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Yunhui Zhang *Editor*

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Editor

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Preface

This book comprises the select peer-reviewed proceedings of the 5th International Symposium on Water Pollution and Treatment (ISWPT 2022).

The book consists of articles written by researchers, practitioners, policymakers and entrepreneurs, which examines the recent advancements in water pollution and treatment.

The topics covered include water pollution and climate change (technologies for reducing greenhouse emissions for water and wastewater treatment), water resources planning and management, the water quality and protection, technologies and processes that control water pollution.

The book will be useful for beginners, researchers and professionals working in the area of water pollution management, policy and governance.

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About the Editor

Dr. Yunhui Zhang is Associated Professor of Faculty of Geosciences and Environmental Engineering at the Southwest Jiaotong University, China, since 2019. He also acts as Associate Dean of Youth Professional Committee of Sichuan Risk Science and Emergency Management Research Society. He focuses on the research of water resource, including hydrochemical analysis, quality evaluation and human health risk assessment. The statistical analysis, GIS software, machine learning and isotopic analysis are combined to address the problems of water environment. He has published plenty of high-quality papers in the SCI journals. He is also Reviewer for international journals: *Geology*, *Engineering Geology*, *Science of Total Environment*, *Economic Geology*, *Ore Geology Review*, *Environmental Science and Pollution Research*, *Applied Geochemistry*, *Energy Report*, *Geological Journal*, *Environmental Monitoring and Assessment* and *Open Geoscience*.

Water Treatment Sludge as Coagulant and Adsorbent: A Recent Review

Abu Zahrim Yaser, Afiq Iqmal Haqim, and Joshua Rechard Mijong

Abstract The use of metal coagulants in water treatment generates huge amounts of sludge. Effective management to mitigate the challenges associated with the increasing amount of WTS remains a significant concern. This paper provides an overview of the beneficial reuses of water treatment sludge (WTS) as coagulant and adsorbent. Recent advancements in coagulant and adsorbent synthesizing techniques are discussed. Recovered coagulant (RC) and adsorbent have been successfully removed several pollutants in both water and wastewater, reducing the need for new coagulant production and disposal of sludge. Coagulant and adsorbent from sludge have potential to be utilized in both water and wastewater treatment processes and, hence promoting sustainability. Sulfuric acid is commonly used to recover contaminated coagulant. Calcination, activation, or impregnation have been studied in adsorbent production. Recovered coagulant/adsorbent could be as effective as or even better than fresh coagulants/adsorbent.

Keywords Water treatment sludge · Acidification · Heavy metal · Impregnation · Circular economy

1 Introduction

The coagulation–flocculation process plays an extremely vital role in water and wastewater treatment due to its low capital cost and easy operation [5, 21]. The use of these chemicals can result in the generation of sludge as a byproduct, which contains contaminants such as organic matter, heavy metals, and pathogens. It is crucial to properly manage this sludge to prevent environmental issues and health risks to public community. However, disposal of water treatment sludge (WTS) in the environment has been restricted for several reasons, including reduction in access

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to landfill site, expensive disposal prices, high transportation costs, and regulatory constraints. These issues have led to the exploration of potential reused of the WTS in various application.

Several studies have investigated the effectiveness of WTS as a coagulant and adsorbent for various contaminants and under different treatment conditions. These studies have shown promising results, indicating that sludge can be an effective coagulant and adsorbent for a wide range of contaminants [11–12] and this paper aimed to expand the knowledge through latest publications.

2 WTS as Coagulant

Acid recovery method widely used for coagulant recovery from WTS because of its high efficiency with superior quality [6]. Among different chemicals used, sulfuric acid showed better results from both practical and cost viewpoints [19]. This can be observed in Table 1 that most study using sulfuric acid for their recovery method. There were also other types of acid used such as nitric acid [3–4] and hydrochloric acid [10].

Water treatment sludge recovery using acidification methods reported to efficiently remove pollutants in wastewater. Mora-León et al. [10] compared the effectiveness of recovered polyaluminum chloride (PAC) coagulant using sulfuric and hydrochloric acid with that of commercial PAC and ferric coagulant. The authors found that the RC showed better turbidity removal of up to 96%, and at the optimal dose of RC, 89% total suspended solid (TSS), 62% total chemical oxygen demand (tCOD), 90% total phosphorus (tP), and 97% soluble phosphorus (sP) were removed from the wastewater. However, Chakraborty et al. [2] found that fresh coagulant outperformed recovered ferric-based coagulant, with RC showing a decrease in TSS, COD, and total nitrogen (tN) removal efficiency and a corresponding 10% increase in these pollutant's concentration in the treated wastewater compared to fresh coagulant; might be due to lower ionic strength of RC.

In comparison, there are studies that directly use WTS to treat wastewater without any recovery method. Kang et al. [7] studied the use of aluminum-based WTS as a substitute for conventional chemicals in animal farm wastewater treatment and found that the removal of TSS, PO_4^{3-}, and total organic carbon (TOC) was 87.8%, 96.9%, and 62.1%, respectively. Khedher et al. [8] studied the use of WTS as a coagulant aid to improve the dissolve organic matter (DOC) in natural surface water. The researchers found that the addition of WTS at a concentration of 3 g/L can reduce the optimum dose of fresh alum sulfate required up to 50% to achieve similar removal efficiency of DOC (70%). They also found that the addition of WTS reduced the sludge produced by approximately 50% compared to when it was not.

Several studies have also utilized sludge from water treatment plants to treat raw water, employing an acidification method to recover the coagulant from the sludge before use. Hamzah et al. [4] investigated the percentage recovery of aluminum-based coagulant by nitric acid and its performance in removing turbidity from raw water.

Table 1 Recovered coagulant performance various pollutant removal

Origin of sludge	Synthesizing method	Coagulant synthesized	Type of water treated	Coagulation condition	Removal performance	References
–	Acidification sulfuric acid	Alum–based coagulant	Raw water	Dosage 25 ppm pH 2.5	Turbidity 93.28%	Ruziqna et al. [14]
Ontario, Canada	Acidification sulfuric acid	Ferric–based coagulant	CEPT effluent	Dosage 40 mg/L pH 1.5	TSS 78% COD 63% tP 42% sP 29% tN 16%	Chakraborty et al. [2]
Sungai petani, Kedah	Acidification nitric acid	Aluminum sulfate	River water	Dosage 2 mg/L pH 7	Turbidity 99.47%	Hamzah et al. [4]
Dublin, Ireland	–	Aluminum–based coagulant	Animal farm wastewater	Dosage 1588 mg/L pH 7	TSS 97.8% (PO4)-3 96.9% TOC 62.1%	Kang et al. [7]
–	Acidification sulfuric and hystochloric acid	Polyaluminum chloride	Domestic wastewater	Dosage 40 mg/L	Turbidity 96% TSS 89% TCOD 62% tP 90% sP 97%	Mora-León et al. [10]
Nagpur, India	Acidification nitric acid	Polyaluminum chloride	Raw water	Dosage 1 ml/L	Turbidity 74%	Dahasahastra et al. [3]
South Australia	–	Aluminum sulfate	River water	Dosage 3 g/L pH 6	DOC 70%	Khedher et al. [8]

The study found that at the optimal dosage, the RC can remove the raw water turbidity up to 99.47%, which is better or comparable to the fresh coagulant. Dahasahastra et al. [3] performed the same recovery method and showed that RC has potential for use as a substitute for commercial alum in water treatment. The finding was that 1 mL/L of RC has a similar removal of turbidity efficiency (74%) to 0.6 mL/L of 1% (w/v) commercial alum solution. The same result was found by Ruziqna et al. [14], where slightly higher doses of RC were required to achieve the quality of pure coagulant in removing turbidity in raw water. They found that 25 ppm of recovered coagulant achieved similar reduction of turbidity of pure alum at 93.26%.

3 WTS as Adsorbent

Although activated carbon is a popular adsorbent for water and wastewater treatment, it can be expensive due to operation and regeneration costs, as reported by Azreen and Zahrim [1]. Thus, many studies have explored the use of adsorbents synthesized from waste materials like WTS as an effective and affordable solution. Among the various synthesis methods available, physicochemical methods have emerged as the most commonly used approach due to their effectiveness and ease of synthesis; needing only heat treatment. Methods such as calcination, activation, or impregnation have been studied to modify the properties of the WTS and create adsorbents with high adsorption capacity. Studies by Shahin et al. [16] and Truong and Kim [18] have demonstrated the high recovery efficiency and good quality of adsorbents synthesized using calcination and pyrolysis. Other synthesizing method also include chemical and physicochemical activation such as impregnation of $AlCl_3$ + Starch and calcination + H_3PO_4/KOH, respectively [9, 20]. These adsorbents have been found to effectively remove heavy metals, dyes, and organic pollutants from wastewater.

WTS has shown great potential as an effective and low-cost adsorbent for various pollutants. Table 2 summarizes some recent studies on the use of WTS as an adsorbent for contaminants in various solutions. The type of pollutant influences the adsorption capacity and removal performance of the adsorbent. Shahin et al. [16] used calcined powder adsorbent synthesized through physical aerobic calcination to remove copper. They obtained a high adsorption capacity of 35 mg/g and a removal performance of 90%. Separate studies found that phosphate achieve removal performance of 86–99% [18, 20], and endocrine disruptors achieving almost 100% [19].

It is worth noting that the adsorption capacity and removal performance of WTS as an adsorbent are generally comparable to or even higher than those of other commercial adsorbents. Zeng et al. [22] compared the adsorption capacity of granular adsorbent synthesized through physical methods with chitosan solution to that of commercial activated carbon and raw sludge for arsenic removal. They found that their adsorbent is able to remove As (V) at 14.95 mg/g adsorption capacity and solves the concern on the application in fixed beds system and the recovery and reuse of adsorbents resulting in lower operation cost. Similarly, Siswoyo et al. [17] compared the adsorption capacity of alum sludge to that of commercial activated carbon for heavy metal removal. They found that the adsorption capacity of alum sludge was comparable to that of commercial activated carbon.

The use of WTS as adsorbents for heavy metal removal has gained increasing attention due to their cost-effectiveness, eco-friendliness, and mainly high removal rate. Studies have shown that the effectiveness of WTS as an adsorbent for heavy metal at optimized condition where a study conducted by Siswoyo et al. [17] showed that WTS can achieve a removal rate of up to 95% for Cd. Furthermore, the removal performance of WTS for copper (Cu) and arsenic (As) achieved 90% and 85%, respectively [17, 22].

WTS as adsorbent has the potential to be utilized in water and wastewater treatment process in removal of pollutants. Further studies on hybridization of adsorbent should also be carried out. For instance, a study by Safie and Zahrim [15], where they studied on the combination of adsorbents to produce higher adsorption capacity which includes zeolites, chitosan, and biochar, and in line with this study, WTS-based adsorbent can be hybridized to achieve higher adsorption capacity.

Table 2 WTS as adsorbent for pollutant removal

Origin of sludge	Synthesizing method	Absorbent synthesized	Adsorption condition	Adsorption capacity (mg/g)	Removal performance (%)	References
PDAM Tirta Binangun, Yogyakarta, Indonesia	Physicochemical; sludge encapsulation	Alum raw, sludge powder Powder activated sludge (H_3PO_4), PAS alginate, PAS agar	Dose: 0.4 g/L pH: 7 CT (RSP, PAS): 30 min CT (PAS-AG/AR): 6 h	RSP: 40.26 PAS: 24.95 PAS–AG: 29.86 PAS–AR: 19.81	RSP: 91 PAS: 95 PAS–AG: 90 PAS–AR: 90	Siswoyo et al. [17]
Nanjing, China	Chemical ($AlCl_3$ + Starch)	PACS granular adsorbent	pH: 4	1.78	P: 86.06	Wu et al. [20]
Zagazig, Egypt	Physical (Aerobic calcination, 500 °C)	Calcined powder adsorbent	pH: 6.6 T: 80 °C	35.0	Cu^{2+}: 90	Shahin et al. [16]
Songbei, Harbin, China	Physical (mixture with chitosan solution)	Granular adsorbent	Dose: 1.8 g/L pH: 6.5	14.95	Ar(V): 85	Zeng et al. [22]
Brazil	Physicochemical (550 °C); (H_3PO_4 and KOH)	PAC modified sludge (PMS) Phosphoric acid sludge (PAS) Potassium hydroxide sludge (PHS)	Dose: 0.5 g/L pH: 5.5	Estradiol (E2): PMS: 8.748, PAS: 16.42, PHS: 17.903 Ethinylestradiol (EE2): PMS: 14.557, PAS: 4.233, PHS: 0.438	Estradiol (E2): PMS: 99.75, PAS: 99.96, PHS: 99.99 Ethinylestradiol (EE2): PMS: 99.99, PAS: 99.80, PHS: 99.75	Martins et al. [9]
Chuncheon City, Korea	Physical (Pyrolysis, 700 °C)	Pyrolyzed alum sludge	pH: 4–6	34.53	Phosphate: 99.0	Truong and Kim [18]
Ho Chi Minh City, Vietnam	Chemical (Precipitation)	DWS500@ZrO_2 ($Fe_2(SO_4)_3.nH_2O$	pH: 2	30.99	NO_3^-: 98.97	Phan Quang et al. [13]

4 Conclusion

The use of RC and sludge adsorbent shows the potential to provide a cost-effective and sustainable solution for water treatment. The acid sulfuric recovery process is widely used due to its high recovery efficiency and good quality. Most studies show that recovered coagulant is as effective as or even better than commercial coagulants, but at a higher dose. The recovered coagulants have been applied in removing pollutants in water treatment, especially in treating wastewater, where it efficiently removes contaminants such as turbidity, TSS, tP, and sP up to 90%. Physical methods have emerged as the most commonly used approach to synthesize adsorbents with high adsorption capacity. Most studies also show that the removal pollutant in wastewater using WTS adsorbent up to more than 90%. Further research should explore the economic potential of these materials in reducing the total operational cost of water and wastewater treatment processes. Multiple-objective optimization on the basis of ratio analysis could be employed to discretely measure multiple response characteristics of various coagulant and adsorbent as a function of assessment value.

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Treatment of Oil-Polluted Seawater by Modified Biochar Immobilized with Petroleum Degrading Bacteria

Qingsheng Li, Kaimei Wang, Qianqian Wu, Yinglu Tao, Kerui Xie, Jincheng Li, and Wenxiang Xia

Abstract The pine sawdust biochar (BC) prepared by pyrolysis at 400 °C for 2 h was modified with different amounts of hydrochloric acid, among which 5H-BC modified by 5 mol·L^{-1} hydrochloric acid had the best oil adsorption efficiency in seawater. Petroleum degrading bacteria (PDB) were immobilized on 5H-BC, and the optimum conditions for immobilization were: inoculating 10% (v/v) PDB suspension, and fixing for 4 h at the speed of 180 r·min^{-1} on the shaking table. 5H-BC and 5H-BC-PDB were added to the simulated oil-polluted seawater. It was found that 5H-BC could quickly transfer the oil in seawater to BC phase through adsorption, but the total oil removal efficiency of 5H-BC-PDB was 23.5% higher than that of 5H-BC. High-throughput analysis of BC phase showed that 5H-BC-PDB contained more *Acinetobacter* and *Pseudomonas*, which indicated that BC immobilized with PDB was not only beneficial to the emulsification of oil, but also to the biodegradation of residual PAHs.

Keywords Marine oil spill · Biochar · Petroleum degrading bacteria · Immobilization · Adsorption

1 Introduction

Oil spill accidents often occur during offshore oil transportation. Adsorption of spilled oil is easy to be carried out, and biochar (BC) derived from natural carbonaceous material is widely concerned in water treatment because of its high oil absorption capacity and low price [1]. BC is a kind of carbon-rich material obtained by pyrolysis of biomass in an oxygen-limited environment at a high temperature with

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large specific surface area. The oil absorption capacity of BC prepared from maple can reach 3.6–6.3 g·g^{-1} [2], and this value increased a lot when wheat straw BC was modified with the mixture of HCl and HCl-HF [3]. However, the adsorption of oil by BC would not eliminate oil, so further treatment process is needed.

The natural petroleum degrading bacteria (PDB) in the ocean will proliferate spontaneously and rapidly after an oil spill accident, but the PDB in the seawater has low oil degradation efficiency. Pore networks in BC can not only wrap oil but also provide a favorable living environment for PDB [4]. After bacteria were immobilized on BC, the removal rates of phenanthrene and pyrene in water increased by 46% and 77%, respectively, compared with free bacteria [5]. When PDB was fixed on BC modified by $MgCl_2$, the degradation rates of total petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) in oil-contaminated soil improved greatly [6].

Previous studies mainly focus on BC and BC immobilized bacteria to remove oil in water and soil, but few studies have been carried on to remove petroleum in seawater by modified BC immobilized with PDB. In this study, BC was modified by hydrochloric acid, and the optimal immobilization conditions were determined. Comparisons were made between BC and BC immobilized with PDB (BC-PDB) in removing petroleum from seawater, and the bacterial community in BC phase was analyzed.

2 Materials and Methods

2.1 Materials

Artificial seawater was prepared from sea salt with pH 7.5 and salinity of 33%; natural seawater taken from No.6 wharf of Qingdao Dagang was used to enrich PDB; 100 mL sterilized artificial seawater, 0.1 g petroleum and 10 mL PDB bacteria suspension were added into a 250 mL conical flask to prepare simulated oil-polluted seawater. The petroleum was taken from Qingdao Petrochemical Plant, and its density, kinematic viscosity and API value were 0.856 g cm^{-3}, 25.57 mm^2 s^{-1} and 33.8, respectively.

2.2 Preparation and Modification of BC

The dried pine sawdust was heated to 400 °C and was pyrolyzed for 2 h to prepare BC, and then it was modified with hydrochloric acid with the concentrations of 1, 5, 10 and 12 mol L^{-1}, respectively. Soaked in the ratio of BC: HCl = 1: 40 for 12 h, BC was washed with deionized water until the pH was constant. The number represents the concentration of hydrochloric acid, and H represents the modification

Table 1 Orthogonal experimental design of fixed PDB with modified BC

Level	Factor A Inoculation amount (%)	Factor B Fixed time (h)	Factor C Rotation speed (r min^{-1})
1	6	0.5	120
2	8	1	160
3	10	4	180
4	12	5	200

of hydrochloric acid. For example, 5H-BC represents BC modified with 5 mol L^{-1} hydrochloric acid.

2.3 Experimental Design

Oil Adsorption Capacity. 100 mL of sterilized artificial seawater, 0.1 g of petroleum, and 0.05 g of BC modified with hydrochloric acid were added to the conical flask. All flasks were put on a shaking table at 25 °C for 12 h. The oil adsorption performance of BC was compared, and three parallel samples were set in each group.

Preparation of PDB suspension. 100 mL artificial seawater and 2 mL trace element culture solution were added into the sterilized conical flask, and then 0.1 g oil and 10 mL oil-polluted seawater were added. Domestication was completed after 4 cycles, and PDB suspension with OD600 of 0.6 was prepared for later use.

Optimization of immobilization process. 50 mL seawater medium and 0.05 g 5H-BC were added to the sterilized conical flask for adsorption experiments. The orthogonal experimental design of three factors is given in Table 1.

High-throughput analysis. The simulated oil-polluted seawater was added into the conical flask, and then 0.05 g 5H-BC and 5H-BC-PDB were added, respectively. The conical flask was oscillated at 25 °C for 15 days on a shaking table with a rotating speed of 120 r min^{-1}. After the experiment, the amount of oil in BC phase was determined, the DNA of BC phase was extracted, and the bacterial community composition was determined by high-throughput method.

2.4 Analysis and Test Methods

Total petroleum hydrocarbon was determined by infrared oil meter (JLBG-125) using tetrachloroethylene (analytically pure) as extracting agent [7]. Grounded BC was evenly dispersed on the carbon film conductive tape and then sprayed with gold, and the surface morphology was observed by scanning electron microscope (FEI quanta

FEG250). Oxygen-containing functional groups on the surface of BC were quantitatively analyzed by Boehm titration [8]; DNA from 5H-BC and 5H-BC-PDB was extracted, and then PCR amplification, construction of Miseq library, and Illumina sequencing were carried out [9] by Shanghai Meiji Biomedical Technology Co., Ltd.

2.5 Calculation Method

Oil adsorption capacity of BC in seawater is calculated as:

$$q_t = \frac{(C_0 - C_t)V}{m} \tag{1}$$

The apparent oil removal efficiency is calculated as:

$$R(\%) = \frac{C_0 - C_t}{C_0} \times 100\% \tag{2}$$

Total oil removal efficiency of BC is calculated as:

$$\eta = \frac{C_0 \cdot V - C_t \cdot V_t - M}{C_0 \cdot V} \times 100\% \tag{3}$$

C_0 and C_t are the oil concentration in seawater at starting time and time T, respectively, mg L^{-1}; V and V_t are the volume of oil-polluted seawater at the initial time and time T, respectively, L; m is the amount of oil trapped in BC, mg.

3 Results and Discussion

3.1 Oil Adsorption Characteristics of BC Modified with Hydrochloric Acid

The adsorption performance of BC modified with different concentrations of hydrochloric acid for petroleum in seawater is shown in Fig. 1.

It is indicated from Fig. 1 that 5H-BC with a hydrochloric acid concentration of 5 mol L^{-1} had the best oil absorption performance (up to 1.96 g g^{-1}). SEM of BC (Fig. 2) shows that the interior of BC before modification was full of tubular channel with obvious micropores, but they were destroyed after modification for the addition of hydrochloric acid oxidation made the channel collapse. BET results showed that the specific surface area and total pore volume after modification were reduced from 53.03m^2 g^{-1} to 48.277m^2 g^{-1} and 0.0430 cm^3 g^{-1} to 0.0370cm^3 g^{-1}, which

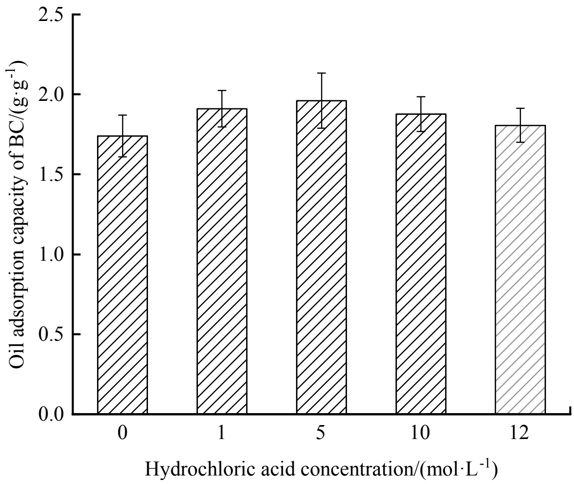


Fig. 1 Oil adsorption properties of BC modified with hydrochloric acid

is consistent with the research results of Wang et al. [10]. The oxygen-containing functional groups on the surface of BC were measured as given in Table 2.

It was found that the increase of hydrophobic groups (lactone groups) in 5H-BC was much larger than that of hydrophilic groups (carboxyl groups and phenolic hydroxyl groups), and the enhancement of BC hydrophobicity was beneficial to the adsorption of petroleum [11].

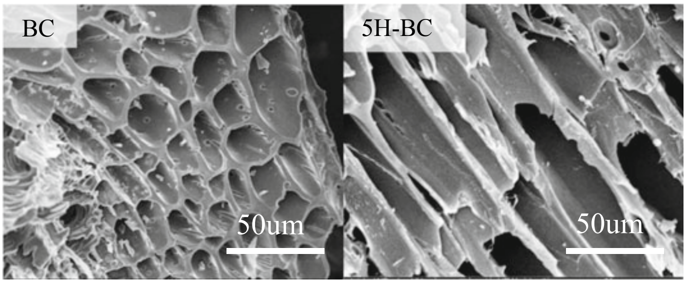


Fig. 2 SEM images of BC and 5H-BC

Table 2 Surface functional group content of BC before and after modification

Sample	Carboxyl group (mmol g^{-1})	Hydroxyl group (mmol g^{-1})	Lactone group (mmol g^{-1})
BC	1.208	0.153	0.265
5H-BC	1.481	0.106	0.634

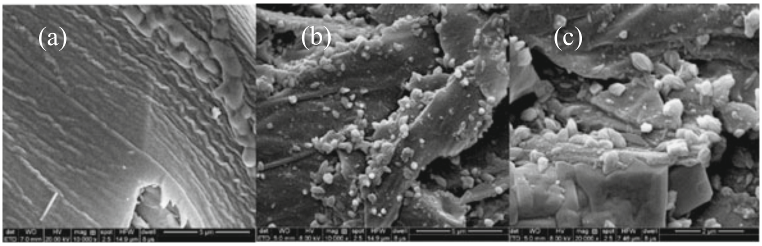


Fig. 3 Morphological characteristics of 5H-BC before and after immobilization (**a** 5H-BC; **b**, **c** 5H-BC-PDB)

3.2 Optimum Conditions for Fixing PDB with 5H-BC

Inoculation amount, rotating speed of shaking table and immobilization time are the main factors affecting BC immobilization of PDB. On the basis of single factor experiment, the orthogonal experiment was conducted at different levels of three factors. The range value R of the three factors from big to small is the shaking speed, fixed time and inoculum amount, so the shaking speed is the biggest factor affecting the immobilization effect of BC [12].

Comparing the values of K, the best conditions for bacteria immobilization are as follows: inoculum amount 10% (v/v), shaking table rotation speed 180 r·min^{-1} and fixation for 4 h. Under optimal conditions, the bacterial fixation efficiency is 65.33%.

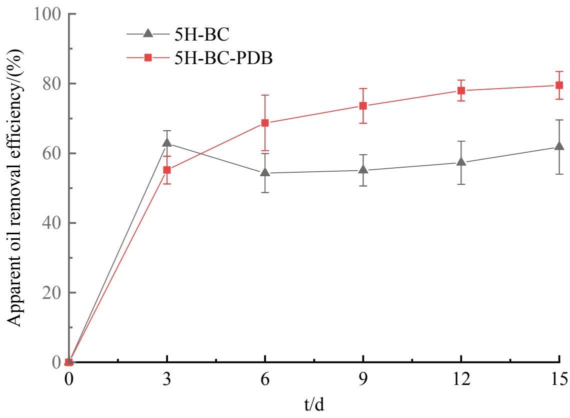
After fixing PDB with the above method, the SEM images of 5H-BC (Fig. 3a) and 5H-BC-PDB (Fig. 3b, c) were compared. It was found that there were a lot of bacteria on the surface (Fig. 3b) and internal pores (Fig. 3c) of 5H-BC-PDB, which proved that PDB could be fixed on 5H-BC well.

3.3 Removal of Petroleum from Seawater by 5H-BC and 5H-BC-PDB

In the simulated oil-polluted seawater, 5H-BC and 5H-BC-PDB were added, respectively, and the concentration of oil in seawater was measured without considering the transfer of oil to BC phase. The change in apparent removal efficiency of oil with time is shown in Fig. 4.

The apparent removal efficiency of oil in seawater by 5H-BC at the initial stage of the experiment is higher than that of 5H-BC-PDB, and it may lie in the occupation of adsorption sites by immobilized bacteria. Afterward, the apparent oil removal efficiency of 5H-BC-PDB showed a steady upward trend and exceeded 5H-BC quickly; indicating that oil in seawater was continuously adsorbed and degraded by immobilized PDB [13]. However, the apparent removal efficiency of 5H-BC decreased first

Fig. 4 Apparent oil removal efficiency by 5H-BC and 5H-BC-PDB



and then increased slowly. This is because part of the oil adsorbed to BC was released into seawater again, and then gradually removed by PDB existing in seawater.

After 15 days of the experiment, oil distributed in water and BC phase in two experimental groups was extracted respectively, and the total removal efficiency of oil in each group was calculated. It was found that the efficiency of 5H-BC-PDB was 23.5% higher than that in 5H-BC group, which indicated that BC immobilized with bacteria could effectively degrade oil both in seawater and biochar [14].

Results from high-throughput analysis of bacterial communities in BC phase of 5H-BC and 5H-BC-PDB indicate the dominant bacterial genera include *Altererythrobacter, Alternaria, Pseudomonas and Alcanivorax*, etc., as shown in Fig. 5. *Acinetobacter* can secrete surface active components, which can promote the emulsification of petroleum hydrocarbons. At the same time, it can also oxidize macromolecular petroleum hydrocarbons into small molecular substances [15]. The proportion of *Acinetobacter* in 5H-BC-PDB was higher than that in 5H-BC, indicating that 5H-BC-PDB could promote the emulsification of petroleum hydrocarbons, which is more conducive to the subsequent degradation of petroleum hydrocarbons. In addition, the proportion of *Pseudomonas* in 5H-BC-PDB was significantly higher than that in the 5H-BC group. *Pseudomonas* is a PAHs degrading bacterium [12], while PAHs in marine oil spill accidents are very difficult to degrade and easy to remain in the environment. The results showed that after BC was used to immobilize PDB, more *Pseudomonas* could be found in the pores of biochar. Even if biochar is deposited on the seabed, *Pseudomonas* in it can continuously degrade the residual PAHs, which is expected to reduce the persistent pollution threat caused by PAHs deposition.

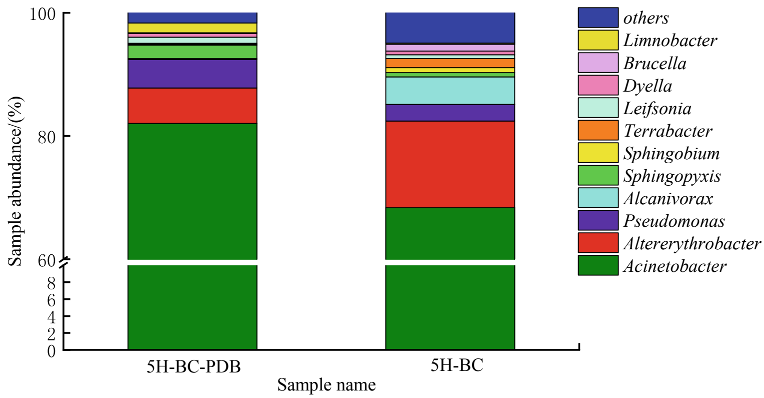


Fig. 5 Classification of bacterial communities at genus level in 5H-BC-PDB and 5H-BC

4 Conclusion

5H-BC modified with 5 mol L^{-1} hydrochloric acid has a strong adsorption capacity for petroleum in seawater. The optimum conditions of BC immobilization of petroleum hydrocarbon-degrading bacteria are as follows: 5H-BC as carrier, inoculation of 10% bacterial suspension and shaking table rotation speed of 180 r min^{-1} for 4 h. The total removal efficiency of petroleum in seawater by 5H-BC-PDB is 23.5% higher than that by 5H-BC. BC phase in 5H-BC-PDB contains more *Acinetobacter* and *Pseudomonas*, which is not only beneficial to the emulsification of petroleum, but also beneficial to the biodegradation of residual PAHs.

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Effect of Percolation Water Quality on Physical and Mechanical Characteristics of Marls

Sabrina Haddad, Bachir Melbouci, and Sonia Outayeb

Abstract The objective of this work is to study the evolution of marls from the Tigzirt landslide, which represents one of the active and spectacular landslides that the Wilaya of Tizi-Ouzou (Algeria) has experienced in recent years; under the effect of environmental conditions and the quality of the percolating water (polluted and unpolluted water). The alteration of rocks subjected to chemical attacks or wet/dry cycles can have a negative impact on the stability of slopes. An experimental study composed of plasticity tests (Atterberg limits), shear tests and odometer tests and was carried out on materials having undergone wetting–drying cycles initially soaked in water containing nitrates and sulfates. The results of the shear tests showed a decrease in the mechanical characteristics of the marl in contact with water containing the salts compared to those of the marl only. The analyses of the odometer tests show that the salts tend to nullify the swelling pressure.

Keywords Marl · Weathering · Nitrate · Sulfate · Strength

1 Introduction

Marls are materials that age in the sense that their physical–mechanical or chemical properties evolve over time, and progressively degrade under the direct influence of the constraints to which they are subjected, and under the influence of the environment in which they are found.

Soil and rock weathering is a complex and multifactorial process [1, 2]. In the geotechnical sense, weathering leads to the degradation of the physical and mechanical properties of rocks, under the action of atmospheric agents and environmental conditions [3–5]. These processes generally decrease the mechanical strength of soils and rocks [6–13]. Weathering also depends on the pH and composition of the water [14]. Indeed, weathering can also be due to human action, such as groundwater

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pollution, polluted air and rain (acid rain), leaking pipes or buried sewage systems and pavement leaching [15, 16]. This weathering process plays an important role in the transfer of many chemical elements such as salts, which play an important role in water–rock interactions. High inputs of aggressive components, such as CO_2, mineral acids (HCl, HNO_3, etc.) or organic acids, increase the rate of weathering. The salts crystallize in the porous structures of the rock, which generates stresses in the pores. According to several authors [17–19], these stresses can exceed the mechanical strength of the rock. Therefore, water circulations in the soil primarily govern the rate of weathering of materials and represent the primary trigger for ground motion [20].

The main problem of this work is the current environmental concerns (pollution), which continue to raise new questions about the evolution of the risks of this landslide. The aim of this work is to analyze the effect of some salts (nitrates and sulfates) on the physical and mechanical parameters of the Tigzirt slope.

2 The Morphology and Structure of the Tigzirt Landslide

The city of Tigzirt is founded in marly grounds surmounted by the recent fissured quaternary deposits. The motion is well localized at average depths of 10–30 m, which evolves slowly over time toward more pronounced depths to the north (the sea). Some signs are visible on the surface (cracks in the walls of houses, bumps in the fields, etc.). These signs make it possible to define the active character of the motion. However, the appearance of the foot of the slope has been largely reshaped by the land motion and the coastal erosion phenomenon. This landslide is explained by a combination of permanent predisposing factors (nature and structure of geological formations, slope, etc.), and trigger factors such as rain, leaking pipes, seismic shocks or polluted groundwater, depending on these fluctuations linked to weather conditions, or sometimes to human actions.

Figure 1 shows disorders caused by the Tigzirt landslide at the level of buildings.

Fig. 1 Disorders caused by the Tigzirt landslide at the level of buildings

The slip surface in this region develops at the weathered fringe of the marl bedrock that has the weakest mechanical characteristics [21]. It is situated at a depth of more than 30 m and has implemented several compartmentalized subsidence mechanisms. It is the gravitational displacement of the clayey scree layer of about 30 m thickness, in relation to the healthy marl bedrock, along a flat sliding surface.

In Tigzirt, three unstable areas have been identified: the central area of Tigzirt stretching from the hollow of Feraoun beach in the east to the ravine of the Azal stream in the west, and two other areas East (Agouni Rehal) and West (right of the port road). In the central area, the east part is subject to coastal erosion. The west part is completely destabilized between the RN24 and the coast with a stronger activity at the level of the place called "Les Bungalows" [22, 23]. In the western part, the steep slope of the RN24 presents two instabilities: a diffuse instability sustained by stormwater discharges and a chronic instability maintained by uncontrolled stormwater instability. In the eastern part, the subsidence of the RN24 in two places can continue and affect the houses. These instabilities can be explained by the lack of natural water systems and the absence of any drainage system, which favors the stagnation and infiltration of different waters (polluted or unpolluted) at the level of the slopes.

3 Materials and Methods

3.1 Geotechnical Characteristics of the Materials

The local geology of the site affected by the ground motion is studied by exploiting the results of eight core drillings carried out in the area in 2002 by the LNHC laboratory and in 2009 (five drillings) by the GEOMICA laboratory. The results of the investigations carried out show the existence in this area of two main soil layers and a reworked zone about 2 m thick (the interface between the clayey sandstone scree and the gray marl). The bedrock consists of grayish laminated marl with a $CaCO_3$ content between 43 and 51% [24]. In this study, the evolving marls of the Tigzirt site region are studied according to their degree of alteration. We try to evaluate the role of the presence of certain salts in water in the phenomenon of alteration of the marl, and its consequences on the landslides of the region.

The main results of the identification tests are presented in Table 1 for the marls of the three landslide zones.

Table 1 Identification characteristics of the marl material at the three slide sites [24, 25]

	γ_d (kN/m^3)	PL (%)	LL (%)	PI	MBV
Altered marl	13.8–15.8	20.0–35.0	30.0–63.0	10.0–18.0	2.6–4.2
Intact marl	19.9–23.4	25.0–31.0	49.0–59.0	23.0–29.0	

Table 2 Atterberg limits results for the central zone marl

Soil	LL (%)	PL (%)	PI	CI
Marl	35.17	21.54	13.63	2.30

In our case, we were interested in the study of the central zone of Tigzirt. The results of the identification tests on this marl are presented in Table 2.

Table 2 gives the physical characteristics of the materials measured in the laboratory. These identifications classify this soil as low plastic clay (Ap) based on the USCS-LCPC classification.

3.2 Experimental Program

An experimental study composed of plasticity tests (Atterberg limits), direct shear tests and odometer tests was carried out in the laboratory on materials having been subjected to six cycles of wetting–drying (humidification for 8 h and drying for 16 h) once in a water containing nitrates, and another time in a water containing sulfates. The work is oriented mainly on the study of the behavior of Tigzirt marl under the effect of alteration by salts and the acceleration of the deformation of this material. The results are compared to those of the material alone.

4 Results

4.1 Influence of Salts on the Atterberg Limits of the Tigzirt Marls

Comparison of the marls containing nitrate and sulfate with the unpolluted material shows that the Atterberg limits decrease for marls mixed with salts. The decrease in these limits, which are used to determine the plasticity of the soil, can be explained by the fact that the salts break the links between the minerals and even between the other components of the marl material. The clay minerals present in marl are reactive components with water and are very sensitive to variations in soil's pH, which decreases plasticity.

Table 3 gives a comparison of soil condition and plasticity results for soil alone and with salt additions.

Table 3 Comparison of soil condition and plasticity results for soil alone and with salt additions

Soil	Consistency		Casagrande diagram		
	CI	Soil condition	LL (%)	PI	Soil plasticity
Marl	2.30	Solid	35.17	13.63	Medium plasticity
Marl + sulfate	1.79	Solid	34.62	17.22	Medium plasticity
Marl + nitrate	1.77	Solid	34.70	17.45	Medium plasticity

4.2 Direct Shear Test

Direct shear tests are performed on at least three cylindrically shaped soil samples subjected to three different vertical stresses. The specimens are subjected to direct shear tests at the same speed (in undrained consolidated conditions) under 100, 200 and 300 kPa normal stresses. Direct shear tests were used to evaluate the strength parameters of marl soils (through friction angle φ and cohesion c after wetting–drying cycles in polluted water.

Figure 2 shows the stress–strain curves before and after salt degradation for a normal stress of 200 kPa. The highest shear stress is obtained for the marl alone. The stress–strain curve for marl + nitrates did not show a peak of failure, but a plateau of resistance appeared from a particular displacement. The marl alone and the marl mixed with sulfates show a fragile behavior, a peak of rupture appeared and the peak is less accentuated for the sulfated marl.

The interpretation of the tests with the Coulomb criterion results in the shear characteristics, which are reported in Table 4. The intact marl soil had a cohesion equal to 250 kPa combined with an average friction angle of about 42°. Concerning the samples soaked in water polluted with salts, it appears that the cohesions and the internal friction angles decrease. Cohesion decreased from 250 to 151 kPa with nitrates, while sulfates induced a more significant decrease to 108 kPa. Sulfates and nitrates break the bonds between the marl particles, which leads to a decrease in cohesion, and tend to make the marl material more friable but water polluted with sulfate and nitrate prevents or reduces the friction between these marl particles and makes this material less resistant, which explains the decrease in these characteristics. This confirms the thesis of authors Cafaro and Cotecchia (2001) who show that

Fig. 2 Stress–strain curves of marl subjected to sulfates and nitrates under a normal stress of 200 kPa

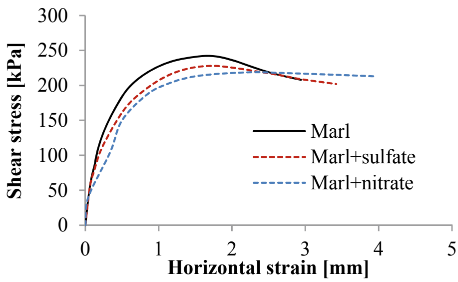

Table 4 Shear characteristics of the marls

	Marl	Marl + sulfate	Marl + nitrate
Cohesion (kPa)	250.0	108.0	151.0
Internal friction angle (°)	42.0	33.2	21.2

weathering is interpreted as a degradation of inter-particle bonds and results in a reduction in soil stiffness and strength.

In addition, geological processes of different nature are at the origin of a reduction of the effects of structure, by damage of the bonds and rearrangement of the joining of the particles under the action of deformations or by the erasure of the bonds under the effect of physicochemical transformations of alteration. On the one hand, the alteration processes highlighted are mainly oxidation and decarbonation (dissolution of carbonates contributing to make the marl fragmentable) which are accompanied by a reduction in the volume of the material. On the other hand, the ionic strength of the pore water influences the chemical equilibrium between the marl and the solution, and when the water is not drained, it reduces the effective stresses and thus reduces the shear strength and the strength of the rocky mass.

4.3 Odometer Test

The specimens are loaded under 25–3200 kPa at loading, and under 1600–25 kPa at unloading of total axial stress, respectively. The evolution of settlement is recorded over time. Depending on the nature of the marl tested, whether it was subjected itself or with the different pollutants (nitrate and sulfate), this operation can cause different behavior, settlements on loading or swellings on unloading. The main results obtained during the odometer test campaign are shown in Fig. 3 and the characteristics are grouped in Table 5.

