Evaluation of the comprehensive efficiency of the interception pipeline in the urban rainwater pipe network for the initial rainwater collection and storage

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Abstract. Urban runoff pollution has become one of the important limiting factors hindering the continuous improvement of water environment. In the process of drainage system reconstruction, the evaluation of interception pipeline for the collection and storage efficiency of initial rainwater is an important work. Therefore, this study uses the analytic hierarchy process to establish an evaluation system and method containing 4 first-level indicators and 10 second-level indicators to evaluate the comprehensive efficiency of the interception pipeline for initial rainwater collection and storage. Taking the interception pipeline in a drainage system in Shanghai as a case study, the established evaluation method was adopted to evaluate it, and the comprehensive indexes under the rainfall return periods of 0.5 year, 1 year, 3 years and 5 years were calculated. The results indicated that the evaluation method could be well applied to the effectiveness evaluation of intercepting pipelines in drainage systems, and could provide technical support for the planning and design of urban runoff pollution control projects in the future.

1. Introduction

After continuous long-term efforts, urban domestic sewage and industrial wastewater pollution have been effectively controlled, with the remarkable progress being made in terms of urban water environment protection, while there still exist enormous challenges in current water environment. The urban non-point source pollution caused by the initial rainwater poses a threat to the continuous improvement of the water environment[1, 2]. The discharge of the municipal pumping station in the dry days and the discharge outfall into rivers in rainy days are still unable to be effectively eradicated. The phenomenon of 'black when it rains' of urban rivers continues to exist. Controlling and reducing the initial rainwater surface source pollution has become the key task of current water environment protection.

In order to effectively deal with the pollution caused by initial rainwater in urban regions and comprehensively promote the continuous improvement of the urban water environment, it is urgent to transform and optimize the rainwater drainage system. Through the construction of interception pipelines, the initial rainwater in the separate system can be collected and stored to alleviate the problem of black and odorous rivers caused by the direct discharge of initial rainwater into urban water bodies[3]. While promoting the construction of river closure pipeline, it is an indispensable work to evaluate its comprehensive efficiency scientifically and reasonably.

Therefore, this study constructs an evaluation system with comprehensive efficiency as the evaluation target, in order to comprehensively evaluate the comprehensive efficiency of the interception pipeline for the initial rainwater collection and storage of urban rainwater pipe network. The evaluation results can indicate the ability of the interception pipeline to control the total amount of rainwater runoff and reduce the pollution of discharge outfall into the river during once precipitation.

2. Methods and Materials

2.1. Evaluation index

In the study, the analytic hierarchy process (AHP)[4] was adopted to construct the evaluation indicator system to evaluate the comprehensive efficiency of the interception pipeline in the urban rainwater pipe network for the initial rainwater collection and storage. The target layer was set as the comprehensive efficiency. The interception efficiency of total runoff, the storage efficiency of total runoff, the interception efficiency of runoff pollution, and the removal efficiency of discharge outfall pollution were selected as four first-level indicators. Appropriate secondary indicators were selected under the first-level indicators to form a complete evaluation indicator system, as shown in Table 1.

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Table 1. Evaluation indicators and corresponding definitions

First-level indicators	Second-level indicators	Definition of indicator
Interception efficiency of total runoff	Rainfall runoff interception rate	It refers to the ratio of the total amount of runoff intercepted by the interception pipe to the total amount of rainfall runoff during once precipitation.
	Interception flow per unit service area	It refers the ratio of the total amount of runoff intercepted by the intercepting pipe to the area of the drainage system service area corresponding to the intercepting pipe during once precipitation.
Storage efficiency of total runoff	Storage volume per unit service area	It refers to the ratio of the volume of the storage tank to the service area of the drainage system corresponding to the intercepting main pipe.
	Storage volume per unit interception volume	It refers to the ratio of the volume of the storage tank to the amount of the runoff intercepted by the interception pipe during once precipitation.
Interception efficiency of runoff pollution	Interception ratio of COD during once precipitation	It refers to the ratio of COD mass intercepted by the interception pipe to the total COD mass in the runoff during once precipitation.
	Interception ratio of NH_3-N during once precipitation	It refers to the ratio of NH_3-N mass intercepted by the interception pipe to the total mass of NH_3-N in the runoff during once precipitation.
	Interception ratio of TP during once precipitation	It refers to the ratio of TP mass intercepted by the interception pipe to the total mass of TP in the runoff during once precipitation.
Removal efficiency of discharge outfall	Removal ratio of COD in the discharge outfall during once precipitation	It refers to the ratio of the difference of the COD mass in the discharge outfall from the pumping station before and after the construction of the interception pipe to the COD mass in the discharge outfall before the construction.
	Removal ratio of NH_3-N in the discharge outfall during once precipitation	It refers to the ratio of the difference of the NH_3-N mass in the discharge outfall from the pumping station before and after the construction of the interception pipe to the NH_3-N mass in the discharge outfall before the construction.
	Removal ratio of TP in the discharge outfall during once precipitation	It refers to the ratio of the difference of the TP mass in the discharge outfall from the pumping station before and after the construction of the interception pipe to the TP mass in the discharge outfall before the construction.

