Performance evaluation of a typical sewage system remediation project in Yangtze River protection

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Abstract—The Yangtze River protection is an important environmental protection strategy for China, and the quality and efficiency of the sewage system is also one of the environmental protection actions that China is working hard to implement in recent years. As the first batch of pilot cities for the protection of the Yangtze River, Wuhu City has significantly improved its sewage system through a series of comprehensive sewage system improvement engineering measures. This paper briefly described the general situation and measures of the sewage system renovation project in the CD area of Wuhu City, and based on the systematic thinking of "source-network-plant-river", the performance of improving the quality and efficiency of the sewage system was evaluated. With the implementation of the sewage system remediation project, the water quality at the source and discharge outlet as well as the water quantity of sewage collected had been greatly improved. The sewage collection volume had been increased from 10,000 m^3/d to 42,000 m^3/d and the COD concentration of the influent has increased significantly. The introduction and analysis of this project may provide some reference for other similar sewage system remediation projects in China and other countries and regions.

1. Introduction

The Yangtze River Economic Belt includes 11 provinces and cities, with an area of about 2.05 million km^2. It is the most developed area in the Yangtze River Basin with high economic density, which is of great significance to the economic development in China. However, due to the development and construction of the Yangtze River Economic Belt, as an important ecological security barrier, its ecological environment has been deteriorated. Many cities face a series of water environment problems such as urban domestic pollution, non-point source pollution, black and odorous water and eutrophication [1-5]. As one of the first pilot cities for the protection of the Yangtze River, Wuhu City in Anhui Province faced many problems such as low-concentration influent in some sewage treatment plants, defects in the pipeline network, direct discharge of sewage to the aquatic environment, and black and odorous water bodies [6,7]. In order to comprehensively build a beautiful Yangtze River (Wuhu) economic belt with clear water, green industry, green industry, Wuhu City has solidly carried out comprehensive improvement of urban water environment, and carried out pilot work on the protection of the Yangtze River, forming the "Wuhu Experience", and innovated the integrated water control model of "plant, network, river and lakeshore", and achieved positive results [8,9].

The water collection area of Wuhu CD Wastewater Treatment Plant (referred to as "CD Area" in the following text), in view of the problems of broken pipe network and low influent concentration of WWTP, the remediation project focused on the construction, improvement and restoration of sewage pipe network and continuously promoted the improvement and remediation of pipe network diseases, mixed joints, mixed connection of rainwater and sewer pipe and other work, gradually improving the sewage collection efficiency of the pipe network and the influent concentration of sewage plants, and further improving the level of water environment management. Due to the continuity and systematic characteristics of water environment governance, scientific assessment of the current work results has important guiding significance for further improvement of environmental quality in the future. Therefore, this paper introduced the main work and the relevant results of improving the quality and efficiency of the wastewater system in the CD area of Wuhu, with a view to summarizing the experience of this area to provide references for the water environment management in other regions.

2. Project Profile

The CD area covered an area of about 90 km^2. The wastewater collection system of the area adopted the separate drainage system. The total length of the sewage

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pipeline was about 151 km, and there were 5 sewage lifting pump stations. The drainage unit in the water collection area of CD WWTP included three types, industrial enterprises, public units and commercial entities, and residential communities. The area had long been faced with problems such as insufficient water inflow and low concentration of WWTP influent. In the water collection area, there were phenomena such as damage, leakage and mix connection of the pipe network. The actual inflow was significantly lower than the designed amount, and the COD concentration of the influent was only about 80 mg/L.

From 2018 to the end of 2021, the Wuhu Municipal Government, together with several institutes, conducted multiple rounds of centralized renovation of the sewage system in the CD area of the city. A number of engineering measures have been implemented to improve the quality and efficiency of the sewage system, such as the diagnostic assessment of the sewage system, pipe network examination and renovation, drainage units' improvement, optimization of sewage treatment plant operation and maintenance, and water environment improvement.

