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Views & Comments

Establishing an Assessment Index System for Sewage Treatment Works in China

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1. Introduction

The urban sewage treatment system, including sewage pipe networks and sewage treatment plants, is an important infrastructure to ensure urban social and economic operation. In the past few decades, due to the unremitting efforts of the Chinese government, the construction of China's urban sewage treatment infrastructure has developed rapidly [1]. During 1991–2019, urban sewage treatment capacity increased from 3.17×10^6 to 1.79×10^8 $m^3 \cdot d^{-1}$, and the treatment rate of urban sewage increased from 14.9% to 96.8% [2]. The sewage pipe networks (including sewage pipelines and combined sewer pipelines) in urban built-up areas also showed a growth trend from 2.69×10^5 to 4.29×10^5 km over the period 2011–2019 [2].

Unfortunately, urban water quality in China has not shown a rapid improvement with the construction of sewage treatment infrastructure. Heavy pollution of urban rivers frequently occurs during rainy weather, especially in the southeast coastal areas [3]. This phenomenon is mainly attributed to problems such as structural defects in sewage treatment systems, which is a challenging issue in urban water environment rehabilitation in China [4]. It is essential to address such issues by accurately assessing urban sewage treatment works for the rehabilitation of heavily polluted urban rivers. Here, for the first time, we establish an assessment index system for urban sewage treatment works and apply it to quantitatively analyze the current state of urban sewage treatment works in China; we also reveal the key parameters affecting the continuous improvement of the urban water environment. These suggestions can be put forward for the rehabilitation of heavily polluted urban rivers.

2. Assessment indexes for sewage treatment works

2.1. Complete indicator for a sewage pipe network

Sewage collection and transportation are very important in the rehabilitation of urban water environment. In principle, sewage pipe networks should be planned and constructed simultaneously with water-supply pipe networks. However, the construction of environmental infrastructure lags behind urban development in China due to the nation's rapid urbanization, and this gap leads to a lack of sewage networks in some areas that have complete water-supply pipe networks [5]. This situation results in a low sewage collection percentage [6]. In order to quantitatively assess the coverage of an urban sewage pipe network, we establish a complete indicator for a sewage pipe network, which is defined as the ratio of the length of the sewage pipe network to that of the water-supply pipe network (Eq. (1)).

$$C = L_S / L_{WS} \tag{1}$$

where C represents the complete indicator for a sewage pipe network, L_S (km) is the length of the sewage pipe network, and L_{WS} (km) is the length of the water-supply pipe network.

A complete indicator assessment for a sewage pipe network is shown in Table 1.

2.2. Normal indicator for a sewage pipe network

In general, the concentration of delivered sewage should be roughly equal to that of the original sewage during the normal operating conditions of a sewage pipe network. Therefore, structural defects (e.g., damage) in a sewage pipe network and the misconnection of stormwater pipelines to the sewage pipe network can be determined using the influent concentration of the sewage treatment plant [7]. Infiltration in a sewage pipe network leads to a low influent concentration in the relevant sewage treatment plant [8,9]. In order to quantitatively assess the operating conditions of a sewage pipe network, we establish a normal indicator for a sewage pipe network, which is defined as the ratio of the influent concentration of the sewage treatment plant to the concentration of the original sewage (Eq. (2)).

$$N = S_I / S_O \tag{2}$$

where N represents the normal indicator for a sewage pipe network, S_I ($mg \cdot L^{-1}$) is the influent concentration of the sewage treatment plant, and S_O ($mg \cdot L^{-1}$) is the concentration of the original sewage.

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Table 1
Complete indicator assessment for a sewage pipe network.

Complete indicator for a sewage pipe network	Assessment
$C \geq 0.90$	The sewage pipe network is complete, and has a high coverage rate.
$0.80 \leq C < 0.90$	The sewage pipe network is relatively complete, and has a relatively high coverage rate.
$0.60 \leq C < 0.80$	The sewage pipe network is relatively incomplete, and has a relatively low coverage rate.
$C < 0.60$	The sewage pipe network is incomplete, and has a low coverage rate.

