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Research on Performance Evaluation of Sponge City Construction based on PSIR Model

Hao Lin[1, a], Jin Chen[2, b, *]

[1] School of Management Science and Engineering, Anhui University of Finance and Economics, Bengbu, Anhui, 233030, China

[2] School of Accountancy, Anhui University of Finance and Economics, Bengbu, Anhui, 233030, China

[a]1085163009@qq.com, [b, *]1730607338@qq.com

Abstract

Sponge city construction refers to the construction of a city that can absorb water like a sponge and has good elasticity. The construction of sponge cities can store and save more water resources for cities, reducing phenomena such as rainwater infiltration, water scarcity, and water ecological environment damage. To scientifically and reasonably evaluate the performance of sponge city construction, this study summarizes the characteristics of sponge city construction models and the current development status of performance evaluation systems in China, and conducts analysis and research on the content of performance evaluation; Establish and screen a performance evaluation indicator system based on relevant theoretical foundations of performance evaluation; Construct a performance evaluation model for sponge city construction based on PSIR to address the design deficiencies of the existing performance evaluation system; And provide specific case studies, taking the sponge city construction in Bengbu City as the research object, to construct and clarify its specific application in project practice from the dimensions of water ecology, water environment, water security, water resources, water system, etc; Finally, a summary and outlook are provided for the entire study.

Keywords

Sponge City Construction; PSIR Model; Performance Appraisal.

1. Introduction

Sponge city construction refers to the construction of a city that can absorb water like a sponge and has good elasticity. The construction of sponge cities can store and save more water resources for cities, reducing phenomena such as rainwater infiltration, water scarcity, and water ecological environment damage. To scientifically and reasonably evaluate the performance of sponge city construction, this study summarizes the characteristics of sponge city construction models and the current development status of performance evaluation systems in China, and conducts analysis and research on the content of performance evaluation.

Bengbu City is located in the northeast of Anhui Province, in the middle reaches of the Huai River. It is situated on the Qinling Huai River line, the geographical boundary between the north and south of China. It belongs to the junction area of the Yellow Huaihai Plain and the Jianghuai Hills, and is one of the important birthplaces of Huai River culture. It has rich historical and cultural heritage and tourism resources. The geographical coordinates are 116 ° 45 ′ E to 118 ° 04 ′ E and 32 ° 43 ′ N to 33 ° 30 ′ N.

The Ministry of Housing and Urban Rural Development has issued the "Performance Evaluation and Assessment Measures for Sponge City Construction (Trial)", which evaluates sponge city

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construction from four quantitative indicators: water resources, water ecology, water environment, and water safety, and two qualitative indicators: display degree, construction system, and implementation status. There are a total of 18 evaluation indicators in six categories. The PISR model is a pressure state impact response model that can form a stable system structure by connecting the four stages mentioned above. This model is an effective tool for studying environmental status and economic and social issues. Currently, most evaluation systems cannot directly demonstrate the role of sponge cities, while the PSIR model can effectively solve this problem. The PSIR model can promote the synergy between environmental performance and economic performance, as well as provide a clear causal loop, which can ensure the rationality of performance evaluation and intuitively demonstrate the effectiveness of sponge city construction.

This article employs the following research methods:

(1) Literature research and comparative analysis methods. On the premise of reading a large number of literature, first read and analyze the domestic and foreign literature related to performance evaluation of sponge cities, and focus on the selection of evaluation indicators and the evaluation methods used. By comparing and analyzing the models proposed by some scholars, select the determined indicator weights to construct a PSIR performance evaluation model.

(2) PSIR model method. By relying on the PSIR model, a new evaluation index system framework can be established based on the dispersed and isolated performance evaluation index system in the past, and corresponding index layer data can be collected for the target sponge city and various criteria layers.

(3) Entropy weight method. The principle of entropy weight method reflects the size of weights from the degree of indicator variability, which can eliminate the interference of human factors when the weights are indeed true as much as possible, overcome the analysis difficulties caused by small differences in the selected indicators, and objectively determine the weights, making the evaluation results more authentic and reliable. Use the entropy weight method to calculate and organize the indicator layer data analyzed by the PSIR model, and finally use the analysis results to comprehensively evaluate the performance of sponge cities.