3. Performance evaluation of sewage system remediation project

3.1. Analysis of the source distribution of sewage production

The distribution area of the main sources of sewage before and after remediation was shown in Fig.1. According to the water supply data collected from 2018 to 2021 in the area and the list of enterprises in the two districts lying in the CD area, the water consumption in the CD area was analyzed and listed separately for each year in Table 1. The saw domestic sewage volume was estimated and calculated according to the ratio coefficient of drainage sewage volume to the total sewage volume referred in the coefficient of production and use of domestic sources in China and standard for design of outdoor wastewater engineering (GB50014-2021)[6] and water usage. The industrial effluent volume was obtained from the collected data of water consumption and effluent discharge of each enterprise and weighted calculation by combining the actual situation of the enterprise with the discharge coefficient of each industry.

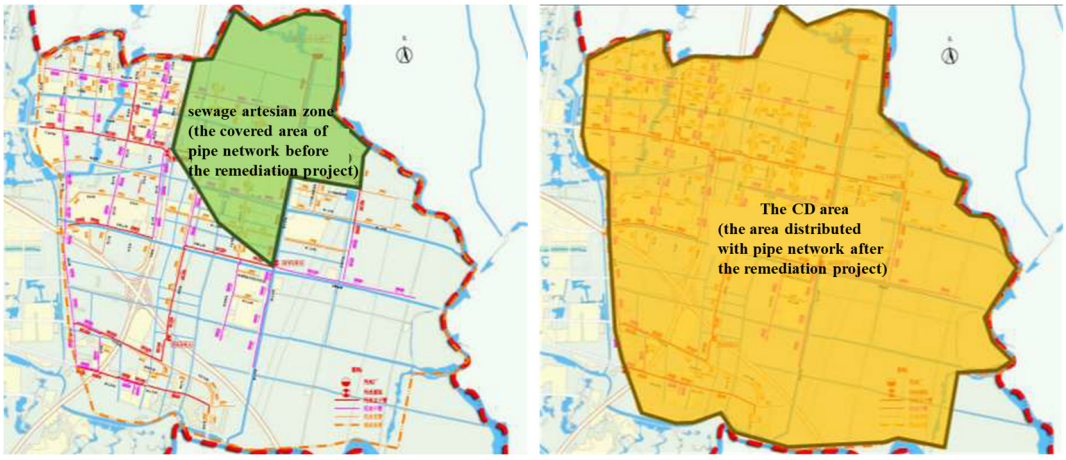

Fig.1 Comparison of the distribution area of the main sources of sewage before and after remediation

Table 1 The amount of water consumed and primary sewage in the area

Year	2018	2019	2020	2021
Water consumption analysis				
Industrial water consumption, $\times 10^4$ m^3/a	597.19	497.13	457.62	553.15
Non-industrial water consumption, $\times 10^4$ m^3/a	611.80	663.69	723.75	760.48
Total water consumption, $\times 10^4$ m^3/a	1209.00	1160.82	1181.37	1313.63
The amount of primary sewage estimated				
Domestic sewage, $\times 10^4$ m^3/d	1.01	1.593	1.737	1.825
Industrial wastewater, $\times 10^4$ m^3/d	0.304	1.199	1.208	1.221

After the remediation of the drainage system in the CD area, the scope and scale of sewage collection were significantly expanded, the number of drainage units increased to 7.4 times the number before the remediation, and the total amount of raw sewage (30.47 million m^3/d) reached 2.3 times the amount before the remediation, of which domestic sewage and industrial wastewater reached 1.8 and 4 times the amount before the remediation, respectively, which indicated the significant improvement in the effectiveness of sewage collection of the drainage system. From 2019 to 2021, the ratio of industrial wastewater volume to total saw sewage volume was steadily maintained at about 40%. The volume and quality of discharged industrial wastewater had a greater impact on the volume and quality of water from the area sewage treatment plant intake.