A normal indicator assessment for a sewage pipe network is shown in Table 2.

2.3. Efficiency indicator for a sewage treatment plant

The sewage treatment capacity in China has exhibited a trend of continuous growth in recent decades and has exceeded the sewage quantity since 2010. The discharge standards for pollutants from sewage treatment plants have become more stringent, and the construction and operation costs of sewage treatment plants have been increasing [10]. In order to quantitatively assess the efficiency of sewage treatment, we establish an efficiency indicator for a sewage treatment plant, which is defined as the ratio of the equivalent sewage inflow to the designed capacity of the sewage treatment plant (Eq. (3)).

$$E = Q_E/Q_C \tag{3}$$

where E represents the efficiency indicator for a sewage treatment plant, Q_E ($m^3 \cdot d^{-1}$) is the equivalent inflow of the sewage treatment plant (i.e., the average daily influent pollution load of the sewage treatment plant divided by the concentration of the original sewage), and Q_C ($m^3 \cdot d^{-1}$) is the designed capacity of the sewage treatment plant (i.e., the daily treatment capacity of the sewage treatment plant).

An efficiency indicator assessment for a sewage treatment plant is shown in Table 3.

2.4. Rate indicator for a sewage treatment plant

In general, the sewage treatment rate released by the Chinese government is determined based on the quantity of sewage discharged into a sewage treatment plant and the quantity of sewage generated from the corresponding sewage treatment plant within service areas. Due to the structural defects of the sewage pipe networks and misconnection of stormwater pipelines to sewage pipe networks, external water can infiltrate into sewage pipe networks and enter sewage treatment plants together with sewage, resulting in an overestimation of sewage inflow [3]. We establish a rate indicator for a sewage treatment plant to assess the actual sewage treatment rate; this indicator is defined as the ratio of the pollution load entering the sewage treatment plant to the sewage discharge pollution load within the service area (Eq. (4)). Generally, the effluents of sewage treatment plants should meet the discharge standard, so the pollutants entering sewage treatment plants can be regarded as effective treated.

$$R = P_I/P_{ST} \tag{4}$$

where R represents the rate indicator for a sewage treatment plant, P_I (kg) is the influent pollution load of the sewage treatment plant, and P_{ST} (kg) is the pollution load generated in the corresponding sewage treatment plant within the service area. For this indicator, a value of 0.50 indicates an actual sewage treatment rate of 50%.

A rate indicator assessment for a sewage treatment plant is shown in Table 4.

Table 2
Normal indicator assessment for a sewage pipe network.

Normal indicator for a sewage pipe network	Assessment
$N \geq 0.85$	The sewage pipe network is in normal operation.
$0.70 \leq N < 0.85$	The sewage pipe network is in relatively normal operation.
$0.50 \leq N < 0.70$	The sewage pipe network is in abnormal operation with external water infiltration.
$N < 0.50$	The sewage pipe network is in extremely abnormal operation with serious external water infiltration.

Table 3
Efficiency indicator assessment for a sewage treatment plant.

Efficiency indicator for a sewage treatment plant	Assessment
$E \geq 0.80$	The efficiency of sewage treatment is high.
$0.60 \leq E < 0.80$	The efficiency of sewage treatment is relatively high.
$0.40 \leq E < 0.60$	The efficiency of sewage treatment is relative low.
$E < 0.40$	The efficiency of sewage treatment is low.

Table 4
Rate indicator assessment for a sewage treatment plant.

Rate indicator for a sewage treatment plant	Assessment
$R \geq 0.90$	The actual sewage treatment rate is high.
$0.70 \leq R < 0.90$	The actual sewage treatment rate is relatively high.
$0.50 \leq R < 0.70$	The actual sewage treatment rate is relatively low.
$R < 0.50$	The actual sewage treatment rate is low.