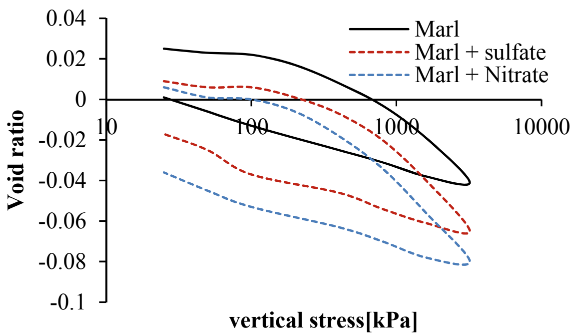

Fig. 3 Odometry curves obtained for marl itself, with nitrate and with sulfate

Table 5 Results of the swelling study with odometer loading for marly material and marly material acidified by sulfates and nitrates

Soil	Marl	Marl + sulfate	Marl + nitrate
Water content	w_{opt}	w_{opt}	w_{opt}
Pre-consolidation pressure σ'_p (kPa)	480.0	475.0	410.0
Compression index C_c	0.06	0.07	0.15
Swelling index C_s	0.02	0.02	0.02
Swelling pressure P_s (kPa)	690.0	210.0	100.0

Figure 3 shows that the initial void indices of the polluted marl are lower than that of the marl alone. The latter tends to pack less than the polluted marl, and the nitrate marl packs more than the sulfate marl.

The analysis of the results in Table 5 shows that the sulfates and nitrates used in the marl tend to significantly reduce the swelling pressure. Therefore, these salts certainly play an important role in the mineralogy of marl soil. Indeed, marl minerals are reactive components with water and very sensitive to the variations of the pH of the soil, which decreases the plasticity of marls as well as their swelling pressure.

The main constituent of marl which is limestone has an important reaction with water and acids. In an acidic environment, $CaCO_3$ is converted into calcium bicarbonate $Ca(HCO_3)_2$ under the effect of carbonic acid H_2CO_3. The chemical reactions occurring between the minerals of the marl material destroy the bonds between the components of the marl, which induces a reduction of the swelling behavior of this material. The swelling pressure of the marl alone is greater than that of the mixtures of marl with the various acids, which then explains the effect of the acids on reducing the swelling pressure.

These results confirm that the infiltration of rainwater and wastewater in the cracks of the marl bedrock destroys the links that existed between the various minerals, and the effect of interstitial overpressures gradually breaks the marl material until the rupture.

5 Conclusion

In Tigzirt landslide area, the infiltration and percolation of polluted water along fractures probably act as a lubricant, to promote the initiation or reactivation of landslide, and such effect was enhanced by a specific soil degradation under wet/dry cycles, combined with the presence of salts in water. The behavior of pure and polluted marl materials has highlighted the effect of the instability of the Tigzirt slope. Indeed, the high permeability of the surface layer, the absence or the dysfunction of surface drainage systems favors the continuous supply of polluted water to the storage area. High cumulative effective precipitation over long periods causes a progressive increase in pore pressures to which the marl reacts, by deforming according to its dilatant behavior. This behavior was highlighted in the laboratory by shear tests. Indeed, the presence of sulfates and nitrates in the marl material reduces considerably their mechanical characteristics. This can be explained simply by the attack of chemical elements. Indeed, the arrival of the polluted fluid in the marl samples triggers chemical reactions. The importance of waste management of sanitation activities, urban and industrial waste, which are among the main sources of pollution in the land, is necessary to reduce the impact of these discharges into the environment.

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Analysis and Suggestion of Water Source Safety Guarantee of Danjiangkou Reservoir

Jian Wang, Haiyang Jin, Li Wang, and Chan Yu

Abstract Danjiangkou Reservoir is the water source for the Middle Route of South-to-North Water Transfer Project, as well as an important drinking water source of Hubei Province. In 2021, Danjiangkou Reservoir has a good safety guarantee situation on the whole. However, there exists some problems such as imperfect water source protection and management mechanism, hidden danger of water quality and inadequate funding investment mechanism. In specific, the hidden dangers of water quality include imperfect isolation facilities, water resource management information system, environmental pollution prevention and control measures and difficult management of water-level fluctuation zone. In this paper, suggestions for water source safety guarantee construction of Danjiangkou Reservoir future are proposed: (1) improve the supervision and management mechanism and the protection and management mechanism of drinking water source, strictly enforce the daily management, supervision and inspection of the water source; (2) strengthen the supervision of water quality risks, carry out the construction of ecological isolation zones of water sources, improve the management system of water-level-fall zones and strengthen the construction of information systems and traffic protection facilities; (3) establish a long-term and stable fund guarantee mechanism, a sound investment and financing system, a special transfer payment mechanism for water source of the middle route of the South-to-North Water Diversion Project and a green development fund for Danjiangkou Reservoir water source area; (4) promote the construction of emergency standby water sources.

Keywords Danjiangkou Reservoir · Drinking water source area · Safety guarantee

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1 Introduction

Strengthening the protection of drinking water sources and effectively ensuring water safety for urban and rural residents is an important task to maintain people's health, life safety and social stability [1]. In 2012, The State Council issued the "Opinions on Implementing the Strictest Water Resources Management System" (Guofa [2012] No. 3). It has made provisions on strengthening the protection of drinking water sources, requiring the people's governments of all provinces, autonomous regions and municipalities directly under the Central Government to delimit drinking water source protection areas in accordance with the law. In 2018, Ministry of Water Resources issued the "about further clarify the important water source of drinking water security standard construction annual assessment work related requirements of the notice letter [2018] No. 204". The document clearly stipulates that the responsible unit must carry out construction to ensure the safety of major drinking water sources to meet standards and clearly stipulates that responsible departments need to carry out construction, inspection and evaluation to ensure the safety standards of major drinking water sources and establish a mechanism to report problems and rectify and cancel their licenses.

Danjiangkou Reservoir is the water source of the middle route of the South-to-North Water Diversion Project, as well as an important source of drinking water in Hubei Province. The degree of security of water sources is directly related to the water safety and health of the people in the water-receiving areas and determines the success or failure of water transfer projects [2]. Based on the previous field survey and relevant data, this paper analyzed and sorted out the current situation and existing problems of security guarantee of Danjiangkou Reservoir water source in 2021, and put forward suggestions for the next step of security guarantee construction of Danjiangkou Reservoir water source referring to the National Guidelines for the Assessment of Security Guarantee of Major Drinking Water Sources (trial). In the end, the research results were expected to provide technical support for the management department to carry out the construction evaluation of the safety guarantee standard of the water source area of Danjiangkou Reservoir and strengthen the water source protection.

2 Basic Situation of Water Source

Danjiangkou Reservoir is the water source of the middle route of the South-to-North Water Diversion Project, as well as a strategic water source in my country. The Danjiangkou Reservoir is located in the upper reaches of the Han River and distributed between Danjiangkou City, Hubei Province (the reservoir area also involves Yun County, Zhangwan District, Yunxi County, Hubei Province, etc.) and Xichuan County, Nanyang City, Henan Province. It is consisted of two major parts, the Hanjiang Reservoir Area in Hubei and the Danjiang Reservoir Area in Henan, and the waters span Hubei and Henan provinces. After heightening the Danjiangkou

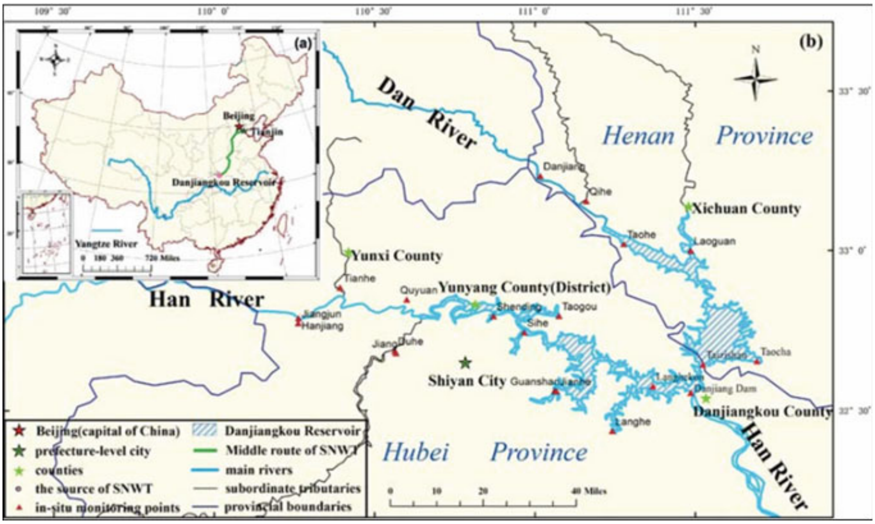

Fig. 1 **a** Overview of the middle route of the SNWT Project and **b** Location of the Danjiangkou Reservoir catchment area, the sampling stations, and the main rivers and cities

dam, the normal water level in front of the dam was increased from 157 to 170 m, the reservoir area from 745 km^2 to 1050 km^2. And the corresponding storage capacity of danjiangkou reservoir was 27.205 billion m^3, the backwater length 194 km in the Han River and 93 km in the Danjiang River after heightening. The location of the reservoir is shown in Fig. 1 [3].

As the water source of the middle route of the South-to-North Water Diversion Project, Danjiangkou Reservoir undertook the task of supplying water to more than 20 large and medium-sized cities in 4 provinces and cities including Henan, Hebei, Beijing and Tianjin, also taking into account both agricultural and ecological water use [4]. The first phase of the water source area of the middle route of the South-to-North Water Diversion Project was planned to divert an average of 9.5 billion m^3 of water annually, and the annual water diversion volume was planned to reach 13 billion m^3 in the medium and long term. It was proposed in the "South-to-North Water Diversion Project Master Plan" that the average planned water supply for the Middle Route Project for many years was 8.54 billion m^3. The diversion canal of the middle line project is located in Taocha, Jiuzhong Town, Xichuan County, Nanyang City, Henan Province. The middle line project was officially opened to water on December 12, 2014. As of 8:00 on July 22, 2022, the cumulative water transfer volume reached 50 billion m^3, directly benefiting about 85 million people.

Danjiangkou Reservoir is an important source of drinking water in Hubei Province and also the main source of water in Shiyan City. On January 30, 2021, Hubei Water Conservancy "No. 1 Project"—Water Resources Allocation Project (Phase 1) in Northern Hubei Province achieved water supply across the board. The project took Danjiangkou Reservoir as the water source [5] and the planned average annual water diversion volume was 770 million m^3. The project started from the Qingquangou Tunnel of Danjiangkou Reservoir, and the whole line will diverted water by gravity to supply water to 4.82 million people in 3 cities and 7 counties along the line in the northern Hubei area. The beneficiary area covered 10,200 km^2 in northern Hubei.

3 Analysis of Current Security of Water Source

3.1 Analysis Method

Investigated the current situation of water quantity, quality, monitoring and management of Danjiangkou Reservoir and analyzed the current situation and existing problems of water quantity guarantee, water quality guarantee, monitoring guarantee and management guarantee in the water source area of Danjiangkou Reservoir in 2021 through collecting the basic data about the Danjiangkou Reservoir water source in 2021 referring to the "Guidelines for the Safety Assurance of Important Drinking Water Sources in China (Trial)".

The analysis indicators refer to the national important drinking water source safety assurance standards construction evaluation indicators [6], which are divided into 4 categories and 25 indicators, namely water quantity, water quality, monitoring and management. Among the 4 categories, the water quantity is divided into four indexes: annual water supply guarantee rate of 95%, emergency standby water source, water quantity dispatching management and water supply facilities operation. Water quality is divided into nine indicators: water quality compliance rate of intakes, sealing management and establishment of boundary markers, setting of sewage discharge ports into rivers, comprehensive treatment of first-level protected areas, comprehensive treatment of second-level protected areas, comprehensive treatment of quasi-protected areas, use of phosphorus-containing detergent, pesticides and fertilizers, management of traffic facilities and vegetation coverage rate. The monitoring is divided into 6 indicators, including video monitoring, inspection system, specific indicator monitoring, online monitoring of water quality and quantity, information monitoring system and emergency response ability. The management is divided into six indicators: such as the division of protected areas, the linkage mechanism of departments, the legal system, the emergency plan and drill, the management team and the fund guarantee.

3.2 Current Situation of Water Source Security

Water amount security. In 2021, the water supply of Danjiangkou Reservoir was in good condition, and the water supply guarantee rate exceeded 100%. In the water supply operation, priority was given to meet the requirements of drinking water supply in order to ensure the water quantity and water level requirements for the normal operation of the water intake project at the corresponding guarantee rate. The regional water resources allocation and water supply joint operation scheme under special circumstances were formulated and implemented. Water supply facilities were in good condition, and water intake and transmission works were in safe operation. But as the source of drinking water in Hubei Province, the construction of emergency water source in some cities was lagging behind.

Water quality assurance. In 2021, the water quality of the water source of Danjiangkou Reservoir was generally good. The water quality of each water intake conformed to the I~II standard of "Surface Water Environmental Quality Standard" (GB3838-2002). Primary protection zones for drinking water sources were basically closed and managed, and boundary markers, warning signs and isolation and protection facilities were improved. Also there was no sewage outlet into the river in the primary and secondary protected areas of water source. In the whole, the comprehensive management situation of the first and second level protected areas was good, but there were sporadic fish farming incidents in the quasi-protected areas. Planting was common in the water-level-fluctuation area, however the use of pesticides and fertilizers was not effectively restricted [7]. There were many bridges in Danjiangkou, but comprehensive and complete facilities for collecting and disposing water from bridge deck and prevention and control measures for environmental pollution were not established. The good news was that vegetation coverage reached more than 80%.

Water monitoring and support. The monitoring and monitoring construction of the water source of Danjiangkou Reservoir in 2021 was relatively complete. With perfect video monitoring capability, it could monitor the water intake in the water source in real time, and also had a sound inspection system and complete inspection records. Further, it could carry out specific indicator monitoring as required and had the emergency monitoring capacity to carry out encrypted monitoring and increase monitoring items in case of early warning and emergency events. Also, it could realize online monitoring of water quality and quantity and set up water quality and quantity safety monitoring system with the ability to collect, transmit, analyze and process hydrological water resources monitoring information such as water quantity, water quality and water level.

Management guarantee. The supervision and management of the water source of Danjiangkou Reservoir in 2021 were good. The works included completing the work of delineating protected areas and submitting it to the provincial people's government for approval and implementation. Also a sound system of laws and regulations was formulated, and emergency plans were formulated to ensure the safety of water supply under special conditions such as sudden water pollution incidents, floods and droughts. But the departmental linkage mechanism needed to be improved and a complete management team was equipped with while a stable funding mechanism was not yet established.

4 Problems in the Security of the Water Source of Danjiangkou Reservoir

4.1 Improving of Protection and Management Mechanism of Water Source

The main responsibility for the management and protection of water source is the local people's government. According to the relevant laws and the "three regulations" of departments, relevant government departments such as ecological environment, water conservancy, urban construction and health have corresponding responsibilities and tasks in the management and protection of drinking water. As the source of water for the middle route of the South-to-North Water Transfer project, Danjiangkou Reservoir involves Hubei and Hunan provinces. Danjiangkou Reservoir belongs to the Yangtze River Water Resources Commission, the operation and management units of the reservoir are Hanjiang Group and Water source Company. The above situation causes the management system not coordinating. All departments are in accordance with the arrangement of the higher authority and the department's "three" responsibilities to carry out the relevant work, but the boundary is not clear and the coordination is not enough, and easy to cause the work of repetition and omission. It can be seen from the current situation of the security guarantee of the water source of Danjiangkou Reservoir that there are many administrative departments, unclear boundary division of responsibilities, and inadequate implementation of the system in the protection and management of the water source.

4.2 Existing of Water Quality Safety Risks

As the water source of the middle route of the South-to-North Water Diversion project, Danjiangkou Reservoir has a wide water area, a long shore-line and a large water-dissipation area. However, there are still some hidden dangers in water quality safety in Danjiangkou Reservoir[8]. In Danjiangkou Reservoir, there were only a few boundary monuments and signs in other reservoir areas except the first level protection zone of Taocha Canal head and water source. Human development and utilization activities around or outside the reservoir easily brought certain pollution problems to local waters in the reservoir area. Secondly, the water resources management information system of the water source area of Danjiangkou Reservoir had not been established, and the video monitoring was not perfect. The reservoir surface is large, the reservoir shoreline is long and only a small amount of manpower patrols the reservoir, which makes it difficult to find problems effectively and timely. Also there are many bridges in Danjiangkou ring reservoir highway. Comprehensive and complete facilities for collecting and disposing water on bridge deck and prevention and control measures for accident environmental pollution had not been established.

In addition, the management task of the fluctuation zone in Danjiangkou Reservoir is heavy and difficult due to its wide range. Lack of relevant supporting implementation rules, guidelines, and imperfect policies and regulations, such as the management unit and local government have no relevant provisions on the scope of functions and powers, personnel allocation, management means and sources of funds, result in the fluctuation zone management into a dilemma [9]. Although agricultural cultivation has been banned in the fluctuation zone at present, there were no relevant management plans and regulations. The use of pesticides and fertilizers has not been effectively restricted, which caused a potential risk to the water quality of reservoirs.

4.3 Imperfect Capital Investment Mechanism

According to the survey, although local governments attach great importance to the safety of drinking water, they can only carried out basic water source protection work such as the establishment of signs and the construction of purse seine due to the limited funds, and it was difficult to guarantee the work funds for the work with high cost, such as full closure management and migration. At the same time, the national level has not established investment channels for the protection of urban drinking water sources, and the investment guarantee mechanism was not perfect, leading to difficulties in the implementation of funds, and the urgently needed protection measures of water sources cannot be carried out as scheduled, which restricted the implementation of the construction plan to meet the standards, and affected the progress of the construction work to ensure the safety of water sources.

At present, the water source of Danjiangkou Reservoir has not established a stable fund investment mechanism for drinking water source protection, and the water resource protection management fund of the reservoir was insufficient. The water charge for the water source of the middle route of the South-to-North Water Diversion Project approved by the state belongs to the operation and loan price, which only included the operation and maintenance cost of the project equipment and does not include the management cost of the reservoir. After the middle line project was completed, the power generation of Danjiangkou Hydropower Station was reduced, and the maintenance cost of the reservoir was greatly reduced.

4.4 The Construction of Some Spare Water Sources Lagging Behind

As a source of drinking water in Hubei Province, Danjiangkou Reservoir had a single water source structure in some cities that supply water, and some spare water sources have not yet been built. Moreover, the existing spare water sources had imperfect supporting facilities for water supply, insufficient emergency spare water supply capacity and lacked of emergency treatment measures to deal with continuous drought or sudden pollution accidents.

5 Suggestions on Danjiangkou Reservoir Water Source Safety Guarantee Construction

5.1 Improve Supervision and Management Mechanism

Improve the protection and management mechanism for drinking water sources According to the regulations requirements of Water law, Yangtze River Protection law of the People's Republic of China and other relevant laws, the local government is the main body of responsibility for the protection of drinking water sources within its administrative area. It is necessary to strengthen the Danjiangkou Reservoir water source development, utilization, conservation, protection and safety guarantee construction, establish department linkage mechanism, implement the system of resource information sharing and consultation on major issues. The departments of water conservancy, environmental protection, housing and construction and public health should be optimized and integrated. In this way, they could strengthen the supervision, inspection and management of the water source area of Danjiangkou Reservoir according to their respective duties, explore and establish a long-term management system and mechanism.

It is essential to effectively implement the management requirements of the "River Chief system" and strengthen coordination and linkage among departments. The "River Chief system" task require to make protection plan according to the actual situation of each river and lake. The local governments should strictly carry out the main responsibility for the management and protection of the Danjiangkou Reservoir water source area, implement unified supervision and management of the water source area and establish a linkage mechanism with relevant departments within the water source area or with other relevant departments of drinking water environment management. The local government and relevant departments should communicate the situation in a timely manner and jointly protect and manage drinking water sources.

Strict daily management, supervision and inspection of water sources

The local government should strengthen daily supervision and inspection and rectify problems. The water source protection of Danjiangkou Reservoir should be included in the strictest water resources management and the problem clues could be found by regular retrieval and comparison through remote sensing and other high-tech means. Supervision could be conducted through the strictest water resources management system and River Chief system in accordance with daily problems, media exposure problems, problems found on site, etc. (such as fish culture in reservoir). The local government should keep an eye on the problems identified and keep track of the progress of rectification. Problems concerning water source protection zones or water pollution should be submitted to local government or ecological and environmental departments for disposal.

5.2 Strengthen Supervision Over Water Quality Risks

Build ecological isolation zones for water sources

On the basis of the existing achievements in the Plan for the Construction of a Water Resources Protection Zone and an Ecological Isolation Zone along the Yangtze River Economic Belt, it is essential to build an ecological isolation zone for the Danjiangkou Reservoir water source area to promote the implementation of measures to protect the water source area. Relevant measures should be explored and conducted including the land isolation shield construction, waterfront buffer construction and repair and water purification zone construction. The land isolation shield construction mainly consists of biological isolation protection, physical isolation protection and publicity warning engineering. The waterfront buffer construction and repair mainly consists of artificial wetland, ecological slope protection engineering and ecological ditch engineering. The water purification zone construction mainly consists of endogenous pollution control, aquatic organisms and front library purification engineering.

Improve the management system of water-fluctuation-zone

The water surface and land in the water-fluctuation-zone formed by the Danjiangkou Reservoir are owned by the State and managed by the Danjiangkou Reservoir management department. Under the premise of obeying the unified operation of the reservoir, ensuring the safety of flood control, engineering and water supply and meeting the requirements of soil and water conservation and water quality and ecological protection, the management department of Danjiangkou Reservoir may entrust the local government at the county level to manage the water-fluctuation-zone through an agreement [10]. The development and utilization activities in the water-level-fluctuation area should be subject to the approval of the Danjiangkou Reservoir management department or the entrusted local government at the county level. No compensation will be made for the economic losses caused by the operation of reservoir to the land users in the water-fluctuation-zone. The above consent is given by the Danjiangkou Reservoir management unit or department or the entrusted local government at the county level which do not replace the administrative licensing procedures carried out by administrative authorities at all levels in accordance with the law.

Strengthen the development of information systems and traffic protection facilities

It needs to establish the water resources management information system of Danjiangkou Reservoir water source area and improve the video surveillance system.

In view of the traffic facilities such as roads and bridges in the protected area, comprehensive and complete bridge deck rainwater collection and disposal facilities and accident environmental pollution prevention measures should be established.

5.3 Establish a Long-Term Stable Funding Guarantee Mechanism

Establish a sound investment and financing system

In view of the complexity and long-term of drinking water source protection work, financial pressure is large completely dependent on government investment. A multi-level and multi-channel, diversification of investment and financing system could be set up through the establishment of perfect investment and financing system, using a variety of policy tools to implement the policy incentives, and gradually form different responsibility subjects which have different sources of funds to support. Adopt flexible ways could be adopted to protect water sources and control pollution, such as sewage treatment, garbage recycling, recycling and other infrastructure construction. Focusing on construction, operation, market-oriented and intensive, the advantages and enthusiasm of private capital could be brought into full play with appropriate financial support from the government.

Establish a special transfer payment mechanism

It is suggested to the state to establish a special transfer payment mechanism for water sources of the middle route of the South-to-North Water Diversion Project gradually increases support for the transfer payment of ecological compensation for the Danjiangkou Reservoir water source protection zone and improves the current standard of transfer payment for ecological compensation. The water resource tax of the middle route project can be taken as one of the fixed sources of transfer payment funds from which special funds can be allocated to support the cities in the water source area to carry out the protection of drinking water sources.

Establish green development fund

Based on the principle of "paid occupancy" and referring to the water resource fee collection and distribution method of the Three Gorges Hydropower Station, the green development fund for the Danjiangkou Reservoir water source area could be set up with a certain proportion of the water resource tax of the inter-provincial Danjiangkou Reservoir hydropower Station project. In this way, a stable and reasonable long-term compensation mechanism will be established to ensure the continuous and rigid expenditure of water source areas in the construction of safety guarantee.

5.4 Advance the Construction of Emergency Water Sources

With Danjiangkou Reservoir as the water source of drinking water in Hubei province, some water supply cities (Suizhou, Xiaogan) faced the problem that the construction of emergency water source lags behind. It is essential to speed up the planning and construction emergency drinking water sources or alternative to drinking water sources. For those who have established emergency water sources, it needs to speed up the improvement of their water supply facilities for existing emergency water sources and ensure the safe operation of the water intake and transmission projects for emergency water sources. For the emergency water source under planning or construction, it needs to accelerate the construction progress of the emergency water source and ensure the project quality. The emergency water source should be put into use as soon as possible to reduce the risk of water supply. In addition, regular inspections of the construction of emergency water sources should be organized. The construction and use of emergency water sources will be included in the assessment of the strictest water resources management system and the River Chief system.

6 Conclusion

As the water source of the middle route of the South-to-North Water Diversion Project and the drinking water source of Hubei Province, the Danjiangkou Reservoir has a good overall security situation in 2021. However, there are still problems such as the protection and management mechanism of the water source to be improved, hidden dangers of water quality and safety and imperfect fund investment mechanism. In specific, the hidden dangers of water quality safety include the incomplete construction of isolation facilities, the unestablished water resources management information system of water source, the imperfect prevention and control measures of accident and environmental pollution and the difficulty in the management of water-level-fluctuation zone.

Suggestions on the follow-up work of the Danjiangkou Reservoir water source safety guarantee construction mainly include: (1) improve the supervision and management mechanism and the protection and management mechanism of drinking water source, strictly enforce the daily management, supervision and inspection of the water source; (2) strengthen the supervision of water quality risks, carry out the construction of ecological isolation zones of water sources, improve the management system of water-level-fall zones and strengthen the construction of information systems and traffic protection facilities; (3) establish a long-term and stable fund guarantee mechanism, a sound investment and financing system, a special transfer payment mechanism for water source of the middle route of the South-to-North Water Diversion Project and a green development fund for Danjiangkou Reservoir water source area; (4) promote the construction of emergency water sources.

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Numerical Simulation for Water Inrush in the University City Tunnel in the Chongqing City, Southwestern China

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Abstract Water inrush has become a significant disaster in the karst tunnel construction. The University City tunnel crosses the Zhongliang Mountain where karst strata are well developed in the Chongqing city, southwest China. This study simulated the groundwater seepage field in the natural and construction conditions by visual Modflow software. Groundwater flows from north to south in natural condition. With the tunnel excavation face as the center, a falling funnel with a large influence range is formed, and the excavated tunnel becomes the local discharge datum. Then, the groundwater flow direction from north to south has changed to the tunnel as the center of the confluence, and the groundwater level in the anticlinal core area has further decreased. The volume of water inrush was estimated. The simulation results are similar to the actual tunnel water influx results obtained from the calculation. Our goal is aimed to simulate the changes in hydrogeological conditions after the tunnel construction and predict the amount of water surge in the tunnel. The achievements of our study would provide a vital reference for groundwater management and protection in the karst tunnel construction.

Keywords Water inrush · Mod flow · Numerical simulation · Kart tunnel · Chongqing

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1 Introduction

In order to improve the transportation system in mountainous areas in China, a large number of highways and railroads are under construction or will be built soon [1–3]. Mountain tunnels are an important part of the lines under construction, providing a smoother way to cross the mountains. Karst geomorphology has a more obvious influence on civil engineering construction because of its special lithological, geological and hydrological characteristics [4–6]. The distribution area of karst strata in China accounts for about 1/3 of the total area of the country, with the most extensive distribution and the most developed karst characteristics in southwest China, including the Chongqing Guangxi, Guizhou, Yunnan, Sichuan, Hunan and Hubei.

As a result of karst tunnel excavation, the formation of a low-pressure water area in the airfront changes the mechanical properties of the surrounding rock and groundwater runoff routes, causing the surrounding groundwater to converge in the tunnel [7–10]. And for high-pressure, water-rich tunnels with strong karst development, gushing water becomes one of the most common geological hazards. Therefore, the problem of water surging during tunnel construction is receiving more and more attention from researchers [11–16].

The University City tunnel project starts at the Xishan interchange on Pingshan Avenue, extends eastward through the Zhongliang Mountain and ends at the inner ring red slot house interchange (Station Road West), with a total line length of about 5.94 km. This study is aimed to simulate the changes in hydrogeological conditions after the tunnel construction and predict the amount of water surge in the tunnel. The achievements of our study would provide a vital reference for groundwater management and protection in the karst tunnel construction.

2 Study Area

Chongqing city is located in the southwest China and belongs to mountainous area. The climate is subtropical monsoon humid climate with annual average temperature of 18.3 °C and annual average precipitation of 1082.9 mm. The Jialing River and Yangtze River traverse through the study area. Through drilling, site investigation and comprehensive analysis of existing regional geological results, the stratigraphy in the proposed site area from top to bottom is the Quaternary Holocene artificial fill layer (Q_4ml), the residual slope deposit powder clay (Q_4el + dl), the collapse slope deposit (Q_4col + dl), the underlying bedrock is the Middle Jurassic Shaximiao Formation (J_2S), the Middle Jurassic Xintiangou Formation (J_2X), the Middle and Lower Jurassic Ziliui Formation (J_{1-2}Z), Lower Jurassic Zhenzhuchong Formation (J_1Z), Upper Triassic Sujiahe Formation (T_3xj), Middle Triassic Leikoupo Formation (T_2l), Lower Triassic Jialingjiang Formation (T_1j), Lower Triassic Feixianguan Formation (T_1f), and Upper Permian Changxing Formation (P_2c).

The surface and groundwater watershed are located about 10 km south of the town of Gele Shan, and the watershed drains to the Jialing River to the north and to the Yangtze River to the south of the watershed [17–19]. The non-soluble rocks on both sides of the trough divide the area into three relatively independent secondary hydrogeological units, i.e., the towering topography formed by the non-carbonate rocks on the two wings of the east and west troughs and the uplifted isolation zone in the middle of the trough, while the soluble rocks of the Feixianguan Section III, Jialing River and Leikoupo Formation are distributed in the trough area on both wings, making the east and west troughs form relatively independent hydrogeological units, and the Feixianguan Formation strata in the nucleus form a relatively independent hydrogeological unit due to its upper and lower. The Feixianguan Group strata in the nuclear part also form a relatively independent groundwater system due to their upper and lower non-soluble rock strata, constituting an independent hydrogeological unit. Since the construction of Xiangyu Railway Tunnel, University City Tunnel, Zhongliang Mountain Tunnel of Chengdu-Chongqing Expressway and Shiban Tunnel, the groundwater system has been fundamentally changed, and the deep groundwater is affected by the tunnel construction, which has a greater attack on the groundwater, forming several hydrogeological units or middle and deep groundwater system s [20–22].

3 Methodology

This paper proposes to use visual Modflow software to make analysis and prediction for a series of groundwater problems in karst tunnels [23]. Through Visual Modflow, which is the simulation of regional geological model (water-bearing medium basis) using finite difference method, the evolution of underground water-bearing space model is realized in the process of crossing the water-bearing medium (aquifer, water barrier, boundary conditions) in the university city tunnel, due to the complex geological structure and fold development in Zhongliang Mountain area, the actual natural conditions of karst medium is non-homogeneous structure, in the model. In the process of model establishment, the non-homogeneous structure is unified into a homogeneous structure, the horizontal permeability is consistent and the vertical permeability is low, so as to establish a strong practical simulation of the seepage model that meets the characteristics of karst water seepage and the actual hydrogeological conditions to achieve the fitting of the groundwater level in the natural state; and then the prediction of the tunnel water influxes under different working conditions in different periods of the tunnel excavation process and the prediction of the evolution of the seepage field.

The scope of the 3D numerical model of the University City tunnel is the whole tunnel line, from Shuangbei Tunnel in the north to Zhongliang Mountain Tunnel of Chengdu-Chongqing Expressway in the south. The length of the model space is about 10 km, and the width is about 4 km. The whole model plane of the University City tunnel is divided into 80×80 units, and the representative parameter values can be assigned according to the karst development characteristics and water richness on the plane, and the tunnel burial depth is larger in the vertical direction because the study area is a karst trough valley. However, the karst development pattern is the basis of the spatial structure of the model. Therefore, in order to make the spatial nature of each unit closer to the actual situation, without considering the change of stratigraphy, the model is evenly divided into 12 layers in the vertical direction, the bottom is taken as 200 m elevation, the surface is the ground surface and the highest mountain. According to the degree of karst development and characteristics, the parameters are assigned to the representative values downward layer by layer according to the tendency, and when assigning parameters, the model grid is refined according to the needs of specific places in order to assign values accurately. The model has a total of 76,800 cells.

Since the main aquifer in the tunnel site area is T_1j, T_2l and T_1f_{1+3}, it is used as the main aquifer in the model. While T_3xj on the east and west sides of the mountain and T_1f_4 on both sides of the trough valley is treated as medium-weakly permeable layers with large thickness, poor groundwater activity relative to the soluble rock, and hydrodynamic conditions for groundwater movement below the ridges on the east and west sides, but in view of the low permeability relative to the soluble rock area, the model treats them as low permeability layers, and the $J_1z + J_{1-2}z + J_2x$ strata outside of them are treated as water barrier layers for low permeability, so the east and west sides of the model are treated as approximate zero-flow boundaries by default. The northern side of the model is the Shuangbei Tunnel and the southern side is the Zhongliang Mountain Tunnel of the Chengdu-Chongqing Expressway, which plays a stable drainage role and can be regarded as a drainage boundary, so it is treated as a constant head boundary. The value of permeability K of each stratum is based on hydrogeological tests, combined with the experience of Chongqing area and the parameter values of similar projects for certain generalization. In the model parameter values, the permeability coefficient is assigned to fit the actual hydrogeological situation of Zhongliang Mountain area as much as possible due to the anisotropy of karst development.

This study focuses on the evolution of the natural seepage field during the excavation of the proposed University City tunnel and the recovery of the tunnel seepage field after the completion of the excavation.

(1) Simulation of the natural seepage field before excavation of the tunnel in the University City multiplex.
(2) Simulation of the excavation process, simulating the evolution of the tunnel seepage field during the 2-year excavation process as well as the prediction of the water surge.
(3) After the tunnel excavation is completed and blocked, the tunnel area seepage field restores the evolution, mainly including changes in the watershed and landing funnel.

4 Results and Discussion

4.1 Numerical Simulation for Groundwater Seepage Field in Natural Condition

According to the aforementioned parameters and boundary conditions, the simulated seepage field was used as the natural groundwater seepage field in the tunnel site area. It was also considered as the initial head for the model calculation in the later tunnel excavation conditions, as shown in Fig. 1, which is the calibrated three-dimensional natural groundwater seepage field in the University City tunnel area. Groundwater level in the anticline core exposed by $T_1j + T_2l$ and T_1f strata was higher, where groundwater level in the non-soluble rock strata was higher than that in the soluble rock strata. The soluble rock strata were blocked by high ridge of non-soluble rock of the T_3xj strata on the outside and the non-soluble rock stratum of the Feixianguan Formation (T_1f_4, T_1f_2) on the inside. The overall flow direction of groundwater was from north to south. Since several tunnels have been operated in the area, the groundwater discharge reference surface in the local area was centered on the built tunnels, forming several groundwater depression cones with large drainage volume. The shallow groundwater was mostly a local runoff system, which is characterized by scattered drainage. Due to the drainage effect of the built tunnels, a large number of shallow groundwater drainage points were dry and the amount of water is low, greatly determined by atmospheric rainfall.

4.2 Numerical Simulation for Groundwater Seepage Field in Construction Condition

The seepage field simulation mainly showed the regional seepage field changes and impact of the tunnel excavation process on the hydrogeological conditions of the tunnel site area. Visual Modflow was used to export the 3D data of the seepage field after tunnel excavation. To better illustrate the influence of tunnel drainage conditions on the system, the tunnel was generalized to a drainage trench boundary to simulate the seepage field of the tunnel under drainage conditions and to compare it with the natural seepage field for analysis. It was helpful to visually show the form of the groundwater depression cone in the tunnel excavation area. Considering the actual length of the tunnel, it was assumed that the tunnel construction period was 2 years and both ends were bored at the same time. Therefore, the changes in the groundwater seepage field and the tunnel surge volume were simulated for one year of excavation and two years of penetration.

Figure 2 displayed the three-dimensional seepage field in the tunnel site area at a distance of 2 km when the tunnel is dug at both ends for one year. The proposed tunnel assaulted the groundwater recharge in the northern part of the existing tunnel,

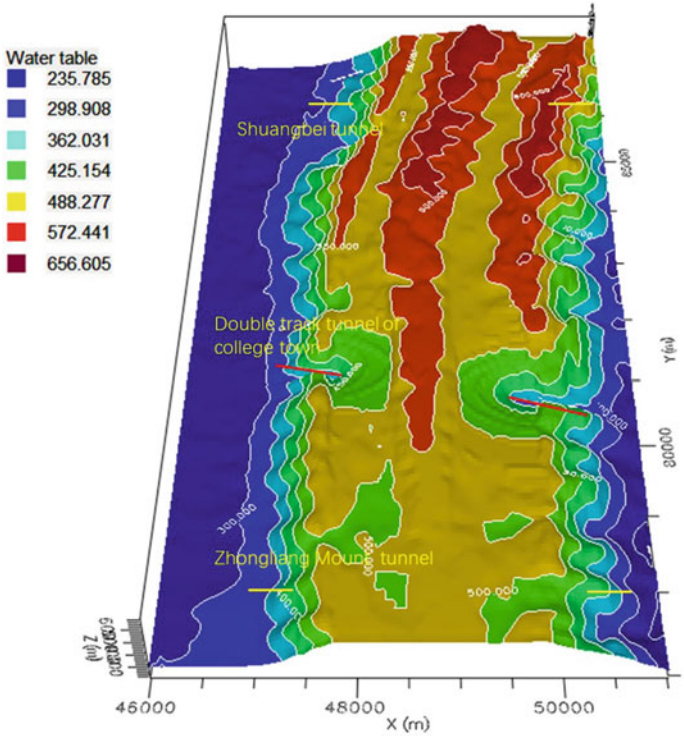

Fig. 1 Groundwater seepage field in natural condition in the University City tunnel area

so the drainage of the original tunnel will be reduced. The whole tunnel group as a drainage benchmark, the landing funnel formed is larger and the impact is more extensive.

Figure 3 shows the three-dimensional numerical demonstration of the seepage field after two years of tunnel excavation. And Fig. 4 shows the seepage field profiles from before to after the tunnel excavation. The radius of influence of the formation of the $T_1j + T_2l$ karst aquifer is larger, the groundwater level near the tunnel site area decreases significantly. The overall groundwater level in the region also decreases to a certain extent, and some groundwater discharge points within the influence of the tunnel construction, such as natural springs which will be further affected by draining the flow. As the overall groundwater flow direction in the region is from north to south, the tunnel is located in the runoff area of the karst water system, in the area north of the proposed tunnel. As the overall groundwater flow direction is from north to south, the tunnel is located in the runoff area of the karst water system.

By comparing the planar change of seepage field and profile after one year of excavation and penetration, the change of seepage field under different working conditions can be clearly seen from Fig. 4. Compared with the seepage field under natural conditions, the influence range of the landing funnel formed at the center

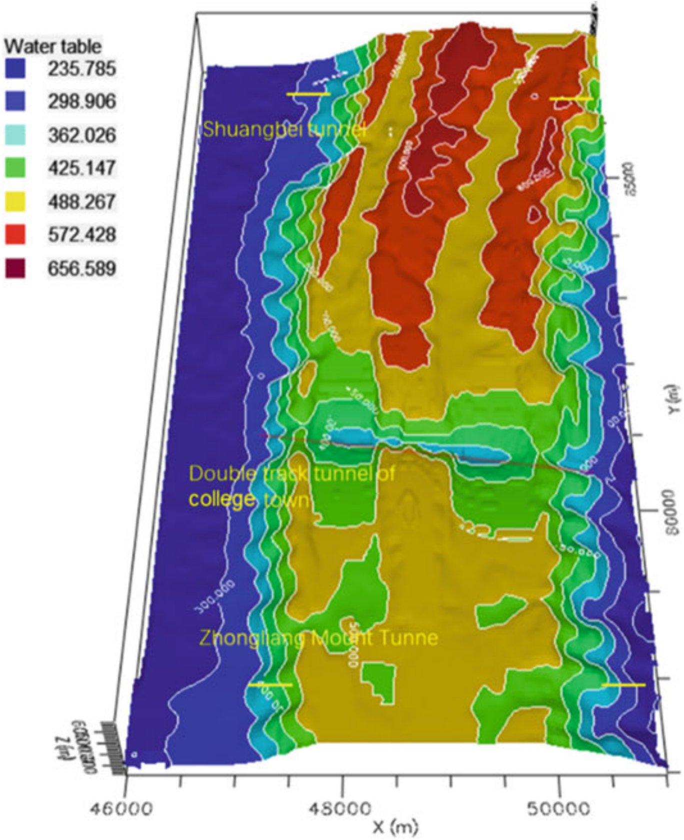

Fig. 2 Groundwater seepage field in one-year construction in the University City tunnel area

of the tunnel excavation surface gradually increases with the increase of excavation time. At one year of excavation, because the excavated section is mainly non-soluble rock. In the first year of excavation, since the tunnel excavation section is mainly non-soluble rock, the radius of influence is small, and the groundwater level in the core of the back slope is basically unchanged. After one year of excavation, since the tunnel excavation reaches the main aquifer $T_1j + T_2l$ tuff in the tunnel site area, a landing funnel with a larger influence range is formed with the tunnel excavation surface as the center. And the excavated tunnel becomes a local discharge datum, while the groundwater level in the core of the back slope also decreases. After the tunnel is completed, the tunnel section has formed. After the tunnel is completed, the tunnel section has become a local drainage reference. And the original groundwater flow direction from north to south has become a confluence with the tunnel as the center, and the groundwater level in the core of the back slope area has further decreased.