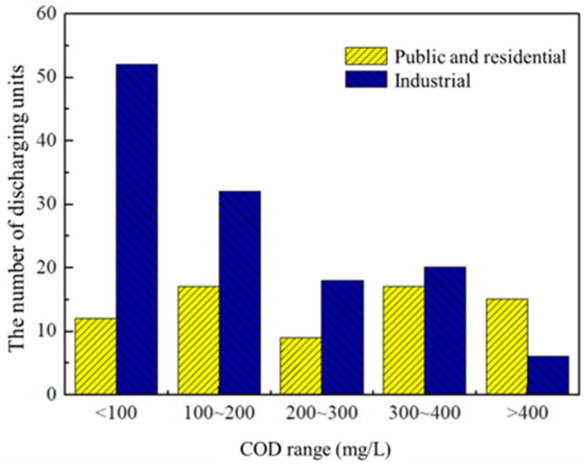

Fig. 2 The distribution of drainage units discharging effluent in different COD ranges

From October to December 2021, the water quality of drainage units in the CD area was sampled and analyzed after the implementation of the remediation project. 262 drainage units discharged sewage with COD concentrations ranging from 12 to 522 mg/L, with the distribution of COD concentration shown in Fig.2. The COD distribution of public institutes and residential communities was relatively balanced in different zones, and the COD of discharged industrial wastewater was mainly below 100 mg/L. With the advancement of source mixing points remediation, the COD concentration of the source outfall had significantly improved compared with that before the remediation project. By the end of 2021, the average COD concentration of the outlet in the sewage artesian zone had exceeded 200 mg/L.

3.2. Evaluation of the effect of drainage pipe network remediation

(a) Drainage pipe network remediation

In 2019-2020, the drainage system in the CD area was investigated with the survey of rainwater and sewage pipe network, rainwater outfall investigation, and mixed connection points being checked, as shown in Table 2. A variety of advanced detection technologies such as CCTV, all-terrain robot, QV, sonar, radar detection, and water quality analysis were tested and adopted comprehensively. According to the investigation results of 61 sewage pipelines along roads in the CD area, there were 3,366 defective points to be repaired, and the main types of defective points were pipe leakage, rupture, deformation and deposition, which were likely to cause sewage spillage and dripping, external water entering the pipes and municipal road settlement, etc. From 2020 to 2021, Wuhu carried out a series of remediation work for the sewage collection system in the CD area, including the repair and restoration of sewage pipe networks, sewage pipe network investigation and defective point rectification, investigation and rectification of mixed connections of rainwater and sewer pipes, etc.

Table 2 The investigation of the drainage system in the CD area

Item	Amount	
Pipeline investigation and examination	Rainwater pipe	266.3 km
	Sewer pipe	151.0 km
	Total	424.3 km
Investigation of drainage outlets	1188	
Investigation of mixed joints	279	
Investigation of water quantity and quality	62	
Defective points of the pipe network to be repaired	3366	

The sewage system remediation project was continuously carried out in the CD area. 56.3 km of pipelines were renovated, 10.57 km of pipelines were repaired by non-excavation, and 15.4 km of pipelines were dredged, achieving the penetration of the drainage pipe network supporting the sewage treatment plant in the area, and the drainage function of the drainage system was fully restored. In particular, through the re-examination of 56 sewage pipes along roads in the CD area, a total of 3,366 defects such as leakage and rupture of pipes were found and repaired, and 279 rain mixed connection points of rainwater and sewage pipes were investigated and rectified, which greatly enhanced the effectiveness of sewage collection.

(b) Analysis of the liquid level of the pipe network

The liquid level of the pipe network can be used to indicate the internal operation efficiency of the pipe network system. The liquid level of the influent of the CD WWTP was shown in Fig.3. The investigation of pipe network showed that there was a large amount of siltation and fouling in the pipe network in this area, and some of the pipe networks worked at high water levels for a long time, with limited sewage conveyance efficiency and impact resistance. The average liquid level before July was 9.57 m, consistent with the investigation results. Through the optimization of pumping station scheduling and wastewater plant operation, the influent liquid level was reduced from 9.57 m in the first half of the year to 4.67 m in the second half of the year. The level data from

the highest value of 8.37 m in April still maintained a downward trend after the rainy summer months including June, July and August to 5.04 m in August, proving that the liquid level of the pipe network had been steadily decreased. The central control inlet liquid level of the CD WWTP also gradually reduced, which also indicated the reduce of the liquid level of the pipe network and the improvement for the blockage and full load operation of the pipe network, further enhancing the health and stability of drainage system in the CD area.