2. Literature Review

Pickets TA analyzed the resilience of sponge cities and demonstrated the design methods for rainwater and flood management at different scales from planning to design using three cases [1]. The LID (Low Impact Development) low impact development plan in the United States achieves the goal of controlling rainstorm disasters and non-point source pollution through the management of scattered water sources [2]. During its use, it incorporates the rainwater collection system on the floor and roof into the architectural design, and alleviates the urban heat island effect and improves the urban beauty through creative landscape design. Water sensitive cities in Australia are further developed based on the concepts of "drainage cities" and "waterway cities", combining urban management with water cycle management and protection to ensure the sensitivity of urban management to natural hydrology and ecological cycles [3-4]. It incorporates groundwater, recycled wastewater, and desalinated water into the overall thematic framework of "water supply catchment areas" cities, excluding precipitation.

At present, the application of PSIR model in sponge city construction performance evaluation mainly focuses on the application of models and methods, such as the performance evaluation of sponge city PPP projects based on set pair analysis and cloud models [5], the construction of drainage models and low impact development models using SWMM model [6], the inspiration of foreign urban rainwater and flood management cases for sponge city performance evaluation [7], and the performance evaluation of provincial green development based on

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DPSIR model [8]. In addition, Zhang Chen [9] proposed a five system sponge city construction indicator system, which effectively guided the planning, construction, and management of Shanghai's sponge city. Zhou Jinjun et al. aimed to analyze the expected effects of sponge city construction, taking Tianshui City as an example, using a multidimensional coupled rainfall runoff model to measure the effectiveness of sponge city construction [10]. Liu Qiuchang et al. proposed a sponge city performance evaluation model based on entropy weight and TOPSIS method, and evaluated the performance of sponge city construction in Hebi City [11].

Based on the above literature, the theoretical research on performance evaluation of sponge city construction in foreign countries is relatively in-depth. Most scholars use commonly used evaluation tools, such as Analytic Hierarchy Process, Fuzzy Comprehensive Evaluation, Fuzzy Rough Set Method, Factor Analysis, etc., to determine the weight of performance evaluation indicators and conduct performance evaluation. However, the above analysis methods ignore the constraints of multiple factors and to some extent rely on the subjective experience and judgment of the subject.

3. Indicator System and Evaluation Model

3.1. Construction of Indicator System

In the performance evaluation of sponge city construction, different evaluation methods may construct different evaluation indicator systems. For example, a study based on set pair analysis coupled with variable fuzzy sets was used to evaluate the performance of sponge cities, and a performance evaluation index system consisting of 5 primary indicators and 21 secondary indicators was constructed. The Analytic Hierarchy Process evaluates the performance of sponge cities by determining weights, which usually involves considering multiple factors comprehensively and assigning corresponding weights.

The performance evaluation of sponge city projects involves multiple aspects and is a complex systematic problem. Establishing a reasonable and effective performance evaluation index system is the key to the performance evaluation of sponge city projects. Taking Bengbu City, Anhui Province as the object of empirical research, a comprehensive set of 18 evaluation factors was developed based on the six categories specified in the "Sponge City Construction Performance Evaluation and Assessment Measures (Trial)" issued by the Ministry of Housing and Urban Rural Development. The systematic indicator body is shown in Table 1.

Table 1. Performance evaluation index system for sponge city construction

Target layer	Criterion layer	PSIR model	Indicator layer
Sponge City Performance Evaluation	water ecology(C_1)	Pressure P	Green space ratio in built-up areas C_{11}
			Built up area water surface ratio C_{12}
		State S	Urban annual runoff control rate C_{13}
	water environment(C_2)	Pressure P	Groundwater quality level C_{21}
		State S	Suspended SS ratio C_{22}
		Response R	Water quality level of drinking water source C_{23}
	Water security (C_3)	State S	Urban waterlogging disaster control rate C_{31}
		Response R	Eliminating flood prone points C_{32}
	water resource (C_4)	Pressure P	Rainwater resource utilization rate C_{41}
		Impact I	Groundwater Resources C_{42}
		Response R	Recycled water utilization rateC_{43}
	Water system (C_5)	State S	Investment and financing situation C_{51}
		Response R	Technical specifications and standardsC_{52}
			Policy and institutional support C_{53}

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3.2. Construction of Performance Evaluation Model based on PSIR Model

At present, the main methods for evaluating the performance of sponge city construction are interval intuitionistic fuzzy set method and grey fuzzy comprehensive evaluation method. Due to the particularity of sponge city construction projects, these evaluation methods are difficult to objectively and accurately reflect the performance level of sponge city projects. This project introduces the PSIR model as the basic support, forms a network of correlation between indicators through the PSIR framework, and constructs a performance evaluation model that can effectively control and guide the mode of sponge city planning, implementation, and evaluation, promoting the synergy between environmental performance and economic performance.

The PSIR model is an environmental impact assessment framework that includes four parts: driving forces, states, impacts, and responses. In the context of sponge city construction, this model can help us systematically analyze and evaluate the effect of sponge city construction.