2.2. Evaluation process

Establish data acquisition and calculation methods. A series of data of urban rainwater pipe network and initial rainwater collection and storage interception pipeline are obtained and input into the SWMM model. Based on the calculation method and model calculation results, the specific values of each second-level indicators are calculated.

Establish the target tree of comprehensive efficiency evaluation of interception pipeline for initial rainwater collection and storage. The target tree is divided into target layer, criterion layer (first-level indicator) and index layer (second-level indicator) from top to bottom.

Determine the indicator weight by AHP. When using AHP to determine the weight of each secondary indicator, it's necessary to determine the weights of the first-level indicators firstly, and then the second-level indicators. Each indicator needs to be compared in pairs, and then the three-scale (0,1,2) method is adopted to arrange the sequence of each indicator, constructing a three-scale comparison matrix C. Among them, c_{ij}=2,1,0 represent that index i is more important than index j, equally important and less important, respectively.

Grading the indicators in the evaluation system. According to the evaluation system, the same level indicator is selected as the matter-element extension evaluation factor. The indicators in the evaluation system are graded and evaluated, as shown in Table 2. The evaluation objects are divided into V, IV, III, II and I levels from high to low. The score value corresponding to each evaluation level is defined as (V, IV, III, II, I) = (80, 70, 60, 45, 15).

Table 2. Evaluation indicator grading standard

Indicators			Grade of indicator				
First-level indicator	Secondary indicator	Third-level indicator	V	IV	III	II	I
Comprehensive efficiency of interception pipeline based on initial rain collection and	Interception efficiency of total runoff	Interception ratio during once precipitation (%)	60	45	30	15	10
		Interception volume per unit service area (m^3/m^2)	6.0	5.0	4.0	3.0	2.0
	Storage efficiency of total runoff	Storage volume per unit area (m^3/m^2)	6.0	5.0	4.0	3.0	2.0
		Interception volume per unit area (m^3/m^2)	1.0	0.9	0.8	0.7	0.6
	Interception efficiency of	COD interception efficiency during once precipitation (%)	60	45	30	15	0
		NH_3-N interception efficiency during once precipitation (%)	60	45	30	15	0

storage	runoff pollution	TP interception efficiency during once precipitation (%)	60	45	30	15	0
	Removal efficiency of discharge outfall	COD removal efficiency during once precipitation (%)	60	45	30	15	0
		NH_3-N removal efficiency during once precipitation (%)	60	45	30	15	0
		TP removal efficiency during once precipitation (%)	60	45	30	15	0

Calculate indication correlation degree. The second-level indicator evaluation vector is determined, and the evaluation indicator matrix is established and standardized so that the evaluation value belongs to the interval of [0, 1]. According to the normalized evaluation indicator matrix, the correlation matrix K is determined by the calculation of the correlation function.

Calculate comprehensive index. The evaluation grade quantifies the comprehensive efficiency of the interception pipeline for the collection and storage of the initial rain by conversion in the form of a percentage score. The correlation degree $K_j(G_i)$ is calculated by the correlation matrix K and the weight vector W.

The comprehensive correlation degree of each grade is normalized, and the comprehensive correlation degree is converted into an index to avoid the limitation of using the correlation degree as an evaluation criterion. The grading level corresponding to the comprehensive index is shown in Table 3.

Table 3. The grading level corresponding to the comprehensive index

Score of comprehensive index	Grade	Level
80~90	V	Excellent
70~80	IV	Good
60~70	III	Average
45~60	II	Fair
15~45	I	Poor

3. Case Study

In this study, the rainwater drainage system around a municipal wastewater treatment plant in Shanghai was selected as a case to evaluate the comprehensive efficiency of interception pipeline for initial rain collection and storage. The information of the rainwater drainage system is shown in Table 4.