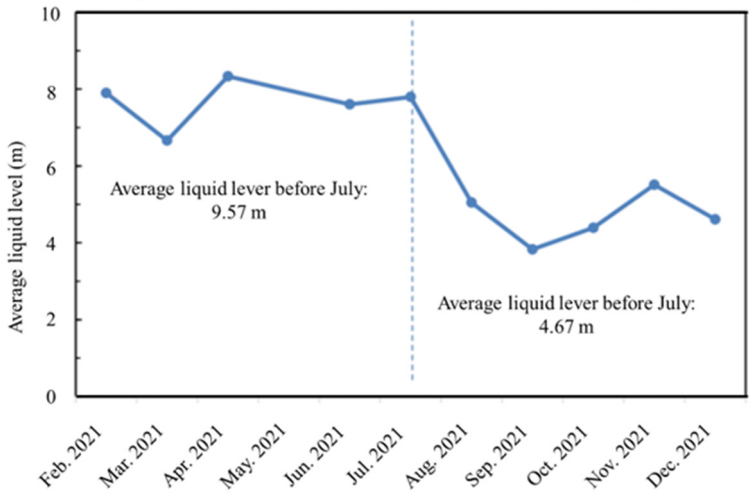

Fig.3 Average liquid level of drainage pipe network

3.3. Water quantity and quality of WWTP influent

The operational data including the influent flow and COD concentration of the CD WWTP from August 2018 to October 2021 was analyzed and shown in Fig.4. The influent volume continued to rise from 10,000 m^3/d to over 50,000 m^3/d from 2018 to August 2021, and from August to November 2018, then dropped to 42,000 m^3/d and and kept stabilized relatively. This trend was in line with the idea of collecting all the sewage in the CD area in the city, and then improving the quality and efficiency of the drainage system, which reflected the significant remediation effect. The COD concentration gradually increased from less than 80 mg/L at the end of 2018 to nearly 130 mg/L in November 2021, showing the improvement of the drainage system performance.

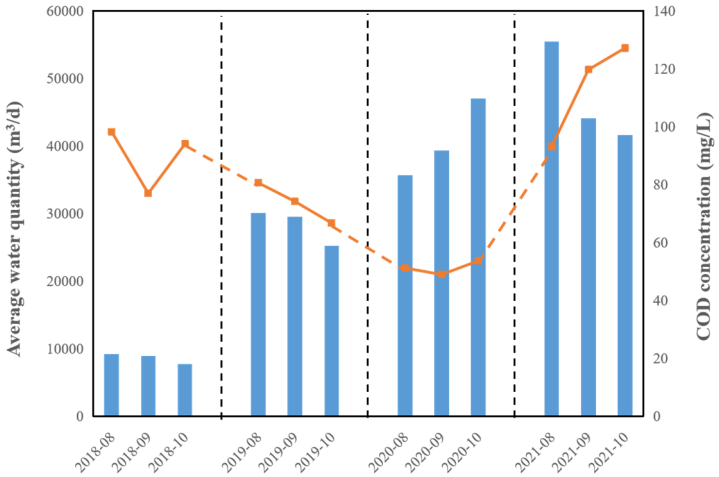

Fig.4 The average water quantity and COD concentration of the influent in the CD WWTP from November 2018 to October 2021

In order to further analyze the improvement of the sewage municipal network, the stability of the average daily water quantity and COD before and after the remediation of the drainage system was analyzed and expressed by the coefficient of variation (CV), with the higher value of CV indicating the lower stability of the data. The CV of water quantity and COD in August and September of 2018 and 2021, excluding the effect of the rainy season, were shown in Fig.5. The CV of water quantity and COD in August and September of 2021 were both lower than those in 2018, indicating that the stability of water quantity and COD of the WWTP influent in 2021 had improved and the water collection performance from the municipal drainage pipe network was enhanced significantly.

