Study on Calculation Methods of Runoff Coefficient in Data-Scarce Areas

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Abstract. After the sponge city construction, it is necessary to carry out quantitative evaluation and assessment of its construction effect. Among them, runoff coefficient is one of the important assessment indicators for the sponge city construction effect evaluation. Starting from the study on the influencing factors and determination method of runoff coefficient and BP neural network model , the main influencing factors and determination methods of runoff coefficient suitable for the study area were determined in this paper. According to the specification-based method, the catchment zones and the comprehensive runoff coefficient of the demonstration area were calculated, and the variation rule of runoff coefficient before and after the sponge city construction was analyzed, and the construction effect of the demonstration area was quantitatively evaluated. The results show that the sponge measures have an obvious effect on reducing the runoff coefficient, indicating that the use of sponge measures can reduce the adverse impact of urban construction on rainwater interception and storage, effectively alleviate the contradiction between urban water resource shortage and frequent waterlogging, and enhance the ability of water resource regulation.

Keywords: Sponge city; Runoff coefficient; Data-Scarce Areas; BP neural network model

1 Introduction

Sponge city is a new generation of urban stormwater management concept, refers to the city can be like a sponge, in the adaptation to environmental change and response to natural disasters brought about by rainfall and other aspects of good elasticity, can also be called "water resilience city" [1]. According to the Ministry of Housing and Urban-

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Rural Development, China, "Sponge city construction technical guidelines" requirements, the effectiveness of sponge city construction should be evaluated quantitatively, in which the runoff coefficient control is one of the important assessment indexes for the evaluation of the effectiveness of sponge city construction [2].

Due to the relative backwardness of China's rainwater pipe network monitoring system[3-5], the measured data required for calculating the annual average runoff coefficient before construction is often missing. Existing runoff coefficient calculation models [6-9]from abroad usually cannot fully meet the actual engineering needs of our country. Therefore, developing a method suitable for restoring historical data of the annual average runoff coefficient has become one of the key issues in evaluating the construction of a sponge city. In this paper, on the basis of systematically sorting out and summarizing the influencing factors and determination methods of runoff coefficient at home and abroad, Qingshan sponge city demonstration area in Wuhan is selected as a typical case, appropriate calculation methods are determined according to the engineering practice, to study and analyze the change law of runoff coefficient before and after the construction of sponge city, and to quantitatively evaluate the effectiveness of the construction of the demonstration area. The results can provide an empirical case for the evaluation of the construction effect of sponge city in Wuhan and other cities in China, and provide some technical support for the management and evaluation of sponge city.

2 Introduction to Qingshan Sponge City Demonstration Area in Wuhan

Qingshan District is a typical old urban area in Wuhan, with a large number of residential buildings built in the 1980s and 1990s, with an old and insufficient underground rainwater pipe network, and serious waterlogging after heavy rains during the rainy season, which has led to large-scale floods in the urban area in both history and recent years. Against this background, Qingshan District has become one of the pilot sites for sponge city construction in Wuhan, with a demonstration area of $23km^2$, including three major demonstration centers, namely, Heping Park, Qingshan Park, Wuhan Railway Station, and the two rivers' ecological watershed demonstration zones (As shown in Fig. 1).

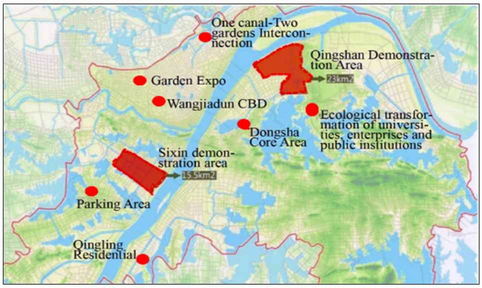

Fig. 1. Schematic location of demonstration area

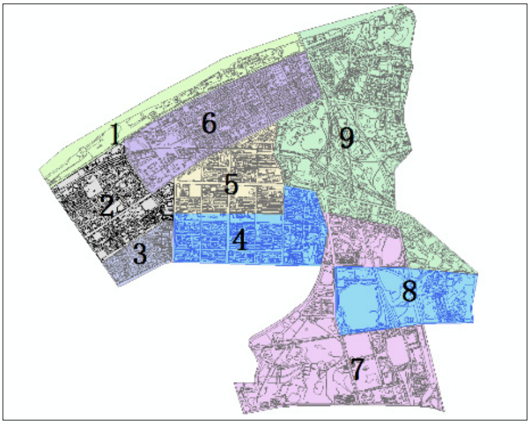

Fig. 2. Catchment zoning diagram

3 Analysis of Changes in Runoff Coefficient Before and after the Sponge Meaures in Qingshan Demonstration Area in Wuhan City