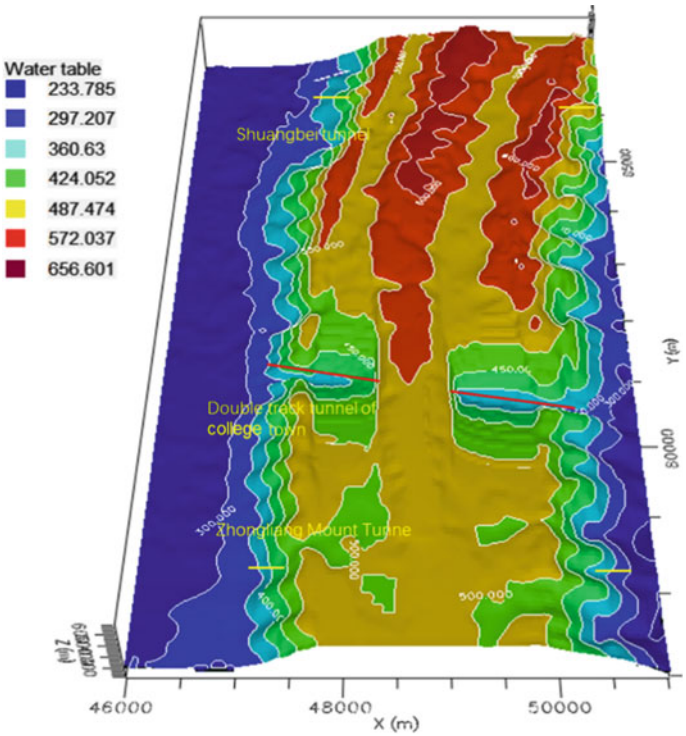

Fig. 3 Groundwater seepage field when completed construction in the University City tunnel area

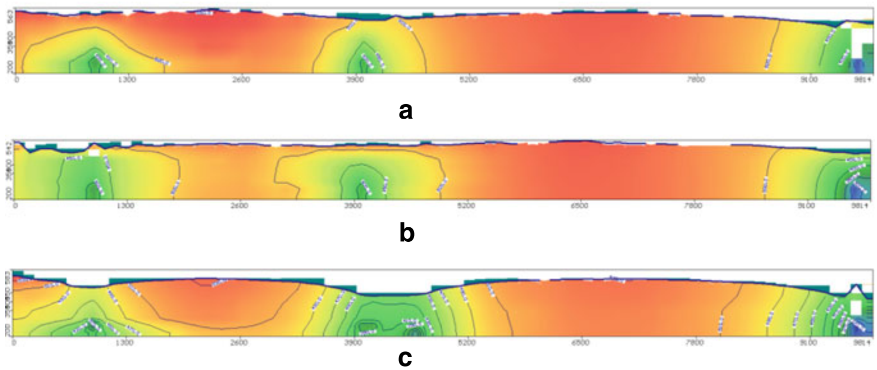

Fig. 4 Profile section of the groundwater seepage field during, **a** natural condition, **b** one-year construction and **c** completed construction

4.3 Numerical Simulation for the Volume Calculation of Water Inrush

The Jurassic stratum, Feixianguan Group four and two strata permeability coefficient is very small, the tunnel excavation after the surge is very small, the total surge is about 120.6m^3/d. When the tunnel construction time is about 100 days, the tunnel water gushing through the sand mudstone stratum of Xujiahe Group is 550.1m^3/d. Because the tunneling stratum is non-soluble rock water barrier, the water gushing is small. In about 260 days of tunnel excavation, tunnel boring through the Leikoupo Group and Jialingjiang Group tuff, the water gushing mainly from the Leikoupo Group and Jialingjiang Group soluble rock. Currently, the back slope of the two wings of excavation digging into the Jialingjiang Group and Leikoupo Group tuff aquifer, groundwater endowment is huge and due to the development of karst, high permeability coefficient, the water gushing about 5919.3m^3/d. In about 330 days of tunnel excavation in Tunnel boring through the three sections of the Feixianguan Group tuff, the tunnel water influx is 1127.2m^3/d, the simulation results are similar to the actual tunnel water influx results obtained from the calculation.

5 Conclusion

This study focused on the water inrush hazard in the University City karst tunnel in the Chongqing city, southwest China. Based on the geological and hydrogeological investigation, we simulated the groundwater seepage field in the natural and construction conditions by visual Modflow software. Overall, groundwater flows from north to south in natural condition. As a number of tunnels have been opened and operated in the region, the built tunnels have become the reference level of groundwater discharge in the local area, forming multiple groundwater drop funnels with large displacement. In the first year of tunneling at both ends of the tunnel, the excavation distance was 2 km for the three-dimensional numerical demonstration of the seepage field in the tunnel site. Due to the initial excavation, the main stratum excavated was Jurassic and non-soluble rock of Xujiahe Formation, which was a relatively waterproof layer with small permeability coefficient, so the water inflow was small. The underground water level drop funnel formed in the middle line of the tunnel has a larger influence range, and the influence radius of the formation of the $T_1j + T_2l$ karst aquifer is larger. The groundwater level near the tunnel site decreases obviously, and the water level in the whole area also decreases to a certain extent. The water inflow of the tunnel during the construction period is 4897m^3/d, and the flood period is 7630m^3 /d.

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The Antibiotic Contamination and Ecological Risks Assessment of Typical Lakes in the Middle and Lower Reaches of Yangtze River in China

Huawei Huang, Chan Yu, and Liangyuan Zhao

Abstract Antibiotics have been detected in natural environment in many regions of the world, and their potential disadvantageous influences on organisms in the environment have attracted widespread attention. The sewage treatment plants don't completely take out antibiotics before tailwater release into the environment. The antibiotic contamination could promote the development of antibiotic resistance genes and drug resistant bacteria and bring irreversible damage to the natural ecosystem and human health. Because of the widespread use and discharge of antibiotics, lakes have become important repositories of antibiotics. With the rapid industrialization and urbanization of the Yangtze River Economic Belt, the Yangtze River basin has already become one of the regions with the maximum antibiotic emissions in China. This review briefly addresses the current situation of antibiotic contamination in the Yangtze River basin and typical lakes in the middle and lower reaches and evaluates the main types of pollution and ecological risks of antibiotics in typical lakes during the dry season.

Keywords Surface water · Antibiotic · Contamination · Ecological risk

1 Introduction

Antibiotics are a kind of synthetic compounds or metabolites produced by microorganisms or higher animals and plants, which can restrain or kill other microorganisms, and are universally applied to prevent and cure human and animal diseases. China is the leading producer and user of antibiotics in the world. In 2013, China used about 162,000 tons of antibiotics, more than 150 times the UK's during the same period

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[1]. Antibiotics are only partly degraded in organisms. Up to 80–90% of antibiotics are excreted as undegraded compounds through urine and feces, and then into the natural environment [2].

Multiple antibiotics have been detected in rivers and lakes. Antibiotics residues can influence the growth of aquatic organisms [3, 4], alter the formation and function of microbial communities [5, 6], and promote the development of antibiotic resistance [7]. The environmental pollution and ecotoxicity induced by antibiotics have become one of the major environmental problems in the world.

About 650 crude lakes with water surface area greater than 1 square kilometer are situated in the Yangtze River basin [8]. And Poyang Lake, Dongting Lake, Taihu Lake, and Chaohu Lake are the four largest freshwater lakes in China. The middle-lower reaches of the Yangtze River include five provinces (Hubei, Hunan, Anhui, Zhejiang, Jiangsu) and Shanghai, supporting 28.6% of the population with 9.53% of the country's land area [9]. As an important aquatic environmental system, lakes can regulate floods, develop aquaculture, and can also be used as important sources of drinking water. Antibiotics might enter the lakes along with medical and livestock wastewater. Most antibiotics can't be usefully removed by existing methods. Lakes have become an important repository of antibiotics, posing a potential risk to the ecological environment and human health.

This research is to investigate the current situation of antibiotic pollution in typical lakes in the middle-lower reaches of the Yangtze River. Then the main pollution types and ecological risks of antibiotics in typical lakes are evaluated during the dry water period.

2 The Antibiotic Contamination in the Yangtze River Basin

According to the report on the national antibiotic pollution map released by the Chinese Academy of Sciences in 2015, the quantity and content of antibiotics detected in water bodies of the Yangtze River Delta are comparatively higher compared with other regions. In the Yangtze River basin, sulfonamides (SAs) and fluoroquinolones (FQs) are the key types of antibiotic contamination, followed by macrolides (MAs) and tetracyclines (TCs).

The middle-lower reaches of the Yangtze River have the character of big population density and developed industry and agriculture, the use and emission of antibiotics are higher. Ten kinds of antibiotics (4 types) were detected in the stem streams and 6 tributaries in the Three Gorges Reservoir area. The mass concentration ranged from 0.6 to 218 ng/L. Sulfamethoxazole (SMX) and ofloxacin (OFX) posed higher toxicity risk to aquatic organisms in the tributaries [10]. Fourteen kinds of antibiotics (5 types) were detected in the drinking source water of the Nanjing reach of Yangtze River. The mass concentration ranged from 13.37 to 780.5 ng/L, which the average concentration was 92.95 ng/L [11]. Nineteen kinds of antibiotics (5 types) were detected in the surface water of the Yangtze Estuary, which the highest concentration was 219 ng/L [12].

3 The Antibiotic Contamination in the Typical Lakes

3.1 Pollution Situation

In this paper, Dongting Lake, Poyang Lake, Taihu Lake, and Chaohu Lake are selected as research areas. This paper collected the relevant data published in the recent years, including the content data of 14 kinds of antibiotics in 4 categories. The types of antibiotic contamination in the surface water of the four typical lakes are given in Table 1, and the levels of the pollution are given in Table 2.

The levels of antibiotic pollution in the same region were different between the dry season and the rainy season. In the Dongting Lake, the concentrations of most antibiotics in the dry season (December) were higher, compared with the rainy season (August), while the concentration of SD in SAs was 61.28 ng/L in the dry season and 8.73 ng/L in the rainy season. In the Poyang Lake, the antibiotic concentration between MLs and FQs was not very different in the two periods, the concentration of SAs in the dry season (December) was higher, compared with the rainy season (June), while the situation of TCs was opposite compared with SAs. In the Chaohu Lake, the concentrations of most antibiotics in the dry season (January) were higher, compared with the rainy season (September), while the concentration of SMX in SAs was 171.6 ng/L in the dry season and 79.6 ng/L in the rainy season.

Investigating the antibiotic contamination in four lakes during the dry season, the antibiotic concentration in Dongting lake, Poyang lake, Taihu lake, and Chaohu lake, was 190.7, 124.1, 184.6, and 352.6 ng/L. During the dry season, the most serious causes of antibiotic contamination in Chaohu Lake were associated with differences

Table 1 Main types of antibiotics of studied compounds [13–15]

Compounds	Acronym	Molecular formula	Primary usage
Sulfadiazine	SD	$C_{10}H_{10}N_2O_2S$	Livestock, aquaculture
Sulfamethoxazole	SMX	$C_{10}H_{11}N_3O_3S$	Human
Sulfathiazole	STZ	$C_9H_9N_3O_2S_2$	Livestock, aquaculture
Sulfamethazine	SMZ	$C_{12}H_{14}N_4O_2S$	Livestock, aquaculture
Erythromycin	ETM	$C_{37}H_{67}NO_{13}$	Human
Roxithromycin	RTM	$C_{41}H_{76}N_2O_{15}$	Human
Tetracycline	TC	$C_{22}H_{24}N_2O_8$	Human, livestock
Doxycycline	DC	$C_{22}H_{24}N_2O_8$	Human, livestock
Oxytetracycline	OTC	$C_{22}H_{24}N_2O_9$	Human, livestock
Chlorotetracycline	CTC	$C_{22}H_{23}ClN_2O_8$	Livestock
Norfloxacin	NOR	$C_{16}H_{18}FN_3O_3$	Human, poultry, livestock
Ofloxacin	OFL	$C_{18}H_{20}FN_3O_4$	Human, poultry, livestock
Enrofloxacin	ENR	$C_{19}H_{22}FN_3O_3$	Human, poultry, livestock
Ciprofloxacin	CIP	$C_{17}H_{18}FN_3O_3$	Human

Table 2 Antibiotic concentrations of four lakes in different periods (ng/L)

Antibiotic		Dongting Lake [16]		Poyang Lake [17]		Taihu Lake [18]	Chaohu Lake [19]	
		2015–12	2016–08	2015–12	2015–06	2018	2013–01	2012–09
SAs	SD	61.28	8.73	56.2	–	30.0	8.4	6.2
	SMX	47.41	5.63	4.7	5.1	23.3	171.6	79.6
	STZ	–	–	16.7	–	19.7	–	–
	SMZ	14.88	2.46	22.2	4.3	14.8	9.9	5.5
MLs	ETM	–	–	4.7	8.1	3.9	–	–
	RTM	–	–	10.1	5.8	–	–	–
TCs	TC	21.51	–	–	10.8	15.7	7.5	7.2
	OTC	–	–	–	8.9	0.9	2.5	–
	DC	–	–	–	8.1	–	–	–
	CTC	6.5	4.08	–	8.4	–	4.0	–
FQs	NOR	1.65	1.11	–	–	13.2	70.2	–
	ENR	0.73	4.61	4.5	–	17.5	4.7	10.8
	CIP	36.17	2.7	5.0	8.6	19.4	23.2	–
	OFL	0.53	–	–	–	26.2	50.6	27.3

"–": below the limit of detection or unreported.

in the use and type of antibiotics, as well as in environmental conditions in different regions. The order of antibiotic contamination from high to low was: Chaohu Lake > Dongting Lake > Taihu Lake > Poyang Lake, and the antibiotic concentration was between 124.1 and 352.6 ng/L in the dry season.

3.2 Ecological Risks Assessment

In order to estimate the harmful effects of antibiotics on ecological environment and human health, the potential ecological risks are estimated according to the risk quotients (RQ = MEC/PNEC) in the EU Technical Guidelines for Risk Assessment. MEC is the measured environmental concentration of pollutants. PENC is the predicted no effect environmental concentration and is calculated from toxicity data divided by an assessment factor (AF) [20]. The values of assessment factor and PENC obtained from literatures in this paper are given in Table 3.

The ecological risk is divided into three levels. The RQ between 0.01 and 0.1 is low risk, between 0.1 and 1 is medium risk, and more than 1 is high risk [21]. The results of dry water period are illustrated in Table 4.

Results exhibited that four antibiotics (TC, CTC, SMX, and CIP) posed at least medium ecological risk in the surface water of Dongting Lake. SMX and CIP posed high risk, which were the key types of antibiotics pollution in this area, and the

Table 3 PENC values of fourteen antibiotics [13, 22]

Compound	Toxicity data (mg/L)	AF	PNEC (ng/L)
SD	2.2	1000	2200
SMX	0.027	1000	27
STZ	13.1	1000	13,100
SMZ	19.52	1000	19,520
ETM	0.02	1000	20
RTM	0.01	100	100
TC	0.09	1000	90
OTC	0.207	1000	207
DC	0.316	1000	316
CTC	0.05	1000	50
NOR	0.01038	100	103.8
ENR	0.00288	100	28.8
CIP	0.005	1000	5
OFL	0.00113	100	11.3

AF: Assessment factor; *PENC*: Predicted no effect concentration.

Table 4 Risk quotients in four lakes during the dry season

Antibiotic	Dongting Lake	Poyang Lake	Taihu Lake	Chaohu Lake
SMX	1.756	0.174	0.863	6.356
CIP	7.234	1.000	3.880	4.640
OFL	0.047	/	2.319	4.478
SD	0.028	0.026	0.014	0.004
ENR	0.025	0.156	0.608	0.163
SMZ	0.001	0.001	0.001	0.001
STZ	/	0.001	0.002	/
TC	0.239	/	0.174	0.083
NOR	0.016	/	0.127	0.676
TC	0.239	/	0.174	0.083
ETM	/	0.235	0.195	/
RTM	/	0.101	/	/
OTC	/	/	0.004	0.012
CTC	0.130	/	/	0.080
RQsum	9.476	1.694	8.186	16.493
Contribution rate	CIP (76.3%)	CIP (59.0%)	CIP + OFL (75.7%)	SMX + CIP + OFL (93.8%)

contribution rate of CIP to risk was as high as 76.3%. CIP posed high risk, which was the key type of antibiotics pollution in Poyang Lake, and the contribution rate of CIP was as high as 59.0%. CIP and OFL posed high risk, which were the key types of antibiotics pollution in Taihu Lake, and the contribution rate of CIP and OFL was as high as 75.7%. SMX, CIP, and OFL posed high risk, which were the key types of antibiotics pollution in Chaohu Lake, and the contribution rate of SMX, CIP, and OFL was as high as 93.8%. The order of ecological risk from high to low was: Chaohu Lake > Dongting Lake > Taihu Lake > Poyang Lake, and the main types of antibiotic pollution were SMX, CIP, and OFL.

4 Conclusion

To sum up, the antibiotic concentrations in this research were at a low contamination state. According to the antibiotic concentrations, the order from high to low was Chaohu Lake, Dongting Lake, Taihu Lake, and Poyang Lake. SAs and FQs were widely found in the water bodies of these four lakes. The results showed that three kinds of antibiotics (SMX, CIP, and OFL) might present high ecological risks to lakes. And high ecological risks could occur because of the reduction of water storage in lakes and the large emission of antibiotics during the dry season. We should make greater efforts to adopt strict pollution control measures to alleviate antibiotic contamination and ecological risks in lakes, particularly during the dry season.

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Research on the Prevention and Control of Carbon Pollution of Drinking Water Sources in Reservoirs and Management Strategies for the Development of Village Economy and Leisure Industry

Guanyu Chen and Hsiao- Hsien Lin

Abstract Drinking water is indispensable among the most available resources of human beings. At present, there is the behavior of “development first, treatment later” for water sources, and there are many problems in the management of water quality, water quantity and carbon pollution prevention and control of drinking water sources. The drinking water source of Qiuci Reservoir is one of the most important centralized drinking water sources in Hezhou city. The carbon pollution problem of the water source source is related to the drinking water safety of Hezhou city residents and the sustainable development of the city. This paper takes the turtle stone reservoir water source as the main research object, by discusses the current situation of carbon pollution control, from the government management, enterprise participation and survival and development of the reservoir residents management department, talent construction, capital investment, and according to the corresponding countermeasures, to improve the local turtle stone reservoir drinking water source carbon pollution control management to provide some reference.

Keywords Drinking water source carbon pollution prevention and control · Water source carbon pollution · Carbon pollution · Water source

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1 Introduce

In China with today's rapid economic development, human beings use more and more drinking water, and the requirements for drinking water safety are also gradually increasing. At present, the safety of drinking water carbon quality still poses a great threat to the survival and development of human beings. Although our country has put the water source protection and management work on the key project, and launched a series of water source protection management work, has achieved great effect, because of the geographical location, the level of social and economic development and the total amount of water resources, drinking water source protection management in legislation, execution level and management means still has a big difference, also lack of unified protection planning and management [1]. Drinking water is a basic demand condition for human survival, and the protection and management of drinking water sources caused by the safety of drinking water are directly related to human survival. In order to ensure the safety of drinking water, China's water conservancy, land and resources, environmental protection, health, and other departments have taken drinking water safety as the current top priority, and have successively issued a series of relevant important guiding documents such as the Safety Guarantee Plan of Urban Drinking Water Sources.

At present, there are two centralized water sources in Hezhou city. By 2022, these two centralized water sources will bear the domestic water consumption of about 2.027 million people. The Guishan Reservoir is one of the water sources, bearing the domestic water for more than 1.3 million people. The Guishan Reservoir is the largest drinking water source in Hezhou city. It is a large national reservoir integrating flood control and drought relief, irrigation and water supply, water source protection, and overall power supply. Therefore, strengthening the management of Guishan Reservoir and water source area plays a very important role in flood control, drought resistance, stabilizing water quantity, and ensuring water quality safety [2]. In recent years, with the development of social economy and other factors, the safety problem of the drinking water source of Guishan Reservoir is becoming more and more problematic, and the management loopholes are becoming more and more prominent. This paper analyzes the current management situation, existing problems, and their causes of the drinking water source of Guishan Reservoir, and puts forward the relevant countermeasures and suggestions for the perfect management measures.

2 Analytical Procedures

The innovation of this study is to negotiate and evaluate the treatment of the carbon pollution event in each water source. The literature analysis method is used to extensively collect books and periodicals related to carbon pollution events in water sources, and consult the research results of many scholars, including papers and books published by scholars, and the collected data are systematically analyzed, sorted out and summarized, and then draw a relatively complete conclusion. Collect the work of carbon pollution events in water sources in relevant government departments, understand the treatment and response measures of carbon pollution events in water source areas in Hezhou city, and sort out and analyze the data of carbon pollution events in water source areas. In the investigation, the author used the interview method to assist the investigation, to better understand the carbon pollution events in the water source area of Hezhou city, and to make the collected data more perfect.

In this paper, several representative towns such as Hezhou city were selected to carry out field investigation and extensively collect carbon pollution incidents in water sources. At the same time, the local government and the residents of the carbon pollution incidents in the water source area were visited on the site, and they communicated with the relevant local government staff and the residents of the carbon pollution areas in the water source area through the interview method [3], so as to record the valuable first-hand information. In addition, by consulting the relevant documents disclosed by Hezhou Municipal Government, valuable data are obtained, and finally all the carbon pollution data collected from the water source are summarized and provided as the demonstration basis for this paper through further sorting and analysis.

This paper thinks that social governance subject—government mismanagement is the cause of water source of carbon pollution, this paper uses the literature and summarizes water source of carbon pollution, related ideas, with Hezhou as the research object, and through the analysis of carbon pollution situation, it points out the water source of carbon pollution management problems, analyzes the causes of the theory of multiple governance and, finally, summarizes the water source of carbon pollution countermeasures. Literature research method is a relatively important research method used in this paper. In the process of research, a large number of research documents involving carbon pollution in water sources are searched and studied, so as to grasp the current advanced theories and academic frontiers of carbon pollution in water sources. By selecting the situation of carbon pollution in the water source area of Hezhou city, the situation of carbon pollution in the water source area is analyzed, and the causes of the problems are comprehensively analyzed. I mainly went to the carbon pollution area of the selected water source for field investigation and observe and record the carbon pollution situation in the water source.

2.1 Tools

This paper studies and analyzes the carbon pollution in water source area from the specific policy implementation, which can effectively clarify the thinking in the dimension of policy implementation, ensure the further optimization of policy ontology, policy executor, target group, and policy environment [4], and provide thinking and reference for promoting the implementation of carbon pollution policy in water source area. The implementation of the policy will face more difficulties in reality, such as the policy itself, the implementation subject, the target group, and the implementation environment will have an impact on the policy implementation. At present, the implementation research of carbon pollution policy in water sources is still relatively weak. This paper to the water source of carbon pollution problem combined with the development status of Hezhou, after influencing the relevant elements of policy implementation research, and learn from the domestic advanced theory of environmental protection policy implementation [5], successful experience, to explore a reasonable and feasible solution to solve the problem, to further enrich and supplement the relevant research results, to provide certain theoretical basis for policy implementation.

2.2 Framework

The concept of drinking water carbon pollution

Drinking water carbon pollution is generally divided into two categories: the first category is safe drinking water carbon pollution, refers to a person drinking all his life, and does not produce obvious adverse reactions to physical conditions. The second is the raw water, without any treatment, directly supplied to the human body drinking water, used for a long time, will produce adverse reactions to human health of drinking water carbon pollution, such as water directly from the river [6]. The quality of carbon pollution in drinking water referred to in this paper refers to the original state of raw water and safe drinking water carbon pollution [7]. The quality of raw water is related to the quality of safe drinking water carbon pollution.

The concept of the water source area

From the definition of water source discussion, the concept has many kinds. Some scholars believe that the water source is in all the water areas on the earth. Some scholars believe that the water source is a natural water area that can be used for human beings. The author believes that the water source is the water scope in each area protected in order to protect the life safety of the people and the local economic development. It can be a section of lakes, rivers, and reservoirs for overall protection and management [8], and provide agricultural irrigation and urban and rural water supply to the region [9]. Local water source managers divide the water source level through the size, water quantity, and water supply area of the water source scale.

3 Results

In China with today's rapid economic development, human beings use more and more drinking water, and the requirements for drinking water safety are also gradually increasing. At present, the safety of drinking water carbon quality still poses a great threat to the survival and development of human beings. Although our country has put the water source protection and management work on the key project, and launched a series of water source protection management work, has achieved great effect, because of the geographical location [10], the level of social and economic development and the total amount of water resources, drinking water source protection management in legislation [11], execution level and management means still has a big difference, also lack of unified protection planning and management [12]. Drinking water is a basic demand condition for human survival, and the protection and management of drinking water sources caused by the safety of drinking water are directly related to human survival [13]. In order to ensure the safety of drinking water, China's water conservancy, land and resources, environmental protection, and health departments have taken drinking water safety as their top priority [14], and have successively issued a series of important guiding documents, such as the National Plan for the Safety Guarantee of Urban Drinking Water Sources.

At present, there are two centralized water intake sources in Hezhou city, China. By 2022, these two centralized water intake sources are responsible for about 2.027 million people. The Guishan Reservoir is one of the water sources, bearing the domestic water for more than 1.3 million people. The Guishan Reservoir is the largest drinking water source in Hezhou city. It is a large national reservoir integrating flood control and drought relief, irrigation and water supply, water source protection, and overall power supply. Therefore, strengthening the management of Guishan Reservoir and water source area plays a very important role in flood control, drought resistance, stabilizing water quantity, and ensuring water quality safety. In recent years, with the development of social economy and other factors, the safety problem of the drinking water source of Guishan Reservoir is becoming more and more problematic, and the management loopholes are becoming more and more prominent. This paper analyzes the current management situation, existing problems, and their causes of the drinking water source of Guishan Reservoir and puts forward the relevant countermeasures and suggestions for the perfect management measures.

On the issue of carbon pollution, the government departments have overlapping functions and powers, and their responsibilities are not fully implemented

Hezhou turtle stone reservoir drinking water source centralized jurisdiction belongs to the municipal-related departments, but it involves two counties area, so the management departments, such as the two counties of water bureau, ecological environment, natural resources departments [15], have to manage the turtle stone reservoir drinking water source protection responsibility; this is dispersed the water management power, caused the turtle stone reservoir between the drinking water source management in marginalized management [2], and scattered the relevant departments of turtle stone reservoir drinking water carbon pollution management responsibility [16]. The decentralization of management responsibilities leads to the failure to deal with the carbon pollution problem in water sources.

The protection and management of the water source area is the primary task of building a resource-conserving and environment-friendly society [17]. It directly affects the drinking water safety and life safety of the residents within the scope of the water source area, and affects the sustainable development of the social economy within the scope. Municipal water bureau, the two counties bureau of water, ecological environment, natural resources, and turtle stone reservoir water conservancy project management office in response to the problem of water source carbon pollution enforcement is crucial, including the government responsibility is not really implemented, is led to the water bureau, ecological environment, natural resources in the source of the main cause of the lack of carbon pollution management behavior. The indifference of the reservoir management members to the awareness of carbon pollution and the ecosystem of the water source is the main reason for the differences in the whole management behavior [18]. The Water Resources Bureau, Ecological Environment Bureau and Natural Resources Bureau of the two counties. There are also Guishi Reservoir water conservancy project management office work members in the work to ignore the communication of the departments. It is leading to the Guishi Reservoir drinking water source of carbon pollution management responsibility cannot be clearly divided. Members of the administrative department do not seriously carry out the work related to carbon pollution control in water sources. It is the main reason for the low efficiency of solving the carbon pollution problem in water sources [19]. County-level administrative departments lack an authoritative linkage mechanism and lack of joint management of cooperation efforts. No one is responsible for the carbon pollution problem in water sources and no one to superiors in time is the main reason for the lag of the superior information received. Although the members of the management department are aware of the dangers of carbon pollution from water sources to the entire city of Hezhou, the awareness of handling carbon pollution in water sources is not enough. There is no human management system and incentive and punishment system implemented layer by layer. Lack of a long-term management mechanism, Leading up to solving carbon pollution in water sources, Simple and rough way without refinement, The main reason for the lack of regular regulatory measures.

The solution is to improve the comprehensive supervision and management system and optimize the functions and powers of departments, and implement the work responsibilities. Drawing on the practice of water source management in some areas of China, the reform of the water source management system of Guishan Reservoir in Hezhou city should be implemented the participation management mode of combining river basin management and administrative regional management under the unified leadership of the municipal government. In terms of organizational structure, the leading group for safety management of drinking water source of Guishan water resources is set up, and relevant departments at all levels shall participate in the management of drinking water sources as the members in drinking water sources, and the county government is specifically responsible for the safety management of carbon pollution of drinking water sources [7]. In terms of management power, the division of authority between watershed and regional management should be clarified, the status and authority of watershed management agencies should be strengthened, and the power to manage all water resources in the basin should be unified. The local governments of the two counties in the basin shall obey the basin management agencies, implement the relevant regulations on the protection and management of the basin water sources, and assist the relevant basin management agencies in achieving the carbon pollution control targets of the basin water sources. In terms of management and coordination, the interest coordination mechanism at all levels should be improved, and the joint conference system of water source protection should be established at each level to be responsible for regulating the conflicts of interest caused by water source protection. Do the responsibility to a department, investigate the responsibility line, no longer appear the phenomenon of no one to bear the responsibility.

Turtle stone reservoir water source need Hezhou, Fuchuan Yao Autonomous County, Zhongshan County government bureau, natural resources, ecological environment bureau coordination management, but also need to and Guishi Reservoir water conservancy project management office to build should management mechanism, strengthen Hezhou, Fuchuan Yao Autonomous County, Zhongshan County related departments, do a good job of drinking water source carbon pollution control, ensure the drinking water source carbon pollution control work smoothly, jointly manage Guishi Reservoir water.

Supervision and management of carbon pollution in water sources, and low work efficiency

Due to the lack of scientific and systematic demonstration and the procedure of listening to the government and participating in the government and feedback, the final decision-making behavior focuses too much on economic development, which reduces the attention of carbon pollution and water sources, and ignores the participation of the masses, thus increasing the consequences of the government's "performance leading." Due to the high cost and cost of the process of correction, the negative effect of carbon pollution in water source is difficult to reverse [20], the carbon pollution and the damage of the ecological environment of water source are difficult to recover, and its impact will certainly be long term [21]. At the same time, the imperfect government performance assessment system leads to some government officials to maximize their own interests, to develop the local economy at all costs, and acquiesce in the existence of carbon pollution in water sources, which has caused considerable management pressure to the management departments.

The control of carbon pollution in water sources requires too much capital investment, but the profit generation is slow and cannot be quickly effective, which cannot be paid attention to by the relevant departments of the winning enterprises. Therefore, the relevant policies of carbon pollution control in water sources are delayed or adapted by the relevant administrative departments. Objectively speaking, the current GDP accounting method has caused, to a large extent, that some departments blindly pursue economic growth and ignore the protection and management of water sources, which leads to carbon pollution, ecological destruction, and water depletion of water sources. Facts have proved that most of those areas with rapid GDP growth are often areas with serious ecological environment damage and serious consumption of natural resources.

The rainfall, water quantity, and water quality detection system of the drinking water source of Guishan Reservoir is not perfect. Although water source water quality automatic remote sensing monitoring and early warning system and mobile emergency monitoring system are still insufficient, the monitoring data is not accurate and comprehensive. It is difficult to control water supply information and flood time for the management, leading to bring difficulties in water carbon pollution [22], at the same time to the lives of residents. The increasing pressure of water source protection, coupled with the imperfect and imperfect linkage mechanism of water source management, as well as the lack of effective supervision, assessment, and accountability system, increases the difficulty of the management of the drinking water source of Guishan Reservoir.

The core of the management of drinking water sources is the water quality testing and the prevention and control of carbon pollution in water sources [23]. The water quality standard should be reached by routine testing every month, the water quality standard should be comprehensively tested every quarter, and the water quality standards should be strictly monitored to avoid water pollution.

The monitoring of illegal breeding of livestock and poultry around the water source area should be strengthened [24]. The signs of illegal breeding of livestock and poultry should be timely monitored. The automatic monitoring station of Guishan Reservoir and its comprehensive monitoring center for water source protection shall be established to carry out automatic video monitoring of water supply engineering facilities for the management of drinking water source [25]. Starting with water quality measurement and video monitoring, the drinking water source of Guishan Reservoir shall reach the standard and ensure the safety of drinking water. As the largest reservoir and the main drinking water source in Hezhou city, Guishan Reservoir shoulders the task of drinking water supply for nearly 30 0,000 people along the downstream counties and Hezhou city districts. It strengthens the ecological compensation for the main water source upstream of Guishan Reservoir, establishes an ecological compensation mechanism, and effectively protects the water source from the source.

Laws and regulations on carbon pollution prevention and control in water sources, and management policies need to be improved

Ecological environment general office of the State Council on June 13, 2022, issued by the pollution reduction carbon reduction synergies implementation plan of China on water source of carbon pollution management laws and regulations system is not perfect, the lack of corresponding laws and regulations as the basis of guidance, lead to the management department in the process of water source protection to "heavy economic development, light water resources protection," "cities, light towns," "heavy surface, light underground," "heavy construction, light protection" and "heavy late governance, light early prevention" phenomenon is difficult to get effective correction and regulation. At the same time, the government administration as a manager of social public affairs, in the public and the water-related behavior to guide and regulation, lack, less relevant legal system as a backing, and appear, "cannot", "law enforcement", "illegal", leading to the government administration caused by the lack of their own behavior. It is also difficult for government administrative departments to work together in the control of carbon pollution in water sources, and the phenomenon of mutual evasion, competing interests, and difficult to coordinate occurs from time to time [7].

In addition, the turtle stone reservoir water source protection management and economic development that makes the interests between the upstream and downstream government is difficult to coordinate, leading to lack of the turtle stone reservoir drinking water carbon pollution sources combined with the actual situation to establish and to improve the safety management system and its operation management, operation, operation, report, duty, patrol system, and so on the management system. Therefore, the water quality testing, water source monitoring and early warning, water source protection area division [26], and mass participation involved in the water source management need to be improved. In Hezhou city, there is no unified provision in the relevant laws and regulations for dividing the drinking water area of the Guishan Reservoir, resulting in the focus of the management work cannot be clear.

The solution is to promote legislative work, strengthen policy management support, establish and improve laws and regulations, and improve supporting management policies.

The legislative research work on the management of the drinking water source of Guishan Reservoir was put on the important agenda, and the research working group was set up to carry out the in-depth legislative research work, so as to lay a good foundation for issuing the laws and regulations on the management of the drinking water source of Guishan Reservoir as soon as possible. First, establish and improve the reservoir inspection system. A section-level unit Guishi Reservoir water source inspection brigade has been established, and rules and regulations such as “carbon pollution control responsibility system of Guishan Reservoir drinking water source,” “Guishan Reservoir safety inspection system,” and “reservoir inspection vessel management system” have been formulated. Second, the establishment of the Guishan reservoir duty office, improve the law enforcement tools and testing equipment, effectively ensure the development of inspection work. We will implement the “carbon pollution control responsibility system for pollution in reservoir water sources,” assign the responsibility for controlling carbon pollution in reservoir water sources to county and township governments, establish a regular prevention and control system, and immediately deal with problems found.

Strengthen supervision and management, and intensify the crackdown on illegal acts

The drinking water source of Guishan Reservoir was adjusted in time, such as unreasonable land division and too large drinking water source area. We will carry out development planning for aquatic and animal husbandry, scientifically delimit prohibited and restricted breeding areas, optimize the industrial layout from the source, highlight the modern ecological breeding of livestock and poultry, and supervise and guide the construction of supporting infrastructure of livestock and poultry farms. Ban the planting of fast-growing eucalyptus trees in drinking water sources, strengthen the prevention and control of carbon pollution in water sources, scientifically plan the planting of fruit trees in reservoir areas, and strengthen the construction of wetland parks and water conservation forests. We will severely crack down on the deforestation and upstream nature reserves in the reservoir area to ensure the safety of forest resources around the reservoir area. We will strengthen the approval of projects, strictly control newly expanded production and construction projects in water sources, prohibit the entry of projects that may lead to carbon pollution in water sources, prohibit unauthorized construction, and promote the ecological and economic development of water sources. The Municipal Bureau of Ecology and Environment, together with the Municipal Bureau of Water Resources and other relevant departments, will carry out regular supervision to urge the implementation of the work in all localities. Those who cause carbon pollution from poor duty performance, fraud, and slow progress in drinking water sources will take measures such as public criticism and public interview to promote the work.

Strengthen the construction of water conservation forests and promote the circular development of ecological chain

Guishan National Wetland Park has completed the restoration and maintenance of infrastructure and equipment, etc. The projects under construction include environmental reservoir plant belt, biological fence, wetland botanical garden, ecological embankment construction, beach vegetation restoration, fish reproduction, and habitat protection. It promotes the planting of water conservation forests in drinking water source protection areas and does a good job in confirming the boundary of natural forests around the reservoir area. It is strictly prohibited to plant fast-growing eucalyptus and other trees harmful to water sources next to the drinking water source. The trees planted currently in the felling state should be cut down and cleared within a time limit to avoid causing carbon pollution in the water source sources, and plant tree species suitable for water source protection such as water conservation forest [27], so as to further protect the ecological environment of the reservoir area and the upstream nature reserves of the reservoir area.

4 Conclusions

Due to the ecological construction, perfect infrastructure, and high accuracy rate of water quality testing [28], the local school has strengthened the prevention and control of carbon pollution in the water source area of Guishan Reservoir. However, due to the high overlap in the nature of the work of government departments and poor coordination between departments, there is still much room for improvement in the prevention and control of carbon pollution in the area [29], which also affects the local economic development. This has also affected the local economic development and people's willingness to invest in leisure, reducing the quality of life.

It is recommended that the government optimize the department's efficiency, invest in talent recruitment and upgrading funds, recruit plumbing talents, and improve equipment. The government can invest in the industrial development of mountain forests, herbs, fruit forests, tea trees, etc., provide agricultural subsidies, bring in management personnel, and establish rural cooperatives. The government can use the low trunk canal water-saving system to regulate water quantity, reduce carbon pollution, utilize the surrounding urban development resources, share water and tourism resources, create a safe leisure tourism environment, and promote development. We believe it will guarantee water quality, consider the economic development of villages, guarantee people's leisure and quality of life, and achieve the goal of sustainable development of water resources.

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Greenhouse Gas Emissions Evaluations of Wastewater Treatment Plant—A Case Study of Jiaxing, China

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Abstract This paper provides a comprehensive analysis of greenhouse gas (GHG) emissions associated with a wastewater treatment plant in Jiaxing, China. The study calculated scope 1–3 GHG emissions for all stages of the wastewater treatment system. The study evaluated the sources of GHG emissions and identified opportunities for reducing emissions in the wastewater treatment plant. The results show that the carbon emissions of each stage vary based on the power consumption and the associated emission factors. The study recommends the use of renewable energy sources, energy-efficient technologies, and green supply chain management practices to reduce carbon emissions. The study highlights the significance of considering indirect emissions such as scope 2 and scope 3 emissions to provide a more comprehensive estimate of a facility's carbon footprint. The findings align with previous studies that have emphasized the importance of reducing energy consumption and adopting sustainable practices to improve the sustainability of wastewater treatment plants.

Keywords Greenhouse gas emission · Wastewater treatment · Carbon emission

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1 Introduction

Global warming is a rising concern in the past few decades. China had pledged to reach its CO_2 emissions peak before 2030 and attain carbon neutrality by 2060 in order to lessen the effects of climate change. This objective drives the Chinese government's efforts to find solutions to lower the greenhouse gas (GHG) emissions produced by all sectors of the economy. Urban water systems are responsible for 1–3% of the nation's GHG emissions [1]. Though the percentage is low, for individual cities with high population, the absolute amount of GHG emission by water system is not to be disregarded [2]. According to the data from National Bureau of Statistics of China (NBS), 575 million people in China lives in urban areas by the year 2020, consuming 581 billion cubic meters of water, and produce 94.6 million tons of CO_2, which is approximately equivalent to the total CO_2 emissions of Columbia in 2020 [3]. The number is still increasing as the total population grows.

Many different evaluation methods have been reported to estimate the GHG emissions of water systems at all stages. The most commonly agreed methodologies to estimate national GHG emission are the *2006 IPCC guidelines for National Greenhouse Gas Inventories* [4]. Besides, the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) released the *GHG Protocol Corporate Accounting and Reporting Standard* to provide guidance on GHG accounting in various industries. It introduced three scopes of GHG emission: scope 1 emissions refer to the direct GHG emissions that result from sources that the entity owns or controls; scope 2 emissions are indirect GHG emissions that result from electricity and heat power that the entity purchases and consumes; scope 3 emissions are all other indirect GHG emissions that result from the entity's operations but come from sources not owned or controlled by the entity.

According to the previous studies, many factors affecting the GHG emissions of wastewater systems including: energy use (diesel, coal, gas, electricity, solar power, etc.), local electrical grid, treatment process, etc. [2, 5]. Therefore, the reported GHG emissions of wastewater systems of different cities varied greatly worldwide. Saidan et al. [6] presented a baseline assessment of carbon emission in water utilities in Madaba, Jordan using Energy performance and Carbon Emissions Assessment and Monitoring tool (ECAM tool), the result showed that the energy consumed by the entire water system in Madaba releases 28.122 thousand tons of CO_2 per year, where the water supply system consumed 89.7% of the energy, whereas the wastewater system consumed only 10.3% of the energy [6]. Racoviceanu et al. [7] estimated the life cycle energy use and GHG emissions for water supply system in Toranto, Canada. It was found that the average carbon emission intensity was 0.144 ~ 0.576 $kgCO_2/m^3$, depending on the electrical grid used [7]. Another study by Ma et al. [8] found that the carbon emission of China's urban water supply system was 0.377 $kgCO_2/m^3$. The number was positively related with the economic patterns as it is higher in eastern coastal areas of China than it was in western regions [8]. A study by Zhang et al. [2] reveals that power use is the greatest source of GHG emissions in drinking water services, while in the wastewater system, non-CO_2 emissions sometimes can be significant, depending on the various regional contexts and wastewater treatment technology.

This study presents a systematic calculation of the GHG emissions of wastewater treatment plant in Jiaxing, China. The scope 1–3 GHG emissions were calculated for all stages wastewater treatment system. The results of GHG emission were presented using CO_2-eq. The study will provide a comprehensive view on the source of GHG emissions associated with wastewater treatment plant, as well as additional guidance on GHG reduction opportunities for the wastewater treatment plant.