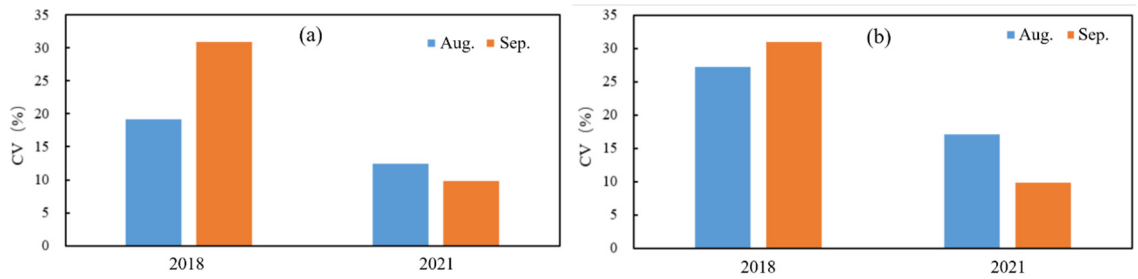

Fig.5 The CV values of water quantity and COD of WWTP influent in 2018 and 2021

The COD loads of industrial wastewater and domestic sewage were shown in Table 3. The COD loads of both industrial wastewater and domestic sewage showed a significant year-to-year increasing trend, with the COD load of industrial wastewater collected in 2021 reaching 3.2 times as high as that in 2018, and the COD load of domestic sewage in 2021 up to 1.44 times as high as that in 2018. The total COD load of raw sewage increased significantly with the implementation of the remediation work, reaching 1.62 times as high as that before the remediation. The COD load of domestic sewage accounted for over 80% of the total load, and was the main source of organic load in the wastewater collection and treatment system in the CD area.

Table 3. COD load of industrial wastewater and domestic sewage

Year	2018	2019	2020	2021
COD load of industrial wastewater (COD/d)	0.38	1.19	1.21	1.22
COD load of domestic sewage (COD/d)	3.40	4.81	4.84	4.88
Total COD load of primary wastewater (t COD/d)	3.78	6.00	6.05	6.11

The comparison of COD loads of the raw wastewater and the WWTP influent between 2018 and from August to November in 2021 was shown in Fig.6. The volume and load of the WWTP influent increased significantly, from about 10,000 m^3/d in 2018 to 42,000 m^3/d in November 2021, and the COD load increased from around 1 t COD/d to the average value of 5.05 t COD/d in the period from August to November in 2021, which showed the significant wastewater collection effectiveness. Considering the concentration of raw sewage monitored in the discharge outlets in the area, biodegradation ratio and theoretical flow of the WWTP influent on sunny and rainy days comprehensively, the theoretical value of inlet sewage volume were estimated to be 43,000 and 53,800 m^3/d on sunny and rainy days, respectively, which was compatible with the water volume value after the completion of the remediation project in 2021, with significant effect of external water intrusion control.

Before the remediation, from August to November in 2018, the COD load of the WWTP influent was maintained at about 1 t COD/d, which was still far from the COD load of raw sewage. After remediation, from August to November in 2021, the influent COD load of the wastewater plant was steadily maintained at around 5 t COD/d, and in November 2021, it was 4.85 t COD/d, which was not only a great improvement compared with 2018 improved, but also closer to the raw sewage COD load, which proved that the remediation work has achieved a good water collection effect.

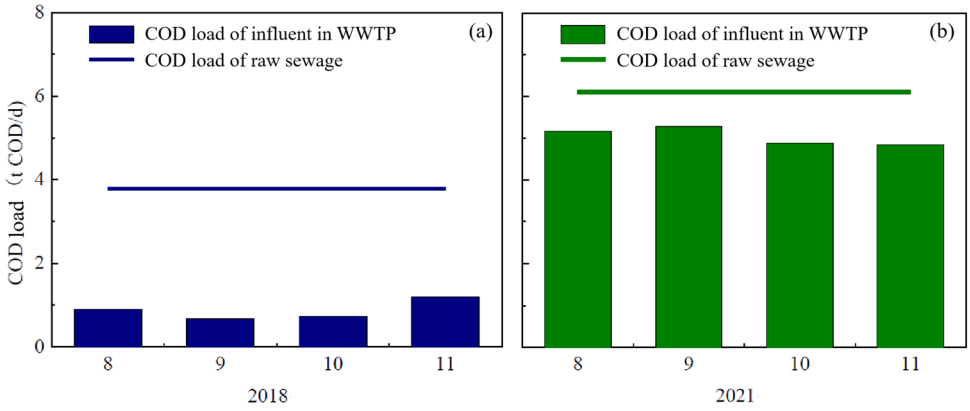

Fig.6 COD load of raw sewage and influent in WWTP in (a) 2018 and (b) 2021 in the CD area

