impact- Response) model is currently the most commonly used theoretical model framework for the solution of environmental problems and the diagnostic evaluation of sustainable development (Holman et al. 2008; Niemeijer and de Groot 2008). Based on its conceptual framework for the complex process of urban land development and environmental change, in this study, we proposed an assessment model framework for urban land development and the efficiency of environmental transformation and named it DPSIP (Driving Forces-Pressure-State-Impact-Policy & Pattern).

- Driving Forces: Driving forces refer to the reasons for the changes in an urban land-use system. They are the underlying causes of the changes in urban land use and environmental status. Driving forces can be divided into natural driving forces and socio-economic driving forces.
- Pressure: The pressure imposed on the environment is expressed as the state of competition of the social and economic driving forces in the utilization of land resources.
- State: The status of this stage could be in a single parcel of land or an area containing adjacent lands with the same kind of changes in the land-use pattern. For the characteristics of environmental transformation in urban development, the stage was divided into economy and environment.
- Impact: The impacts were regarded as two parts, including positive impact and negative impact for the characteristic of urban development.
- Policy and pattern: For the demand of urban development and the generated development issues, urban managers will respond with corresponding strategies and policies or guidance for urban development. The primary purpose of these policies is to respond to the driving forces and pressures of urban development.

2.3. Definition of Spatial Efficiency

To assess the impact of urban development on the urban ecology, sustainable living, and production environment with the theoretical perspective of the environment efficiency, the urban development was set as a production activity in this study. The model of production and management of an enterprise was used as an analogy of the urban development process. The relationship of efficiency includes two important concepts of the inputs and outputs. The indicators of the inputs and outputs to measure the efficiency were defined for the sustainable development of life, production and ecology. The definition is shown as the following equation:

SE (Spatial Efficiency)

$$= \frac{I_1(positive\ impact)}{I_2(negative\ impact)} = \frac{\sum_{j=1}^{n} O_j}{\sum_{i=1}^{m} I_i} \tag{1}$$

I_1 = Positive impact resulting from the accumulation of state changes in life and economy, which indicates the benefit of urban development

I_2 = Negative impact resulting from the accumulation of state changes in related natural environmental resources and ecological environment

2.4. The Indicators of Input and Output

The major considerations for the construction of the indicators included the DPSIP model structure, the indicators related to sustainable urban development, the indicators for the environmental impact of urban land development, the characteristics of the spatial scale in a neighborhood, and the representation and usability of data analysis. The outputs were set for quality of life as the population of the residents living in urban, quality of public facilities and services, and the income level for production as the industrial and commercial value and accessibility; the inputs were mainly ecology-oriented, including the surface temperature of the urban land, the surface runoff, habitat quality, and the water usage.

2.5. DEA

The data envelopment analysis (DEA) approach is able to assess indicators of different types and data patterns comprehensively and is widely used in economic science, agricultural economics, public economics, financial economics, and overall economic policy. DEA is also considered an appropriate analysis method for many studies that are related to environmental efficiency (De Koeijer et al. 2002; Kuosmanen and Kortelainen 2005). Therefore, considering the characteristics of complexity and development for urban areas and the advantages of DEA, this analytical method was applied for the efficiency assessment in this study.

The analysis in this study was used to search for the minimal inputting environmental impact cost and natural resource depletion with the current output level. Therefore, the input-oriented model (Banker et al. 1984) was used in this study for the efficiency assessment.

3. Results

3.1. Scores of Spatial Efficiency

The average efficiency value of the 233 neighborhoods was 89.44%, with a maximum efficiency value of 100% and a minimum of 61.90%. A total of 48 neighborhoods had an efficiency of 100%. Comparing among the districts, the ratios of effcient DMU to all of the DMUs of all of the districts were 28.95% in the Mid-Western District, 27.66% in the Eastern District, 25.58% in the North District, 20.00% in the Anping District, 12.82% in the Southern District, and 84.03% in the Annan District. Further comparing the mean and standard deviation of each district, the Mid-Western District had the highest average (95.96%) and the lowest standard deviation (3.63%), followed by the Anping District (92.42%, 7.35%) and the North District (91.79%, 8.29 %). The district below the average in Tainan City was the Southern District, with 86.13% and 84.03% for the average and standard deviation, respectively.