3. Assessment of urban sewage treatment works in China

The urban sewage treatment works in China were assessed at the national level, provincial level, and city level using the four indicators described above, based on publicly available data from 2019. Data on the length of sewage pipe networks, length of water-supply pipe networks, designed capacity of sewage treatment plants, and discharged sewage were obtained from the *China Urban Construction Statistical Yearbook* [2]. The influent quantity and quality of sewage treatment plants were calculated using data from the National Urban Sewage Treatment Management Information System [11]. Statistics on the concentrations of original sewage were obtained from the Second National Census of Pollution Sources [12].

3.1. Assessment of sewage treatment works at the national level

In 2019, the length of the sewage pipe networks in urban built-up areas of China was 4.29×10^5 km and that of the water-supply pipe networks was 9.20×10^5 km. The average influent chemical oxygen demand (COD) concentration of the sewage treatment plants was around 244 mg·L^{-1}, which is only two-thirds of the average COD concentration of original sewage (~373 mg·L^{-1}). The average equivalent inflow of the sewage treatment plants in China was 8.16×10^7 m^3·d^{-1}, the designed capacity of the sewage treatment plants was 1.79×10^8 m^3·d^{-1}, and the officially released sewage treatment rate was about 96.8%.

On this basis, an assessment of urban sewage treatment works at the national level was calculated, as shown in Table 5. The complete indicator and the normal indicator for sewage pipe networks were about 0.47 and 0.66, respectively, and the efficiency indicator and the rate indicator for sewage treatment plants were around 0.46 and 0.62, respectively. These findings indicate that the coverage rate of sewage pipe networks in urban built-up areas of China was less than 50% in 2019, and that the normal indicator for sewage pipe networks was relatively low. The equivalent inflow of sewage treatment plants was less than half of the sewage treatment capacity, and the efficiency indicator for sewage treatment plants was at a low level. The national average rate indicator for sewage treatment plants (0.62) indicates that the actual sewage treatment rate in China was only 62% in 2019. Therefore, the construction and repair of China's sewage pipe networks should be listed as an investment priority within China's urban sewage treatment.

3.2. Assessment of sewage treatment works at the provincial level

The assessment of urban sewage treatment works at the provincial level includes 30 provinces and regions in China, excluding Tibet, Hong Kong, Macao, and Taiwan. As shown in Fig. 1, the complete indicators for sewage pipe networks were in the range of 0.26–0.79, with a median of 0.50. Among the 30 provinces and regions, the complete indicators for sewage pipe networks in six provinces fell in the range of 0.60–0.80, and those in 24 provinces were less than 0.60. In addition, none of the 30 provinces have achieved complete coverage of sewage pipe networks, and the sewage pipe networks in half of the provinces have not even covered 50% of the urban built-up areas.

The normal indicators for sewage pipe networks in the 30 provinces were in the range of 0.52–0.86, with a median of 0.66. Only one province had a normal indicator for sewage pipe networks of greater than 0.85, while seven provinces had normal indicators of between 0.70–0.85. The normal indicators in the other 22 provinces fell in the range of 0.50–0.70, indicating that the sewage pipe networks in 73% (i.e., 22 of 30) of the provinces were damaged in China.

The efficiency indicators for sewage treatment plants in the 30 provinces were in the range of 0.34–0.64, with a median of 0.54. Among them, the efficiency indicators for sewage treatment plants in six provinces were 0.60–0.80, and those in 23 provinces were between 0.40–0.60, with one province having an efficiency indicator of less than 0.40. These low efficiency indicators for sewage treatment plants suggest that sewage treatment capacity is not fully utilized in most provinces.

The rate indicators for sewage treatment plants in the 30 provinces were in the range of 0.49–0.81, with a median of 0.63. The rate indicators for sewage treatment plants in six provinces were between 0.70–0.90. Those in 23 provinces were between 0.50–0.70, while one province had a rate indicator of less than 0.50, indicating that the actual sewage treatment rate in 80% (i.e., 24 of 30) of the provinces was less than 70%.