The runoff coefficient is an important indicator for sponge city construction, and accurate determination of the runoff coefficient is crucial for evaluating the success of sponge city development. The calculation method defined in the runoff coefficient is the ratio of total runoff volume in the catchment area to the total precipitation in the catchment area. Although the calculation itself is straightforward, obtaining accurate measured data for the runoff coefficient can be challenging. Currently, there are four primary methods for determining the rainfall runoff coefficient: measured data analysis, hydrological model calculation, empirical statistical methods such as normative approach, and black-box models such as the BP neural network model [10,11]. Given the lack of historical data and limited measured data in the project area, this study will employ both the normative method and the BP neural network model to investigate the runoff coefficient. Additionally, measured data from cities with similar climates will be used for supplementary corrections to ensure the accuracy of the reproduction results as much as possible.

3.1 Specification-Based Method

At present, in the study of the urban average annual runoff coefficient, the runoff coefficient under different types of ground cover is usually taken empirically according to the change of ground cover in the study area, based on the existing design specifications "Code for design of outdoor wastewater engineering" (GB 50014-2006, 2014 edition) and "Technical code for rainwater management and utilization of buildings and subdistrict" (GB 50400-2016) , the average annual runoff coefficient of the study area was comprehensively determined based on the weighted average of the area of the underlying surface.

3.1.1 Determination of Runoff Coefficient of Sub-items

Since the permeable road and permeable pavement (non-grass planting) are uniformly recorded as permeable pavement in the sponge city measures statistics, the runoff coefficient of permeable pavement is 0.3 in this calculation, which is no longer subdivided.

The rest of the surface types refer to the classification types determined in the "Code for design of outdoor wastewater engineering" (GB 50014-2006, 2014 edition) and "Technical code for rainwater management and utilization of buildings and sub-district" (GB 50400-2016),and the surface types that interpreted by remote sensing images. After that,it is comprehensively determined as the following 16 categories, and the initial value of the runoff coefficient is as follows table 1:

Table 1. Values of runoff coefficients

No.	**Surface Type**	**Ψ**	**No.**	**Surface Type**	**Ψ**
1	Pond	1	9	Gravel road	0.4
2	Ditches	1	10	Green roof	0.33
3	River	1	11	Dirt road	0.3
4	Lake	1	12	Loose land to be developed	0.3
5	Concrete and asphalt roads	0.87	13	Agricultural land	0.18
6	Impervious roof, surface	0.85	14	Green land	0.15
7	Plastic ground	0.7	15	Woodland	0.05
8	Block stone and other paved roads	0.55	16	Pervious paving (average)	0.3

3.1.2 Calculation Results of Catchment Subareas

According to the above runoff coefficients, the integrated runoff coefficient of each sub-catchment area within demonstration area is calculated by area weighting. The calculation method is shown in the following equation:

$$\Psi=\sum_{i=1}^{n} S_i \Psi_i / S \tag{1}$$

In the formula: Ψ - Regional comprehensive runoff coefficient; S_i - The area of a single surface type; Ψ_i - Runoff coefficient of a single surface type; S - The area of the selected area; i - Serial number of the surface type.

The Qingshan demonstration area is divided into 9 catchment areas(As shown in Fig.2). According to the surface interpretation results map, the data is extracted according to the determined catchment area, and then the same surface types are summarized to obtain the total surface type area of the catchment area in each year.

3.1.3 Comparative Analysis of Runoff Coefficient Before and After the Construction of Qingshan Demonstration Area

According to the existing data, the runoff coefficient changes of Qingshan demonstration area in 2005,2013 and 2015 were preliminarily calculated. The calculation was carried out in two ways : full catchment area and excluding water area. Due to the large number of area types, it was divided into water surface (runoff coefficient = 1), strong permeable ground (runoff coefficient ≤ 0.35), weak permeable ground (0.7 ≤ runoff coefficient < 1), and other (0.35 < runoff coefficient < 0.7) for summary analysis. The sponge measures were revised according to the design data provided by the sponge company.