2 Material and Methods

The Jiaxing United Sewage Treatment Co., Ltd. (hereinafter referred to as "United Sewage") was established in April 2000 and is mainly responsible for the collection, transportation, treatment, and discharge of industrial and domestic wastewater in Jiaxing city (except Tongxiang and Haining). The service area covers more than 1860 km^2 and serves a population of about 2.5 million people. The company has one sewage treatment plant with a processing capacity of 600,000 tons/day, 200 km of transmission pipelines, and 20 transmission lift stations.

Carbon emissions of United Sewage mainly include indirect emissions generated by drug consumption, pump stations, and equipment power consumption, and direct emissions generated by wastewater biological treatment. In this study, the carbon emissions and emission efficiency of each process stage were calculated based on the electricity consumption, drug consumption, and effluent quality of each process stage according to the sewage treatment process of the plant. The process flowchart of the United Sewage Treatment Plant is shown in Fig. 1. For convenience of calculation, the treatment process is divided into three stages, namely (1) pretreatment; (2) oxidation ditch + AAO + MBR; (3) deep treatment; (4) sludge treatment.

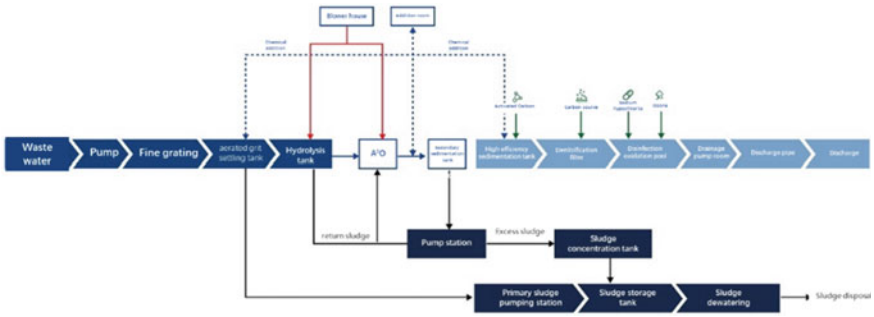

Fig. 1 Water treatment process of the united sewage treatment plant

Wastewater treatment process involves the direct GHG emissions (scope 1), consumption of electricity (scope 2) and chemicals (scope 3). The direct GHG emissions mainly include CH_4, N_2O, and CO_2. The emission of CH_4 is usually generated during the anaerobic digestion process, and it can be calculated as follows:

$$C_{CH_4} = P \times D_{dom} \times \mathrm{B}_0 \times \mathrm{MCF} - R \quad (1)$$

where P is the population which is serviced by the wastewater treatment plant, D_{dom} the per capita annual BOD discharge; B_0 the maximum potential for CH_4 production; MCF the modifying factors and R the volume of recovery CH_4.

In the aerated zones of wastewater treatment, the nitrogen is removed from the system by both nitrification and denitrification reactions, releasing N_2O into the atmosphere. The emission of N_2O is difficult to be quantified by stoichiometry, so empirical conversion rate is required to calculate the emission:

$$C_{N_2O} = Q \times (\mathrm{TNe} - \mathrm{TNo}) \times \mathrm{EFNi} \times 10^{-3} \times \mathrm{GWP}(N_2O) \quad (2)$$

where Q is the total inflow of plants, TNe is the total nitrogen of inflow water, []; TNo is the total nitrogen of effluent water, EFNi is the N_2O–N emission factor of denitrification process and the GWP(N_2O) is the global warming potential of N_2O which is taken value as 265 from the 2019 IPCC guidelines.

There are two sources of CO_2 emissions in wastewater treatment process, one is generated by aerobic decomposition of organic matter, and the other is caused by the microbial endogenous respiration and metabolism, described as follows:

$$C_{CO_2,a} = 1.62Q \times \left(\mathrm{BOD_{e,a}} - \mathrm{BOD_{o,a}}\right) \times 10^{-3} - 1.56yY_t Q\left(\mathrm{BOD_{e,a}} - \mathrm{BOD_{o,a}}\right) \times 10^{-3} \quad (3)$$

$$C_{CO_2,M} = 1.947Q \times \mathrm{HRT_a} \times \mathrm{MLVSS_a} \times K_0 \times 10^{-3} \quad (4)$$

$$K_0 = Kd_{20} \times (\theta_T)^{T-20} \quad (5)$$

where Q is the total inflow of plants; $\mathrm{BOD_{e,a}}$ is the BOD of inflow water; $\mathrm{BOD_{o,a}}$ is the BOD of effluent water; y is proportion of MLVSS in MLSS; Y_t is total sludge yield coefficient, unit kgMLSS/kgBOD_5. Q is the total inflow of plants; HRT_a is the hydraulic retention time of aerobic zone; MLVSSa is the MLVSS in the aerobic zone; K_0 is the attenuation coefficient. Kd_{20} is the attenuation coefficient under 20 °C circumstance, and the study takes 0.04; θ_T is the temperature coefficient, value 1.03; T is the design temperature.

Due to the availability of total sludge yield coefficient, the study use the default value from Wang's study [3]. What's more, greenhouse gas emissions caused by this process are caused by biological catabolism, and the organic carbon degraded in this part is not fossil carbon.

During the water treatment process, the indirect GHG emission is caused by both electricity consumption (scope 2) and the chemical consumption (scope 3), expressed as:

$$W_{WM-E} = P \times EF_{CO_2} \tag{6}$$

$$W_{WM-C} = M_{al} \times EF_{al} + M_{cl} \times EF_{cl} + M_{pp} \times EF_{pp} \tag{7}$$

where W_{WM} is the carbon emission of water treatment, $[M]$; P is the consumption of electricity, $[W]$; M_{al} is the consumption of alums, $[M]$; EF_{al} is the carbon emission factor of alums; M_{cl} is the consumption of chlorine, $[M]$; EF_{cl} is the carbon emission factor of chlorine; M_{pp} is the consumption of potassium permanganate, $[M]$; EF_{pp} is the carbon emission factor of potassium permanganate.

3 Results

In this wastewater treatment plant, the wastewater will be treated by the A_2O biological pool, denitrification deep bed filter, and membrane bio-reactor. So the study also calculates the N_2O emission of the denitrification and the CO_2 emission of aerobic decomposition and microbial endogenous respiration besides the carbon emission of wastewater collection and sludge treatment.

3.1 Wastewater Treatment

Direct carbon emission (scope 1)

The result of direct carbon emissions is calculated according to Eqs. (1–5). The calculated result is given in Table 1. In a word, the total direct carbon emission is 2.66×10^4 tCO_2. The carbon emission of aerobic decomposition takes 65.39% of the total carbon emission. The N_2O emission accounts for 34.56% of the total emission. The emission of microbial endogenous respiration is least part, taking only 0.05% of total emission.

Table 1 Direct carbon emission for wastewater treatment system

N_2O emission (tCO_2-eq)	Carbon emission of aerobic decomposition (tCO_2)	Carbon emission of microbial endogenous respiration (tCO_2)	Total direct carbon emission (tCO_2)
9.19×10^3	1.74×10^4	13.42	2.66×10^4

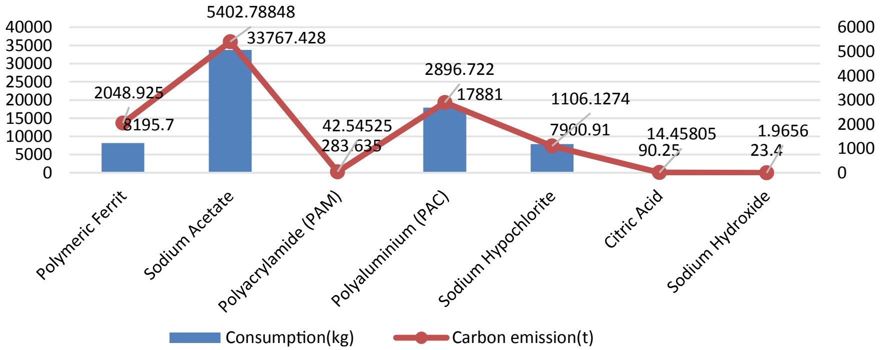

Fig. 2 Carbon emission of agenda consumption

Indirect carbon emission (Scope 2 and scope 3)

The scope 2 carbon emission includes the consumption of agent and electricity. Firstly, the emission of agent consumption is calculated according to Eq. (7). The consumptions of polymeric ferrit, sodium acetate, polyacrylamide (PAM), polyaluminium (PAC), sodium hypochlorite, citric acid, and sodium hydroxide are 8.20×10^6, 3.38×10^7, 2.84×10^5, 1.79×10^7, 7.90×10^6, 9.03×10^4, and 2.34×10^4 kg according to the record provided by the United Sewage. The calculated results are shown in Fig. 2.

The consumption of various agents has resulted in a total carbon emission of 1.15×10^4 tCO_2. Sodium acetate contributes to the majority of this emission, accounting for 44.3% (5.40×10^3 tCO_2) due to its extensive use. The emission caused by PAC accounts for 25.16% of the total emission, while the combined emissions of PAM, citric acid, and sodium hydroxide only amount to 0.52% of the total.

Furthermore, indirect carbon emissions arise from electricity consumption. In this study, we obtained data on the electricity consumption of wastewater treatment equipment from a reliable source. Using Eqs. (8–9), the total electricity consumption of 6.19×10^7 kWh is divided by the volume of sewage treated ($1.90 \times 10^8 m^3$), resulting in an energy intensity of 0.33kWh/m3. The total amount of CO_2 emission is 4.90×10^4 tCO_2.

3.2 *Sludge Treatment*

In the wastewater treatment process, a substantial amount of sludge is generated annually, totaling approximately 1.76×10^5 t per year. The sludge is collected, pumped into a storage tank, dewatered, and then sent to three different refuse incineration plants for disposal. The agent consumption during the sludge dewatering process includes lime (11.4 kg/t), polyacrylamide (0.97 kg/t), and ferric chloride (11.50 kg/

t). The total carbon emissions resulting from these processes were calculated to be 5.279×10^3 tCO_2-eq, which is equivalent to 29.94 kg CO_2-eq per ton of sludge.

The electricity consumption associated with the dewatering process is another important factor to consider. This includes the pumps (5.26 kWh/t) and the centrifuge dewatering machine (5.26 kWh/t). The total carbon emissions resulting from electricity consumption were estimated to be 2.587×10^3 tCO_2-eq, or 29.94 kg CO_2-eq per ton of sludge.

4 Discussion

Only two levels of headings should be numbered. Lower level headings remain unnumbered; they are formatted as run-in headings.

Table 2 gives the carbon emission of wastewater treatment process at different stages. The findings suggest that there is a significant variation in the carbon emissions of different stages, which can be attributed to the energy consumption and the types of emissions associated with each stage. Our results are consistent with the previous studies that have reported the importance of wastewater treatment processes in reducing carbon emissions and mitigating the impact of climate change [2].

The study examined the carbon emissions and energy consumption of different stages in wastewater treatment plants. The pretreatment stage was found to have the lowest power consumption and carbon emissions, with only 1.96% of total carbon emissions. The low carbon emissions of the pretreatment stage can be attributed to the water inlet pump and agent consumption. These findings are consistent with Svardal and Kroiss's (2011) study, which reported that the pretreatment stage has low energy requirements and produces fewer greenhouse gas emissions [9].

On the other hand, the oxidation AAO + secondary oxidation stage had the highest carbon emissions due to its high power consumption and large amount of agent

Table 2 Carbon emissions of wastewater treatment process at different stages

Treatment unit	Power consumption (kWh/m3)	Carbon emission ($kgCO_2$-eq/t)	SCOPE1	SCOPE2	SCOPE3	Total carbon emission (tCO_2-eq)
Pretreatment	0.03	0.02	0.00	2140.77	0.00	2140.77
AAO + secondary oxidation	0.26	0.66	9519.26	19,373.26	32,168.41	61,060.93
Denitrification + Disinfection	0.36	0.40	0.00	27,058.40	10,904.34	37,962.74
Sludge dewatering	18.52	44.62	0.00	2587.53	5279.90	7867.43
Sum	19.18	45.70	9519.26	51,159.95	48,352.65	109,031.87

consumption. Liao et al. (2020) reported that energy consumption in the biological treatment stage is a significant contributor to carbon emissions [10]. Thus, the optimization of energy consumption in the biological treatment stage can help reduce carbon emissions.

The denitrification + disinfection stage was found to have high scope 2 emissions, consistent with He et al.'s (2018) study. The electricity consumption of the denitrification stage is a significant contributor to indirect carbon emissions. However, alternative processes like biological nitrogen removal through oxygenic denitrification can help reduce energy consumption [11].

The sludge dewatering stage was found to have the highest power consumption, which is consistent with Chen and Kuo's [12] findings. The authors reported that the sludge dewatering stage is the most energy-intensive process in wastewater treatment plants and significantly contributes to greenhouse gas emissions [12]. Thus, the implementation of energy-efficient technologies and the recovery of energy from sludge can help reduce the carbon emissions of this stage.

5 Conclusion

The wastewater treatment plant emitted 109,031.87 tCO_2, with scope 2 emissions being the highest due to electricity consumption, accounting for 35.81%. Sludge dewatering and incineration had the highest carbon emissions per ton at 236.46 kg CO_2-eq/t. The carbon emissions of each process were analyzed, with biological treatment in the first and second phases being the highest. The carbon emissions in the first phase were mainly due to drug agents in scope 3, accounting for 52.01%, while electricity consumption accounted for 28.34%. In the second phase, the carbon emissions of AAO were also dominated by scope 3, accounting for 53.12%, while electricity consumption accounted for 33%.

In conclusion, the findings of this study highlight the importance of wastewater treatment processes in reducing carbon emissions and mitigating the impact of climate change. Companies can adopt energy-efficient technologies and renewable energy sources to reduce their carbon emissions and contribute to a sustainable environment. Further research is needed to investigate the potential of carbon capture and utilization technologies in wastewater treatment plants to reduce carbon emissions.

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Comprehensive Evaluation of Water Resources Use in Shandong Province Based on Water Footprint and LMDI Model

Yanlei Duan and Lili Rong

Abstract Based on the water footprint theory, a regional water use evaluation index system was constructed to analyze the temporal change of water footprint in Shandong Province from 2011 to 2020, and the LMDI model was used to explore the degree of influence of the driving factors such as population, economy and technology on the change of water footprint. The results show that the total water footprint of Shandong Province first fluctuates and then decreases. The degree of dependence on water resources is high, and the economic benefit value of water footprint has increased significantly year by year. The water resource stress index and water resource load index are high, the water resources system in Shandong Province is overloaded, the development and utilization of water resources are high, and the potential for redevelopment and utilization is very small. Economic effects have a greater impact on the water footprint than technological effects, and technological effects are greater than population effects.

Keywords Water footprint · Evaluation system · LMDI model drivers

1 Introduction

As a strategic economic resource, water resources play an important role in the sustainable development, namely human well-being, economic development and environmental health [1]. Shandong Province is located in the eastern coast of China and the lower reaches of the Yellow River, with a resident population of 101,645,100 at the end of 2020, accounting for 7.2% of the country's total population. The average water resources per capita is less than 1/6 of the national average, with resource water shortage, engineering water shortage and water quality water shortage co-existing. Water scarcity is the basic situation of Shandong Province and is also an important constraint to national economic and social development [2]. In recent years,

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Shandong Province has taken the lead in exploring and implementing the strictest water resource management system in China, strictly controlling the total amount of water consumption, water use efficiency and the restricted pollution absorption capacity of water function zones, which has significantly improved the level of water conservation. The study of the trend of changes in total water consumption and its driving factors is an important reference for promoting the rational development, use and protection of water resources, optimizing water resources management and building a water-saving society.

2 Review of the Literature

Currently, scholars at home and abroad have carried out many analyses of the drivers of changes in water use and water use structure, with research objects mainly focusing on water use, water use structure and industrial water use [3–7], and research methods including information entropy [5, 10], principal component analysis, structural decomposition analysis methods [11, 12] and exponential decomposition analysis methods. Among them, the logarithmic mean dichotomous index (LMDI) model is simple and convenient to calculate and is widely used in the study of carbon emission and water use driver decomposition [11]. Studies have shown that economic and social development and population growth are the dominant factors influencing the structure of water use [5]. Increasing population numbers, urbanization levels and higher levels of economic development will promote increased water use [10], while technological progress and industrial restructuring will inhibit increased water use [12], with economic restructuring, water conservation levels, population evolution and water demand being the main drivers of change in water use structure [8]. Population growth and changes in residents' lifestyles will lead to an increase in domestic water use [9], and industrial water use is mainly due to a combination of economic growth, industrial restructuring and technological progress [7].

The article uses the water resources data of Shandong Province from 2011 to 2020 to analyze in depth the characteristics of the changes in water resources use in Shandong Province during this period and the differences in spatial and temporal distribution, and based on the LMDI decomposition model, to accurately identify and analyze the factors influencing the changes in total water resources use, with a view to providing scientific reference for optimizing water resources management and building a water-saving society in Shandong Province in the future.

3 Research Methodology

3.1 Water Footprint Calculation Method

Water footprint refers to the amount of water required to consume products and services in a region over a certain period of time, characterizing the use of water resources in the region. The bottom-up approach is used in the paper to divide the regional water footprint into a direct water footprint (physical water) and an indirect water footprint (virtual water) from the perspective of residents' consumption of regional products, where virtual water is the water implicit in residents' consumer goods and can be obtained by multiplying the consumption of agricultural products with the virtual water content per unit of product. The water footprint accounts are composed as follows.

$$\mathrm{WFP} = \mathrm{IWFP} + \mathrm{EWFP} \tag{1}$$

$$\mathrm{IWFP} = \mathrm{WU_a} + \mathrm{WU_i} + \mathrm{WU_d} + \mathrm{WU_e} - \mathrm{VWE_{dom}} \tag{2}$$

$$\mathrm{EWFP} = \mathrm{VWI} - \mathrm{VW}_{i-e} \tag{3}$$

The total water footprint (WFP) is equal to the internal water footprint (IWFP) of the region plus the external water footprint (EWFP). IWFP is defined as the total water demand within the region to supply the goods and services consumed by the local population; EWFP is the total virtual water imported from outside the region. WU_a is the water demand for agricultural production in the region (excluding losses in agricultural irrigation), including crop water demand (WU_{a1}) and animal water demand (WU_{a2}); WU_i, WU_d and WU_e, respectively, represent the water demand for industrial production, domestic use by the population and ecological environment in the region; $\mathrm{VWE_{dom}}$ and VWI denote the virtual water exported and imported in the region; VW_{i-e} denotes the virtual volume of water exported to other countries or regions for reexport of imported products.

3.2 Construction of a Comprehensive Evaluation Index System for Water Use

The water use evaluation indicator system includes three main levels of water footprint structure, namely indicators, efficiency indicators and pressure indicators Table 1.

Table 1 Water use evaluation indicator system

Evaluation indicators		Formula	Meaning
Water footprint structure indicators	Water import dependency	VWE/WFP	Dependence on external water resources
	Water self-sufficiency rate	IWFP/WFP	Dependence on internal water resources
Water footprint benefit indicators	Water footprint per capita	WFP/P	Water footprint possession per capita
	Water footprint economic benefit values	GDP/WFP	Level of economic benefits from water footprint consumption
	Water footprint land density	WFP/T	Consumption of water resources per unit of land area
	Water footprint net trade volume	VWE − VWI	The role of water resources in trade
	Water resource value conversion rates	VWI/VWE	The proportion of currency value exchange exhibited by the water footprint in import and export trade
Water footprint pressure indicators	Water loading index	$\mathrm{CK}\sqrt{PG}/\mathrm{W}$	Water resources in relation to population and economic development
	Water stress index	WFP/WA	Water consumption as a proportion of total available water resources
	Water footprint and economic development decoupling index	$E_g = (G_t - G_{t-1}) \big/ G_{t-1} - \mathrm{WF}_t - \mathrm{WF}_{t-1} \big/ \mathrm{WF}_{t-1}$ $E_p = (P_t - P_{t-1}) \big/ P_{t-1} - \mathrm{WF}_t - \mathrm{WF}_{t-1} \big/ \mathrm{WF}_{t-1}$	Water consumption as a proportion of total available water resources

3.3 Calculation of the Contribution of Water Footprint Drivers

The LMDI model is commonly used to predict the degree of influence and driving force of different influencing factors in relation to the study subjects. Based on the LMDI model, the article divides the social factors among the driving influences of water footprint change into three parts: demographic factors, economic factors and technological factors, and the contribution calculated as (4)–(8).

$$\mathrm{WFP} = \sum_i \mathrm{WFP}_i = \sum_i P_i \times \frac{\mathrm{GDP}_i}{P_i} \times \frac{\mathrm{WFP}_i}{\mathrm{GDP}_i} \tag{4}$$

$$\Delta\mathrm{WFP} = \mathrm{WFP}_t - \mathrm{WFP}_0 = P_e + A_e + T_e \tag{5}$$

$$P_e = \Delta\mathrm{WFP} \sum_t \frac{\ln P_t - \ln P_0}{\ln \frac{\mathrm{WFP}_t}{\mathrm{WFP}_0}} \tag{6}$$

$$T_e = \Delta\mathrm{WFP} \sum_t \frac{\ln \frac{\mathrm{WFP}_t}{\mathrm{GDP}_t} - \ln \frac{\mathrm{WFP}_0}{\mathrm{GDP}_0}}{\ln \frac{\mathrm{WFP}_t}{\mathrm{WFP}_0}} \tag{7}$$

$$A_e = \Delta\mathrm{WFP} \sum_t \frac{\ln \frac{\mathrm{GDP}_t}{P_t} - \ln \frac{\mathrm{GDP}_0}{P_0}}{\ln \frac{\mathrm{WFP}_t}{\mathrm{WFP}_0}} \tag{8}$$

where and respectively refer to the contribution of demographic, economic and technological factors to the change in the water footprint; ΔWFP refers to the change in water footprint from the base year to year t. refer to the total population in the base year and in year t. refer to the total water footprint in the base year and in year t. and means the GDP in the base year and in year t.

3.4 Data Sources

Data on crop water requirements were obtained from meteorological stations in the FAO CLIMWAT 2.0 and the Water Resources Bulletin of Shandong Province 2011–2020. Data on environmental and economic indicators were obtained from the Statistical Yearbook of Shandong Province 2011–2020 and the EPS database. Virtual water data for animal products were obtained from the study on China [13].

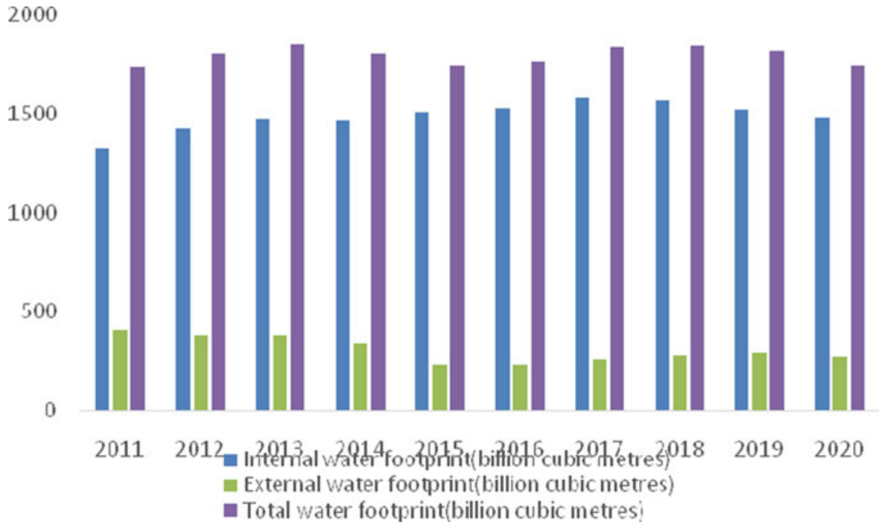

Fig. 1 Total water footprint of Shandong province, 2011–2020

4 Results and Analysis

4.1 Total Water Footprint Change

As can be seen from Fig. 1, the total water footprint of Shandong Province in the past 10 years has shown a cycle of first increasing and then decreasing. The average growth rate of water footprint from 2011 to 2020 is nearly 0.30%, and the average per capita water footprint is 1805.29, which is lower than the national level. The internal water footprint also increases first and then decreases, which accounts for most of the total water footprint, indicating that the change of the water footprint is mainly dominated by the internal water footprint; the external water footprint is highly volatile, with its value fluctuating from high to low. Especially under the adverse impact of financial crisis and US-China trade war, the external water footprint declined more significantly, indicating that Shandong Province's external economic trade is vulnerable to market, policy and other factors and is more volatile.

4.2 Changes in Water Footprint Structure

From 2011 to 2020, Shandong's water resources self-sufficiency rate will be over 75%, which is lower than the current average of 84.0% for China and 93.6% for the world. This shows that Shandong's water resources self-sufficiency rate is low and its dependence on water imports has been at a high level, which is closely related to the uneven distribution of precipitation and low water use efficiency in Shandong.

4.3 Changes in Water Footprint Benefits

Calculated from the water footprint benefit indicators, the economic benefits of water footprint continue to grow, with a maximum value of 38.88 RMB/m^3 in 2020.Water footprint land density is affected by the level of urban development, industrial layout and other factors and grows year by year, and the trend is similar to the total water footprint. Water footprint net trade fluctuates greatly. The water footprint net trade volume is positive and the water footprint value conversion ratio < 1, indicating that Shandong Province is the water exporting place in the virtual water trade in this period.

4.4 Water Footprint Pressure Changes

Calculated from the water footprint pressure indicators, both the water stress index and the water load index for Shandong Province show fluctuations. Analysis of the water resource load index shows that water resources are highly exploited and have little potential for re-exploitation, requiring water transfers or the use of guest water. The water stress index is generally on the rise and all values are greater than 1, indicating that the water resources system in Shandong Province are severely overloaded. The decoupling index of water footprint and economic development shows that economic growth and water resources use in Shandong Province have been decoupled in the last decade, indicating that economic development and water resources use are relatively well coordinated. However, the decoupling relationship between water resources and population growth is reversed. In years where water resources and economic development are well coordinated, population growth is not decoupled from water resources use, and the two are in a state of dissonance.

4.5 Water Footprint Driver Changes

The article further explores the drivers of water footprint in Shandong Province based on the LMDI model, and the contribution of each driver is shown in Table 2.

In terms of population effects, the population of Shandong Province increases steadily between 2011 and 2020. There are fluctuating changes in the total water footprint, and there is no significant correlation between total population and changes in the total water footprint. The population effect shows a positive driving force during the study time period and the contribution rate is the smallest, for 3.10%. In

Table 2 Breakdown of water footprint drivers in Shandong province, 2011–2020

Driving factors	Multi-year average contribution	Percentage of contribution (%)	Direction of drive
Population	0.79	3.10	Positive
Technology	− 10.41	40.76	Negative
Economy	14.33	56.13	Positive

terms of economic effects, rapid economic development has accelerated urbanization, resulting in an increase in the total water consumption of the three major industries. Overall, the economic effect is the most significant cause of change in water use, accounting for 56.13% of the human drivers. In terms of the technology effect, with technological innovation and the use of various water-saving devices, the efficiency of water resources use has been improved, and the water consumption per unit of product has started to decrease. Therefore, the technology effect shows a negative driving effect on the water footprint. The contribution of the technology effect to the change in water footprint is second only to the economic effect at 50.76%.

5 Conclusion and Outlook

(1) During the period 2011–2020, the total water footprint of Shandong Province first increased and then decreased, and the trend of change in per capita water footprint is similar to the trend of change in total water footprint. The self-sufficiency rate of water resources in Shandong Province is low, and the degree of external dependence on water resources is high. (2) Among the indicators of water footprint benefits in Shandong Province, the value of water footprint economic benefits increased significantly year by year from 2011 to 2020, and water use benefits continued to improve, and the trend of change in water footprint land density was basically consistent with the trend of change in total water footprint. The net trade volume of water footprint is positive and the water footprint value conversion rate < 1, indicating that Shandong Province is the water exporting place in the virtual water trade in this period. (3) Based on the LMDI model, the degree of influence of human drivers on the change of water footprint in Shandong Province is: economic effect > technological effect > demographic effect, which shows that the economic effect is the most important reason for the change of water use. (4) In order to promote the sustainable use of regional water resources, in response to the shortage of water resources caused by population factors, the local government should vigorously promote knowledge of water resources protection and continuously increase people's awareness of water conservation and protection in order to cope with the decline in the capacity of water resources to support the population in recent years. As economic and technological factors are the main factors influencing changes in water resources use, the authorities also need to take into account the protection of water resources in parallel with

economic development, to make reasonable and effective adjustments to the industrial structure and encourage the development of industries that require less water, as well as to promote the use of water-saving technologies in production and daily life, so as to further improve the utilization of water resources and thus promote the sustainable use and development of water resources in Shandong Province. Due to the limited length of the time series of the relevant statistics, the calculations of the internal and external water footprints are sketchy, and the improvement of the formulae is an area that needs to be strengthened for future research. Future research will also need to consider the heterogeneous spatial distribution of water resources in Shandong Province in order to better optimize the allocation of water resources within the region.

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Analysis of the Current Situation, Demand, and Factors Influencing Agricultural Water Rights in China

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Abstract By combing the literature on water resources property rights and water rights confirmation, we summarize the experience and shortcomings in the construction of China's water rights system and put forward corresponding suggestions on China's agricultural water rights confirmation through the current situation, influencing factors and the experience of confirmation of rights in foreign countries with high efficiency in water use. Agricultural water rights should be confirmed according to the actual local situation, promote the policy of confirming agricultural water resources rights to households, strengthen the maintenance and renewal of old water conservancy facilities, improve the system of confirming and registering agricultural water rights, optimize the allocation of agricultural water rights, promote agricultural water conservation, and improve the efficiency of water resources utilization.

Keywords Water rights · Rights experience · Rights registration · Water conservation in agriculture.

1 Literature Review

Water rights refer to the right to obtain the maximum water intake from a certain water body (surface or groundwater) within a certain period of time. Agricultural water right is a water right closely related to the irrigation behavior of farmers [1], the concept of water right has formed "one right," "two rights," and "multiple rights". The "one right theory" believes that the right to water is the right to use or benefit from water resources [2]. According to the "multiple rights theory," the water right is a collection of all rights, such as ownership, possession, domination, and disposal rights [3]. Agricultural water right is the right to take water in agricultural irrigation [4]. Agricultural water rights are divided into ownership, abstraction, and water supply rights [5]. Regarding the research on the initial water rights of basin water resources

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to confirm the rights, Wu and Ge [6] constructs a provincial initial water rights allocation model based on the mechanism of rewarding the best and punishing the worst to unify the allocation of water rights and sewage rights, Guan et al. [7] applied the Gini coefficient method to allocate water rights among farmers in irrigation districts, providing a new idea for water rights allocation in irrigation districts. Yao et al. [8] established a multi-objective planning model to reasonably allocate county water rights to various water use sectors in response to the increasingly intense water use conflicts between different water use sectors. In terms of the demand for confirmation of rights, a good water rights market is one of the effective means to break the main contradictions of water resources management in the new era [9, 10]. The initial water rights allocation and redistribution mechanism in the water rights system is concretized in practice as water rights confirmation and water rights trading. Although many studies have been conducted on water rights and various practical attempts have been made to promote water rights, in general, the practice has only had good results in some pilots, showing small scale and decentralization, and the universal aspect of the rights recognition method still needs to be verified. In the following part of this paper, we will propose a practical and feasible solution for water rights recognition based on the current situation of water resources in China and the experience of foreign countries in water rights recognition.

2 Analysis of the Demand for Agricultural Water Rights in China

2.1 The Current Problems of Agricultural Water Resources Utilization

As shown by the China Water Resources Bulletin, China's total water resources in 2021 was 2.95 trillion cubic meters, ranking sixth in the world, with a per capita water possession of about 2007 m^2, only 25% of the world's per capita level, making it one of the 21 water-poor and most water-scarce countries in the world. China as a large agricultural country, the total amount of water used in agriculture accounts for more than 60% of the total water consumption, but the problem of water shortage in agricultural production is still serious; in July 2022, due to weather and other aspects of the Yangtze River Basin, there is a major drought, many provinces, lookout fields, and irrigation areas at the end of serious drought gets affected; Anhui, Jiangxi, Hubei, Hunan, and, Chongqing, which are Sichuan six provinces (municipalities directly under the Central Government) about 830,000 people and 160,000 large livestock due to drought water shortage affect. The shortage of agricultural water resources and water conservation once again attracted widespread public attention. In the agricultural water shortage at the same time, there is a serious waste of agricultural water, the effective utilization coefficient of agricultural irrigation water in 2020 is

0.565, and the efficiency of water use is only one-third of the efficient water use countries.

2.2 The Premise of Agricultural Water Rights Trading

As a basic production factor of industrial production, water resources have a direct impact on industrial output and high-quality development. With the development of industry, some regions and industries have serious water shortage problems, and in order to meet this part of industrial water demand, some regions have serious groundwater overdrawing leading to the emergence of a large number of leakage areas, in order to protect the ecological environment and prevent the phenomenon of groundwater overdrawing in that regions. In order to protect the ecological environment and prevent the phenomenon of groundwater over-exploitation, some regions have banned new water use targets and promoted water conservation in industry in this way, but local governments have even transferred agricultural water targets to industry without compensation in order to maintain economic development, which greatly damages the interests of farmers. The theory of political economy shows that there are two prerequisites for commodity exchange: firstly, there is a social division of labor, and only agricultural irrigation water savings can be exchanged; secondly, there is a need for a clear property rights system, and agricultural water rights need to be defined.

3 The Current Situation and Problems of Agricultural Water Rights Affirmation

In July 2014, the Ministry of Water Resources selected seven provinces (autonomous regions), namely Inner Mongolia Autonomous Region, Jiangxi Province, Henan Province, Hubei Province, Guangdong Province, Gansu Province, and Ningxia Hui Autonomous Region, to launch a national pilot project on water rights to carry out water resources use rights affirmation, water rights trading and flow, and water rights system construction. By the end of 2018, all seven provinces (autonomous regions) passed the joint acceptance of the Ministry of Water Resources and the relevant provincial people's governments, while Hebei Province, Xinjiang Uyghur Autonomous Region, Shandong Province, Shaanxi Province, Zhejiang Province, and Heilongjiang Province have also carried out provincial water rights pilot projects, exploring in pilot areas around regional water extraction rights, irrigation water users' water rights, etc., basically exploring the main types and ways to confirm the rights. In the pilot areas, the main types and ways of water rights have been identified, the boundary constraints of water rights have been clarified, and the ways and means of water rights have been identified. In Ningxia Autonomous Region, e.g., through water rights reform, water use efficiency has been significantly improved, and compared with 2013, the effective utilization coefficient of agricultural irrigation water in the whole autonomous region increased from 0.464 to 0.511; in 2016, the initial establishment of the water rights system has promoted economic and social development and water ecological environment restoration and improvement. Although the development of agricultural water rights in China has been rapid, the following problems still exist.

3.1 Willingness to Confirm the Right

In the Yellow River, inland river areas in Northwest China and North and Northwest China, where water resources are seriously scarce and water use conflicts are prominent, farmers' willingness to save water and to confirm their rights is strong. Farmers in the Yellow River Basin have a certain awareness of water conservation and water saving potential. Farmers lack enthusiasm for agricultural water rights confirmation in most water-abundant areas in the south, where water use conflicts are small; according to the China Statistical Yearbook and the China Population and Employment Statistical Yearbook, the average years of education in rural areas nationwide in 2019 was 7.94 years, which is the average level of junior high school, and the education level is low, so farmers have less knowledge about agricultural water rights confirmation, and the work of confirming rights to households is slow. In order to protect farmers' rights and guarantee food security, the price of irrigation water for farmers is very low, and the national average price of irrigation water is 0.1 yuan/m^3 in 2021, while the price of domestic water is basically 3–5 yuan/m^3.

3.2 The Degree of Agricultural Water Rights

At present, agricultural water rights are mainly divided into three levels. At the first level, based on the established total water resources control in the city, the water administration department determines water rights to the township level with reference to the Agricultural Water Quotas, taking into account the agricultural water use over the past few years, groundwater volume and other factors; at the second level, the township is the main body of distribution, and the irrigation quota is used as the measure, and water rights are determined to the village or water use according to the irrigation area, planting structure, surface water supply, and other conditions. The third level, the administrative village or water use association in accordance with the village or the water use association of the total control indicators, irrigation area, and planting crops as the basis for the right determine the right to agricultural water rights to individual farmers. According to the water rights pilot projects that have been conducted, only in a few areas in some provinces, agricultural water rights have been confirmed to the third level, and the vast majority of areas in China currently only have agricultural water rights confirmed to the first or second level. Since the relevant statistical data and yearbooks do not provide accurate statistics on the level of rights confirmation in each region, a questionnaire for farmers in nine provinces of the Yellow River Basin was used to illustrate.

3.3 The Right to Confirm the Equipment and Means

The current agricultural water measurement methods are: in the irrigation canal system supporting the sluice gate, the ferry and other buildings, the use of the principle of measuring water hydraulics to measure overflow; facilities water ruler to observe the water level, the use of water level flow relationship to calculate the flow; the use of mechanical water meter, electromagnetic flow meter ultrasonic flowmeter and other instruments automatically measured; according to the water and electricity relationship to turn the coefficient and other indirect estimation methods for measurement; lead canal irrigation, and the use of irrigation area to calculate irrigation way of time. More accurate ways are supporting sluice and mechanical water meter way, but at present these facilities and technology are vulnerable to section instability, backwater, winter freezing, and swelling, and water rich in sand and impurities and many other affects, resulting in increased difficulty and accuracy of measurement; especially for the Yellow River sediment transport, high sand content of the river, the water meter is very easy to damage, and supporting sluice and mechanical water meter installation requires not only a single installation in fields, while the need to build reservoirs, rivers, and irrigation in districts between the water network pipeline at some areas, construction costs are huge due to urban development; the continuous implementation of urban village transformation, relocation of villages and other programs resulting in for rural metering equipment is old, and the government is not willing to update maintenance. If pipeline deployment and installation of metering equipment are carried out by farmers at their own expense, then the cost of defining and allocating exclusive water rights borne by each farmer is very high.

4 The Impact of Agricultural Water Rights to Confirm the Analysis of Factors

4.1 Economic Factors

At the township level, the cost and benefit of defining water rights is the main reason for the impact of agricultural water rights, the cost of defining water rights is mainly composed of the exclusive cost of property rights and internal management costs, including the exclusive cost of defining property rights, allocation, implementation and follow-up supervision, and implementation costs. Internal management costs are the management costs, time costs, and information costs incurred within the club. The benefits of carrying out the definition of water rights mainly consist of the amount of water savings transactions to gain revenue (see Fig. 1), in the first stage, the average amount of water savings increasing, the club property rights should not stay at this stage and should continue to promote the identification of rights to make the amount of water savings rise; in the second stage, the starting point, the average yield of water savings reached the highest point, at the end of the marginal yield of water savings to zero. The average yield decreases, the marginal yield is less than the average yield, and the total yield increases. In the third stage, the marginal yield is negative, and the inputs consumed to further promote the rights are higher, and instead of increasing the water savings, they will make the water savings decrease. It can be seen that in the second stage the water rights club carries out water rights to confirm the decision space to generate water savings and to define the marginal yield for the lower right slope. MCA indicates the marginal exclusion cost of defining water rights, with N denoting the number of people chasing the value of water resources, as N increases, MCA decreases, MCB is the marginal internal management cost, as N increases, MCB increases. MCA and MCB together constitute the total marginal cost of defining water rights MTC.

MTA represents the boundary exclusion cost of water rights definition (see Fig. 2), MB represents the marginal benefit of defining water rights, because in reality, only the marginal exclusion cost is considered, so the intersection of MTA and MB represents the "realistic scale" of water rights transactions, the number of members of agricultural water rights clubs at this time is Q_A, but the cost of defining water rights also includes internal management costs, so the total marginal cost of implementing water rights definition of agricultural water rights clubs is MTC, and the intersection of MB is Q_B, $Q_B < Q_A$, that is, under the existing factors, the degree of agricultural water rights validation is high, and there is still potential to further reduce the size of the right.

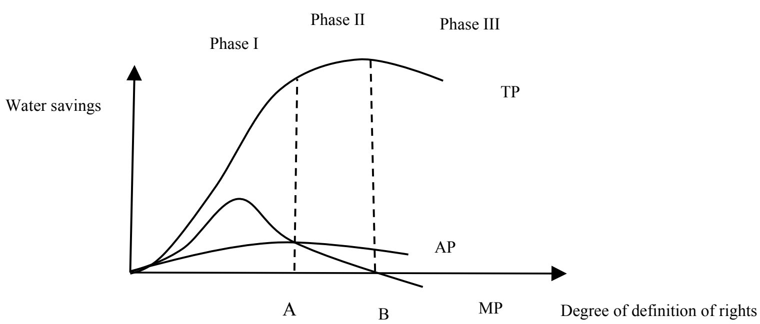

Fig. 1 Agricultural water rights club to identify the right interval

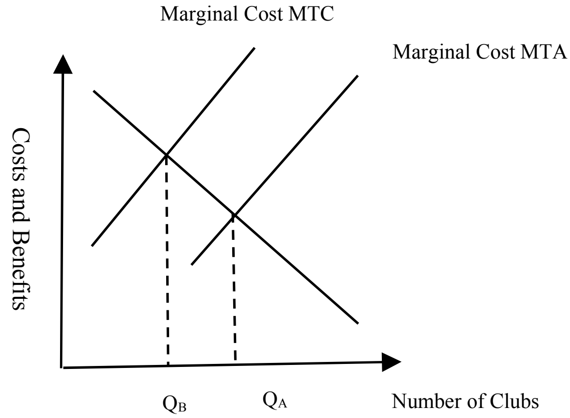

Fig. 2 Size of agricultural water rights clubs

5 The Experience of Agricultural Water Rights and the Proposal to Confirm the Rights to Households

5.1 Foreign Experience

Australia's Water Rights Experience

Australia is a world-renowned agricultural and livestock country, about 35% of the water used for livestock, about 27% of the water used for agriculture, the per capita arable land area of about 27 acres/person, which is the largest per capita arable land area of the country, Australia's annual precipitation of about 4600 mm, and seriously uneven distribution, for water shortage countries. Australia's water resources use rights which are divided into coastal water rights, irrigation water rights, and water abstraction rights, and their rights and management are characterized by hierarchical management, clear rights, and responsibilities. According to the Victorian Water Act, water rights are rights to abstract, use, divert, transfer, and deliver water rights according to conditions. Australian water rights are characterized by the registration of water rights in as much detail as possible, similar to "real estate registration" including: water quantity, water use, type of water conveyance rights, subject of rights, duration of rights, location, effective quantity of water, allocation of water, basic use, obligations associated with the rights, and changes in rights. Australia, like China is a water shortage country, but through the water rights registration system and water rights trading system and water rights trading system, Australia has improved the efficiency of water facilities and water supply systems, improved the management of water resources, given full play to the role of the market mechanism for the allocation of water resources, and promoted the sustainable development of water resources, and brought significant economic, social, and environmental benefits. Australia's experience in water rights registration, the registration of water rights in as much detail as possible to record all the rights and obligations, improve the role of market mechanisms for the initial allocation and reconfiguration of water rights. China's experience: In the implementation of water rights, China should focus on the relationship between natural resource property rights and real estate registration, the implementation of a hierarchical management system, and the development of a detailed water rights registration system.