3.2. Patterns and Slack Analysis of Spatial Efficiency

The administrative boundaries of a district have the characteristics of the actual geographical location of space. Therefore, the spatial distribution of the DMU efficiency values showed an overall decreasing trend in the distribution of efficiency values outward from the central area the city, forming two spatial development axes $\overleftrightarrow{AC}$ and $\overleftrightarrow{DE}$ (see Fig. 3.), with relatively efficient urban development. The $\overleftrightarrow{AC}$ efficiency axis was from the southeast side of Tainan City, across the downtown area, and extending to the northwest; the $\overleftrightarrow{DE}$ axis was the efficiency axis extending from northeast to southwest. In areas farther from downtown, the performance of efficiency subsequently deteriorated. Overall, except for a few efficient DMUs showing dispersed development characteristic in space, the most efficient DMUs showed a clustered or adjacent development characteristic in space, with the concentrating phenomena across the administrative districts, such as the areas adjacent to the Annan District, Anping District, and North District and the DMU in the North and Mid-Western Districts, with a neighboring administrative range.

Based on the calculated difference between the variables, the important indicators of future efficiency improvement were the improvement of the quality of public facilities and services (62.23%), the increase in family income (57.51%), the increase of industrial and commercial output value (35.19%), the reduction of surface runoff (25.75%), the reduction in water use (18.88%), the improvement in habitat quality (17.60%), the increase in the population of urban residents (16.31%), the reduction of the urban surface temperature (12.02%), and the increase in accessibility (8.58%).

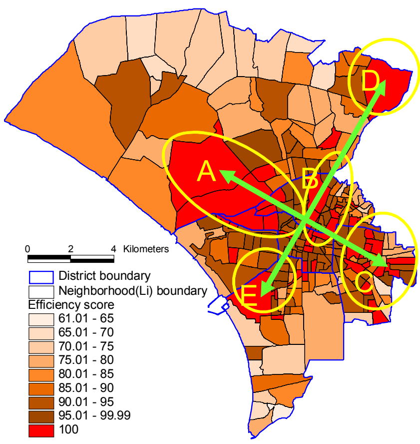

Fig. 3: Spatial pattern of efficiency score

4. Conclusion

As the focus of early development in Tainan City, some neighborhoods in the Mid-Western District had the characteristics of high population density, high building density, low plant coverage, and high proportion of impermeable layer. These characteristics were reflected in the input indicators of environmental resources in the assessment of the indicators of spatial efficiency in the urban land development, with relatively poor performance for surface runoff, urban heat island, and habitat diversity. The development of such kinds of spatial units showed signs of saturation. To improve its development efficiency in the future, the current urban development strategies of Tainan City, including urban renewal or local environment transformation, reforesting, and landscaping of empty space, should be executed. By increasing the green coverage and habitats for wildlife, the impact on the natural environment generated during the process of urban development can be reduced.

To improve the spatial efficiency of urban land development with the sustainable development of urban areas and the environment, the focuses of the future improvement for Tainan City, in descending order, are reducing surface runoff, reducing water consumption, improving the quality of habitats, and reducing the surface temperature. For urban managers, the strategies of phased and zoned development, retaining the existing natural open space in urban districts, and increasing the area of green space with ecological functions in urban areas can be applied in the future based on the standardized review of urban design and the implementation of a comprehensive urban planning process. With the improvement of input and output indicators, the overall efficiency can be indirectly improved, achieving the long-term goal of reducing the impact of global environmental change. In addition, when developing a strategy to improve efficiency with the output indicators in the future, for those areas with differences in the quality of public facilities and services and the adjacent areas or those spatially clustered, the development of public facilities in these areas should be given a high priority to achieve the goal of an effective use of public facilities and an improvement of the environmental efficiency in the adjacent areas. The development of strategies improving the efficiency can not only improve the overall efficiency of the urban development but also mitigate the global environmental impact caused by the altered urban land.

5. Acknowledgement

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