3.3. Assessment of sewage treatment works at the city level

There are 297 cities in China that are at the prefecture level and above (including 293 prefecture-level cities and four municipalities directly under the central government, excluding regions, autonomous prefectures, and alliances). Due to the lack of relevant data for some cities, our assessment of sewage treatment works at the city level includes 219 prefecture-level and above cities, accounting for 74% of the prefecture-level and above cities in China. The population of these 219 cities accounts for 79% of the population of the 297 prefecture-level and above cities in China. The assessment was conducted based on Tables 1–4.

The frequency distribution of the complete indicator for sewage pipe networks at the city level is shown in Fig. 2. The complete indicators for sewage pipe networks were relatively low, with large differences among the cities. Only five cities had high pipe network coverage rates with complete indicators of sewage pipe networks that was greater than 0.90, followed by 24 cities with complete indicators of between 0.80–0.90. The complete indicators of sewage pipe networks in 47 cities were between 0.60–0.80, indicating relatively low pipe network coverage rates in these cities, and 143 cities had terrible sewage pipe networks with complete indicators for sewage pipe networks of less than 0.60. Thus, sewage pipe

Table 5
Assessment of urban sewage treatment works at the national level.

Complete indicator for sewage pipe networks (C)	Normal indicator for sewage pipe networks (N)	Efficiency indicator for sewage treatment plants (E)	Rate indicator for sewage treatment plants (R)
0.47	0.66	0.46	0.62

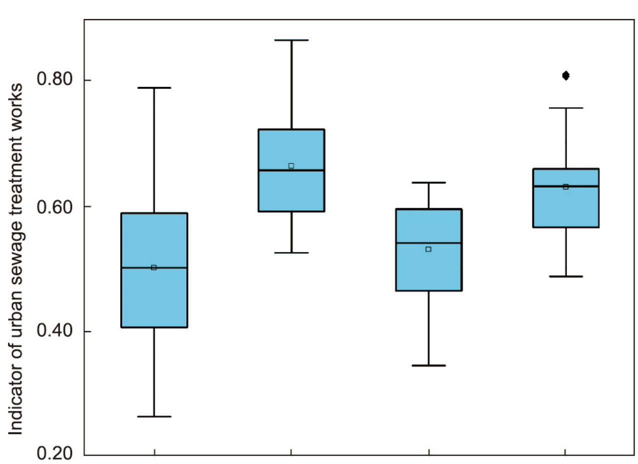

Fig. 1. Assessment of urban sewage treatment works at the provincial level.

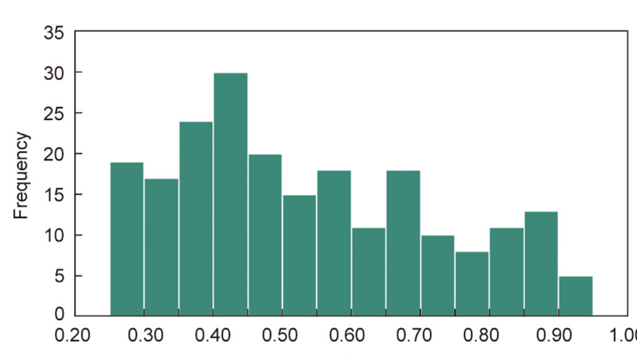

Fig. 2. Frequency distribution of the complete indicator for sewage pipe networks (C) at the city level.

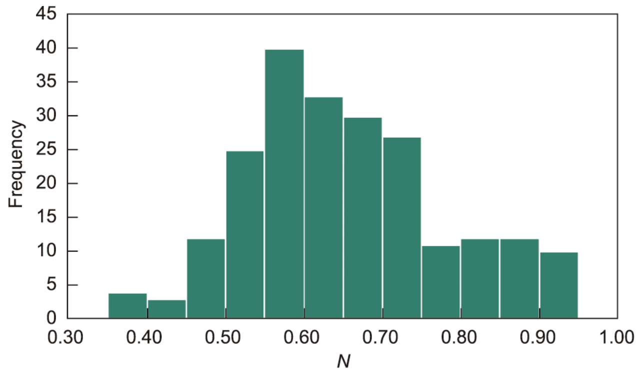

Fig. 3. Frequency distribution of the normal indicator for sewage pipe networks (*N*) at the city level.