3.4. The remediation of receiving waterbodies

The original 12 black smelly water bodies were remediated consecutively through projects started from 2018 to 2019. Long-term water quality monitoring of these water bodies showed that their water quality had met the requirements for surface water in China, and until October 2021 there was no return to the black smelly phenomenon. Moreover, the long-term management and

prevention system for the water body had been established, and the responsibility system and assessment mechanism of the river chief had been implemented to compact the main responsibility for water quality safety.

4. Conclusion

Through the advancement of the sewage system renovation project, the pipe network system in this area had been connected, the drainage function had been restored, and the sewage collection efficiency had been significantly improved. The water quality at the source and discharge outlet had been greatly improved. The sewage collection volume had been increased from 10,000 m^3/d to 42,000 m^3/d, which solved the problems of direct sewage drainage had been effectively solved, and the COD concentration of the influent has increased significantly. From September to November 2021, the influent COD reached more than 114 mg/L. The COD load of the influent of the WWTP basically matched the COD load of the primary sewage, exhibiting that the improvement performance was remarkable. The liquid level of influent of the WWTP was significantly reduced, and the pipe network blockage and full pipe operation had been completely improved, enabling normal operation at low liquid levels. The water quality of 30 rivers outside the river networks in the CD area was stable.

The sewage system renovation project in the CD area had achieved a good effect of improving quality and efficiency, providing experience and reference for improving the quality and efficiency of sewage systems in other areas of the city and other cities under the protection of the Yangtze River. It was a multi-party cooperative governance model led by the government, led by enterprises, and participated by the society, a systematic diagnosis and rectification of "source-network-factory-river", and an intelligent management decision-making platform with monitoring, analysis and control optimization as the core. As a new exploration practice in the remediation project of this area in Wuhu City, it’s necessary to further improve and popularize the engineering experience.

Acknowledgments

This research was funded by the scientific program from PowerChina Huadong Engineering Corporation Limited, grant number KY2018-SHJ-02 and KY2021-HS-02-11.

References

[1] Zhou X., Hui E., Peng S., et al. Investigation and analysis of BOD5 concentration for sewage plants and pipe network operation along the Yangtze River [J]. Water & Wastewater Engineering, 2021, 47(S1): 129-133.

[2] Li D. Study on monitoring and estimation of non-point pollution load in polder area of Yangtze River Basin [J]. Yangtze River, 2016, 47(14):26-30.

[3] Yang Q., Wang H. Regional disparity and influencing factors of water pollution emissions in the Yangtze River Economic Belt: 2004-2014 [J]. Review of Economy and Management, 2016,32(05):141-147.

[4] Shen L. Current status of water pollution in Nanjing section of Yangtze River and total discharge limit [J]. Water Resources Protection, 2013, 29(01): 55-60.

[5] Gui Z. Disease diagnosis and quality improvement of urban wastewater systems along the Yangtze River Methods and practices of efficiency enhancement [C]. Proceedings of the China Water Resources Society 2021 Annual Academic Conference, Beijing, China, 25 October 2021.

[6] Zhang H. Analysis and research on the problems of urban sewage system in Wuhu City [J]. Intelligent City, 2018, 4(21):62-63.

[7] Wu W., Wei J., Zhou C., et al. Research on the control capacity of surface source pollution of primary rainfall runoff in the central city of Wuhu [J]. Yangtze River, 2020, 51(S1):35-37+46.

[8] Weng W., Lyu Y., Kang J., et al. Exploration and practice on new models and mechanisms of urban wastewater treatment in the Yangtze River protection[J]. Water & Wastewater Engineering, 2021, 47(11): 48-53.

[9] Xie Z. Wuhu, the model of Three Gorges for the Great Protection of the Yangtze River [J]. China Three Gorges, 202(01):124-131.

[10] GB50014-2021, Standard for design of outdoor wastewater engineering in China [S].