Chilean Water Rights Experience

The type of water right in Chile is a proportional water extraction system. Chile's arable land area is 16,600 km^2, Chile's agricultural population is 2,374,000, the per capita arable land area is 0.007 ha, about 0.01 acres per person, while Chile's water resources are seriously scarce, Chile through continuous improvement of laws and regulations will use water rights and land use and ownership rights separate, encourage the government to intervene in private water rights as little as possible, to protect private water rights, and reduce transaction costs and barriers to trade. The Chilean government attaches importance to the rationality of the initial allocation of water rights and implements a centralized water rights allocation based on respect for historical water use, with the national public sector registering the initial allocation of water rights, and the Chilean Water Use Association playing a larger role in the management of water rights, responsible for managing water facilities and the transfer of water rights. Chile's experience with water rights: the government has strengthened the protection of private water rights and promoted the role of market mechanisms in promoting water rights. China's experience: agricultural water rights need to improve the relevant laws and regulations, clear protection of agricultural water rights and explore the use of market-based ways to promote agricultural water rights, such as local water enterprises to invest in agricultural rights.

5.2 *The Proposal of Confirming the Right to the Household*

The confirmation of agricultural water resources rights to households is based on insisting that the ownership of water resources belongs to the state, and confirming the ownership and revenue rights of agricultural water resources to households by calculating the irrigated area and crops of farmers (households are the most basic production and consumption units in rural areas). Farmers' water conservation, at present, about the rural arable land, grassland, forest land, and other resources basically realizes the confirmed right to the household, but water resources are different from other natural resources, high mobility hinders the accurate measurement of agricultural water use, then in the case of non-measurement to the household to promote the confirmed right to agricultural water use to the household, the following recommendations will be given.

5.3 Calculate the Amount of Allocable Water Rights for Agricultural Irrigation

First, on the basis of securing ecological water, implement step-by-step water withdrawal measures for irrigation districts or organizations with water withdrawal certificates, first determining the water withdrawal rights of irrigation districts, and then determining the water consumption rights of farmers or individuals. To calculate the amount of water rights that can be allocated for agricultural irrigation, at this stage, China's agricultural water rights are still determined based on the irrigation area, and the principle of "water goes anywhere, water is determined by mu," the irrigation area of farmers is approved according to the law, and the crops are planted, the net irrigation quota of crops, the area proportion of crops, and the water utilization coefficient are fixed, and for each irrigation area, a "standard field," according to the water consumption of the standard field to calculate the average mu quota to go in and establish the right.

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Economic Vessel to Clean the Polluted Water by Solid Waste in Waterway

Milad Khatib and Bassam Mahmoud

Abstract Lebanon is a country known for its abundance of water resources (natural and artificial). Numerous ports and tourist beaches exist along its coastline with the Mediterranean Sea. This positioning provides high resources, which are essential for the Lebanese economy. Solid wastes polluted almost all rivers and lakes for several reasons: Most of them are related to bad sewage systems, industrial wastes, and even from the Flora distributed along the rivers. Unfortunately, today, the Lebanese water pollution problem has become severe. Worse than the 2015 garbage crisis, which remains unsolved so far, Lebanese beaches are covered by solid wastes, besides that rivers and lakes are polluted with poisonous substances. It becomes urgent to find a solution for the accumulated solid wastes in the waterways and in the coastal regions. To maintain the environmental system, several researchers, around the world, designed and produced different machines to collect aquatic solid wastes, and to check their physical characteristics. Such machines are expensive referring to the bad economic crisis that occurred in Lebanon and the surrounding countries. The aim of this study is to produce a new vessel machine that has a navigation ability to reach the polluted zone in the waterways, collect the floating solid waste, and transport it to the shore to evacuate them. This new vessel still has the same quality and performance already existing in the international market, while reducing the cost of manufacturing, operation, and maintenance.

Keywords Environmental sustainability · Solid waste · Physical characteristics · Waterways · Vessel

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1 Introduction

The term “solid waste” refers to a wide range of garbage substances produced by both human and animal activities that are disposed of as undesirable and unusable. Solid waste is produced in a given area by factory, domestic, and business operations and can be disposed of in a variety of forms. As a result, waste is divided mainly into hygienic, provincial, demolition, construction, and industrial waste places. In addition, waste is classified according to its composition, such as glass, plastic, metal, and organic waste. The term hazard potential, such as radioactive, flammable, contagious, poisonous, or non-poisonous wastes, is also used to classify waste. Solid waste includes not only solid but also semi-solid, semi-liquid, and solid in liquid wastes too [1].

The reason for the exponential rise in the generation of solid wastes and rise in solid waste pollution is attributed to uncontrolled human population growth, rapid urbanization, and industrialization. Environmental contamination caused by inadequate solid waste disposal is a worldwide problem. The primary waste treatment and disposal systems used in low-income countries are dumping and burning [2].

Inappropriate municipal solid waste management causes problems with health and safety. Mosquitoes and rats are attracted to the waste, where they may spread illnesses such as cholera and typhoid fever. The Health Department of the United States analyzed 22 viral infections related to inappropriate municipal solid waste management [3, 4].

According to the United Nation Environment Program, an estimated 11.2 billion tons of solid waste is collected worldwide every year. In addition, the decay of the organic proportion of solid waste is contributing to about 5% of global greenhouse gas emissions [5].

Water is a natural resource that is important for all kinds of life, agricultural production, and economic growth. Water is also among the most controllable land and resources since it can be diverted, transported, stored, and recycled. All of these characteristics contribute to water’s high value for humanity. The country’s groundwater and surface water are essential to cultivation, energy production, animal development, industries, aquaculture, waterways, and other industries. The world’s aquatic ecosystem cover just around 0.5% of the earth’s crust with a volume of approximately 2.84×105 km^3. Rivers cover a little portion of the earth’s surface (0.1%). River channels contain just 0.01% of the world’s water. Despite their little quantity, rushing waterways are extremely important [6].

The need for freshwater has risen significantly in recent years because of rapid population increase and the increased rate of modernization [6]. Many agricultural production projects endanger health and nature, especially those that involve a high level of pesticides and filthy environments [7]. The quality of the water has deteriorated in many regions of the world because of human activities such as intensive agriculture and manufacturing, in addition to population and urban growth [8–10]. Moreover, limited water supplies have made water contamination control and water performance improvement extremely difficult [11]. Because of severe water contamination and worldwide lack of water resources, maintaining river water quality is vital.

Regarding pollution controls that protect the cleanliness of rivers, ponds, and wetlands, garbage, litter, and rubbish often finish up in such surface waterways. Since surface waters accumulate in poor places, everything deposited or thrown into a watershed will end up in a drainage way. Trash and litter (solid waste) are frequently carried by drainage systems in urban centers. These things are occasionally improperly thrown directly in a waterway, or dumped on shoreline in urban and rural regions.

Waste management is one of the biggest environmental challenges in Lebanon. The waste stream is steadily increasing in volume, especially with respect to municipal solid waste, industrial waste, hazardous waste, and agricultural waste. The composition of waste is also becoming more complex and varied, containing increasing amounts of plastics, chemicals, and electronics, placing increasing demands for sustainable waste management strategy in Lebanon in order to safeguard human health, natural ecosystems, and sustainable development.

Almost, 80% of ocean plastic comes from 1000 main rivers of the world. A recent study estimates that more than a quarter of all that waste is pouring in from just ten rivers, eight of them in Asia [12]. Demand for measures to tackle plastic waste is on the rise. On March 2 2022, 175 countries supported a historical decision at the United Nations Environment Conference in Nairobi to stop plastic pollution and build a worldwide written legal accord through the end of 2024 [13].

2 Methods

Many methods and equipment were developed to cutting down on single-use plastic and increasing recycling rates, because they are important measures to combat ocean and sea waste. A $250G trash-skimming ship was purchased to help clean up the Merrimack River [14].

Every year, the countries around the world produce 2.01 × 109 tons of municipal solid wastes. At least 33% of this amount was not treated in an ecologically professional way. Wastes produced per person per day in the world averages 0.74 kg but varies greatly, ranging between 0.11 and 4.54 kg. Despite having just 16% of the planet's population, the high-income economies produce around 34% of the world's garbage, or 6.83 × 108 tons [15]. As per conservative estimates, Lebanon generates around 7200 tons of municipal solid waste per day, out of which 48% is land filled, 29% openly dumped, 15% composted, and only 8% recycled. Waste distributions per caza and compositions are represented in Figs. 1 and 2, respectively [17].

In Lebanon, several municipalities (especially those located outside Beirut and Mount Lebanon) engaged in waste disposal, which include riverbank dumping [16]. The aim of this research is to develop a new economic vessel that can be useful in the country having low or bad economic. This vessel was designed regarding the

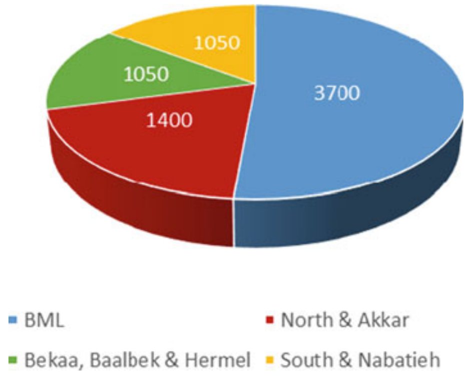


Fig. 1 Waste distribution in Lebanon (tons/day) [17]

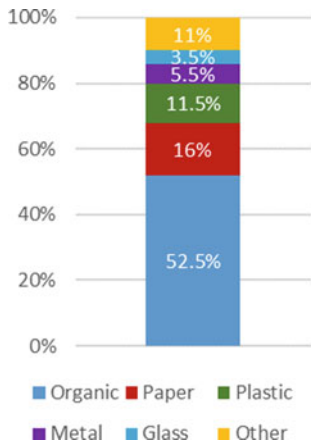


Fig. 2 Urban/rural in Lebanon [17]

international quality and high performance. In this research, the mechanical parts will be studied, and moreover the cost efficiency will be mentioned to show the achieved reduced amount for execute it.

3 Design of the Vessel

This new vessel, which serves as waste collector, is constituted from eight different sections, depending on their mechanical roles. This collector is made up of the floating body (the Catamaran pontoon). All equipment, system of conveyors for collecting floating solid waste, storage and final unloading of waste, in addition to other tertiary systems, such as the control cabin, the propulsion engine, the hydraulic system, which are integral for the operation of the collector form the different parts of this vessel (Fig. 3).

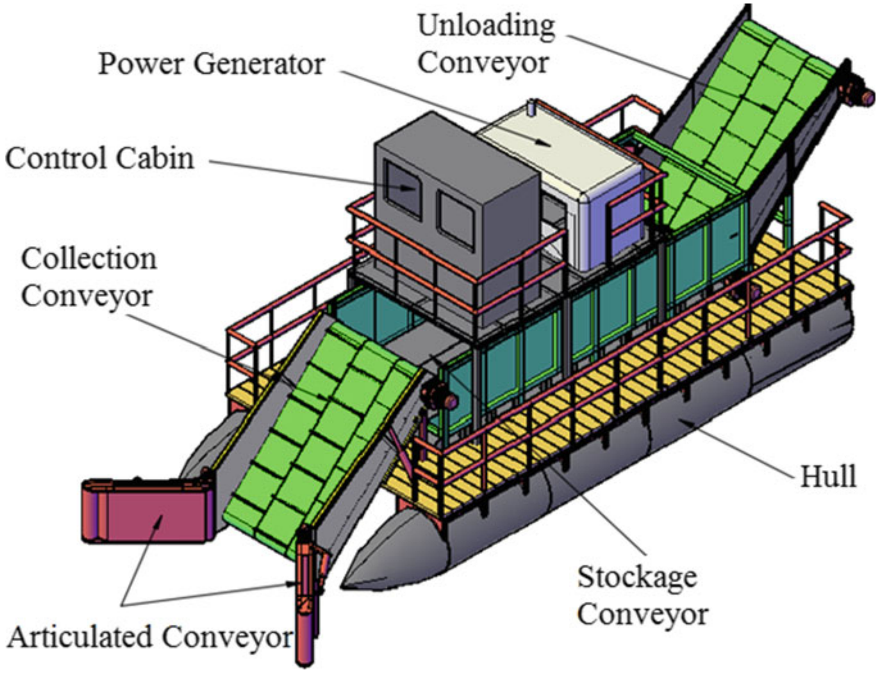


Fig. 3 Proposed vessel

3.1 The Catamaran Pontoon

It is the most important element in the vessel, as it consisted of the floating element (the hulls) and the support frames. The Catamaran pontoon designed to have two parallel floating hulls connected through lateral and longitudinal beams. This type of pontoon is the most suitable one, since it separated the floating element of the boat on two identical hulls at each side. It offers high stability while reducing the drag of water, and consequently the power required from the boat propulsion engine (Fig. 4).

These hulls are proposed to be manufactured using marine aluminum sheets, which have high resistance against salinity effect. They had an assemblage of a cylindrical shape with a conical section affixed to the front for a more streamlined profile. In addition, for more safety, each hull should be partitioned into five watertight sections to ensure the buoyancy of the vessel in case one of them deteriorated during navigation (Fig. 5).

Furthermore, the support frame, or the support base of the collector, is designed from Omega profile aluminum (Fig. 6a) beams welded together and fixed directly to the hulls. The Omega profile was chosen due to its high resistance against torsion and bending. Furthermore, all the machinery, equipment and wood planks of the deck

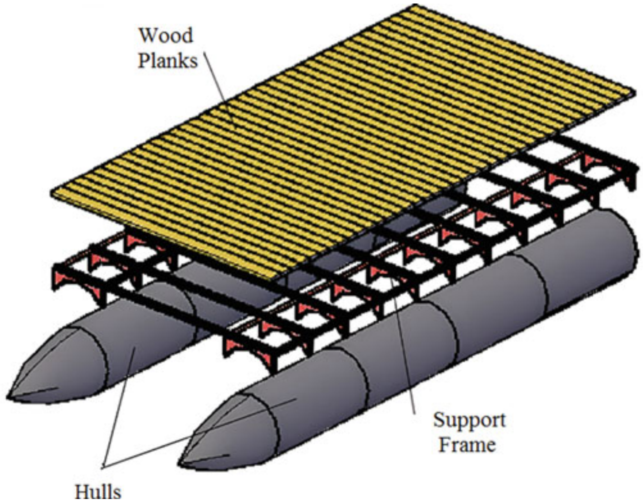
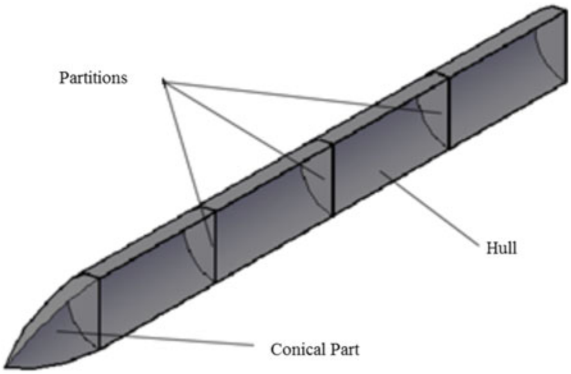


Fig. 4 Catamaran pontoon

Fig. 5 Hulls' cross section



are fixed directly to the support frame to achieve the necessary stability of the vessel during navigation.

By checking the sketch plan of the collector, the minimum length needed to install the conveyors (collection, storage, and unloading) is Lc = 8 m, with 1 m as corresponding diameter. According to the catalogs of U-fabboats, the chosen hulls should have length (*L*) equal to 9.144 m, diameter (*D*) equal to 1 m, with weight equal to 6671.43 kg.

The designed support frame consists of three main parts. The hull supports that are made of flat bars and sheet metal (15 mm thick). They were welded directly on the hulls, and had joining role between 11 secondary beams and hull on each side. The support angles, which resist the bending moment supported on the hulls due to the waves. They were welded to the shell supports and parallel to them. These

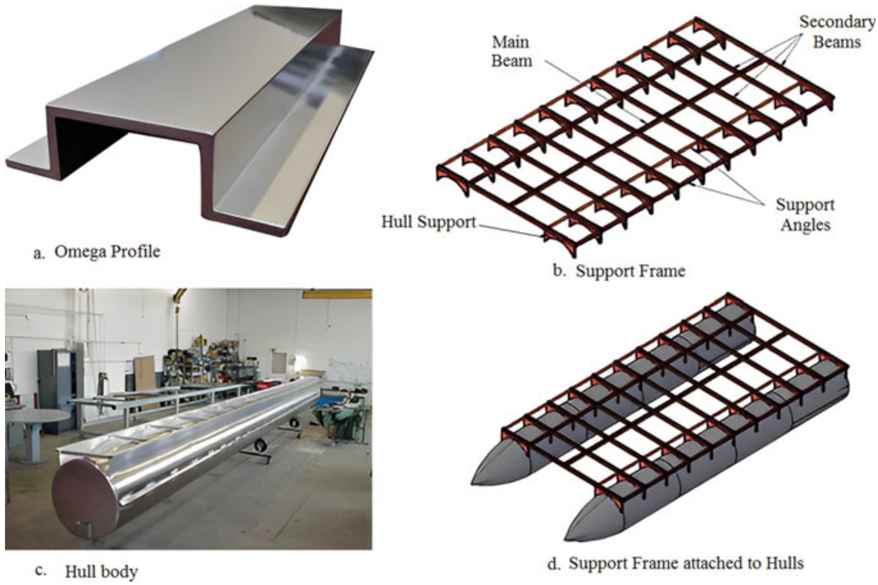


Fig. 6 Lower parts of the vessel

beams support the weight of the collector machines and the forces generated by the operation of the latter, the distribution of waste in the collector (during the collection and unloading phase) and the waves. All the dimensions were verified using the robot software.

3.2 The Collection Conveyor

This conveyor, located at the front of the boat, is the best waste collection device (Fig. 7). It ensures the collection of floating waste on the surface of the water and their transport to the storage section.

During the collection stage, this conveyor is tilted at an angle of 45°, horizontally, and remains at a depth of 40 cm below the water surface (Fig. 8). However, during the transport stage, this conveyor pivots upwards using two hydraulic cylinders (Fig. 9). This repositioning eliminates the instability of the vessel during movement due to the turbulence produced by the conveyor in the water.

The mesh belt (type compact-grid 15 mm) for this conveyor designed to be from stainless steel wires (Fig. 10). It designated to ensure the water drainage of the solid waste before its storage. The insulated drive pulley (min diameter 7.5 in.) method is recommended for cases of large loads and long chains. It allows benefiting from the maximum permissible tension, and reduces the wear of the rods. For the same conditions, a sprocket drive system requires the use of special sprockets.

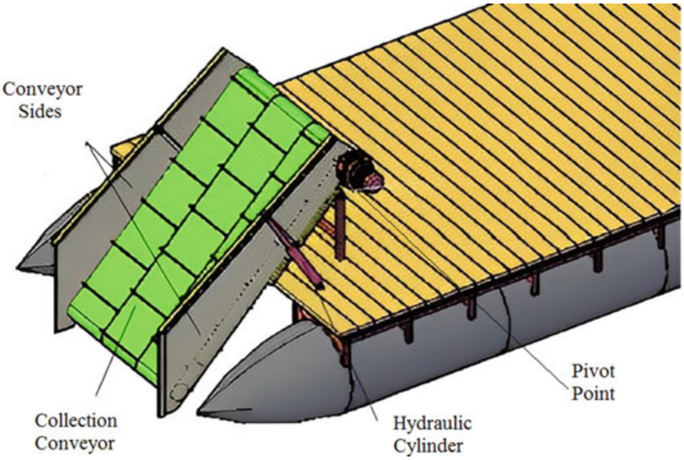


Fig. 7 Collection conveyor

Fig. 8 Collection stage

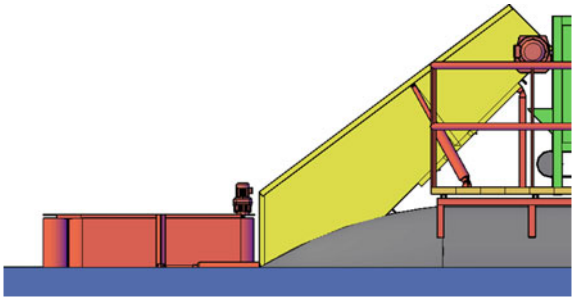
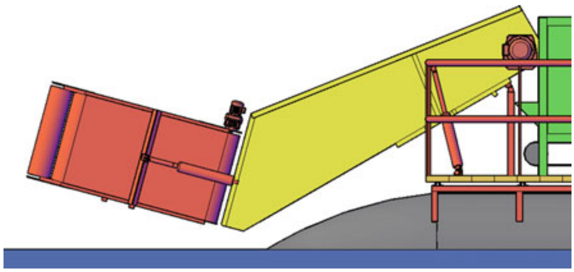
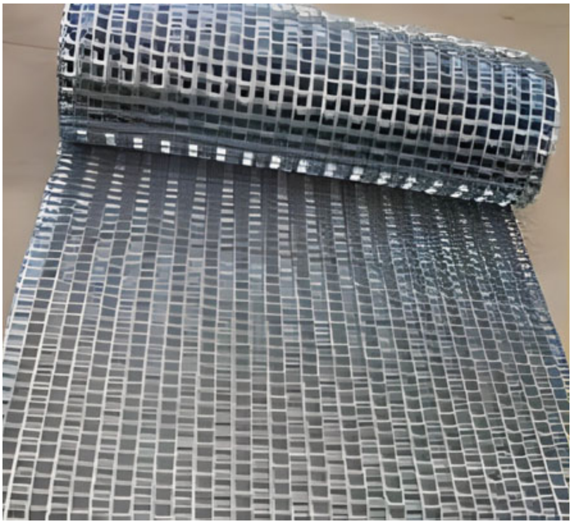


Fig. 9 Transport stage



The lifting plates (width ½ inch, thickness ½ inch, and height 2 inches) which have the role of stopping the waste from slipping during the operation were attached to the belt by a clip in the case of angles.

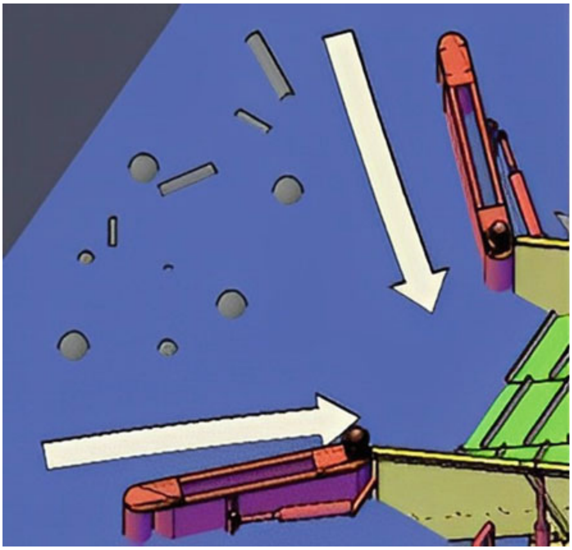
Fig. 10 Mesh belt



3.3 Articulated Conveyors

Articulated conveyors, in reality, are not conventional conveyors (Fig. 11). They are more like articulated arms, capable of dragging the waste located against the walls of the port toward the collection conveyor. These conveyors are essential to avoid the contact of the hulls with the walls of the port and consequently damage them or even the sinking of the ship.

Fig. 11 Articulated conveyors



Two hydraulic cylinders, each of them offering an articulation angle of 45° horizontally, drive the pivoting of these conveyors, like the collection conveyor. The hydraulic system is better than the pneumatic one, despite the increased cost; the hydraulic cylinder can exert a greater force in the positive direction (push) and negative (pull). It is more rigid and supports the shocks in an easiest way than the pneumatic cylinder. Moreover, it is easier to control electronically the stroke of the cylinder in a hydraulic system and give the pilot more control over the positioning of the collection conveyor and articulated conveyors.

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3.4 The Storage Conveyor

The purpose of the storage conveyor (Fig. 12) is to store the collected waste, to ensure that this waste does not accumulate on one side of the conveyor and to feed the unloading conveyor during the final stage of the collection (the unloading stage). It is directly downstream of the collection conveyor and above the cabin and power motor. It was made from stainless steel metal mesh belt, for its durability and ability to drain collected waste during transport and storage.

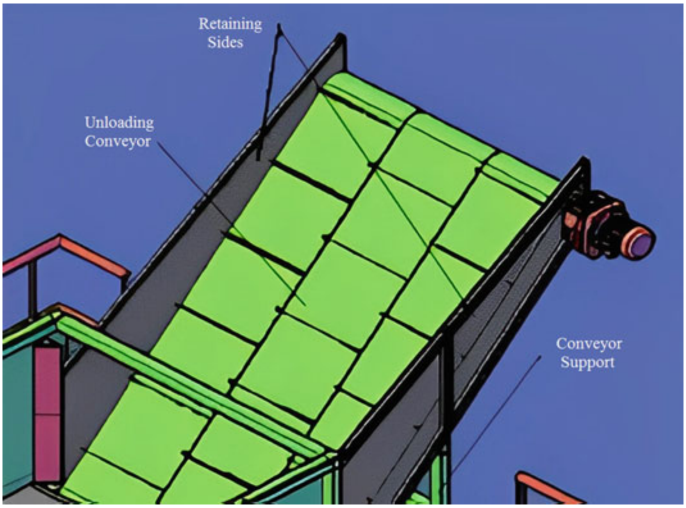

Fig. 12 Storage conveyor

3.5 Propulsion Motor

The collector utilizes a twin Yamaha F15 marine-powered outboard motor (Fig. 13) capable of shallow water operation, allowing the collector to operate in rivers and other shallow waterways. Additionally, these motors provide a relatively small turning radius, which provides the manifold with a great degree of mobility to navigate tight spaces. This type of engine is easily available in the market. It is used in several applications (fishing, sports, leisure, etc.) which make it economical and most reliable option. This engine is accompanied by a 143 L fuel aluminum tank attached below the deck of the boat on the side beams (Fig. 14).

Fig. 13 Propulsion moto

Fig.14 Fuel tank

Fig. 15 Electric motor

3.6 The Electric Motor

It is a diesel generator, Onan Marine, specialized in marine application, which guarantees sealing against the corrosive conditions of salt water (Fig. 15). Due to the space limit and the importance of maintaining the balance of the collector in the water, the electric generator and its fuel tank are installed on the platform located above the storage conveyor. An in-depth study of the performance specifications of this generator and its effect on the stability of the vessel in the water is accomplished.

3.7 The Control Cabin (Control Center)

It was made from aluminum cockpit. It manages the navigation of the boat and the conveyors. This cabin stay on a platform above the storage conveyor is to ensure the best visibility of the collector machines.

From this cabin, using software systems, the pilot is able to monitor the power motor and control the navigation of the pontoon, the operation of the conveyors, the hydraulic cylinders of the collection conveyor, and the articulated conveyors. In addition, the pilot can eliminate, with the help of a video surveillance system, the blind spots that exist below and behind the control cabin (Fig. 16).

4 The Unloading Conveyor

This conveyor is located at the rear of the pontoon and inclined at an angle of 45°. It has the role of emptying the storage conveyor during the unloading phase (Fig. 17). This conveyor is identical to the collection conveyor except that the belt is not subject to the friction effects of water and waves. On each side of the conveyor, there are metal plates that prevent the waste from falling down during rotation of the conveyor.

Fig. 16 Control cabin

This engine is accompanied by a 143-L fuel tank attached below the deck of the boat on the side beams.

At the end and after checking the price for all the elements, the production cost of this vessel ($50,850 USD) is found to be better discounted compared to the TrashCat MS8-1500A ($250,000 USD). It is a 79.66% reduction in the total price that will surely make the collector designed the best choice among interested companies and government and ecological organizations. The mass of all the maximum equipment is around 5500 kg. By choosing a 15% safety factor of the calculated mass, the total weight of the vessel is almost 6325 kg (Table 1).

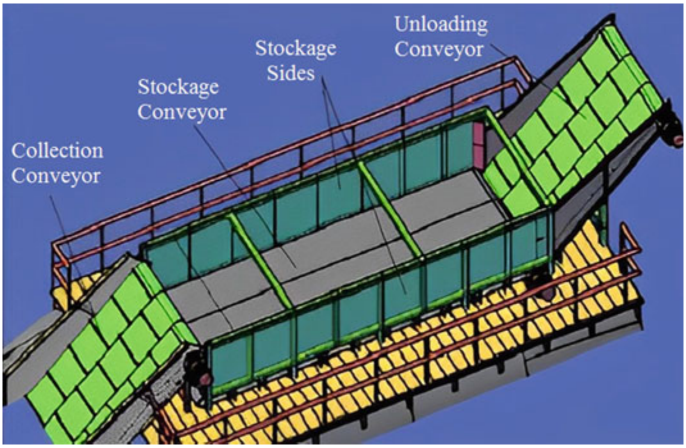

Fig. 17 Collection and the unloading conveyors

Table 1 Items properties and prices

Items	Type	Price ($)
Hulls	Catamaran (U-fabboats)	2600
Beams	Omega profile	2000
Conveyors		5000
Metal structure		1500
Hydraulic system		500
Control cabin	Aluminum	800
Electric motor	Onan Marine	5000
Propulsion motor	Twin Yamaha F15	1200
Electrical installation		800
Welding and assembly		800
Workman fees		30,000
Performance analysis		650
Total		50,850

5 Conclusion

The design of a waste collector for 2 tons floating solid waste and transporting it to the shore has been detailed, which satisfies the international requirements.

In addition, from an economical view, the manufacturing cost of such vessel in Lebanon was determined. There is a cost saving about 79.66% by comparing to a similar international one.

It can be a better competitor in the regional and even international market, and the demands of a country in ecological crisis.

The requirements for a control system for such a machine were detailed, noting its importance in maintaining operator safety for the longevity of collectible machines.

Finally, it has been demonstrated that the design of the collector, with the help of the different modifications that can be applied to the collector, can be adapted in order to satisfy the demands of the market in the future, regardless of the technical, logistical, and financial difficulties that can probably found.

In conclusion, this vessel is a product that almost guarantees a great possibility of a financial profit while helping to alleviate a colic and even global crisis.

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Research on Engineering Education and Management of Early-Strength Sludge Fluidized Soil Used for Backfilling of Pipes and Trenches of Polluted Water

Yuan Fang, Pengming Jiang, Haoqing Xu, Aizhao Zhou, Yiyan Lv, and Heng Zhang

Abstract In order to resourcefully utilize the sludge generated every year, guarantee the backfilling quality of pipes and trenches of polluted water, and accelerate the construction progress, as well as reduce the cement usage amount to lower the engineering costs, the experiment was carried out to prepare the early strength sludge fluidized soil by replacing sulphoaluminate cement with slag in equal amount. Through exploring the influence of different sludge moisture contents and slag replacement rates on the fluidity and filling ability of fluidized soil, and analyzing the influence of different sludge moisture contents, slag replacement rates and periods on the compressive strength of fluidized dynamic soil, it is inferred that the fluidity of the fluidized soil increases linearly with the increase of the moisture content of sludge and remains basically unchanged with the changes of the slag replacement rate. The compressive strength decreases linearly with the increase of sludge moisture content and slag replacement rate, and increases with the increase of period. The filling rate of fluidized soil can reach over 97%, which can solve the backfilling quality problem of pipes and trenches of polluted water better.

Keywords Fluidized soil · Fluidity · Compressive strength · Backfilling quality

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1 Introduction

With the continuous progression of urbanization process, the demand for municipal pipe and trench works is also increasing. However, it is hard for the backfilling using traditional methods to guarantee the construction quality and speed. The annual sludge dredging volume in China is about 1 billion m^3 [1]. The large amount of dredged sludge accumulation not only occupies land, but also damages ecology. The sludge is high in water content and poor in engineering properties, but its soil properties provide the possibility for resource utilization. The researchers process the sludge to be used as road and embankment fills [2], ceramics [3], and seedling soil [4], all showing relatively good effects. The controlled low-strength material is a cement-based backfill, which is applicable to all types of backfill due to its self-compactness and controllable strength. Due to the few restrictions on raw materials for its preparation, the researchers add the waste materials, such as red mud [5], sludge [6], and pool ash [7], into the preparation of CLSM, creating both ecological and economic benefits. CLSM prepared in this experiment uses sludge as the raw material, so it is named as fluidized soil.

Blanco et al. [8], through finite element simulation, optimized the proportioning design of CLSM used for backfilling and pipes and trenches and discovered that its utilization in pipe backfilling can reduce the upper load of pipes, further proving its feasibility in backfilling of pipes and trenches. Park et al. [9] used the CLSM prepared using waste paper sludge ash to backfill the pipes and trenches and presented the excellence of using CLSM for backfilling of pipes and trenches through the measurement of unconfined compressive strength of CLSM (hereinafter referred to as compressive strength) and soil sedimentation around pipes after backfilling. The demand for pipe and trench works in China is large; however, it is hard to guarantee the backfilling quality and construction speed, and a large amount of sludge is in urgent need of processing. Under this circumstance, using sludge as the raw material to prepare the fluidized soil for backfilling of pipes and trenches referring to the existing CLSM related research can not only improve the construction quality but can also resourcefully utilize the sludge, achieving two advantages simultaneously.

In this paper, sludge, sulphoaluminate cement, slag, and water are used to prepare fluidized soil and the influence of different sludge moisture content and slag replacement rate on the fluidity of fluidized soil is studied. Through analyzing the influence of different moisture contents of sludge, slag replacement rates and periods on its compressive strength, and measuring the filling rate of fluidized soil used for backfilling of pipes and trenches by model, the filling effects can be intuitively manifested.

2 Experiment Materials and Methods

2.1 Experiment Materials

The sludge used in the experiment is collected from the riverside of the Yangtze River to ensure the result accuracy. The sludge is dried first, and then screened by 2 mm sieve after crushing. And finally the sludge is put into the sealing boxes for standby. Referring to the geotechnical specifications [10], the measured basic parameters and particle size grading of sludge are illustrated. The physical parameters and particle grading cumulative curves of the sludge are presented in Table 1 and Fig. 1, respectively. The sulphoaluminate cement used in the experiment is produced by Shanxi Yangquan Tianlong Engineering Materials Co., Ltd., with the number of 42.5 and the specific surface area of 462 m^2/kg. The slag used in the experiment is produced by Nanjing Nangang Jiahua New Building Materials Co., Ltd., with the fineness of S95 and the specific surface area of 430 m^2/kg.

Table 1 Physical parameters of dredged sediment

Specific gravity	Plastic limit (%)	Liquid limit (%)	Plasticity index	Liquidity index	Clay content (%)	Fine particle content (%)
2.67	20.58	34.58	14.00	1.84	10.00	85.15

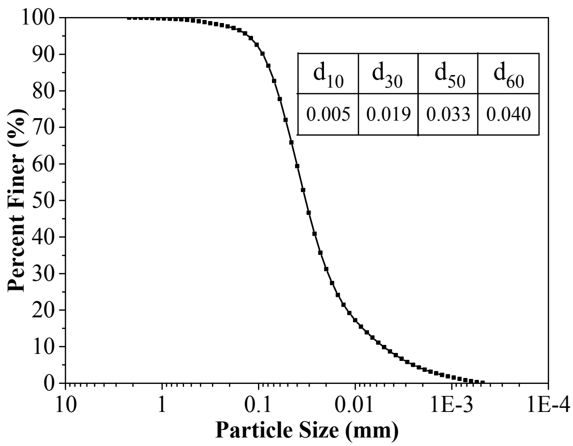


Fig. 1 Cumulative curve of sludge particle size grading

2.2 Experiment Scheme

(1) Experiment Schemes of Fluidity and Compressive Strength

In this experiment, the fluidized soil is prepared by replacing sulphoaluminate cement with slag in equal amount, and the sludge moisture content and slag replacement rate are confirmed as the control parameters through pre-experiment. In the experiment, the sludge content is kept at 500 g, and the total contents of sulphoaluminate cement and slag are kept at 70 g. a total of 10 g slag is used to replace sulphoaluminate cement each time. The moisture contents of sludge are set as 63%, 65%, 67% and 69%, respectively. The slag replacement rates are set as 0, 14.3%, 28.6%, and 42.9%, respectively. The maintenance periods of samples are set as 1 d, 3 d, 7 d, and 14 d, respectively. There are 16 groups in the experiment in total, and the experiment scheme is presented in Table 2.

(2) Model Experiment Scheme

In order to guarantee the experiment effects, two moisture contents of sludge are set in the experiment, which is 63 and 69%, and two slag replacement rates are set, which is 0 and 14.3% to test the filling rate of fluidized soil. There are four groups in the experiment in total, and the experiment scheme is presented in Table 2.

Table 2 Fluidity and compressive strength test scheme

Experiment group no	Sludge:sulphoaluminate cement:slag:water (g/g/g/g)	Moisture content of sludge	Slag replacement rate	Period
1	500:315:70:0	63	0	1, 3, 7, 14
2	500:315:60:10		14.3	
3	500:315:50:20		28.6	
4	500:315:40:30		42.9	
5	500:325:70:0	65	0	
6	500:325:60:10		14.3	
7	500:325:50:20		28.6	
8	500:325:40:30		42.9	
9	500:335:70:0	67	0	
10	500:335:60:10		14.3	
11	500:335:50:20		28.6	
12	500:335:40:30		42.9	
13	500:345:70:0	69	0	
14	500:345:60:10		14.3	
15	500:345:50:20		28.6	
16	500:345:40:30		42.9	

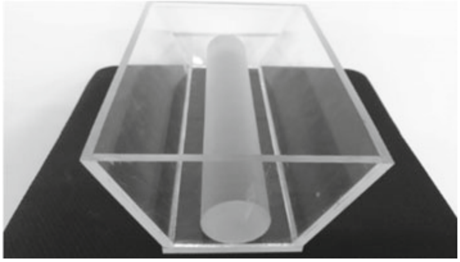


Fig. 2 Dimensions of the model box

2.3 Experiment Method

The fluidity is tested as illustrated in the literature [11] with fluidity as the evaluation index. The compressive strength is tested as illustrated in the geotechnical specifications [10]. When carrying out the model experiment to measure the filling rate, the fluidized soil is firstly prepared to measure the slurry density ρ and then pour it into the model box (see Fig. 2 for size) to measure the mass of slurry filled into the model box m, based on which the volume of slurry inside the model box V_0 can be obtained and the filling rate $F = V_0/V$ can finally be obtained.

2.4 Engineering Application Requirements

The gap between the horizontal pipe diameter and the pipe bottom foundation is called armpit angle, which is relatively narrow, and thus, it is difficult for manual operation and machines to function. It can be known from the literature [12] that the fluidity of fluidized soil for backfilling of pipes and trenches needs to be larger than 200 mm. The underground pipes and trenches cross vertically and horizontally, so the roads are often excavated during construction. In order to restore the transportation as quickly as possible, the early strength needs to be enhanced. Gan et al. [13] believed that when the compressive strength of sludge solidified using sulphoaluminate cement reaches about 80 kPa, the rolling degree can be reached. When the compressive strength is lower than 0.3 MPa, the excavation difficulty can be reduced [12]. In conclusion, it is relatively reasonable to set the compressive strength standard to be larger than 100 kPa. The filling can test the quality of pipeline backfilling, and the filling rate standard can be set to be larger than 90% [14].

3 Results and Analysis

3.1 Fluidity of Fluidized Soil

In order to obtain the influence rules of moisture content of sludge on fluidity of fluidized soil, the relationship between the fluidity data obtained from the experiment and the moisture content of sludge is plotted and linearly fitted to produce Fig. 3. It can be seen from the figure that the fluidity of all the experiment groups is larger than 200 mm, thus meeting the engineering application standards.

(1) Influence of Moisture Content of Sludge on Fluidity

When the slag replacement rate remains unchanged, with the gradual rise of moisture content of sludge, the fluidity will linearly increase, which is because water forms a water film on the particle surface while mixing the fluidized soil. The thickness of water film determines the degree of fluidity. With the increase of moisture content of sludge, the water film thickens. And consequently the fluidity of slurry becomes better. When the moisture contents of sludge reach 0, 14.3, 28.6, and 42.9%, the fitted R^2 value is always 0.99, showing relatively good fitting effects and keeping consistent with the research conclusion of Ding et al. [15].