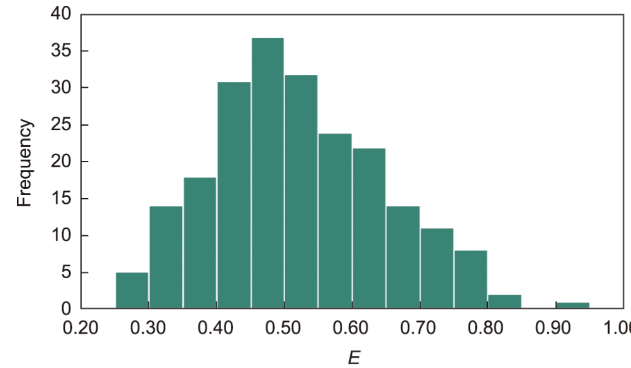

Fig. 4. Frequency distribution of the efficiency indicator for sewage treatment plants (*E*) at the city level.

networks with low coverage rates ubiquitously exist in China, posing a huge challenge to sewage pipe network construction during China's 14th Five-Year Period (2021–2025).

The frequency distribution of the normal indicator for sewage pipe networks at the city level is shown in Fig. 3. Only 22 cities, most of which are located in areas with a low groundwater level, had high normal indicators for sewage pipe networks ($\geq$ 0.85). The normal indicators for sewage pipe networks were between 0.70–0.85 in 50 cities, indicating relatively normal operating conditions. However, other cities had low normal indicators (0.50–0.70 for 128 cities and < 0.50 for 19 cities). These cities were mainly located in coastal areas where the groundwater level was higher than the buried depth of the pipelines, leading to serious external water infiltration. In addition, due to the misconnection of stormwater pipelines to sewage pipe networks, a large amount of groundwater and stormwater enters sewage pipelines and is transported to sewage treatment plants. The results showed that the sewage pipe networks in 67% of the cities were abnormal, exerting pressure on sewage treatment plants.

The frequency distribution of the efficiency indicator for sewage treatment plants at the city level is shown in Fig. 4. Among these cities, 58 had high efficiency indicators ($\geq$ 0.80 for three cities and 0.60–0.80 for 55 cities). In comparison, the efficiency indicators for sewage treatment plants in 124 cities were between 0.40–0.60, and the efficiency indicators in 37 cities were even less than 0.40. Thus, a total of 74% (i.e., 161 of 219) of the cities had a relatively low or low efficiency indicator, indicating that the equivalent inflow of the sewage treatment plants in these cities was far below the designed capacity. Therefore, the operation efficiency of sewage treatment plants constructed with high standards is still at a low level.

The frequency distribution of the rate indicator for sewage treatment plants at the city level is shown in Fig. 5. The rate indicator for sewage treatment plants was greater than 0.90 in only one city, and the rate indicators of 51 cities were in the range of 0.70–0.90. The rate indicators in 130 cities were between 0.50–0.70, and those in 37 cities were less than 0.50—that is, the actual sewage treatment rates were less than 50%. This finding shows the generally low actual sewage treatment rate of sewage treatment plants.

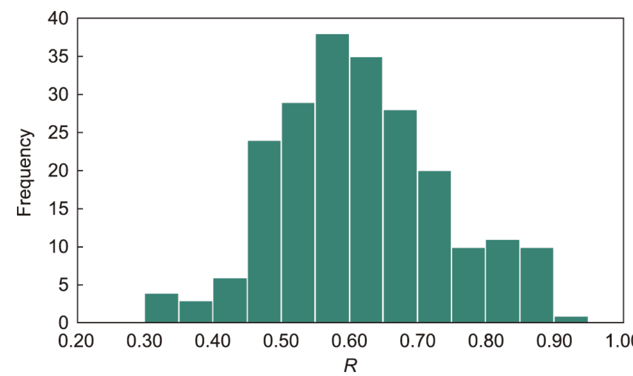

Fig. 5. Frequency distribution of the rate indicator for sewage treatment plants (*R*) at the city level.