Table 4. Information of rainwater drainage systems around a municipal wastewater treatment plant in Shanghai

No.	Rainwater system	Service area (km^2)	Sewer system	Rainfall return period	Rainwater pumping station scale (m^3/s)
1	Area 1	1.47	separate system	P=1	9.32
2	Area 2	4.08	separate system	P=1	21.0
3	Area 3	1.70	separate system	P=1	10.7
4	Area 4	3.57	separate system	P=1	16.9
5	Area 5	3.95	separate system	P=1	19.6
6	Area 6	3.27	separate system	P=1	16.7
7	Area 7	5.83	separate system	P=1	28.5
8	Area 8	1.29	separate system	P=1	7.1
Total		25.16	/	/	129.82

As mentioned above, the target tree of the comprehensive efficiency of the interception pipeline for the initial rain collection and storage was established. Here, the target tree was divided into target layer, criterion layer (first-level indicator) and index layer (second-level index) from top to bottom. The target layer was the comprehensive efficiency of the initial rainwater collection and storage. There were four criteria in the criterion layer, including interception efficiency of total runoff, storage efficiency of total runoff, interception efficiency of runoff pollution, and removal efficiency of discharge outfall, numbered A, B, C, D. The index layer consisted of 10 evaluation indicators evaluating the influence of these characteristics on the interception time, numbered A1, A2, B1, B2, C1, C2, C3, D1, D2, D3. Based on the evaluation mathematical model, the weights of these indicators were calculated as shown in Table 5.

Table 5. Weight calculation of comprehensive efficiency evaluation index of interception pipeline for initial rainwater collection and storage in urban rainwater pipe network

First-level indicator	Secondary indicator	Weight
A-Interception efficiency of total runoff	A_1-Interception ratio during once precipitation	0.076
	A_2-Interception volume per unit service area	0.076
B-Storage efficiency of total runoff	B_1-Storage volume per unit area	0.076
	B_2-Interception volume per unit area	0.076

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C-Interception efficiency of runoff pollution	C_1-COD interception efficiency during once precipitation	0.116
	C_2-NH_3-N interception efficiency during once precipitation	0.116
	C_3-TP interception efficiency during once precipitation	0.116
D-Removal efficiency of discharge outfall pollution	D_1-COD removal efficiency during once precipitation	0.116
	D_2-NH_3-N removal efficiency during once precipitation	0.116
	D_3-TP removal efficiency during once precipitation	0.116

In the evaluation process, the corresponding data was collected based on the survey data and model simulation. Under the rainfall conditions with a return period of 0.5 year, 1 year, 3 years and 5 years, the indicator classification and correlation degree corresponding to each indicator we calculated as shown in Fig. 1-4, respectively, and the evaluation index was shown in Fig. 5.

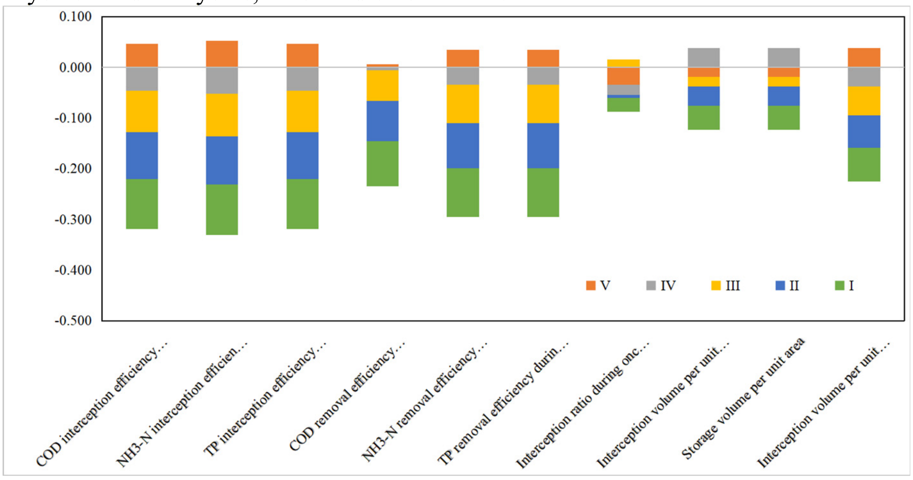

Fig. 1. Calculation of second-level indicator correlation degree of comprehensive efficiency evaluation system of interception pipelines (P=0.5)