(1) Driving force: refers to the socio-economic or socio-cultural factors that drive the construction of sponge cities. For example, the acceleration of urbanization, frequent urban waterlogging, and shortage of water resources are all important driving forces for the construction of sponge cities.

(2) Status: describes the actual situation of sponge city construction, including implemented projects, technological applications, management measures, etc.

(3) Impact: refers to the impact of sponge city construction on the environment and socio-economic development. This includes improving urban water ecology, enhancing urban water security, and promoting ecological civilization construction.

(4) Response: refers to the measures and strategies taken to address the aforementioned impacts, such as policy formulation, funding investment, technology promotion, etc.

When constructing a PSIR model, it is necessary to first clarify the purpose and objectives of the evaluation, and then identify and analyze the various components and their relationships by collecting relevant data and information. Through various data collection and analysis methods, such as literature review, expert interviews, questionnaire surveys, etc.

4. Empirical Analysis of Sponge City Performance Evaluation

Using the established sponge city evaluation index system and PSIR model, the entropy weight method is used to analyze the performance of sponge cities, aiming to eliminate other accidental errors as much as possible. From the perspective of information entropy, the weights of each indicator can be determined through information entropy, and further exploration of other main influencing factors of sponge city performance can be carried out.

(1) Building the original matrix. Take the data of sponge city indicators for n years and construct the original matrix:

$$X = (x_{ij})_{m\times n}\ (i = 1,2,\cdots m; j = 1,2,\cdots, n) \tag{1}$$

Among them, xij is the initial value of the performance evaluation index for sponge cities, representing the value of the i-th index in the j-th year.

(2) Data standardization

$$f_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{2}$$

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Among them, fij is the standardized value of xij, and n is the number of regions.
(3) Calculate entropy value

$$U_j = -\frac{1}{lnn}\sum_{i=1}^{n} f_{ij} ln f_{ij} \quad (3)$$

Among them, Uj is the entropy value of the jth evaluation indicator.
(4) Calculate entropy weight

$$W_j = \frac{1-U_j}{\sum_{j=1}^{m} U_j}. \ j=1,2,3,\ldots,m. \quad (4)$$

Among them, Wj is the entropy weight of the jth evaluation indicator.
By analyzing the indicator data, from the perspective of the indicator system, the sponge city performance evaluation indicator system constructed by this research institute includes five criteria layers: water ecology, water environment, water safety, water resources, and water system, as well as 14 indicator layers including geological water level of drinking water sources, sewage control rate, green space rate in built-up areas, and water surface rate in built-up areas. From the perspective of indicator weights, the performance evaluation index system of sponge cities in this study is more important in terms of water safety, water environment, and water ecology in the criterion layer, and more important in terms of rainwater resource utilization rate, urban waterlogging disaster control rate, and recycled water utilization rate. From the perspective of the evaluation process, the evaluation levels of water safety, water ecology, water resources, and water system are all excellent, reflecting that Bengbu City is outstanding in water quality standards, runoff and pollution control, drainage facilities, relevant technical specifications, investment and financing, and demonstration; The water environment assessment level is qualified: there are still problems such as soil erosion and weak sewage regeneration. From the evaluation results, it can be seen that the construction of sponge cities in Bengbu City has achieved initial results, and the overall performance is at an excellent level. This performance evaluation result is consistent with the assessment results of sponge city construction in Bengbu City.

Empirical research has shown that the construction of sponge cities has achieved significant results in improving urban water environment and preventing urban waterlogging. The performance evaluation results of Bengbu City show excellent performance, indicating that sponge city construction activities have been effectively implemented and managed. In addition, through case studies of other cities, the feasibility and effectiveness of sponge city construction can be evaluated, thereby optimizing planning and design construction.

5. Conclusion and Discussion

One of the important contents of sponge city construction is to conduct comprehensive and orderly performance assessment and evaluation of construction results. A reasonable and efficient performance evaluation system can provide decision support, clarify responsibilities of all parties, and achieve optimization among subsystems. This article takes Sponge City in Bengbu City, Anhui Province as the research area, constructs an evaluation index system using the PSIR model, and analyzes the health changes of the ecological environment in Bengbu City. Due to the rapid development of the economy, human beings have had a certain impact on the ecological environment, which is not conducive to the sustainable development of the ecological environment. From the current development trend, the country is paying more and more attention to the benefits of the ecological environment. Therefore, the study of the

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comprehensive performance evaluation system for sponge city construction has a guiding role for the innovation of subsequent sponge city construction models.

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