From table 2 and fig.3, it can be seen that the comprehensive runoff coefficient of Qingshan demonstration area shows a continuous decreasing trend, mainly due to the decrease of water surface area. The runoff coefficient of water surface is 1, which accounts for a large proportion of the comprehensive coefficient. The area of strong and weak permeable ground increased but changed little. As the water area decreased to a certain extent, the change of weak permeable ground became the main influencing factor of the change of comprehensive runoff coefficient in the demonstration area. Before 2010, the runoff coefficient did not change much. In 2010, compared with 2005, the weak permeable ground increased by 6 % (compared to the total area, the same as the following), but at the same time, the water surface area decreased by 7.1 %. The runoff coefficient decreased by 0.01 after the interaction of the two changes. At this time, the change of water surface area was the main change factor. In 2013, compared with 2010, the water area decreased by 1.3 %, the weakly permeable area decreased by 2.8 %, the strongly permeable area increased by 4.1 %, and the runoff coefficient decreased significantly. In 2015, compared with 2013, it can be seen that under the condition of little change in water body, the area of strong permeable ground decreases, and the area of weak permeable ground increases, which leads to a slight increase in the comprehensive runoff coefficient. At this time, water surface area changes very little, and the main influencing factors of runoff coefficient become the mutual transformation of strong and weak permeable ground. In 2017, compared with 2015, the strong permeable ground increased. Compared with 2017 (without sponge measures), it can be found that the construction of sponge city laid 1.079 km2 of permeable pavement, which changed the trend of permeable ground change. If the sponge city was not built, the area of strong permeable ground will continue the decreasing trend from 2013 to 2015, and the sponge measures were additionally equipped with 47,200 m3 of water storage volume (including rainwater bucket, rainwater storage module, subsided green space storage volume, etc.) and it was directly used for runoff control. These volumes were calculated as a full use of every 24.5mm of rainfall according to their design standard. The comprehensive runoff coefficient was 0.1 less than that without sponge measures, and the effect of sponge measures is very significant.

Table 2. Calculation of runoff coefficient in Qingshan Demonstration area

Qingshan Demonstration area								
Year	**2002**	**2005**	**2010**	**2013**	**2015**	**2017**	**2017(Non-sponge)**	**2017 Versus 2002 (Absolute change)**
	(Area Proportion)	**(Area Proportion)**	**(Area Proportion)**	**(Area Proportion)**	**(Area Proportion)**	**(Area Proportion)**	**(Area Proportion)**	
Water surface	17.3%	16.8%	9.7%	8.4%	8.3%	8.4%	8.4%	-8.9%
Strong permeable ground	44.1%	44.9%	45.2%	49.3%	47.7%	50.8%	46.4%	6.7%
Weak permeable ground	37.7%	37.4%	43.2%	40.4%	41.7%	39.5%	44.0%	1.8%
Other	0.9%	0.9%	1.6%	1.9%	2.3%	1.2%	1.2%	0.3%
Comprehensive runoff coefficient	0.551	0.553	0.542	0.504	0.511	0.428	0.532	-0.123
Comprehensive runoff coefficient(Excluding water area)	0.457	0.465	0.493	0.460	0.468	0.376	0.489	-0.081

Comments: In 2017, there is 47200 m3 new water storage capacity (including rainwater bucket, rainwater storage modules, and ssubsided green space storage volume) in the demonstration area.

After removing the water body, the change trend of runoff coefficient increased first and then decreased. In 2010, the proportion of weakly permeable ground area was higher, and its runoff coefficient was also the highest in the calculation years. After that, the runoff coefficient fell back, and it decreased significantly after the construction of sponge project. This phenomenon is related to the degree of land development in Qingshan demonstration area. The development led to the change of the original surface type, the increase of impermeability of the surface, the increase of the proportion of weak permeable ground, the weakening of the rainfall interception capacity of the original land surface, and the increase of the proportion of rainfall converted into surface runoff. The runoff coefficient showed an increasing trend from 2002 to 2010, and decreased after 2010, and then changed little. The runoff coefficient in 2017 was 0.081 lower than that in 2002, indicating that the sponge measures played an important role in runoff control. The rainfall was effectively intercepted on the surface, offsetting the adverse effects of ground construction on the runoff coefficient.