(2) Influence of Slag Replacement Rate on Fluidity

When the moisture content of sludge remains unchanged, with the gradual rise of slag replacement rate, the fluidity of fluidized soil has little change, which is because the specific surface area of slag is large, reaching 430 m^2/kg, similar to the specific surface area of sulphoaluminate cement, specifically 462 m^2/kg. Therefore, from the perspective of specific surface area, there is little difference between replacing sulphoaluminate cement with slag in equal amount and not replacing. Additionally, when completing the mixing of fluidized soil, the influence of sulphoaluminate

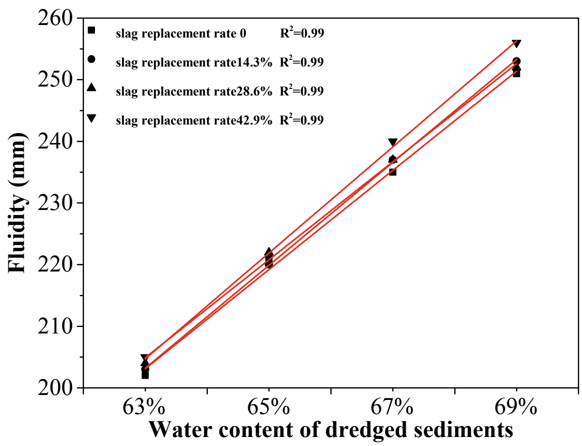


Fig. 3 Relationship between water content and fluidity of dredged sediments

cement particles on fluidity is mainly manifested in adsorption and hydration reaction. Replacing sulphoaluminate cement with slag in equal amount can keep the fluidity of fluidized soil basically unchanged, which is because the slag particles after grinding are rough with many edges and corners, and the adsorption effect is also strong after mixing with water.

To sum up, the influence of moisture content of sludge on fluidity is greater than that of slag replacement rate. Therefore, in engineering application, if the fluidity of fluidized soil does not reach the standards, the adjustment of moisture content of sludge shall be the priority.

3.2 Compressive Strength of Fluidized Soil

(1) Influence of Moisture Content of Sludge on Compressive Strength

In order to study the relationship between moisture content of sludge and compressive strength, the moisture content of sludge and compressive strength data on 1d, 3d, 7d, and 14d in the 16 experiment groups is plotted and conducted with linear fitting to produce Fig. 4. When the period is 1 d and slag replacement is 42.9%, the compressive strength of fluidized soil does not meet the engineering requirements. When the period is 3d, the moisture contents of sludge are 67% and 69%, the slag replacement rate is 42.9%, the compressive strength of fluidized soil does not meet the requirements. When the period reaches 7d, the compressive strength of all proportions of fluidized soil can meet the engineering requirements.

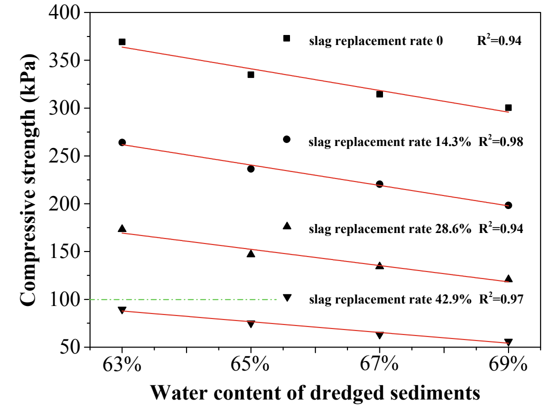
When the slag replacement rate and period remain unchanged, the compressive strength of fluidized soil will linearly decrease with the increase of moisture content of sludge. R^2 value basically remains above 0.90, showing relatively good fitting goodness.

Water is closely related to the engineering properties of fluidized soil. Some water forms surface water after pouring, some water forms bound water after hydration reaction inside the slurry, and some water remains in the fluidized soil, which is called free water. Though the surface of fluidized soil has hardened, higher moisture content of sludge will cause more free water to stay in the interior of the fluidized soil and the water leaked from samples during axial compression is shown in Fig. 5. When the loading rate is low, the free water inside fluidized soil can reduce the mutual Van Der Waals force through the interface between hydrated cements, further weakening the compressive strength [16]. When the slag replacement rate remains unchanged, the higher the moisture content of sludge is, the more the free water inside the fluidized soil is. And thus the compressive strength correspondingly reduces.

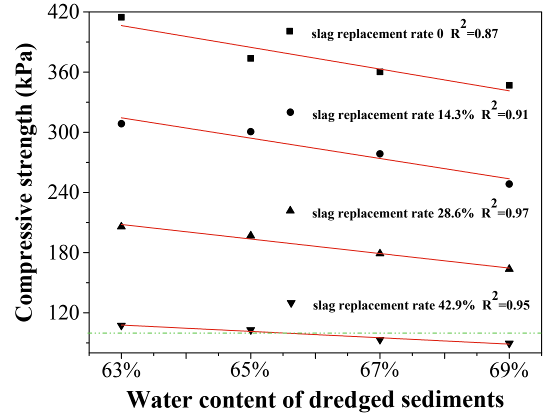
(2) Influence of Slag Replacement Rate on Compressive Strength

In order to explore the relationship between slag replacement rate and compressive strength of fluidized soil, the experiment data of compressive strength related to slag replacement rate of each period is plotted and conducted with linear fitting to produce

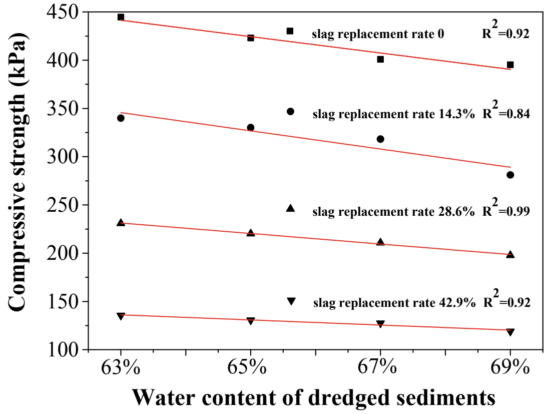
Fig. 4 Relationship between water content and strength of dredged sediments at different ages



(a) age is 1 d

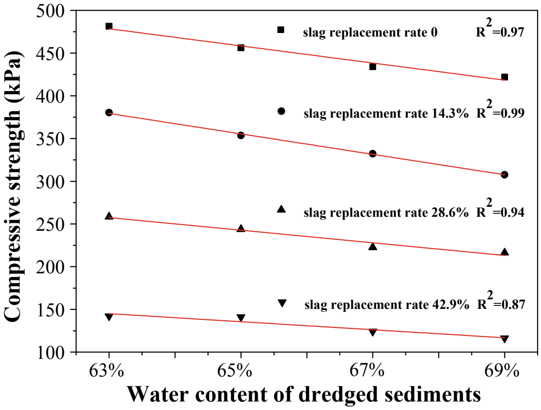


(b) age is 3 d



(c) age is 7 d

Fig. 4 (continued)



(d) age is 14 d

Fig. 5 Free water in the sample

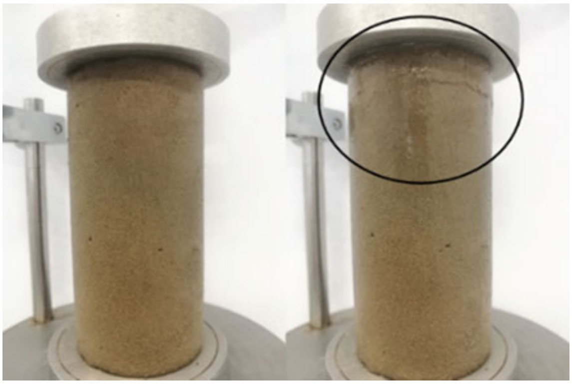


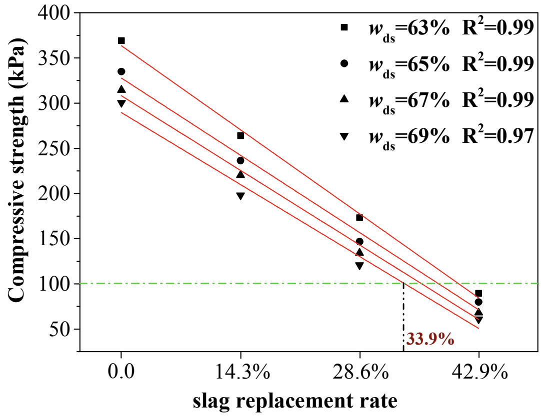
Fig. 6. It is shown in the figure that when the moisture content of sludge and period remain unchanged, the compressive strength of each period will linearly decrease with the increase of slag replacement rate and all the fitting R^2 value is above 0.90, indicating that the fitting effect is significant. When the slag replacement rate is less than 33.9%, the fluidized soil within 1d can meet the engineering requirements and further realize the rapid construction.

The increase in compressive strength of fluidized soil originates from hydration reaction of sulphoaluminate cement whose chemical equation is shown as follows [17]:

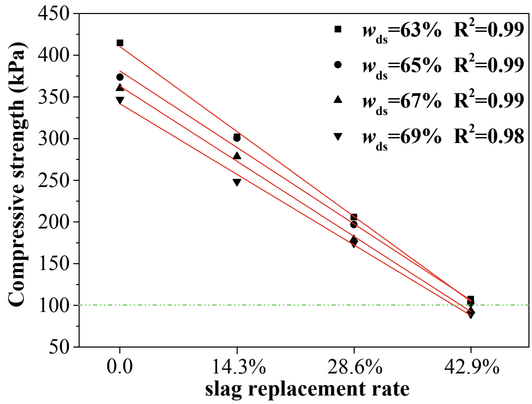
$$\begin{aligned} &3CaO \cdot 3Al_2O_3 \cdot CaSO_4 + 2(CaSO_4 \cdot 2H_2O) \\ &+34H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O+ \\ &2(Al_2O_3 \cdot 3H_2O)(gel) \end{aligned} \tag{1}$$

$$2CaO \cdot SiO_2 + 2H_2O \rightarrow CaO - SiO_2 - H_2O(I) + Ca(OH)_2 \tag{2}$$

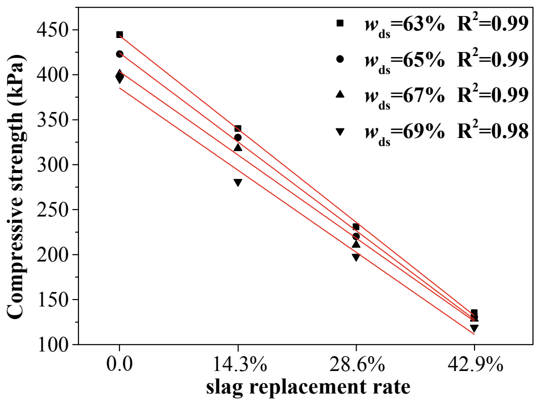
Fig. 6 Relationship between water content and strength of dredged sediments at various ages



(a) age is 1 d

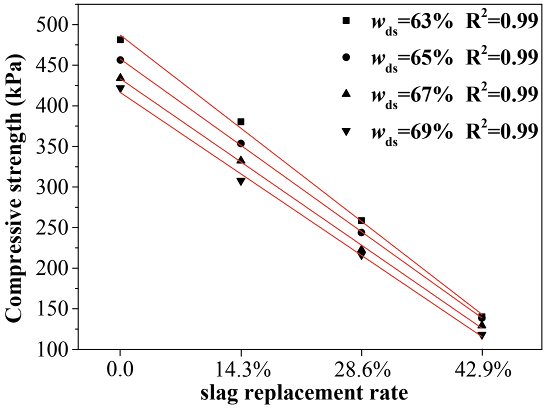


(b) age is 3 d



(c) age is 7 d

Fig. 6 (continued)



(d) age is 14 d

The main hydration products of sulphoaluminate cement are as follows:

(1) High-sulfur calcium sulphoaluminate (AFt, ettringite)

The chemical equation of one of the main hydration products of sulphoaluminate cement is $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$. AFt is a product with micro-expansion property, which can fill the gap between the particles in fluidized soil, increase its compactness, and greatly promote the development of the early compressive strength of fluidized soil [18].

(2) Low-sulfur calcium sulphoaluminate hydrate (AFm)

It is a common AFm whose chemical equation is $\cdot 3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O$, which can mutually transform with AFt under different gypsum concentrations or temperature conditions.

(3) Hydrated calcium silicate gel (CaO-SiO_2-H_2O(gel),C-S-H gel)

C-S-H gel is featured by nanocrystals and can play the role of cementing particles, make the cement skeleton more dense, and greatly increase the compressive strength after massive hydration generation [19].

(4) Alumina gel ($Al_2O_3 \cdot 2H_2O$ (gel) or Al_2O_3(aq), AH_3 gel)

The early-generated alumina gel is relatively fragile and contributes little to strength [20]. However, with the increase of period, its contribution to compressive strength will greatly increase. Zhang [19] discovered in research that AH_3 phase has microcrystalline or nanocrystalline structure. Hu et al. [21] discovered that AH_3gel in hydration products of sulphoaluminate cement is more advantageous in elastic modulus and hardness compared to Aft, indicating that AH_3gel unnegligibly contributes to the compressive strength of fluidized soil.

In the hydration reaction of sulphoaluminate cement, the generation amount of $Ca(OH)_2$ is small, so it is impossible to excite the hydraulic activity of slag. However, the specific surface area of slag particles is small, so they can be filled in the structural network gaps inside the fluidized soil to give play to the micro-aggregate and compaction effects, microcrystalline nucleus effect, evenly disperse sulphoaluminate cement particles and improve the integrity of the fluidized soil. However, the effects of slag cannot make up for the reduction of compressive strength caused by the reduction of sulphoaluminate cement content. With the increase of slag replacement rate, the amount of hydration products will be reduced, which will cause the compressive strength of fluidized soil to decrease with the increase of slag replacement rate. Wang et al. [22] also drew the similar conclusion when using slag to replace sulphoaluminate cement to produce self-leveling mortar.

3.3 Filling of Fluidized Soil

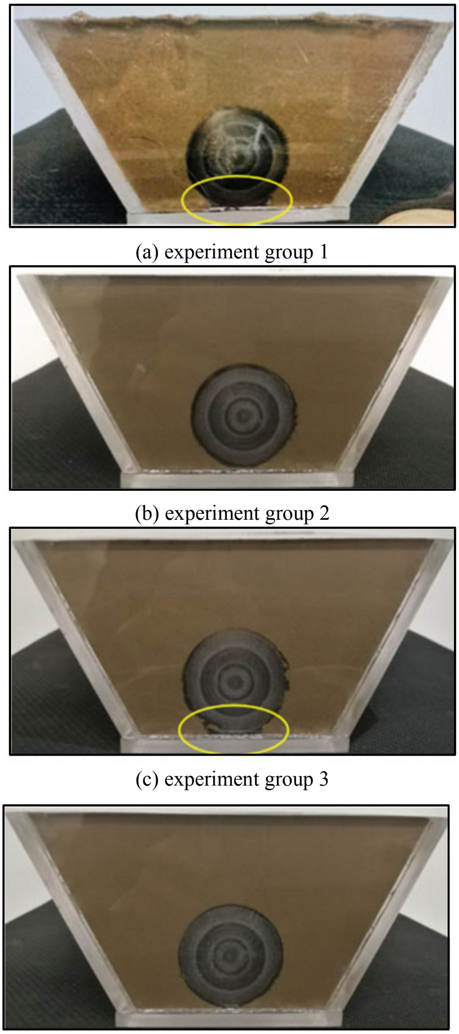
The side view of filling experiment is shown in Fig. 7. There are still some gaps in the axilla of experiment groups 1 and 3 while those of experiment groups 2 and 4 are almost filled, showing good backfilling effects and indicating that the problem of poor backfilling quality can be better solved by backfilling the pipes and trenches with fluidized soil.

It can be known from Fig. 7 that the filling rates of the four experiment groups are above 97%, meeting the filling rate engineering requirements. It can be known from the experiment results above that the fluidity changes little after replacing sulphoaluminate cement with the same amount of slag. In addition, as shown in the figure, the filling rates of experiment groups 1, 3 and 2, 4 are also similar when the fluidity does not differ greatly. When the moisture content of sludge rises from 63 to 69%, the fluidity increases while the filling rate also increases. After replacing sulphoaluminate cement with 10 g slag in equal amount, the fluidity of fluidized soil basically remains unchanged and the filling rate is also similar. And therefore, there is a certain scientific basis for evaluating the filling effect of fluidized soil with fluidity.

4 Conclusion

In this paper, a type of fluidized soil used for backfilling of pipes and trenches is studied. Through studying the influence of moisture content of sludge and slag replacement rate on its fluidity, taking moisture content of sludge, slag replacement rate, and period as the research parameters, the influence on compressive strength is

Fig. 7 Model box filling side view



(a) experiment group 1

(b) experiment group 2

(c) experiment group 3

(d) experiment group 4

analyzed, and the feasibility of backfilling of pipes and trenches is verified through model test, from which the following conclusions can be drawn:

(1) The fluidity of fluidized soil can meet the engineering requirements. When the slag replacement rate remains unchanged, the fluidity of fluidized soil will increase linearly with the increase of moisture content of sludge. When the moisture content of sludge remains unchanged, the fluidity basically remains unchanged with the change of slag replacement rate. When the fluidity of the fluidized soil needs to be adjusted to meet the requirements in the project, the moisture content of sludge should be controlled first.

(2) When the slag replacement rate and period keeps unchanged, the compressive strength of fluidized soil will linearly decrease with the increase of moisture content of sludge. When the moisture content of sludge and period remain unchanged, the compressive strength will linearly decrease with the increase of slag replacement rate. When the slag replacement rate is less than 33.9%, the rapid construction requirement can be met, facilitating the faster transportation restoration. When the moisture content of sludge and slag replacement rate remain unchanged, the compressive strength will increase with the increase of period and the increase speed will lower with the increase of period.
(3) The filling properties of fluidized soil are relatively good with the filling rate above 97%, which can effectively solve the incomplete backfilling of pipe axilla.

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Application of Fuzzy Decision in Wastewater Treatment Project: A Case Study of Taizhou Pharmaceutical Park in China

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Abstract Pharmaceutical wastewater is one of the most difficult industrial wastewaters to treat. The environmental protection department must supervise the enterprises to choose the appropriate wastewater treatment process and strengthen the management of wastewater treatment at the organizational and operational level. This paper designs the evaluation index system of sewage treatment supervision by consulting data, enterprise research, collecting expert opinions, and other work, and uses analytic hierarchy process (AHP) to calculate the weight of each index to fully reflect the value status of each index in the system. This paper first constructed a hierarchical structure model of the evaluation index system of pharmaceutical enterprises' sewage treatment supervision, and then took China Medical City, a national pharmaceutical park in Taizhou, Jiangsu Province, as a case study. Experts and scholars who have participated in environmental protection work of the park for a long time as well as management personnel of HSE department are invited to conduct pair-wise comparison and score for the final weight calculation of indicators. From the weight results, it is found that input cost and pollutant reduction are the indicators with the highest weight. Therefore, in the future, the park needs to improve its pollution reduction ability on the basis of cost consideration.

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1 Introduction

The Action Plan for Water Pollution Prevention and Control issued by The State Council on April 16, 2015, referred to as the "Ten Water Regulations," are laws and regulations formulated to effectively strengthen the prevention and control of water pollution and ensure the national water security. Pharmaceutical industry is the key monitoring industry of our environmental governance, which is one of the ten key remediation industries in our "Action plan for Water pollution prevention and control." In recent years, with the rapid development of pharmaceutical industry, the kinds of drug production are increasing and the scale of production is expanding. At the same time, more and more attention has been paid to the environmental pollution caused by the production of wastewater in the pharmaceutical industry. Pharmaceutical wastewater is one of the most difficult industrial wastewater treatment, and with complex water quality, high chemical oxygen demand (COD), high concentration of toxic and harmful substances, poor biodegradability, high chroma characteristics, direct discharge will cause great threat to human and the environment. In view of the large amount of industrial wastewater produced by the pharmaceutical industry in the production process, the environmental protection department must supervise the enterprises to choose the appropriate wastewater treatment process, and strengthen the management of wastewater treatment at the organizational and operational level.

China's environmental regulatory laws and regulations are composed of environmental laws and regulations, environmental policies, environmental standards, environmental management systems, and international conventions. China has formed an environmental management system that combines centralized management with local management at different levels and division of labor. Environmental protection departments are mainly responsible for the prevention and control of industrial pollution, and their functions include environmental management, supervision, education, and monitoring. Environmental regulation is an important part of environmental management and an important guarantee for achieving environmental protection goals. Most of China's pharmaceutical enterprises are wholly owned subsidiaries of large group companies, with long business chains, complex production and management links, large annual pollutant discharge, numerous environmental risks, and difficult environmental supervision. In recent years, a number of environmental incidents with great impact have fully exposed the lack of environmental supervision capacity of enterprises. Pharmaceutical enterprises urgently need to carry out research on environmental protection supervision system, establish and improve environmental protection supervision index system, and effectively guide enterprises to carry out supervision ability evaluation. In this paper, the evaluation index system of environmental protection supervision is designed through consulting data, enterprise research, and collecting expert opinions, and the analytic hierarchy process (AHP) is used to calculate the weight of each index to fully reflect the value status of each index in the system.

In this paper, the hierarchical structure model of the evaluation index system of pharmaceutical enterprises' sewage treatment supervision is firstly constructed, and then the state-level pharmaceutical park, Taizhou Pharmaceutical High-tech Industrial Development Zone (China Medical City), is taken as the case study. Experts and scholars who have participated in environmental protection work of the park for a long time as well as management personnel of HSE department are invited to conduct pair-wise comparison and score for the final weight calculation of indicators. Taizhou Pharmaceutical High-tech Industrial Development Zone is a pharmaceutical park integrating research and development and production. Its main products are antibiotic active pharmaceutical ingredients (APIs) and preparations. A large amount of organic solvents and chemical raw materials are used in production and research and development, and a large amount of industrial wastewater is generated. All kinds of production wastewater generated by the project (wastewater containing virus activity is first treated by inactivation, and high concentration wastewater is pretreated) is treated by the existing wastewater treatment station (secondary "A/O" + sedimentation) of the park enterprise, and then partially filtered by sand filter and reused, and the remaining wastewater is discharged into the park wastewater network and taken over by Jiangsu Gangcheng Wastewater Treatment Co. Ltd. for deep treatment, and in the long term, it will take over the sewage treatment plant for deep treatment; pure water preparation waste water and circulating cooling water will be discharged into the rainwater network of the park through the rainwater outlet. The wastewater discharge implements the indirect emission limits in the "Emission limits for water and air pollutants in biopharmaceutical industry" (DB32/3560-2019) and the takeover standard of wastewater treatment plant. For long-term operation of environmental protection facilities, how to strengthen site management and continuous improvement to ensure stable operation of wastewater discharge standards has become a very important part of the enterprise operation.

2 Literature Review

AHP (hierarchical analysis) is an effective multi-criteria decision analysis method that has been widely used in industrial wastewater treatment research. In this paper, we will review some literature on the application of AHP in industrial wastewater treatment studies. First, some studies have used AHP to evaluate the advantages and disadvantages of different wastewater treatment technologies, e.g., in the treatment of industrial wastewater containing high concentrations of organic matter, Chen et al. [1] used the AHP method in order to determine the best treatment technology. They used different treatment technologies (e.g., biofilm reactor, activated sludge reactor, and anaerobic digestion reactor) as different levels of the hierarchy and evaluated their relative importance in terms of efficiency, feasibility, and economy. The results of the study showed that the biofilm reactor is the optimal treatment technology because it has higher efficiency and better economy. The AHP is also very effective in assessing the sustainability of different wastewater treatment processes. Agarwal and Singh [2] used the AHP to assess the sustainability of different membrane wastewater treatment processes. They treated different membrane wastewater treatment processes (e.g., reverse osmosis, nanofiltration, and ultrafiltration) as different levels of a hierarchy and assessed their relative importance in environmental, social, and economic terms. The results of the study indicate that the reverse osmosis process is the most sustainable process because it has the least environmental and social impact and better economic efficiency. In addition, several studies have used AHP to assess the risk and safety of different wastewater treatment options, e.g., Ghavami et al. [3] used AHP to assess the risk and safety of different wastewater treatment options. They used different treatment options (e.g., physical, chemical, and biological treatment) as different levels of the hierarchy and assessed their relative importance in terms of risk and safety. The results of the study showed that biological treatment is the safest treatment option because it has the least impact on the environment and human body. The application of AHP in healthcare environmental studies is also common, e.g., some scholars have used AHP to evaluate the environmental and economic benefits of different medical waste treatment methods, e.g., Ho [4] used AHP to determine the priority treatment methods for medical waste. They treated different treatment methods such as incineration, chemical treatment, and microbiological treatment as different levels of the hierarchy and assessed their relative importance in terms of environmental protection, economic benefits, and operational risks. Zamparas et al. [5] used AHP to assess the environmental and economic impacts of different components of medical imaging equipment. They used different components such as probes, controllers, and displays as different levels of the hierarchy and assessed their relative importance in terms of environmental and economic aspects, e.g., Etim et al. [6] used AHP to assess the environmental benefits of different medical waste policies. They used different policies such as government subsidies, environmental taxes, and penalty policies as different levels of the hierarchy and evaluated their relative importance in terms of environmental benefits. In addition, many environment-related researches also combine subjective psychological indicators, environmental monitoring indicators and questionnaires with AHP to conduct environment-related researches [7–13]. In summary, AHP is a very useful method for evaluating multiple decision problems in industrial wastewater treatment and environmental aspects of the pharmaceutical industry. The use of AHP can help researchers to better understand the relationship between different factors and evaluate the advantages and disadvantages of options and establish a system of indicators.

3 Hierarchical Analysis Method to Calculate the Weights

In this paper, by reviewing the relevant literature, we investigate the current situation of environmental protection regulation of pharmaceutical enterprises and carry out the identification of potential factors and key links that may affect the environmental protection regulatory capability of pharmaceutical enterprises according to the environmental protection regulatory implementation level and operational level, in order to help construct an index system. In this paper, the pharmaceutical enterprise water treatment regulatory evaluation index system is set as a target level, a level of indicators from the regulatory organization system, regulatory system, regulatory funding guarantee system, regulatory assessment system of four parts, a level of indicators under the enterprise group level, enterprise level, comprehensive management, special management, and a number of secondary indicators, each secondary indicator under one or more tertiary indicators, constituting a multi-level indicator system. On the basis of a clear indicator system, a hierarchical structure model of the pharmaceutical enterprise water treatment regulatory evaluation index system was established, as presented in Table 1.

3.1 Calculation Method

Based on the expert scoring, taking into account the opinions of several experts, the judgment matrix form of pharmaceutical enterprise water treatment regulatory capacity assessment is constructed, and the weight of each indicator is calculated using hierarchical analysis. According to the weight calculation method, five experts were asked to independently conduct two-by-two comparison scoring, comprehensive consideration of the five experts on the relative importance of each element scoring opinions and assigned values, the construction of evaluation indicators of the judgment matrix **A**, according to formula (1), the maximum eigenvalue of the judgment matrix, as well as the corresponding eigenvector **W**, can be derived from the relative weight; then according to formula (2) for consistency testing, calculate the index **CI**;. Finally, according to formula (3) combined with the consistency index **RI**, the consistency ratio **CR** is derived, and if **CR** < 0.1, it is considered that the consistency of the judgment matrix is reasonable.

$$AW = \lambda \max W \tag{1}$$

$$\mathrm{CI} = \frac{\lambda \max - n}{n - 1} \tag{2}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{3}$$

Table 1 Hierarchical structure model of evaluation index system of sewage treatment supervision of pharmaceutical enterprises

Target (A level)	First indicator (B level)	Secondary indicators (C level)	Tertiary indicators (D level)
Supervision and evaluation index system of pharmaceutical wastewater treatment station	Technical performance (B1)	Technological advancement (C1)	Technology update cycle (D1)
			Service life (D2)
		Technical reliability (C2)	COD removal rate (D3)/%
			Ammonia nitrogen removal rate (D4)/%
			Total phosphorus removal rate (D5)/%
		Technology applicability (C3)	Operation complexity (D6)
			Operational security (D7)
			Impact load resistance (D8)
	Economic performance (B2)	Input costs (C4)	Infrastructure investment cost (D9)/(yuan/t)
			Wastewater treatment cost (D10)/(yuan/t)
			Annual operation and maintenance cost (D11)/(yuan/t)
	Environmental benefits (B3)	Pollutant reduction (C5)	COD reduction effect (D12)

(continued)

Table 1 (continued)

Target (A level)	First indicator (B level)	Secondary indicators (C level)	Tertiary indicators (D level)
			Ammonia nitrogen reduction effect (D13)
			Total phosphorus reduction effect (D14)
		Secondary pollution (C6)	Sludge generation (D15)

3.2 First-Order Indicators Weights

AHP hierarchy study was conducted by constructing a third-order judgment matrix for a total of three items: technical performance (B1), economic performance (B2), and environmental benefits (B3), and the feature vectors were (0.672, 1.108, and 1.219), and the corresponding weights of the total three items were 22.407, 36.944, and 40.648%. In addition, the maximum eigenroot (3.009) can be calculated by combining the eigenvectors, and then the CI value (0.005) is calculated by using the maximum eigenroot value, which is used for the following consistency test. In this study, the third-order judgment matrix is constructed, and the random consistency RI value of 0.520 can be obtained by querying the above table, and the RI value is used for the following consistency test calculation. Usually the smaller the CR value, the better the consistency of the judgment matrix, and in general the CR value is less than 0.1, the judgment matrix satisfies the consistency test; if the CR value is greater than 0.1, it means that there is no consistency, and the judgment matrix should be analyzed again after appropriate adjustment. The CI value calculated for the third-order judgment matrix is 0.005, and the table check for the RI value is 0.520, so the calculated CR value is 0.009 < 0.1, which means that the judgment matrix of this study satisfies the consistency test and the calculated weights are consistent.

3.3 Secondary Indicators Weights

AHP hierarchy study was conducted for the total three items of technical advancement (C1), technical reliability (C2), and technical applicability (C3) by constructing a third-order judgment matrix (calculation method: sum–product method), and the feature vectors were (0.316, 0.812, and 1.873), and the corresponding weights of the total three items were 10.523%, 27.060%, and 62.417%, respectively. In addition, the maximum eigenroot (3.090) can be calculated by combining the eigenvectors, and then the CI value is 0.045 calculated by using the maximum eigenroot value. Usually the smaller the CR value, the better the consistency of the judgment matrix, and generally the CR value is less than 0.1, then the judgment matrix satisfies the consistency test; if the CR value is greater than 0.1, then it does not have consistency, and the judgment matrix should be adjusted appropriately and then conducted again. The matrix should be analyzed again after appropriate adjustment. The CI value calculated for the third-order judgment matrix is 0.045, and the table check for the RI value is 0.520, so the calculated CR value is 0.086 < 0.1, which means that the judgment matrix of this study satisfies the consistency test and the calculated weights are consistent.

3.4 Tertiary Indicators Weights

For the technical update cycle, the second-order judgment matrix was constructed for a total of two items to conduct AHP hierarchy study (calculation method: sum–product method), and the feature vector was obtained as (0.500 and 1.500), and the corresponding weight values of the total two items were 25.000 and 75.000%. In addition, the maximum eigenroot (2.000) can be calculated by combining the eigenvectors, and then the CI value (0.000) is calculated by using the maximum eigenroot value. In this study, the second-order judgment matrix was constructed and the random consistency RI value of 0.000 was obtained, and the RI value was used for the following consistency test calculation.

When using AHP hierarchical analysis for weight calculation, a consistency check analysis is needed to study the consistency test results of the evaluation weight calculation results, i.e., to calculate the consistency index CR value (CR = CI/RI).

First: first describe the CI value obtained from the above calculation [CI = (maximum characteristic root − n)/(n − 1)].
Second: obtain the RI value by combining the judgment matrix order.
Third: calculate the CR value and perform consistency judgment.

Usually the smaller the CR value, the better the consistency of the judgment matrix, and in general the CR value is less than 0.1, the judgment matrix satisfies the consistency test; if the CR value is greater than 0.1, it means that there is no consistency, and the judgment matrix should be analyzed again after appropriate adjustment. This time, the CI value is 0.000 for the second-order judgment matrix, and the table is 0.000 for the RI value. The data is a second-order matrix (the RI value is 0, and the CR value cannot be calculated), but the second-order data all satisfies the consistency test, and the weights finally calculated have consistency.

Similarly, we constructed the computational matrix of D3–D15 and performed the consistency test, and the final weighting results are presented in Table 2.

Table 2 Weight value of each indicator

Target (A level)	First indicator (B level) (%)		Secondary indicators (C level) (%)		Tertiary indicators (D level) (%)		Weighting results (%)
Supervision and evaluation index system of pharmaceutical wastewater treatment station	Technical performance (B1)	22.407	Technological advancement (C1)	10.523	Technology update cycle (D1)	25.000	0.59
					Service life (D2)	75.000	1.77
			Technical reliability (C2)	27.060	COD removal rate (D3)/%	13.203	0.80
					Ammonia nitrogen removal rate (D4)/%	28.850	1.75
					Total phosphorus removal rate (D5)/%	57.947	3.51
			Technology applicability (C3)	62.417	Operation complexity (D6)	12.113	1.69
					Operational security (D7)	24.616	3.44
					Impact load resistance (D8)	63.271	8.85
	Economic performance (B2)	36.944	Input costs (C4)	100	Infrastructure investment cost (D9)/(yuan/t)	13.046	4.82
					Wastewater treatment cost (D10)/(yuan/t)	31.175	11.52
					Annual operation and maintenance cost (D11)/(yuan/t)	55.779	20.61
	Environmental benefits (B3)	40.648	Pollutant reduction (C5)	62.500	COD reduction effect (D12)	10.302	2.62

(continued)

Table 2 (continued)

Target (A level)	First indicator (B level) (%)		Secondary indicators (C level) (%)		Tertiary indicators (D level) (%)		Weighting results (%)
					Ammonia nitrogen reduction effect (D13)	27.177	6.90
					Total phosphorus reduction effect (D14)	62.521	15.88
			Secondary pollution (C6)	37.500	Sludge generation (D15)	100	15.24

4 Discussion

As a high-tech industrial cluster area, Taizhou Pharmaceutical High-tech Park has a relatively large amount of wastewater discharge, so wastewater treatment is an issue that cannot be ignored in the future development of the park. In order to take a series of measures to strengthen wastewater treatment in the park in the future, this paper established an indicator system and conducted weight calculation by visiting local experts. It can be seen from the weight that input cost (C4) and pollutant reduction (C5) are the indicators with the highest weight. Therefore, in the future, the park needs to improve its pollution reduction ability on the basis of cost consideration. First, the park can strengthen the construction of wastewater treatment facilities. Advanced wastewater treatment equipment and technology should be introduced to improve the efficiency and quality of wastewater treatment. Meanwhile, the daily maintenance and management of wastewater treatment facilities in the park should be strengthened to ensure their long-term effective operation. Second, the park can set stricter standards for wastewater discharge. Before enterprises can obtain a business license, they must meet strict wastewater discharge standards to avoid the situation in which enterprises arbitrarily discharge wastewater. At the same time, strengthen the supervision of enterprises to ensure that enterprises' waste water discharge in line with relevant national regulations. Third, the park can promote waste water resource utilization technology, to turn waste water into reusable resources, e.g., organic matter in wastewater is used to make products such as organic fertilizer or biodiesel to reduce environmental pollution in the park. At the same time, the park should strengthen publicity and education to raise people's awareness and attention to wastewater treatment. The park may organize some publicity activities on wastewater treatment knowledge to popularize the importance of wastewater treatment to enterprises and the public and encourage everyone to actively participate in wastewater treatment. The implementation of these measures will help protect the environment and promote sustainable development of the park.

5 Conclusion

Based on the interpretation of domestic laws, regulations, and the integration of indicators identified in the pharmaceutical wastewater literature in the past, combined with the actual environmental management situation of enterprises and expert investigation, this paper established the evaluation index system of environmental supervision ability of pharmaceutical enterprises and calculated the weight index of each index by using the analytic hierarchy process. The research results can guide and help enterprises to establish and improve the establishment of environmental protection supervision system, evaluate various indicators in environmental protection supervision, and effectively guide enterprises to carry out the evaluation of sewage treatment supervision ability.

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Combined High-Temperature Acid Digestion, Iron-Carbon Micro-electrolysis, and Coagulation Reaction for Degrading Pharmaceutical Wastewater with a High Concentration of Dimethylformamide

Mengnan Ma and Jianjun Cai

Abstract The degradation of pharmaceutical with high concentrations of *N*,*N*-dimethylformamide (DMF) mainly includes chemical oxidation and physical adsorption. However, these methods have low efficiencies and high expensive. Hence, this study combined the high-temperature acid digestion, iron-carbon micro-electrolysis, and coagulation reaction, which was used to degrade the pharmaceutical wastewater with a high concentration of dimethylformamide. These results showed that the organic nitrogen of wastewater was mostly converted to ammonia nitrogen as the high-temperature acidolysis reaction. The ammonification rate of DMF wastewater increased with the increase of acidity and reaction time. The ammonification rate of DMF wastewater reached more than 80% as the high-temperature acidolysis reaction, the degradation rate of chemical oxygen demand (COD) reached 30%, and the removal rate of total nitrogen was 15%. After pretreatment, iron-carbon micro-electrolysis in combination with coagulation reaction further increased the COD degradation (about 25%). The removal rate increased with the increase of dosage. This method had a noticeable effect on the ammonification, COD degradation, and biochemical enhancement of high-concentration DMF pharmaceutical wastewater in pharmaceutical plants.

Keywords DMF · High-temperature acid digestion · Iron-carbon micro-electrolysis · Coagulation reaction · Pharmaceutical wastewater

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1 Introduction

With the rapid development of modern industrialization and economic globalization, the discharge of large amounts of industrial wastewater from various factories is becoming a serious worldwide problem [1], seriously affected the ecological environment and seriously endangering health. DMF is a widely used chemical material in the chemical industry. Under room temperature condition, it is completely miscible in any proportion with water, ethers, alcohols, esters, ketones, hydrogen chloride, and aromatics [2]. DMF wastewater is also a common wastewater in chemical wastewater treatment projects [3]. Moreover, DMF has stable physical and chemical properties [4] and is difficult to degrade when released into the environment [5, 6]. It damages human health through breathing or dermal exposure and may result in cancer and liver damage [7]. Therefore, it is urgent to solve the environmental problems caused by DMF.

Pharmaceutical wastewater has a complex composition, high concentration of organic matter, high toxicity of microorganisms contained, high salt content, and difficult to biodegrade [8]. At present, the domestic pretreatment methods for DMF wastewater mainly include physical and chemical methods (distillation method, adsorption method [9], extraction method [10], membrane separation method, etc.), chemical methods (photocatalytic oxidation [11], supercritical water oxidation [12], alkaline hydrolysis [13], etc.), and biochemical methods [14, 15].

DMF usually all flows into the wastewater on the production line, which causes high concentrations of wastewater pollutants. Currently, the industry treats most DMF wastewater as a separate distillation to prevent the effluent from exceeding the standard [10]. This unit of wastewater no longer enters the wastewater treatment system, but the cost is high. Due to the chemical stability of DMF, direct biochemical treatment is difficult to effective, and therefore, urgent need to seek a pretreatment process can improve the ammonification rate of DMF wastewater in the pretreatment section.

Therefore, based on the characteristics of DMF wastewater, a pretreatment process for high-concentration wastewater was proposed, this process combines the characteristics of high-temperature acid hydrolysis (DMF wastewater), iron-carbon micro-electrolysis (mixed wastewater), and coagulation reaction, expecting to improve the ammonification rate of DMF wastewater.

2 Experimental Materials and Methods

2.1 Pharmaceutical Wastewater Sources

The pharmaceutical wastewater chosen for this study came from a wastewater treatment station of a pharmaceutical company in Guangxi. This company had two streams of high-concentration wastewater: one is DMF wastewater with a volume of about

20 m^3/d, COD above 100 g/L, and total nitrogen up to 20 g/L. The other is dimethyl sulfoxide (DMSO) high-concentration wastewater, with a volume of around 80 m^3/d, COD above 100 g/L, total nitrogen is low, and due to the presence of salinity and by-products, the biochemical characteristics are not very high.

2.2 High-Temperature Acid Digestion Experiment

The water samples were reacted at $t = 80$ °C and 90 °C, pH = 1 and 2, and investigated the changes of COD, biochemical oxygen demand (BOD), NH_3–N (ammonia nitrogen), and TN (total nitrogen) of wastewater. During the experiment, it is necessary to add acid or alkali in time to maintain the pH of the water sample. The dosage agents were 98% concentrated sulfuric acid and 30% liquid alkali.

2.3 Iron-Carbon Micro-electrolysis + Coagulation Reaction Experiment

The water sample of DMF wastewater after 24 h high-temperature acid digestion was mixed with the mixed wastewater in the ratio of 1:5 and then carried out iron-carbon micro-electrolysis experiment. The initial pH of the reaction was controlled at 3.5 (acid consumption 0.31 ml/L), the reaction time was 12 h, and the samples were taken every 2 h for detection, and the COD, BOD, NH_3–N, TN contents, and pH were detected, respectively. Coagulation experiments were carried out on the effluent after 12 h of iron-carbon micro-electrolysis reaction.

3 Results and Discussion

3.1 Effect of High-Temperature Acid Digestion on DMF

Figure 1 is the acid digestion experiment results of DMF wastewater at 80 °C, pH = 1 (the values are detailed in Table 1). It can be seen from the table, the contents of COD, TN, and NH_3–N in DMF wastewater without high-temperature acid digestion reaction were 78.09, 18.59, and 0.24 g/L, and its pH was 3.381 at this time. The wastewater was under the conditions of reaction pH is 1 and temperature is 80 °C, with increasing reaction time, the ammonification rate increased gradually, when the reaction time reached 24 h, the removal rate of COD was 33.27%, the removal rate of TN was 12.4%, and the ammonification rate could reach 61%. The result indicated that high-temperature acid digestion has a significant effect on reducing the content of COD and TN in DMF wastewater.