Table 6
Assessment of urban sewage treatment works in China.

Level	Indicator			
	C	*N*	*E*	*R*
Country	0.47	0.66	0.46	0.62
Province	0.26–0.79	0.52–0.86	0.34–0.64	0.49–0.81
City	0.26–0.93	0.37–0.94	0.28–0.91	0.30–0.91

3.4. Discussion

Table 6 summarizes the results of the assessment of sewage treatment works in China at the national level, provincial level, and city level. The complete indicator for sewage pipe networks in China was about 0.47, and those at the provincial level and city level were 0.26–0.79 and 0.26–0.93, respectively. The normal indicator for sewage pipe networks in China was about 0.66, and those at the provincial level and city level were 0.52–0.86 and 0.37–0.94, respectively. The efficiency indicator for sewage treatment plants in China was about 0.46, and those at the provincial level and city level were 0.34–0.64 and 0.28–0.91, respectively. The rate indicator for sewage treatment plants in China was about 0.62, and those at the provincial level and city level were 0.49–0.81 and 0.30–0.91, respectively.

Overall, the urban sewage treatment works in China were still at a relatively low level in 2019, with great differences among provinces and cities, as indicated by the inferior complete indicator and normal indicator for sewage pipe networks. The low complete indicator for sewage pipe networks reveals the fact that a large amount of sewage in China cannot be effectively collected, while the low normal indicator for sewage pipe networks shows that a large amount of groundwater and stormwater is transported to sewage treatment plants. The efficiency of pollutant collection and transportation is also low. Therefore, source control and interception of pollutants is a challenge in the rehabilitation of heavily polluted urban rivers, and the construction and repair of sewage pipe networks should be made a top priority in China.

4. Conclusions and suggestions

This study established an assessment index system for urban sewage treatment works for the first time, including a complete indicator for sewage pipe networks, a normal indicator for sewage pipe networks, an efficiency indicator for sewage treatment plants, and a rate indicator for sewage treatment plants. An assessment was then carried out at the national level, provincial level, and city level in China by means of a statistical analysis of publicly available government data. The following suggestions are put forward based on the assessment results:

(1) The construction of urban sewage collection pipe networks should be strengthened to connect every household in order to improve sewage collection; the complete indicators for sewage pipe networks will increase accordingly. It is necessary to provide fully packaged solutions that include design, construction, and supervision within specific areas of responsibility. The assessment and acceptance of sewage pipe network construction projects should be based on the quantity and concentration of the sewage inflow. Charging standards should be adjusted for the design and construction of small-diameter sewage collection pipe networks to improve the initiatives of design and construction companies and to ensure the quality of the design and construction of sewage collection pipe networks.

(2) The repair and upgrading of sewage pipe networks require great attention in order to solve the problem of the low normal indicators for sewage pipe networks in many cities in China. We suggest the development of a simple, efficient, trenchless, and non-interfering detection technology for the damage location of sewage pipe networks, and the strengthening of the promotion of trenchless repair materials and construction techniques for underground pipe networks. This can help avoid the excavation and reconstruction of urban sewage pipes in most cities in China.

(3) To solve the problem of the low efficiency indicators and rate indicators for sewage treatment plants in many cities in China, we do not recommend constructing new sewage treatment plants or extending existing sewage treatment plants. Instead, more efforts should be made to increase the collection rate of sewage and the influent concentration of sewage treatment plants, enhance the capacity of sewage treatment plants in response to impact load, and rationally utilize the water environment capacity and set discharge standards for sewage treatment plants in order to improve the efficiency of sewage treatment works.

(4) In terms of the assessment of water environment rehabilitation, there is a need to improve the assessment indicators to concentrate the workforce, resources, and capital on urban sewage pipe network construction and improvement, as well as on sewage interception and treatment works. In this regard, improvement of the urban water environment will finally be achieved via an accurate technical roadmap for river pollution control, the maximum utilization of funds, and efficient governance.

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