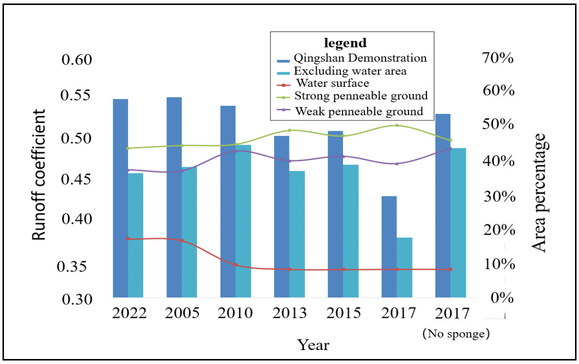

Fig. 3. variation curve of runoff coefficient

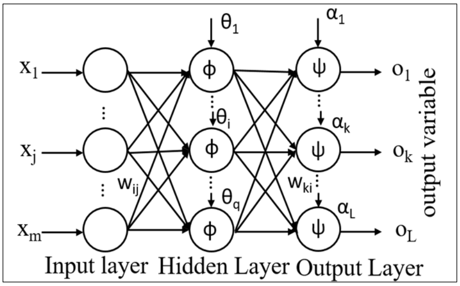

Fig. 4. BP neural network structure diagram

3.2 The BP Neural Network Model

3.2.1 Model Construction

BP neural network is a multi-layer forward neural network based on error back propagation algorithm. Its model topology includes input layer, hidden layer and output layer. Its learning process includes forward propagation of signals and back propagation of errors. In the process of back propagation, the network weights are adjusted according to error feedback, so that the actual output is closer to the expected output. The structure is shown in figure 4.

In the figure: x_j is the input of the jth node of the input layer; W_{ij} is the weight between the ith node of the hidden layer and the jth node of the input layer; θ_i is the threshold of the ith node of the hidden layer; $\varphi(\mathrm{x})$ is the activation function of the hidden layer; W_{ki} is the weight between the kth node of the output layer and the ith node of the hidden layer; a_k is the threshold of the kth node of the output layer; $\psi(\mathrm{x})$ is the activation function of the output layer; O_k and is the output of the kth node of the output layer.

3.2.2 Analysis of Calculation Results

Data from 2009 to 2014 were input into the trained neural network model, and the runoff coefficient of each rainfall was simulated and calculated, and the average annual runoff coefficient was calculated, as shown in Table 3. It can be seen that the multi-year average relative error of was 1.06%, which is a small error. Clearly, this method is feasible.

The runoff coefficient in Qingshan Demonstration Area has shown a continuous downward trend. Before 2010, the main factor affecting the change was the change in water body area, and after 2010, it shifted to the change in the area of weak permeable ground. The continuous construction after 2013 slightly increased the runoff coefficient, but after the adoption of sponge city measures, the runoff coefficient returned to the lowest level in the calculation years.

Table 3. Neural network simulation results

Runoff coefficient	**Specification-based method**	**Specification-based method (Excluding water surface)**	**Simulation results**	**Relative error (Compared to 'excluding water surface')**
2014	0.508	0.464	0.420	-9.58%
2013	0.504	0.460	0.580	26.09%
2012	0.517	0.438	0.506	15.57%
2011	0.529	0.449	0.483	7.60%
2010	0.542	0.493	0.419	-15.06%
2009	0.544	0.488	0.399	-18.28%
Multi-year average	0.524	0.465	0.468	1.06%

4 Conclusions and Suggestions

Starting from researching the influencing factors of runoff coefficients and methods for determining them, this paper identifies the main factors affecting runoff coefficients and the methods suitable for the study area. Based on normative methods and the BP neural network model, the catchment area and comprehensive runoff coefficient of the demonstration zone are calculated, and the main conclusions are as follows:

Qingshan Demonstration Area selected 2002 as a typical year before the construction of sponge city, runoff coefficient of Qingshan Demonstration Area in 2002 was 0.551, runoff coefficient after sponge city construction was 0.428, and runoff coefficient was 0.532 assuming that no sponge measures were built. After the construction of the sponge city in the demonstration area, the runoff coefficient becomes smaller, indicating that the construction of the sponge city has played a positive role in the regulation of rainwater runoff. By increasing the area of strong permeable ground and increasing the volume of rainwater storage, the purpose of controlling runoff can be achieved. The calculation results show that sponge measures play a significant role in reducing runoff coefficient. It shows that the use of sponge measures can reduce the adverse impact of urban construction on rainwater interception and storage, and can effectively alleviate the contradiction between urban water shortage and frequent waterlogging, and enhance the water resources regulation capacity.

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