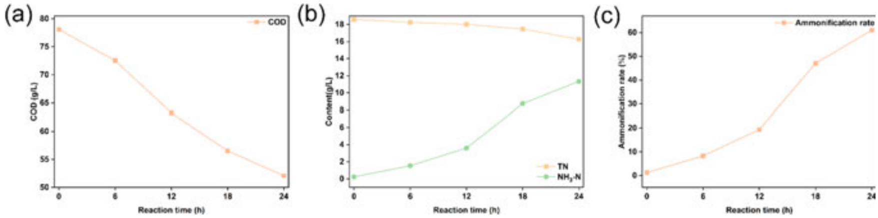

Fig. 1 Effect of high-temperature acid digestion on DMF, acid digestion temperature 80 °C, pH = 1, DMF wastewater: **a** COD; **b** TN, NH_3–N; **c** ammonification rate

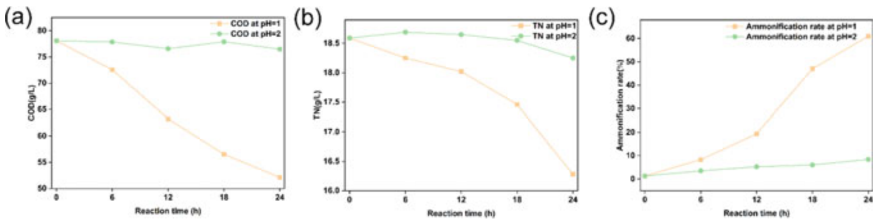

Fig. 2 Effect of high-temperature acid digestion on DMF at 80 °C, pH of 1 or 2, DMF wastewater: **a** COD; **b** TN; **c** ammonification rate

Figure 2 is the comparative analysis of the acid digestion experiments of DMF wastewater at 80 °C, pH is 1 or 2 (the values are detailed in Table 1). The experimental results showed that the pH of the high-temperature acid digestion reaction also had an effect on the contents of COD and TN in DMF wastewater. Specifically, when the reaction temperature was 80 °C, the reaction time was 24 h, and pH was reduced from 2 to 1, the COD and TN contents were decreased by 31.88 and 10.8%. This result indicated that the stronger the acidity, the more beneficial it is to reduce the COD content (Hanxiang Yang et al.) and TN content in DMF wastewater, and the ammonification rate is higher.

Figure 3 is the acid digestion experimental results of mixed water at 80 °C, pH = 1 (the values are detailed in Table 2). It can be seen from the table, the contents of COD, TN, and NH_3–N in the mixed wastewater without high-temperature acid digestion reaction were 111.63, 4.16, and 26 g/L, and its pH was 4.573 at this time. Under the conditions of reaction pH = 1 and temperature is 80 °C, with the increase of reaction time, the ammonification rate increased gradually, and when the reaction reached 24 h, the removal rate of COD was 13.2%, the removal rate of TN was 10.9%, and the ammonification rate could reach 88%. This result indicated that high-temperature acid digestion also has some effect on reducing content of COD and TN in mixed water, but not as obvious as DMF wastewater, because the sample contains a large amount of DMSO, and the biodegradability is reduced and the processing difficulty is increased.

Figure 4 is the comparative analysis of the acid digestion experiments of mixed wastewater at 80 °C and pH is 1 or 2 (the values are detailed in Table 2). The

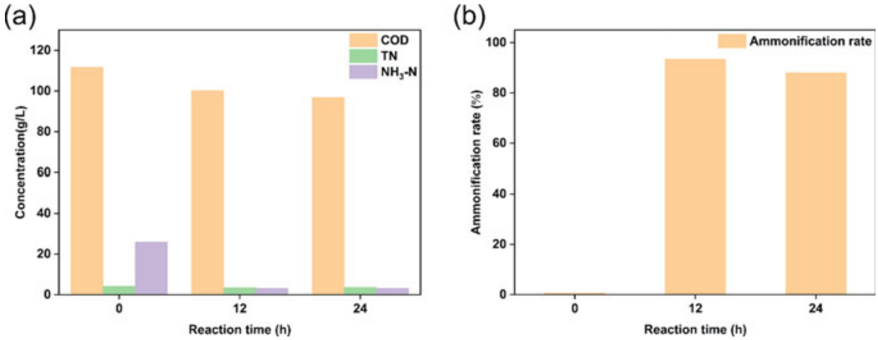

Fig. 3 Effect of high-temperature acid digestion on mixed wastewater, acid digestion temperature 80 °C, pH = 1, mixed wastewater: **a** COD, TN, NH_3–N; **b** ammonification rate

experimental showed that the pH of the high-temperature acid digestion reaction also had an effect on the contents of COD and TN in the mixed wastewater. Specifically, when the reaction temperature was 80 °C, the reaction time was 24 h, and the pH was reduced from 2 to 1, the COD and TN contents decreased by 4.9 and 3%, and the ammonification rate increased by 74.2%. This result indicated that the stronger the acidity, the more beneficial it is to reduce the content of COD and TN in the mixed wastewater, and the ammonification rate is higher.

Figure 5 is the comparative analysis of the acid digestion experiments of DMF wastewater at pH = 1 and acid digestion temperature of 80 and 90 °C (the values are detailed in Table 3). It can be seen from the table, the contents of COD, TN, and NH_3–N in DMF wastewater without high-temperature acid digestion reaction were 78.09, 18.59, and 0.24 g/L, and its pH was 3.381 at this time. Compared with the data in Table 1, the COD and TN contents of this wastewater decreased by 14.4 and 18.6%, and the ammonification rate increased by 85% when the pH was 1, and the temperature was changed from 80 to 90 °C. This result indicated that the higher the temperature is, the more beneficial it is to reduce the content of COD and TN in DMF wastewater, so that the ammonification rate is higher.

Operation cost analysis: As the reaction proceeds, the pH of the water sample will gradually increase, and the acid needs to be replenished in time to maintain the pH

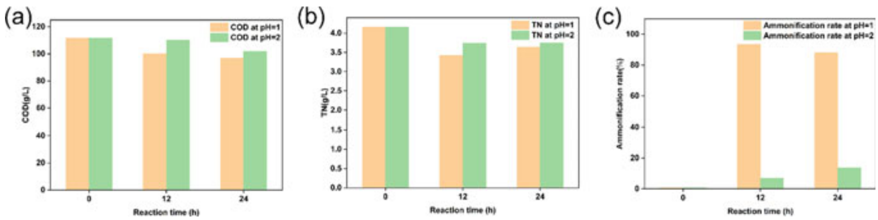

Fig. 4 Effect of high-temperature acid digestion on mixed wastewater, acid digestion temperature 80 °C, pH 1 or 2, mixed wastewater: **a** COD; **b** TN; **c** ammonification rate

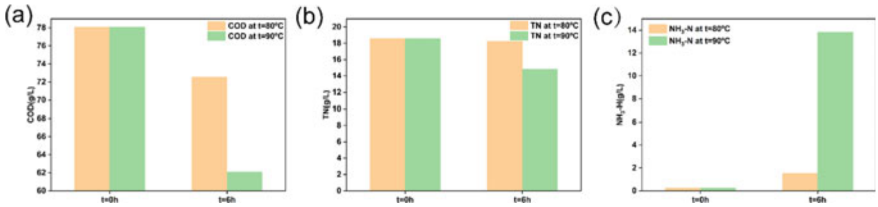

Fig. 5 Effect of high-temperature acid digestion on DMF, acid digestion temperature 80 °C, 90 °C, pH = 1, DMF wastewater: **a** COD; **b** TN; **c** NH_3–N

of the reaction; according to the calculation of the reaction for 24 h, the amount of concentrated sulfuric acid needs to be 22.4 mL/L, which is equivalent to 41.2 kg/ton of water, and the cost of 20.6 yuan/ton of water; 1 ton of wastewater is heated from 20 to 80 °C by steam heat exchange, 0.10367 tons of saturated water vapor (pressure is 0.6Mpa) at a temperature of 158.84 °C is required, then the cost of ton water vapor per ton is 29 yuan. Therefore, the total cost of high-temperature acid digestion is 49.6 yuan.

3.2 Effect of Iron-Carbon Micro-electrolysis + Coagulation Reaction Experiment on DMF

Figure 6 is the experimental results of iron-carbon micro-electrolysis of mixed wastewater (values are detailed in Table 4). It can be seen from the table, the contents of COD, BOD, TN, and NH_3–N in the mixed wastewater without iron-carbon micro-electrolysis were 99, 0.06, 5.31, and 1.84 g/L, and its pH was 3.508 at this time. When the reaction time reaches 12 h, the removal rate of COD was 13.4% and the ratio of B/C 0.0006 was increased from 0.006. From the data, after the iron-carbon micro-electrolysis reaction, the concentration of BOD in the wastewater increased, but due to the limitations of the assay, the change trend was not obvious and fluctuated greatly.

Figure 7 is the experimental results of the coagulation reaction of mixed wastewater (the values are detailed in Table 5). It can be seen from the table that with the increase of poly aluminum chloride (PAC) content, the removal rate of COD reached 9.7%. After the wastewater was subjected to iron-carbon micro-electrolysis and coagulation reaction, there is no obvious change in TN and NH_3–N, indicating that the ammonification effect of iron-carbon micro-electrolysis and coagulation reaction on the wastewater was not apparent; the degradation effect on COD was more obvious, which can effectively reduce the load on the back-end biochemical system.

Operation cost analysis: the acid adjustment amount of iron-carbon reaction is 0.5 kg/ton of water, and the cost is 0.25 yuan/ton of water; the amount of PAC in coagulation reaction is calculated as 1 kg/ton of water, and the cost is 1.6 yuan; the dosage of PAM is 4 ppm, and the cost is 0.088 yuan/ton tons of water, so the total cost of iron-carbon micro-electrolysis + coagulation reaction is 1.94 yuan/ton of water.

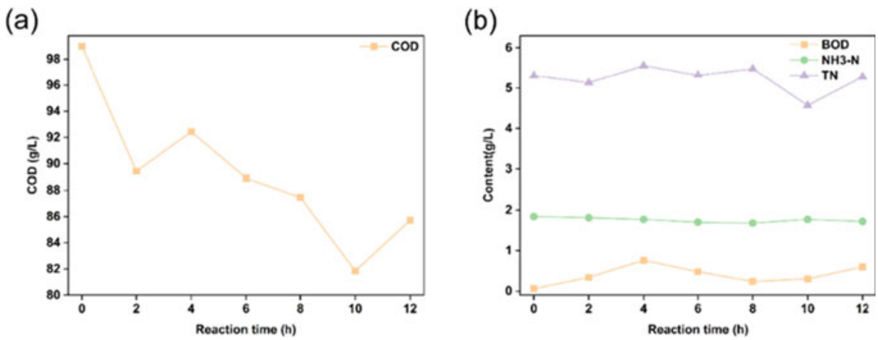

Fig. 6 Effect of iron-carbon micro-electrolysis on mixed wastewater with **a** COD; **b** BOD, NH_3–N, TN

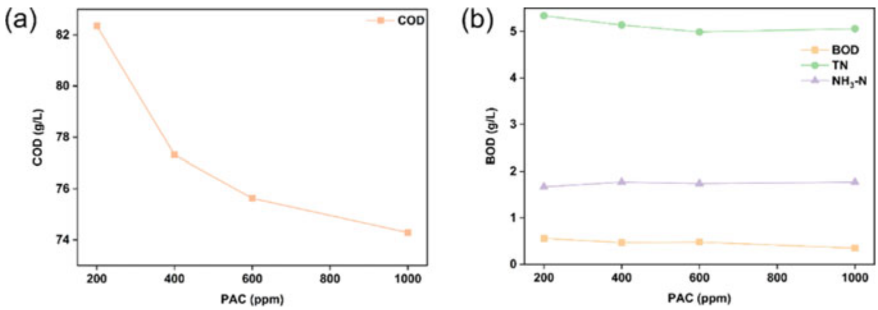

Fig. 7 Effect of coagulation reaction on mixed wastewater: **a** COD; **b** BOD, TN, NH_3–N

4 Conclusion

Through the experiment, the treatment process of high-temperature acid digestion + iron-carbon micro-electrolysis + coagulation reaction has a more noticeable effect on the ammonification of high-concentration wastewater, degrading part of COD and improving the biodegradability of wastewater. The experimental results and operating dosing and steam costs are summarized as follows:

(1) High-temperature acidification reaction has a good effect on converting organic nitrogen in DMF wastewater into NH_3–N. As the more robust the acidity, the ammonification rate of DMF wastewater increased with the increase of acidity and reaction time. The ammonification rate of DMF wastewater reached more than 80%, the degradation rate of COD reached 30%, and the removal rate of total nitrogen was 15%.

(2) Iron-carbon micro-electrolysis in combination with coagulation reaction further increased the COD degradation (about 25%). The removal rate increased with the increase of dosage; from the data, the process has a specific effect on

improving the biochemical properties of wastewater, but due to the limitations of the assay, the change trend was not obvious.

(3) The cost of high-temperature acid digestion of DMF wastewater is 49.6 yuan/ton of water, and the dosing cost of iron-carbon micro-electrolysis + coagulation reaction is about 1.92 yuan/ton of water.

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Appendix

See Tables 1, 2, 3, 4 and 5.

Table 1 Experimental results of acid digestion of DMF wastewater at 80 °C

	pH	Temperature (°C)	Reaction time (h)	Drug consumption (ml/L)	COD (g/L)	TN (g/L)	NH_3–N (g/L)	Ammonification rate (%)
DMF wastewater	3.381	18	/	/	78.09	18.59	0.24	1.30
Water sample 1	1	80	6	8.4	72.54	18.25	1.54	8.3
Water sample 1	1	80	12	12.5	63.25	18.02	3.60	19.37
Water sample 1	1	80	18	16.8	56.54	17.46	8.75	47.04
Water sample 1	1	80	24	22.4	52.10	16.28	11.34	61.01
Water sample 1	1	80	36	22.4	50.25	16.03	13.82	74.4
Water sample 2	2	80	6	1.00	77.85	18.69	0.65	3.52
Water sample 2	2	80	12	1.28	76.58	18.65	0.98	5.26
Water sample 2	2	80	18	1.56	77.90	18.55	1.13	6.05
Water sample 2	2	80	24	1.87	76.49	18.25	1.56	8.39
Water sample 2	2	80	36	1.87	78.66	15.87	2.38	12.7

Table 2 Results of mixed water acid digestion experiments at 80 °C

	pH	Temperature (°C)	Reaction time (h)	Drug consumption (ml/L)	COD (g/L)	TN (g/L)	NH_3–N (g/L)	Ammonification rate (%)
Mixed wastewater	4.573	80	/	/	111.63	4.16	26.0	0.6
	1	80	12	13	100.22	3.42	3.20	93.4
	1	80	24	/	96.88	3.64	3.21	88
	2	80	12	0.74	110.24	3.74	0.26	6.9
	2	80	24	/	101.89	3.75	0.52	13.8

Table 3 Results of acid digestion experiments of DMF wastewater at 90 °C

	pH	Reaction time (h)	pH after reaction	Drug consumption (ml/L)	COD (g/L)	TN (g/L)	NH_3–H (g/L)
DMF wastewater	3.381	/	/	/	78.09	18.59	0.24
Water sample 1	1	1	2.017	11.2	/	/	/
Water sample 1	1	2	1.558	8.9	/	/	/
Water sample 1	1	3	1.534	/	/	/	/
Water sample 1	1	4	1.501	12	/	/	/
Water sample 1	1	5	0.835	/	/	/	/
Water sample 1	1	6	0.639	/	62.07	14.85	13.85
Water sample 2	2	1	2.761	1.66	/	/	/
Water sample 2	2	2	2.359	1.08	/	/	/
Water sample 2	2	3	2.358	/	/	/	/
Water sample 2	2	4	2.355	0.92	/	/	/
Water sample 2	2	5	1.792	/	/	/	/
Water sample 2	2	6	1.866	/	97.42	14.87	2.41

Table 4 Experimental results of iron-carbon micro-electrolysis

Reaction time (h)	COD (g/L)	BOD (g/L)	NH_3–N (g/L)	TN (g/L)	pH
0	99.00	0.06	1.84	5.31	3.508
2	89.42	0.34	1.81	5.13	4.536
4	92.44	0.76	1.77	5.56	4.678
6	88.91	0.48	1.70	5.32	5.01
8	87.46	0.24	1.68	5.48	5.338
10	81.85	0.30	1.77	4.57	5.347
12	85.72	0.60	1.72	5.28	5.383

Note The ratio of ammonia/total nitrogen decreased because the concentration in the mixed water was only 0.026 g/L, and the total nitrogen concentration was 4.2 g/L, which pulled down the ratio of ammonia/total nitrogen after mixing with the acid-dissolved DMF wastewater

Table 5 Experimental results of coagulation reaction

Water sample no.	PAC (ppm)	COD (g/L)	BOD (g/L)	TN (g/L)	NH_3–N (g/L)
1	200	82.36	0.56	5.34	1.67
2	400	77.31	0.47	5.14	1.77
3	600	75.63	0.48	4.99	1.74
4	800	79.00	0.20	4.88	1.70
5	1000	74.29	0.35	5.06	1.77

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Research on the Current Problems, Potential, and Countermeasures of Sewage Treatment and Reuse in Yan'an

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Abstract Yan'an is located in the loess hilly-gully area and belongs to a typical mountainous strip city with very scarce water resources. The current reclaimed water supply is less than 1.3% of the total urban water supply. There are three sewage treatment plants in the central city, the sewage collection pipeline network has been built for 238.16 km, and the reclaimed water pipeline is about 28 km. In the utilization of urban sewage water in Yan'an, there are problems such as imperfect sewage collection and reuse pipe network, unsmooth management system, unsound policy system, and insufficient funds. The sewage water utilization potential in Yan'an which predicted by index analysis is 44,900 m^3/d in 2025 and 68,600 m^3/d in 2030. Engineering countermeasures for the construction of sewage treatment facilities and pipe networks, with non-engineering countermeasures for the mechanisms, systems, funds, water prices, operation modes, professionals, propaganda, and demonstration are proposed, which has reference significance for similar cities to use sewage water.

Keywords Sewage treatment · Reuse · Problems · Potential · Countermeasure

1 Overview of the Study Area

Yan'an is located in the northern Shaanxi Province of China, in the middle reaches of the Yellow River, and in the southern Loess Plateau. It is a typical mountainous belt city with more than 90% of the land covered by hills and gullies, forming a long, narrow valley city that is 20 km long and 300 m wide along three mountains and two rivers: the Yan River, Nanchuan River, Baota Mountain, Qingliang Mountain, and Fenghuang Mountain. The kiln-dwelling villages are generally built spontaneously

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against the mountain-cut slopes. A portion of the population lives in the mountains or the gullies. The villages have a dispersed architectural design.

Yan'an city is in a warm-temperate, semi-arid monsoon climate zone. Its annual average total water resources are 1.356 billion m^3, the water resources per unit area are 37,000 m^3/km^2, the per capita water resources are 594 m^3, and per capita water resources distribution is uneven, more in the south and less in the north. Total water supply in 2020 is 312 million m^3, of which less than 4 million m^3 were recycled water.

2 Sewage Treatment and Reuse Projects in Yan'an

2.1 Sewage Treatment Plants

There are three sewage treatment plants in the central city of Yan'an (Baota District), of which the current capacity of Yan'an Water Environmental Management Co., Ltd. (formerly known as Yan'an City Sewage Treatment Plant) is 70,000 m^3/d, the effluent water quality comes to level A standard, mating Liushudian sewage lifting pumping station and Dongguan sewage lifting pumping station, lifting capacities are both 50,000 m^3/d; the capacity of Hezhuangping sewage treatment plant is 1800 m^3/d; the capacity of Yaodian sewage treatment plant is 50,000 m^3/d in the short term, 130,000 m^3/d in the long term.

Yan'an New Area underground sewage treatment plant with design scale of 15,000 m^3/d in the short term, and 30,000 m^3/d in the long term has not yet been put into use. Yan'an New Area North (first stage) reclaimed water plant is built in conjunction with the sewage plant, with a design scale of 24,000 m^3/d of reclaimed water supply, and the current output of reclaimed water is 6000 m^3/d.

2.2 Sewerage Network

The built-up area in Yan'an city uses an intercepting combined drainage system, only built interceptor drainage trunk pipe and part of the branch pipe, the sewage collection system is not perfect, and rainwater and sewage are mixed then discharge into the interceptor drainage trunk pipe. Newly built areas use the rainwater and sewage diversion drainage system.

There are sewage collection network of 238.16 km, two lift pumping stations, and 120 interception gates in Yan'an city, and the collection coverage area is 37 km^2. The current sewage collection trunk pipes are mainly arranged in the Yan River, Nanchuan River, Xichuan River, and Dufuchuan River, and other branch pipes are connected to these trunk pipes and finally discharged into the Yan'an city sewage treatment plant.

2.3 Reclaimed Water Pipe Network

Yan'an city wastewater treatment plant has built about 28 km of reclaimed water pipeline, of which 8 km under the Baimi Avenue, pipe diameters are DN50–DN400; 20 km under the Dongbin Road, pipe diameters are DN600–DN700.

In Yan'an new area, except for Shao Street, Zunyi Street, South Gongxue Road and South Beihuan Road, all other existing roads have been paved with reclaimed water pipes. Except for the east area, the reclaimed water pipe network in the rest of the new area under construction is completed.

3 Problems in Sewage Treatment and Reuse in Yan'an

3.1 Inadequate Collection and Reuse Pipe Network

City buildings in Yan'an are arranged in a tight "Y" shape along the river road, the terrain has a significant height difference, the laying of pipe networks is difficult, and the sewage collection rate is low. The geography of the mountain is complex, the road up the mountain is steep and narrow, and the settlement is scattered and chaotic, therefore, it is difficult to construct, the construction cost is high, and the maintenance management is inconvenient and expensive. Compared to other types of cities, the collection of the same amount of sewage requires a longer trunk pipe network, and construction and operation costs are higher.

Due to historical restrictions on relatively narrow streets, high building density, and a dense underground pipe network, Yan'an old city has no new pipe position option and is unable to transform its rainwater and sewage diversion systems; instead, sewage is still discharged using a combined flow collection. It is challenging to achieve 100% collection, and it is even more challenging to build a reclaimed water reuse pipeline. As a result, half of the treated reclaimed water (20,000 m^3/d) from Yan'an city sewage treatment plant can only be replenished for the downstream river currently, leaving some potential users without access to it.

3.2 Poor Management System

Yan'an city water conservation, water extraction, and sewage treatment reuse work are handled by the Urban Administrative Bureau, county water conservation is handled by the Water Bureau, and the administrative approval of related projects is handled by the Administrative Approval Bureau. Sewage treatment and reuse by different departments' management not only seriously affects the unified planning of sewage treatment and reuse but also restricts the full implementation of the relevant projects. And sewage treatment and reuse involves development and reform, water conservancy, housing and construction, environmental protection, resource planning, finance, and other functional departments. Subject to the impact of the departments' inability to effectively collaborate, it often appears that it is difficult to establish projects after the planning of a sewage treatment reuse project and is difficult to raise sufficient funds for construction, and part of the project is delayed due to the construction of land.

3.3 Inadequate Policy System

Within the past five years, Yan'an city and its counties (districts) have revised and improved 43 management measures relating to the sewage treatment and reuse, including the Measures for the Management of Water Resources in Yan'an City, the Notice on the "Three Simultaneous" Work of Water Conservation in Construction Projects in Yan'an City, and the Measures for the Management of Water Conservation in Yan'an City, while the city and counties (districts) have set up water conservation management agencies. It has formulated and issued the implementation plan for the construction of a water-saving society in Yan'an city and promulgated regulations such as the Measures for Supervising the Construction and Operation of Urban Sewage Treatment Facilities in Yan'an city. In addition, some overall and special plannings in Yan'an, such as the Yan'an City Urban Overall Planning (2015–2030), the Yan'an City Urban Water Conservation Plan (2018–2030), the Yan'an City Urban Sewage Special Plan (2013–2030), the Yan'an City Central Urban Sewage Engineering Special Plan (2020–2030), and the Yan'an New District Recycled Water and Rainwater Comprehensive Utilization Plan (2021–2030), Special Planning of Municipal Infrastructure-Reclaimed Water in North District of Yan 'an New District (2011–2030), the special planning of municipal engineering in the eastern area (closing area) of the northern area of Yan 'an New District—the special planning of reclaimed water (2020–2030), the "14th Five-Year" Plan for the construction of a water-saving society, all have the content of wastewater treatment and reuse.

In general, Yan'an city has introduced a series of policies in water conservation and has planned the reuse of sewage in the city, but it still has not established a systematic and detailed supervision mechanism, a compensation mechanism, or a reward and punishment mechanism. Moreover, the legal, administrative, and economic instruments for wastewater treatment reuse are still imperfect, and the mandatory and incentive embodiment in the approval of water use project, urban planning, and municipal facility construction is still insufficient [1].

3.4 Insufficient Supporting Funds

Local financial resources in Yan'an city and its counties (districts) are constrained; the provincial water conservancy department allocated to Yan'an city sewage treatment-related funds of only one million yuan a year, and the provincial housing construction department also did not allocate related funds. Coupled with the fact that the government and related departments did not include the sewage and reclaimed pipeline network, facility construction, and other projects in the financial budget, the project planning and construction are greatly constrained. Yan'an city established the Yan'an Water and Environmental Protection Group in recent years to promote market-oriented sewage treatment and reuse, however, the lack of diversification of financing channels and insufficient innovation of financing mode due to a high project debt rate and a large capital gap of construction.

3.5 Mismatch Between Treatment Costs and Water Prices

Through investigation, the ordinary treatment cost of the Yan'an city sewage treatment plant to meet the emission requirements is 2.5 yuan/m^3, but the cost of the membrane treatment process with higher quality is 4 yuan/m^3, and if you consider the construction, operation, and maintenance of the pipe network, the cost of water treatment will be increased. In comparison with the Yan'an Municipal Development and Reform Commission's determination in 2019 for the Yan'an Water and Environmental Protection Group to supply the counties and districts with urban domestic water at a basic water price of 1.94 yuan/m^3, a metering water price of 1.97 yuan/m^3, and a reclaimed water trial factory price of 2 yuan/m^3. In the newly revised Yan'an City Water Supply Price Management Measures, the price of domestic water for residents in Yan 'an city is 3.95 yuan/m^3, and there is no unified pricing for reclaimed water. Yan'an city sewage treatment plant currently provides reclaimed water for free for river and lake replenishment.

The unreasonable exploitation of water resources, unreasonable subsidies for public water use, low water prices, and low charges have led to high raw water prices for reclaimed water compared to fresh water, and the cost of high-quality reclaimed water to meet the needs of residents is higher than the price of tap water, which not only leads to a lack of motivation to use but also causes sewage treatment plants to run continuously in debt. The price mechanism of "quality-divided water supply and a high price for good water" has not yet been formed, and as a result, the leverage of water price cannot be effectively exerted.

3.6 Incomplete Grassroots Team Construction

The water resources sector in Yan'an is at the forefront of team construction in Shaanxi Province. The Municipal Water Affairs Bureau has a secondary bureau for water resources management, with a water conservation section responsible for reclaimed water management. The Water Resources Management Bureau has an administrative establishment of 19 people, and the Water Conservation Section has an administrative establishment of 3 people. In recent years, as the country's investment in water resources and the management of rivers and lakes has continued to increase, the tasks undertaken by grassroots managers have become increasingly heavy, the workload has increased exponentially, and the professional skill requirements have increased year on year. But because of staffing, staff mobility, aging knowledge and other factors, especially below the county level, not only the number but also the quality of staff cannot meet the professional requirements.

3.7 Low Level of Social Awareness

Although Yan'an city was selected as the tenth batch of national water-saving cities in 2020, sewage resource utilization is still in its infancy. Every year, water departments of Yan'an use "World Water Day", "China Water Week", and "Water Conservation Publicity Week" for centralized publicity, but due to the lack of publicity, single form, limited coverage, and the people's own cultural level, the masses have insufficient understanding of the feasibility and safety of sewage resource utilization and have doubts about the use of reclaimed water [2].

4 Prediction of Sewage Resource Utilization Potential

4.1 Prediction Methods

Prediction of wastewater resource utilization potential uses the indicator analysis method. According to the scale of urban construction, population size, industrial policies and other information to calculate the residential water demand, industrial water demand. With the predicted residential and industrial water demand in Yan'an city as the amount of sewage generated, according to the relevant policy requirements and local economic and social development, predict the centralized collection rate of urban sewage, the centralized treatment rate of sewage treatment plants, the standard discharge rate of sewage treatment plants, and the utilization rate of reclaimed water, integrated to obtain the potential of sewage resource utilization. The calculation formula is as follows:

$$Q_s = (Q_r + Q_i) \times P1 \times P2 \times P3 \quad (1)$$

where

Q_s Sewage resource utilization potential, in million m^3
Q_r Residential water demand, in million m
Q_i Industrial water demand, in million m^3
$P1$ Centralized collection rate of urban sewage
$P2$ Sewage discharge factor
$P3$ Utilization rate of reclaimed water.

4.2 The Potential of Sewage Resource Utilization

According to the "Special Planning for Sewage Engineering in Yan'an city center (2020–2030)," the residential and industrial water demand in Yan'an city center is 215,100 m^3/d in 2025 and 281,000 m^3/d in 2030. According to the "14th Five-Year" Urban Sewage Treatment and Resource Utilization Development Plan issued by the National Development and Reform Commission and the Ministry of Housing and Urban–Rural Development, the discharge factor is 0.80 in 2025 and 0.85 in 2030; the utilization rate of reclaimed water is 25% in 2025 and 27% in 2030; and the centralized collection rate of urban sewage is 95% in 2025 and 97% in 2030.

Given that Yan'an is an old city, most of the main sewage interception pipes are in the river, some pipelines are still combined flow systems, and the water in some current ditches are also included in the sewage network, 10% of river water and groundwater infiltration are taken into account in the short and long term. Therefore, a combination of factors determines the potential for reclaimed water supply in Yan'an to be 44,900 m^3/d in 2025 and 68,600 m^3/d in 2030 [3].

According to the planning, Yan'an city will form several areas including the old town core area, the northern district group, the high-tech zone, the Wanhua group, and the Nanniwan group. The predicted sewage resource utilization potential of each area is shown in Table 1.

5 Countermeasures for the Resourceful Use of Wastewater in Yan'an

5.1 Engineering Countermeasures

Centralized sewage treatment facilities. Deep treatment facilities are currently being built at Yan'an Qiaogou sewage treatment plant and Yaodian sewage treatment plant. According to the "Yan'an downtown sewage treatment special planning", the future cancellation of the Qiaogou sewage treatment plant and its service water

Table 1 Predicted sewage resource utilization potential in Yan'an city

Zoning	Group name	2025 (million m^3/d)	2030 (million m^3/d)
Old town core area	Hezhuangping Residential Community	0.17	0.26
	Shengdi Community	0.30	0.46
	Phoenix Hill Residential Community	0.28	0.42
	Nanchuan Residential Community	0.39	0.59
	Liulin Residential Community	0.42	0.64
	Huangsongwan Residential Community	0.29	0.44
	Dongchuan Residential Community	0.31	0.47
	Ershilipu Residential Community	0.20	0.30
Northern district group	Central Residential Community	0.28	0.43
	Dongsheng Residential Community	0.08	0.12
	Yangjialing Residential Community	0.42	0.63
	Yinjiagou Residential Community	0.25	0.39
High-tech zone	Square Tower Residential Community	0.17	0.26
	Yaodian Residential Community	0.29	0.45
	Liqiu Residential Community	0.43	0.66
Wanhua group	Wanhua Residential Community	0.11	0.17
Nanniwan group	Nanniwan Group	0.11	0.17
Total		4.49	6.86

transfer to the Yaodian sewage treatment plant will result in the Yaodian sewage treatment plant's size increasing to 175,000 m^3/d, while the treatment scale of 30,000 m^3/d will be implemented at a new sewage treatment plant in the Yan'an New District (North sub-district). As a result, as long as the necessary planning is in place, the engineering construction of centralized sewage treatment facilities will meet the future needs of sewage treatment and reuse. Planning of centralized sewage treatment facilities in Yan'an is shown in Fig. 1.

Fig. 1 Planning of centralized sewage treatment facilities in Yan'an

Given the narrow river valley geomorphological characteristics of the Yan'an urban area, if the Qiaogou sewage treatment plant is eliminated and be merged with the Yaodian sewage treatment plant which located downstream of the city and further from the downtown area, which is not conducive to use reclaimed water. Therefore, from the perspective of sewage resource utilization, it is recommended that do not cancel the Qiaogou sewage treatment plant, in this way, reclaimed water can be used to upstream roads watering, green watering and river water replenishment, and can also be supplied to car wash shops and communities along the Baimi Avenue, and the Yaodian sewage treatment plant focuses on supplying industrial cooling water to Yan'an thermal power plant, Liqu town, Yaodian industrial park, and Yaodian power plant nearby, can also consider supplying recharge water to the surrounding oil injection wells [4].

Decentralized sewage treatment facilities. The terrain of the eastern part of Yan'an city is relatively open, and the distance between both the Qiaogou sewage treatment plant and the Yaodian sewage treatment plant is closer, and the city has built reclaimed water pipe networks under the Baimi avenue, Dongbin Road to basically meet the centralized sewage treatment and reuse needs. The northwestern and southwestern parts of the central city have narrow terrain and limited public space, so it is extremely difficult to build a pipe network there. Therefore, to alleviate the regional water shortage problem, Yan'an city can only vigorously develop decentralized sewage treatment facilities.

To achieve zero regional discharge, it is recommended that decentralized sewage treatment and reuse facilities be built in areas with large public spaces such as Yan'an University, Yan'an Vocational and Technical Institute, Yan'an Cadre Institute, Revolutionary Memorial Hall, Stadium, Railway Station, Xibeichuan Park, Victory Square, Yan'an Hotel, and so on [5].

Reclaimed water pipeline network. Currently, Yan'an city has built a connection to the Qiaogou sewage treatment plant and the Yaodian sewage treatment plant, a total length of 28 km of reclaimed water pipeline network, including the Baimi avenue and Dongbin Road reclaimed water pipeline network, and the North District reclaimed water pipeline network is building, these pipeline networks basically covering the eastern and northern parts of the central city. In the future, the reclaimed water pipeline network can be further extended along the main roads such as Shengdi Road and Nanbin Road to supply reclaimed water to the northern and southern areas of the central city. In addition, considering the higher terrain and the higher coverage of the reclaimed water pipe network in the northern area, it is also possible to build a connection project between the reclaimed water pipe network under the Northern Ring Road and the northern area to achieve the purpose of replenishing the reclaimed water to the northwest of the central city and upstream of the Yan River.

5.2 Non-project Countermeasures

Policy and Regulations. It is recommended that regulations such as the Yan'an City Water Conservation Regulations, the Yan'an City Sewage Treatment and Reclaimed Water Use Regulations, and the Implementation Opinions on Utilization of Reclaimed Water Resources in Yan'an city be formulated and promulgated to provide a regulatory basis for the use of reclaimed water. Formulating the "Regulations on the Construction of Reclaimed Water Supply Systems for Residential and Public Buildings in Yan'an City" to set out requirements for the construction of reclaimed water can lay the foundation for the resourceful use of sewage within buildings. Formulating the local standards such as the "Technical Specification for Reclaimed Water Reuse in Oil Injection Wells in Yan'an City" to ensure the scientific and reasonable reuse of reclaimed water in oil injection wells. In addition, it is recommended that the "Yan'an City Reclaimed Water Use Plan" includes a systematic analysis of water resources and sewage resources in Yan'an city, reclaimed water use pathways, the scale of the sewage treatment and reuse facilities, a time plan for the implementation of the project be established, with the establishment of a regular revision of the planning system [6].

Institutional mechanisms. It is recommended that the Yan'an Sewage Resource Utilization Leading Group be established with the deputy mayor in charge as the head, water, housing and construction, urban management law enforcement departments as the deputy head, development and reform, national assets, approval services, audit, statistics, science and technology, education, industry and information, human resources and social security, business, cultural and tourism, ecological and environment, agriculture and rural areas, natural resources, rural redevelopment as the members, which is responsible for coordination and implementation work. Establishing a target responsibility assessment mechanism, including clarifying the responsibility and authority between governments at all levels and between departments, clarifying the annual targets and tasks, establishing an assessment and accountability mechanism with cascading decomposition and responsibility to the people and establishing a reward and punishment mechanism linked to the post promotion, title evaluation, and fund distribution. Playing the role of party committee inspections, government supervision, and through the supervision of the People's Congress, the Political Consultative Conference and the public [7].

Financial Security. First of all, it is recommended that the Yan'an municipal government incorporate the sewage resource utilization project into the annual national economic implementation plan, increase the scale of investment, implement the funding sources, and gradually increase the proportion of sewage resource utilization projects within the financial budgets of governments at all levels to ensure that the sewage resource utilization funds are invested at the same proportional growth as the fiscal revenues. Secondly, seek subsidies from water conservation, environmental protection, housing and construction, natural resources, agriculture, and rural areas and apply to major policy banks for the use of long-term low-interest loans, national and local government bonds, or special bonds, and the investment and financing function of water environmental protection group can also be used to attract social funds. Finally, project financing methods such as PPP, BOT, TBT, and ABS can also be adopted according to the characteristics of the project to widely attract social capital investment [8].

Water Pricing Policy. At present, the sewage treatment fee of Yan'an residents is 0.95 yuan/m^3, and the sewage treatment fee of non-residents is 1.40 yuan/m^3, which are far lower than the sewage treatment cost. It is suggested to deepen the research on water pricing mechanism, on the one hand to widen the price difference between tap water and reclaimed water in order to improve the competitiveness of recycled water prices, and on the other hand to explore the implementation of benchmark price, negotiation price, market adjustment price, government guidance price and regressive price mechanism, and formulate guidance on reclaimed water price management in line with local actual conditions as soon as possible.

It is recommended that the government provide preferential loans or construction loans at reduced or no interest rates for sewage treatment and reuse projects, the construction land of the project implements municipal infrastructure policies and preferential land acquisition and demolition prices. Exemption from VAT, income tax, and urban public utility surcharges for a certain period for enterprises operating in sewage treatment and reuse; sewage treatment and reuse electricity should enjoy preferential prices. Enterprises using reclaimed water are exempt from VAT and income tax for a certain period; the internal pipe network renovation projects of sewage treatment and reuse enterprises are allowed to be included in the technical renovation, and the expense can be included in the cost. Reclaimed water users should be exempt from the sewage treatment fees [9].

Operating model. It is suggested that the construction of centralized sewage treatment facilities should be financed by reclaimed water management enterprises, and the land should be allocated administratively to avoid high land transfer costs; the public reclaimed water pipe network under the urban planning road should be transferred to the water and environmental protection group for operation and management by the government after the construction charging matching fees. The large-scale supporting reclaimed water pipeline of industrial infrastructure (technical transformation) projects not included in the large-scale supporting fees shall be constructed by the construction enterprise (industrial users) with their own investment, and the decentralized sewage treatment facilities are responsible for investment, construction, and operation by enterprises and institutions.

Talent team construction. In response to the shortage of staffing in the grassroots water resources management departments, it is suggested to fully implement the personnel employment system of water conservancy institutions and further expand the autonomy of personnel management in institutions, either by outsourcing technical staff or introducing services with the help of human service resource companies, and actively promote government purchase of services. At the same time, introducing the preferential policies for the introduction of talent, such as setting up special funds and projects, improves the logistical support policies for the children schooling, medical care, housing, etc., while increasing the security of basic living facilities through the local characteristics and advantages that attract talent.

To address the mismatch between the knowledge structure of the talent team and the needs of the work, targeted training of human resources and cultivation of reserve forces should be implemented. Taking advantages of universities and colleges inside and outside the province, invite experts and scholars as resident consultants to conduct regular technical and theoretical training, while annually sending technical personnel to study in areas where reclaimed water utilization is better developed. Regular competitions can also be organized for expertise in water resources, water conservation, and other related areas.

To ensure the stability of the talent team, a scientific and socialized talent evaluation mechanism oriented by ability and performance should be established, the reform of the income distribution system of water conservancy institutions should be promoted, in order to guide income distribution toward outstanding talents, key positions, and hardship areas. At the same time, implementing the water resources talent reward policy guided by government incentives, employing unit rewards as the main body and social force rewards as a supplement.

Propaganda and demonstration. It is suggested that new media is used to use new media to carry out online publicity during World Water Day, China Water Week, and Water Conservation Awareness Week. Public awareness of the use of reclaimed water could be raised through the carriers such as decorative items, household utensils, cultural walls, stations, public transport tools, and activities such as knowledge competitions, results displays, themed class meetings, and essay-writing activities.

Broadening the channels for public participation in the use of reclaimed water and enriching the forms of participation through timely and multi-channel publication of management policies and guidance measures on reclaimed water use, as well as hearings or online questionnaires organized for decisions on major issues.

Government agencies should take the lead in institutions and families residential areas to carry out demonstration projects on the use of sewage resources and continue to increase the use of sewage resources in institutions, campuses, and communities in demonstration. Relying on the construction of a water-saving society [10], actively declare national and provincial pilot projects and report typical projects that are carried out faster and better or distinctive in resourceful use of sewage.

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Simulation and Prediction of Water Quality in Huangjinxia Reservoir on Hanjiang River Based on MIKE21

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Abstract Huangjinxia Reservoir is a crucial source project in the Hanjiwei River diversion project. After the completion and operation of the reservoir, the water level reaches of the reservoir will rise, change the original water flow structure, greatly increase the submerged area of the original basin, and reduce the self-purification capacity of the water body. Under the existing pollution load conditions, the MIKE21 model is used to predict and calculate the concentrations of chemical oxygen demand, total phosphorus, and total nitrogen in the water body of the reservoir. The calculation results show that after the construction of Huangjinxia Reservoir, the concentrations of chemical oxygen demand and total nitrogen in the river reach the Class III water quality target requirements of the state, and the concentration of total phosphorus reaches the Class II water quality target requirements of the state. The overall water quality in the region is good. The possibility of water eutrophication is not high in the initial stage of reservoir construction and operation. However, due to the complex topography of some river channels (Jinshui River, Youshui River, etc.) and reservoir bay, poor water quality, poor water exchange performance, and the phenomenon of stem and leaf loss and death of flooded plants, the concentration of pollutants in some areas exceeds the standard. The long-term retention of pollutants does not rule out the possibility of water eutrophication. The water quality can be purified, and local water eutrophication can be controlled through rational use of the corresponding aquatic biological control technology.