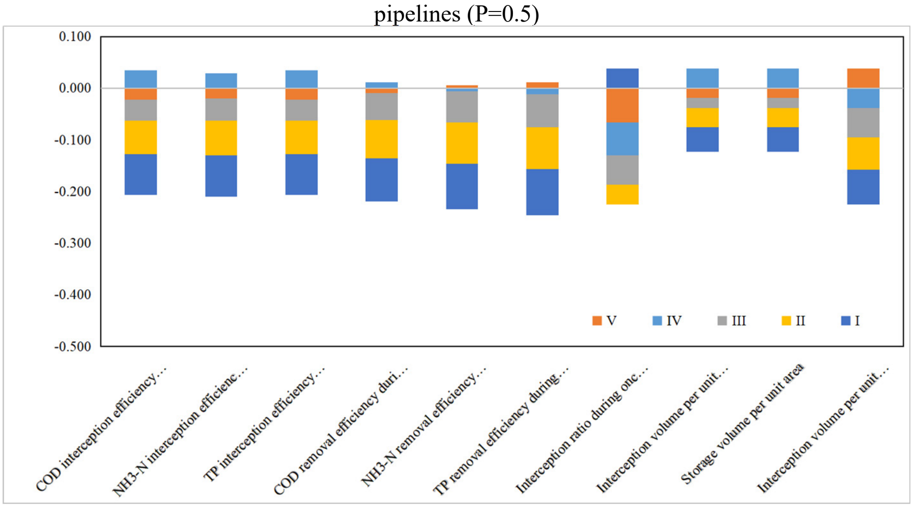

Fig. 2. Calculation of second-level indicator correlation degree of comprehensive efficiency evaluation system of interception pipelines (P=1)

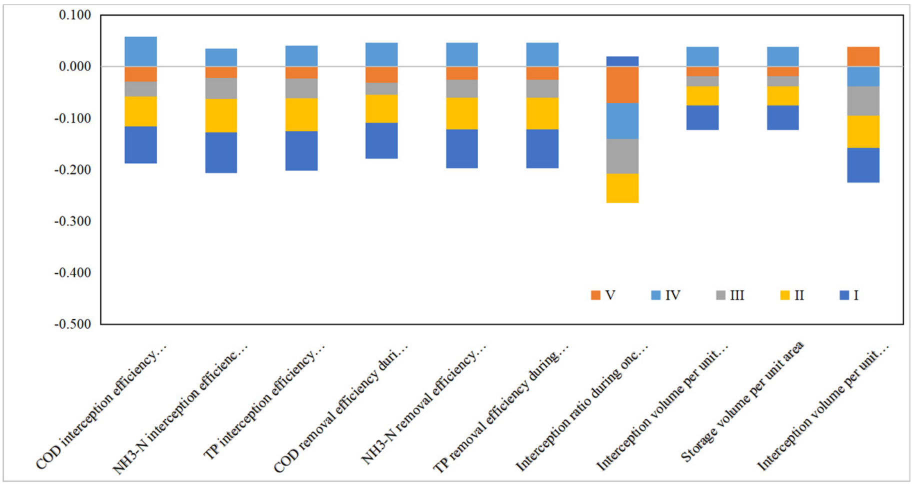

Fig. 3. Calculation of second-level indicator correlation degree of comprehensive efficiency evaluation system of interception pipelines (P=3)

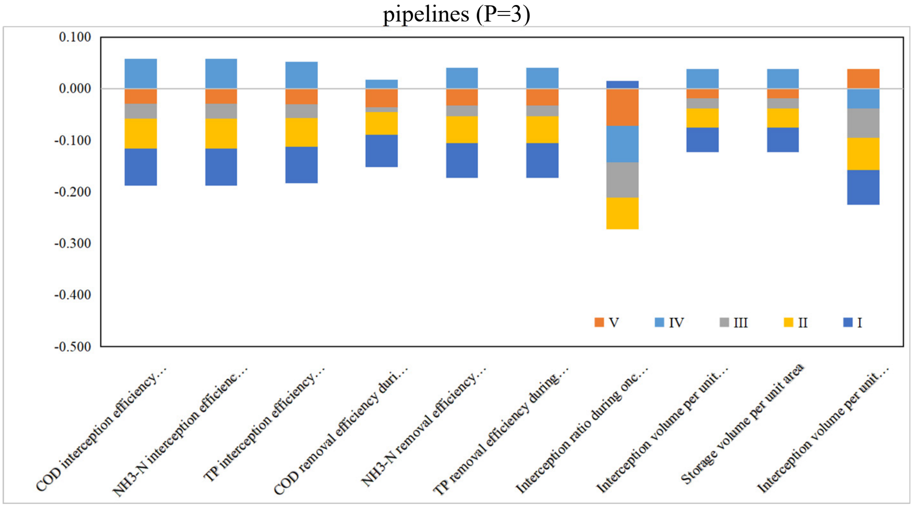

Fig. 4. Calculation of second-level indicator correlation degree of comprehensive efficiency evaluation system of interception pipelines (P=5)

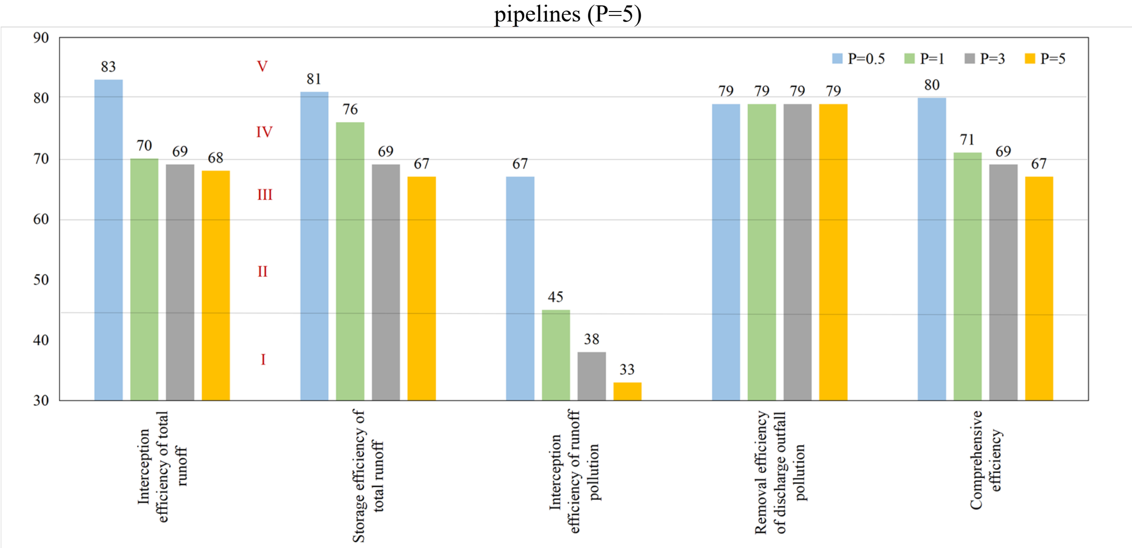

Fig. 5. Comprehensive efficiency index of interception pipeline in the case

Under the condition of the return period of 0.5 years, 1 year, 3 years and 5 years respectively, the comprehensive efficiency index value of the interception pipeline was 80, 71, 69 and 67, respectively, which was at the level of III and IV, and could meet the engineering objectives. In terms of the first-level indicators, with the increase of rainfall intensity, interception efficiency of runoff pollution and removal efficiency of discharge outfall pollution gradually decreased, and interception efficiency of total runoff decreased rapidly. Because the rated interception amount of the drainage system storage project was 5 mm and could be transmitted to the storage tank through the interception pipe, the total runoff storage efficiency remained unchanged. In general, under different rainfall intensities, there were obvious differences in the comprehensive efficiency of the interception pipe, which could achieve the engineering objectives. With the increase of the long-term engineering interception flow planned, the interception efficiency of the interception main pipe would be further improved.

4. Conclusion

The comprehensive efficiency evaluation method of interception pipeline for initial rainwater collection and storage in urban rainwater pipe network was proposed in this study. The comprehensive efficiency index evaluation system of interception pipeline for initial rainwater collection and storage in urban rainwater pipe network was established by analytic hierarchy process, and the comprehensive efficiency of interception pipeline for initial rainwater collection and storage in urban rainwater pipe network was evaluated by matter-element extension-analytic hierarchy process comprehensive evaluation model. The evaluation system is suitable for the pre-judgment of the sewage interception efficiency in the early stage of the construction planning and construction of the interception pipeline of the initial rainwater storage project, which provides a basis for scientific decision-making and has strong practicability. The evaluation method is suitable for this evaluation system and can also be widely used in similar evaluation systems in other fields.

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