Keywords Water eutrophication · Water quality · MIKE21 model · Huangjinxia Reservoir

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1 Introduction

The water level of Huangjinxia Reservoir, a key water conservancy project in the Hanjiang-to-Weihe River water transfer project, will rise after construction, thus flooding vegetation on the banks [1]. As a result, individual vegetation loses its growing environment, finally damaging the original eco-system of vegetation on banks. Such impact is irreversible. Because Huangjinxia Reservoir is an important water resource of Hanjiang-to-Weihe River water transfer project, it is particularly critical to ensure water quality security of the rivers. The shrinkage of the wetland area may cause reduction of flora and fauna as well as biodiversity, erosion of river beds and banks, water loss and soil erosion, and environmental pollution [2]. Finally, original wetland vegetation may degrade or disappear due to changes in the ecological environment [3]. Therefore, it is an urgent demand to study ecological environmental protection of the wetland of Huangjinxia Reservoir and its upstream, particularly the feeding grounds of Crested ibis. It is necessary to analyze changes in water quality before and after construction of Huangjinxia Reservoir, which is of important practical application significance.

2 Research Region

The research region was the wetland on both banks of Yangxian County-Huangjinxia water conservancy project (107° 31′–107° 57′ E, 33° 10′–33° 17′ N) in the Hanjiang River basin in Shaanxi Province, China. Branches including trunk stream of Hanjiang River (58 km), Youshui River (6 km), and Jinshui River (8 km) are located upstream of the reservoir. According to the topographic map of Huangjinxia Reservoir, the area of the research region was statistically estimated to be 142 hm^2. The large reservoir is designed to have a normal water level of 450 m, dead water level of 440 m, and barrage height of 63 m. Backwater of Huangjinxia Reservoir on the trunk stream of Hanjiang River flows to the estuary of Dangshui River in Yangxian County, and the reservoir is about 55.68 km long [4, 5].

For the Hanjiang-to-Weihe River water transfer project, the base year of design is 2007 and its short-term target year is 2025, with a water transfer scale of 1×109 m^3; the long-term target year is 2030, with a water transfer scale of 1.5×109 m^3 [6, 7]. After implementing water transfer using the project, Huangjinxia Reservoir needs to discharge at the minimum flow rate of 25.0 m^3/s in the operation period of the project in a bid to guarantee the ecological flow of downstream rivers. In the environment impact assessment report of Hanjiang-to-Weihe River water transfer project, 2007 was selected as the base year of design to predict data in 2025 and 2030. Considering this, the measured influent runoff from February to August 2007 was used in the research to construct a two-dimensional (2D) hydrodynamic model.

3 Methods

MIKE21 HD and AD modules were adopted to simulate Yangxian segment in the research region and calculate the hydrodynamic force and water quality. MIKE21 is a piece of 2D numerical simulation software for simulating various flow-field problems (rivers, lakes, estuaries, and bays) and environmental problems based on flow fields (water quality, and sediment). It has been widely acknowledged by numerous researchers in China and abroad, proven to have high precision and efficiency in practical application to engineering projects, and therefore can be used for Ref. [8].

In the research, MIKE21 was applied to simulate changes in the water level and water quality of rivers. The software presents and visualizes changes in the water level and water quality before and after construction of the reservoir, which provides convenience for the subsequent analysis.

3.1 Establishment Method of the Hydrodynamic Model

The governing equations of the MIKE21 hydrodynamic module are a numerical solution method based on 2D shallow water equations. The module also forms the incompressible average Reynolds equation and the Navier–Stokes equation that follow the assumption of hydrostatic pressure [9]. The equations are expressed as follows:

$$\frac{\partial h}{\partial t} + \frac{\partial h\bar{u}}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = hS \tag{1}$$

$$\frac{\partial h}{\partial t} + \frac{\partial h\bar{u}}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = f\bar{v}h - gh\frac{\partial \eta}{\partial x} - \frac{h}{\rho_o}\frac{\partial Pa}{\partial x} - \frac{gh^2}{2\rho_o}\frac{\partial \rho}{\partial x} + \frac{\tau_{sx}}{\rho_o} - \frac{\tau_{bx}}{\rho_o} - \frac{1}{\rho_o}\left(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{xy}}{\partial y}\right) + \frac{\partial (hT_{xx})}{\partial x} + \frac{\partial (hT_{xy})}{\partial y} + hu_s S \tag{2}$$

$$\frac{\partial h\bar{v}}{\partial t} + \frac{\partial h\bar{u}\bar{v}}{\partial x} + \frac{\partial h\bar{v}^2}{\partial y} = -f\bar{u}h - gh\frac{\partial \eta}{\partial y} - \frac{h}{\rho_o}\frac{\partial Pa}{\partial y} - \frac{gh^2}{2\rho_o}\frac{\partial \rho}{\partial y} + \frac{\tau_{sy}}{\rho_o} - \frac{\tau_{by}}{\rho_o} - \frac{1}{\rho_o}\left(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}\right) + \frac{\partial (hT_{xx})}{\partial x} + \frac{\partial (hT_{yy})}{\partial y} + hv_s S \tag{3}$$

where t, (x, y), η, and d separately represent time, coordinates in the Cartesian coordinate system, water level, and still-water depth; h is identical to $\eta + d$ and denotes the total water depth; u and v separately denote the velocity components in the x and y directions; f is the Coriolis force coefficient ($f = 2w \sin \phi$); w, φ, g, and ρ separately represent the rotational angular velocity of the earth, local latitude, gravitational acceleration, and water density; s_{xx}, s_{xy}, and s_{yy} are components of radiation stress; S is the source item; is the water flow velocity of the source item. Symbols with a short line above represent mean values. $\bar{u}$ and $\bar{v}$ are defined by the following formulas:

$$h\bar{u} = \int_{-d}^{\eta} u\,\mathrm{d}z, \quad hv = \int_{-d}^{\eta} v\,\mathrm{d}z \tag{4}$$

where T_{ij} is the item of horizontal viscous stress, including viscous force and turbulent stress. It is calculated using the eddy viscosity equation:

$$T_{XX} = 2A\frac{\partial \bar{u}}{\partial x}, \quad T_{XY} = A\left(\frac{\partial \bar{u}}{\partial y} + \frac{\partial \bar{v}}{\partial x}\right), \quad T_{YY} = 2A\frac{\partial \bar{v}}{\partial y}(1-\zeta) \tag{5}$$

3.2 Simulation Method of the Water Quality Model

The established water quality model is coupled by the hydrodynamic model and the convection dispersion model [10, 11].

(1) Water quality control equation

Diffusion of pollutants in water is described using the convection dispersion equation:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial y} + v\frac{\partial C}{\partial y} = D_X\frac{\partial^2 C}{\partial x^2} + D_y\frac{\partial^2 C}{\partial y^2} \tag{6}$$

where C is concentration (mg/l); D_x and D_y separately denote the diffusion coefficients in x and y directions.

(2) Water quality degradation equation

Degradation of pollutants in water can be described using the first-order reaction equation:

$$\frac{\partial C}{\partial \mathrm{t}} = -KC \tag{7}$$

where t, C, and K denote time (s), concentration (mg/l), and attenuation coefficient (s^{-1}), respectively.

4 Results and Discussion

4.1 Hydrodynamic Simulation Results in the Research Region

Influences of construction of Huangjinxia Reservoir on the flow velocity of the upstream rivers were analyzed. Two cases are considered for the water levels after construction, namely 450 and 455 m. The specific changes are shown in Fig. 1.

It can be seen from the figure that construction of the reservoir does not greatly influence and change the flow velocity in segment I in the research region, while significantly affects segments II and III. Flow velocities in segments II and III before constructing the reservoir are faster than those after construction. Although the flow velocity along the central line of the river slows down to some extent with the rise of the water level, the originally unaffected waterfront will be affected by water flows as the flooded area on both river banks enlarges, which will scour the banks. Due to influences of water flows, water loss and soil erosion will occur to waterfront with weak soil consolidation capacity, which damages the living space of vegetation and in turn aggravates water loss and soil erosion to form a vicious circle.

4.2 Simulation Results of Water Quality in the Research Region

Change characteristics of water quality indices including chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) before and after construction of the reservoir were analyzed. Two water levels (450 and 455 m) after reservoir construction were selected.

4.2.1 Change Characteristics of COD

Influences of construction of Huangjinxia Reservoir on the COD concentration of pollutants in upstream rivers were analyzed. Two water levels (450 and 455 m) after reservoir construction were considered. The specific changes are illustrated in Fig. 2.

As shown in the figure, the COD concentration in the rivers mainly changes in the range of 14.8–16 mg/L before constructing the reservoir. When the water level rises to 450 m after constructing Huangjinxia Reservoir, the COD concentration in most areas of the rivers will exceed 17.3 mg/L; if rising the water level to 455 m, the area with the COD concentration in the rivers exceeding 17.3 mg/L will narrow substantially compared with that at the water level of 450 m, and the COD concentration in the second half will be mainly concentrated in the range of 16–17 mg/L. On the whole, the COD concentrations in the selected rivers after constructing Huangjinxia

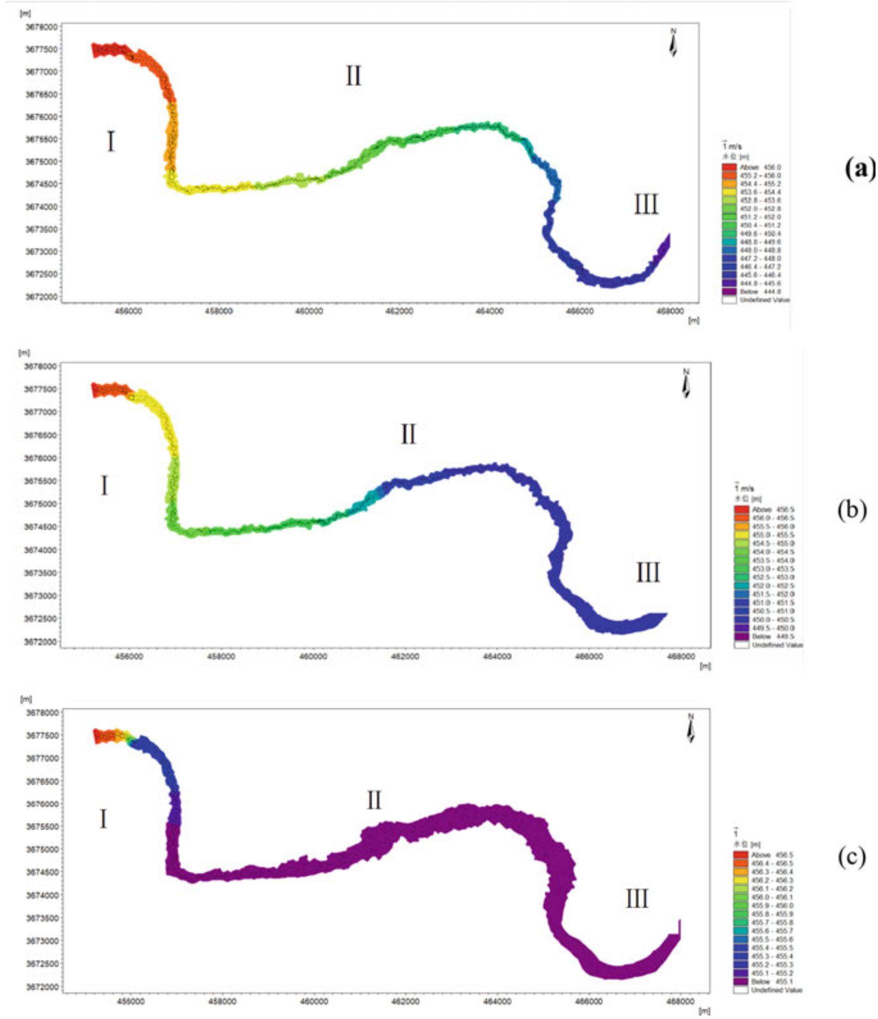

Fig. 1 Change characteristics of flow velocities before and after constructing Huangjinxia Reservoir. **a** Flow velocity profile of the research region before constructing the reservoir. **b** Flow velocity profile of the research region after constructing the reservoir (450 m). **c** Flow velocity profile of the research region after constructing the reservoir (455 m)

Reservoir are all predicted to increase to different extents compared with those before constructing the reservoir.

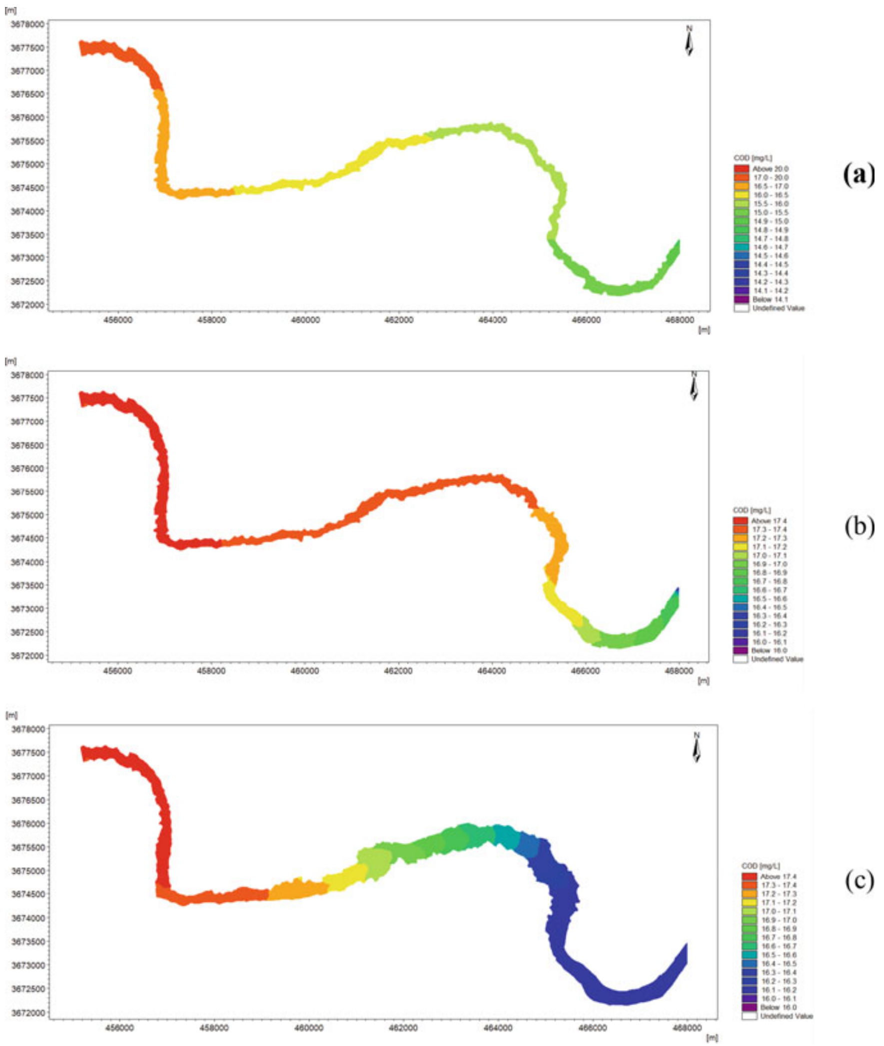

Fig. 2 Change characteristics of the COD concentration before and after constructing Huangjinxia Reservoir. **a** Changes in the COD concentration in the research region before constructing the reservoir. **b** Changes in the COD concentration in the research region after constructing the reservoir (450 m). **c** Changes in the COD concentration in the research region after constructing the reservoir (455 m)

4.2.2 Change Characteristics of TN

Influences of construction of Huangjinxia Reservoir on the TN concentration of pollutants in upstream rivers were analyzed. Two water levels (450 and 455 m) after reservoir construction were considered. Figure 3 shows the specific changes.

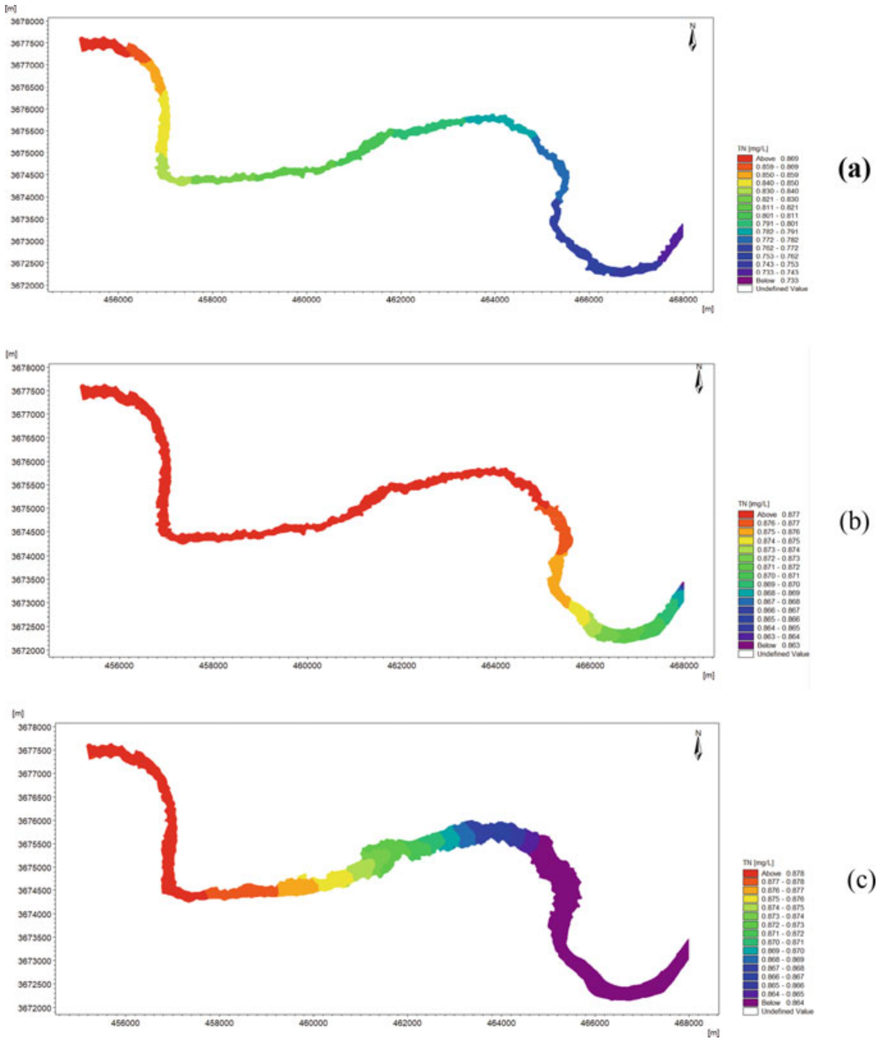

Fig. 3 Change characteristics of the TN concentration before and after constructing Huangjinxia Reservoir. **a** Changes in the TN concentration in the research region before constructing the reservoir. **b** Changes in the TN concentration in the research region after constructing the reservoir (450 m). **c** Changes in the TN concentration in the research region after constructing the reservoir (455 m)

As can be seen, the TN concentration of pollutants in rivers before constructing Huangjinxia Reservoir basically changes in the range of 0.762–0.840 mg/L. When the water level rises to 450 m after constructing the reservoir, the TN concentration in most areas of rivers will exceed 0.876 mg/L; once rising the water level to 455 m, the change range of TN concentration in the second half of rivers is predicted to be concentrated in the range of 0.864–0.875 mg/L. Generally, TN concentrations in various areas of rivers will rise to different extents after constructing the reservoir.

4.2.3 Change Characteristics of TP

Influences of construction of Huangjinxia Reservoir on the TP concentration of pollutants in upstream rivers were analyzed. Two water levels (450 and 455 m) after reservoir construction were considered. Figure 4 shows the specific changes.

As can be seen, the TN concentration of pollutants in rivers before constructing Huangjinxia Reservoir basically changes in the range of 0.762–0.840 mg/L. When the water level rises to 450 m after constructing the reservoir, the TN concentration in most areas of rivers will exceed 0.876 mg/L; once rising the water level to 455 m, the change range of TN concentration in the second half of rivers is predicted to be concentrated in the range of 0.864–0.875 mg/L. Generally, TN concentrations in various areas of rivers will rise to different extents after constructing the reservoir.

The pollutant concentrations in rivers at the water level of 450 m are larger than the case at the water level of 455 m. This is because the overall flow velocity in rivers slows down. At the low flow velocity, the pollutant degradation time prolongs and the attenuation degree of pollutants rises, so that pollutant concentrations indicated by water quality indices at the water level of 455 m are higher than those at the water level of 450 m.

5 Conclusions

The rise of the water level and changes in water quality indices after construction and operation of Huangjinxia Reservoir were analyzed. On this basis, hydrodynamic change characteristics (flow velocity profiles, water levels, and distribution maps of flooded areas) and change characteristics of water quality (COD, TN, and TP) were simulated using MIKE. The following conclusions are made:

(1) After construction of Huangjinxia Reservoir, the flow velocity in the computation region is predicted to slow down with the rising water level. As a result, some originally unaffected areas will be flooded, which may lead to water loss and soil erosion, are unfavorable for ecological stability, and exert great impact on habitats of rare birds such as Crested ibis.
(2) It is predicted that the pollutant concentrations of three water quality indices (COD, TN, and TP) in rivers after constructing the reservoir will be obviously higher than that before construction. The complex topography of the reservoir and bay, poor water quality, weak water exchange, and stem and leaf shedding and death of submerged plants cause the pollutant concentrations in local areas to exceed standards. The pollutants will retain for a longer time, and the possibility of water eutrophication cannot be ruled out. This will in turn reduce

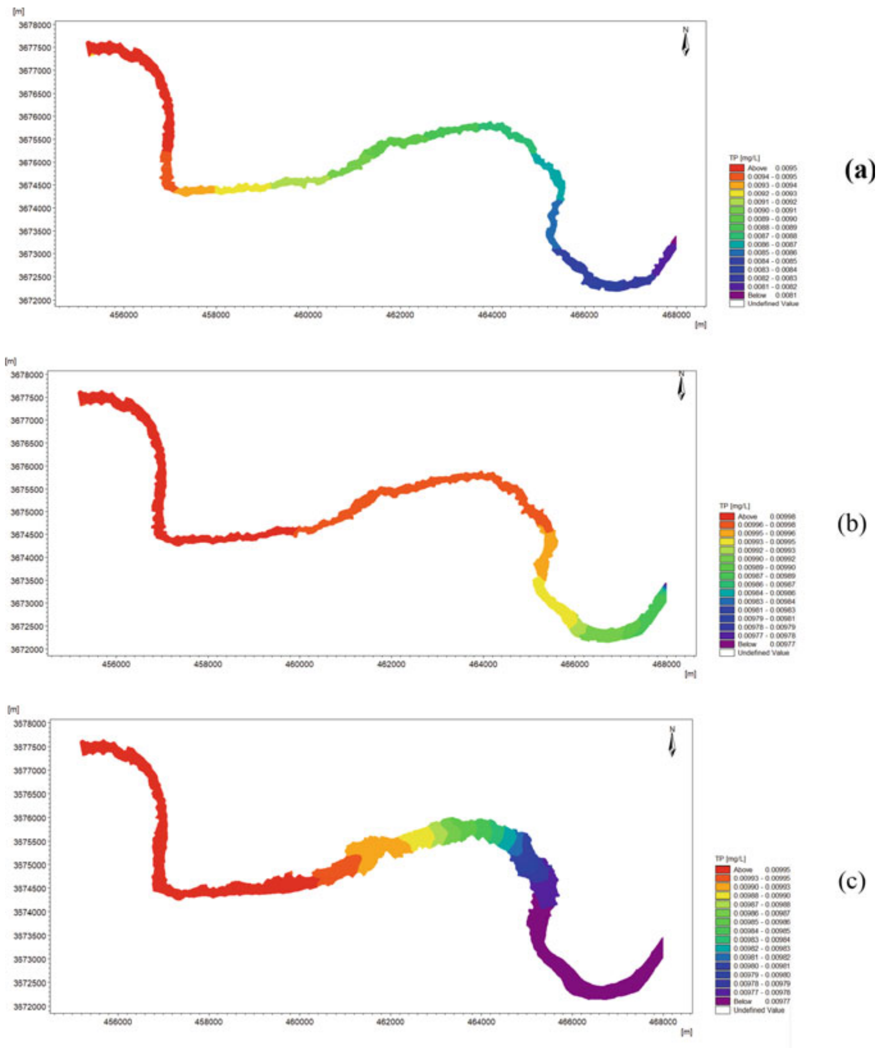

Fig. 4 Change characteristics of the TP concentration before and after constructing Huangjinxia Reservoir. **a** Changes in the TP concentration in the research region before constructing the reservoir. **b** Changes in the TP concentration in the research region after constructing the reservoir (450 m). **c** Changes in the TP concentration in the research region after constructing the reservoir (455 m)

the vegetation species in the region, aggravate water eutrophication, and finally threaten safety of the entire eco-system.

(3) Under comprehensive consideration, a certain amount of vegetation can be planted in regions heavily affected by flows on both banks to offset influences of changes in the water level and water quality of upstream rivers on the soil and vegetation of both banks. This can well nourish water and preserve soil, weaken

water scouring, and improve self-cleaning capacity of water. On the premise of ensuring stability of the vegetational community, the ecological stability of the research region can be better maintained and the habitats of rare birds such as Crested ibis can be protected.

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A First Study of the Residual Circulation Profile in the Bouregreg Estuary (Morocco)

S. Haddout, A. M. Hoguane, Joan Cecilia C. Casila, K. L. Priya, and I. Ljubenkov

Abstract The residual circulation in the Bouregreg Estuary (Morocco) was modeled using a simple model to reduce degrees of freedom and modeling effort. The Moroccan Estuary's residual circulation profile has never been studied to our knowledge. Direct current measurements were used to determine residual currents using Hansen and Rattray's analytical solution. According to MacCreary and Geyer, Reynolds-averaged equations in hydrostatic form and Boussinesq approximations are used to determine water salinity and momentum along channels. Besides momentum advection and Coriolis forces, only gradients along the channel were considered. An analytical solution combining Hansen and Rattray's classical theory with Geyer and MacCready's analysis of residual flow was used to model a fixed station in a river using residue flow, temperature, and salinity flow. The residual flow of Bouregreg Estuary was well described by a simplified model approach that was in agreement with observed data. Observation data was used to calibrate Hansen and Rattray flows. The residual circulation model can be used to predict chemical pollution in estuaries.

Keywords Bouregreg estuary · Gravitational circulation · Estuarine circulation · Net flow

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1 Introduction

Water mixing between ocean and river in estuaries affects the health of aquatic ecosystems and plays a vital role in the human-earth system [1]. Therefore, estuarine systems play a critical role in research. Salt and freshwater interactions play a crucial role in estuarine dynamics [2, 3]. As a result, estuarine systems constitute a valuable research area. Seawater and freshwater interactions are crucial to estuarine dynamics. Saline water moves landward due to density gradients when the river directs freshwater into estuaries. Freshwater flushing and gravitational infiltration of saltwater determine the temporal and spatial variation of salinity in an estuary [4]. There are many dynamic factors at play in estuaries, making them highly important bodies of water. Estuaries have faced numerous environmental concerns because of the explosive increase in industrial and agricultural productivity [5].

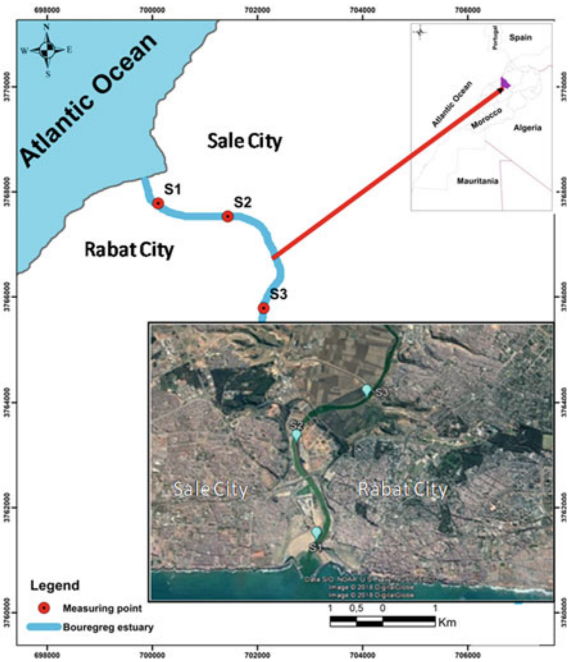
Residual circulation in estuaries determines the flow of water, heat, salt, and biological pollution. Freshwater and saltwater have different densities, which causes residual flow downstream in surface layers to occur and upstream in deeper, saltier layers near the bottom [6]. During different stages in their development, fish and crustaceans have been able to transition between nearshore shelf environments and estuarine environments due to tidal and residual currents [7]. Residual water also transports fine sediments. Fluvial sediments are transported downstream by surface flow in rivers and upper estuaries [8], but marine sediments are imported by surface flow into lower estuaries. After Pritchard [2], Hansen and Rattray [6] developed the classical theory of two-layer estuarine circulation [9] in which longitudinal pressure gradients balance stress divergence. Even though hydrodynamic modeling has advanced, the classical theory remains valid. The classical model is more appropriate for mixed estuaries than partial mixes, according to Priya et al. [10]. It offers easy-to-understand analytical solutions for management decisions [11] that are derived from a simple classical model.

2 Materials and Methods

2.1 Study Site

The Bouregreg Estuary is situated between the cities of Sale and Rabat along the Atlantic coast at 34°N and 6°50′W (Fig. 1). With a maximum length of 23 km and a typical width of 150 m., it is constrained by the Sidi Mohammed Ben Abdellah Dam. The average freshwater flow ranged from 3 to 84 $m^3 s^{-1}$. Furthermore, the tide at the mouth of the estuary is primarily semi-diurnal with a tidal cycle of 12. 25 h and is a meso-/micro-tidal estuary with an average tidal range of only 2.3 m [12, 13]. Most of the year, there is little freshwater influx into this estuary, which is primarily composed of seawater. Since the Sidi Mohammed Ben Abdellah Dam was built, it has been observed that the estuary's saltwater intrusion has gotten worse over time.

Fig. 1 Bouregreg Estuary and location of measuring sites



2.2 *Circulation Model*

To determine residual currents, Hansen and Rattray [6] provided an analytical solution. In terms of salinity and momentum with Reynolds-averaged equations, the basic equations are the hydrostatic equations in Boussinesq approximation. Only gradients along the channel were considered, excluding momentum advection and Coriolis forces. As a result, we had the following equations:

$$\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} = \frac{\partial}{\partial z}\left(k\frac{\partial S}{\partial z}\right) \tag{1}$$

$$\frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{\partial}{\partial z}\left(A\frac{\partial u}{\partial z}\right) \tag{2}$$

The salinity is determined by S, the distance along the channel from the mouth elevation, the water level in the water column measured from the surface, and the water density (kg m^{-3}) of water, and the water density (kg m^{-3}) is determined by negative down (kg m^{-3}). Pressure (N m^{-2}) is calculated by the hydrostatic equation, k is the eddy diffusion coefficient (constant at 0.006 m^2 s^{-1}; [14]), velocity (m s^{-1}), u(m s^{-1}) is velocity along the channel longitudinal axis, and eddy viscosity is determined by A. The vertical profile of the subtidal velocity along the channel, without wind effects, was obtained by averaging all variables tidally and width-wise and assuming constant longitudinal salinity gradients and constant tide-averaged eddy viscosities [15]:

$$U = U_r(1.5 - 1.5\zeta^2) + U_g(1 - 9\zeta^2 - 8\zeta^3) \quad (3)$$

where $U(\mathrm{ms}^{-1})$ is the observed velocity with depth, positive for upstream velocity (flood), $U_r(\mathrm{ms}^{-1})$ is the residual velocity, $U_g(\mathrm{ms}^{-1})$ is the gravitational velocity, $\zeta = \frac{z}{h}$ is the normalized depth, and h(m) is the local depth. The Eq. (3) was calibrated by regression analysis using the observed velocity, to estimate U_r and U_g.

3 Results and Discussion

Longitudinal Variation in Salinity, Water Temperature, Density, and Velocity

In-situ measurements of water were conducted at the stations indicated in Fig. 1 during 7–23/11/2020. During spring and neap cycles, sampling was conducted during slack periods. In-situ measurements were carried out with a YSI Pro30 conductivity meter and Seaguard Recording Current Meter (RCM) to measure salinity, water temperature, and flow velocity. The positions of every measurement were also recorded using a global positioning system (GPS). Various measurements can be carried out efficiently with the equipment used. Moving upstream with the tide, measurements started from the mouth. Bouregreg Estuary salinity concentration varies between 30 and 35 ppt at the mouth but does not exceed 2 ppt at 20 km (i.e., downstream part of the estuary). Freshwater input was observed along the reach at high tide, as shown by an increase in salt concentration. In accordance with the Venice System [16], marine waters are classified from limnetic waters (salinity 0.5–3 ppt) to freshwater (salinity 30 ppt). In Bouregreg Estuary, the limnetic regime is situated between 15 and 25 km where salinity does not exceed 2 ppt. The mesohaline/oligohaline regime is situated between 10 and 15 km, where the salinity is between 2 and 20 ppt, and is considered a transition zone influenced by tidal dynamics and river flow. The polyhaline/euhaline zone is situated between 0 and 14 km, where the oceanic influence is permanent.

Vertically, all stations show a weak stratification of salinity. Water movement is regulated by ebb and flood tides as well as differences in water density, as shown in Fig. 2a, b, during spring-neap tides. As a consequence of density differences, the movement of water is reflected by estuarine gravitational circulation. The weak stratification in the estuary may be caused by these regulatory mechanisms. Results like these are consistent with those documented by Haddout et al. [12], Haddout [13] in the same estuary. It can be seen in Fig. 2a, b that the density profiles also followed a similar pattern to the salinity profiles; density during spring-neap tides did not differ by depth but decreased longitudinally, from 1000 to 980 kg/m^3 near the mouth to 670–655 kg/m^3 near the upper estuary. Water input from the ocean was slightly cooler during the spring-neap tides (Fig. 2a, b), whereas water upstream became warmer. In the vertical profiles of the stations, the water temperature varied between 19 and 22 °C during the study period. During the study period, there was a temperature variation of one unit (°C) or less. Temperature variations within profiles of < 2 units indicate weak stratification, indicating water mixing. This mixing is thought to be regulated mostly by the water movement following ebb and flood tides in the estuary.

In the Bouregreg Estuary, it varies between −1.9 and 0.89 m/s at the mouth and is not > 0.07 m/s downstream (at the high tide during spring-neap tides) (Fig. 2c). During the study period, there were variations in velocity of one or less than one unit (m/s). Generally, there is less variation for velocity than pressure within the profiles, which indicates slight stratification, while there is none at the upstream section of the estuary.

Tidally Averaged Vertical Profiles

In spring-neap tides (November 7–23, 2020), salinity, densities, water temperatures, and velocity profiles measured at Station 1 showed less variation in temperature

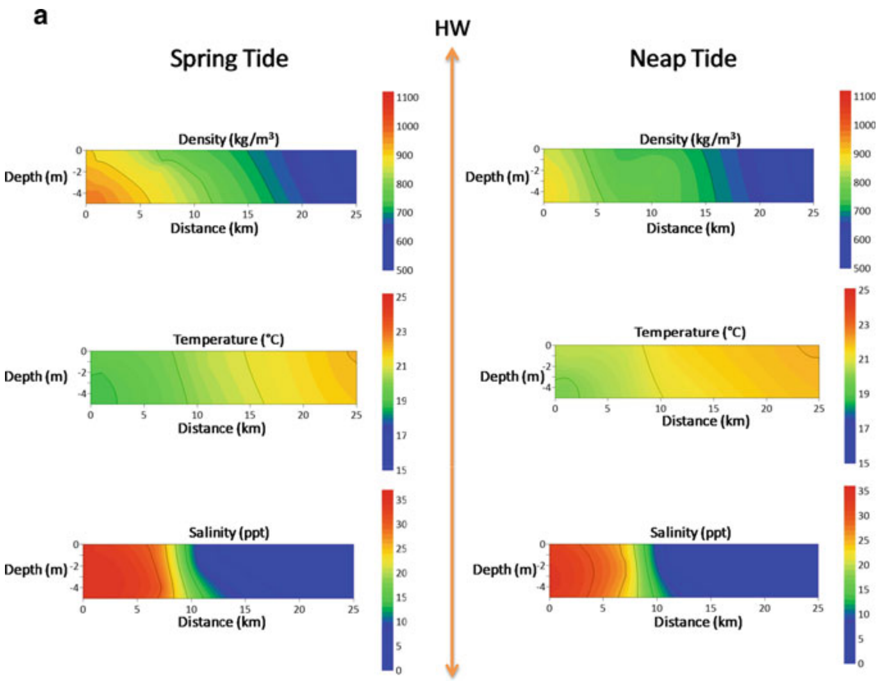


Fig. 2 **a** Longitudinal distribution of density, water temperature, and salinity in the Bouregreg Estuary during: spring-neap tides at high water (HW) (measured 7–23 November 2020). **b** Longitudinal distribution of density, water temperature, and salinity in the Bouregreg Estuary during: spring-neap tides at Low Water (LW) (measured 7–23 November 2020). **c** Longitudinal distribution of velocity in the Bouregreg Estuary during: spring-neap tides at (HW) (measured 7–23 November 2020 (The LW has not been recorded)

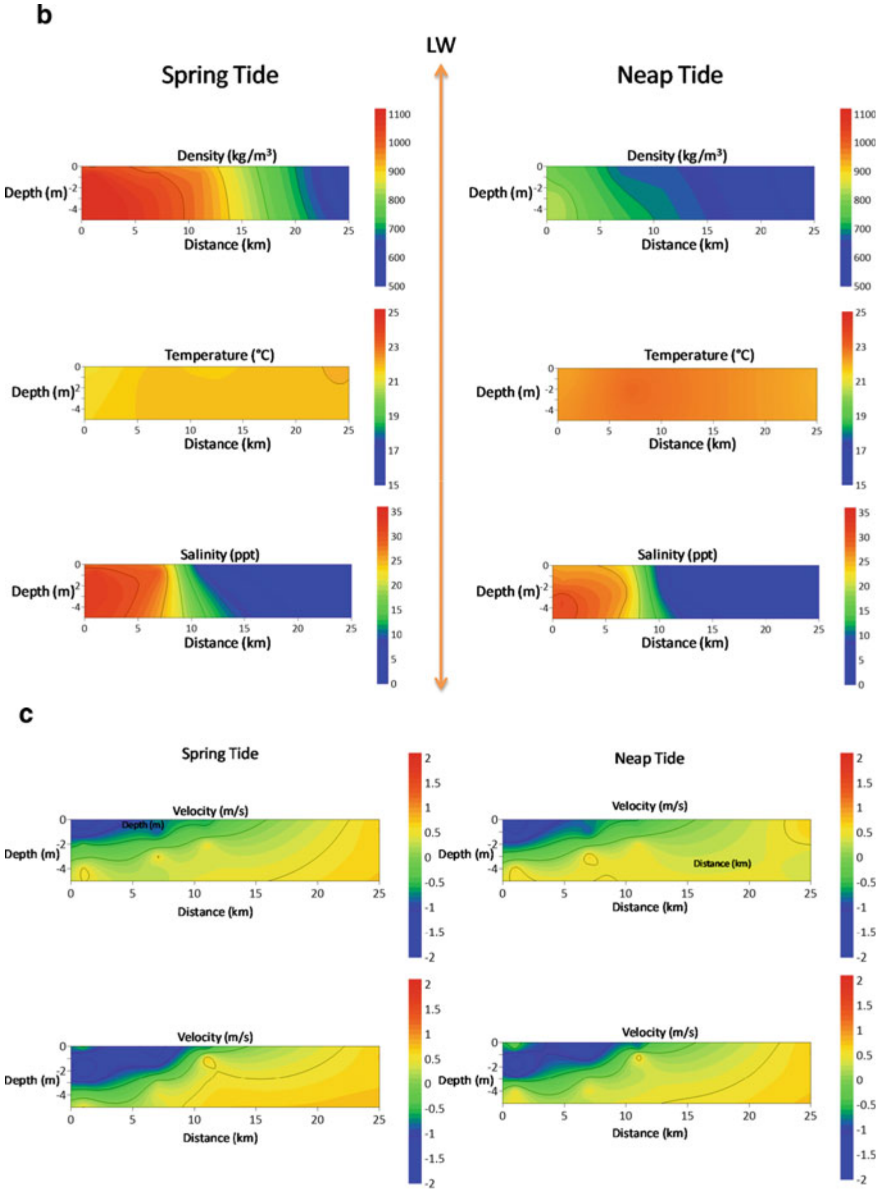


Fig. 2 (continued)

and depth (Fig. 3). There were two layers of salinity and density at spring-neap tides. Using the tide-averaged velocity profile, we identified a two-layer circulation model with downstream net flow at the surface and upstream net flow at the bottom. A spring-neap tide resulted in residual flows of 0.35 m/s downstream and 0.85 m/s upstream. A greater discharge of river water into the estuary contributes to the intensification of downstream flow at the surface.

Residual Flow Applying Hansen and Rattray Equations

As a result, Hansen and Rattray [7] model was used to explain the vertical profiles in the Bouregreg Estuary throughout most of the year [12, 13]. It has been demonstrated by several researchers that estuarine remnant circulation weakens with increasing tidal importance [9, 17], as is the case at spring tide in the Bouregreg Estuary. Based on observed data from November 7 to 23 2020, the modeled velocity profile was similar to the observed data. A number of studies suggest that U is directly proportional to gradient in density (or salinity), indicating a lower salinity at the estuary tip at LW than at HW, according to Geyer and MacCready [15]. As well as reproducing the observed values during spring nap tides (Fig. 4), the depth of the modeled zero-velocity estimate was well reproduced when compared to the observed values (Fig. 4). Thus, dispersion patterns and vertical positioning can be combined for management purposes.

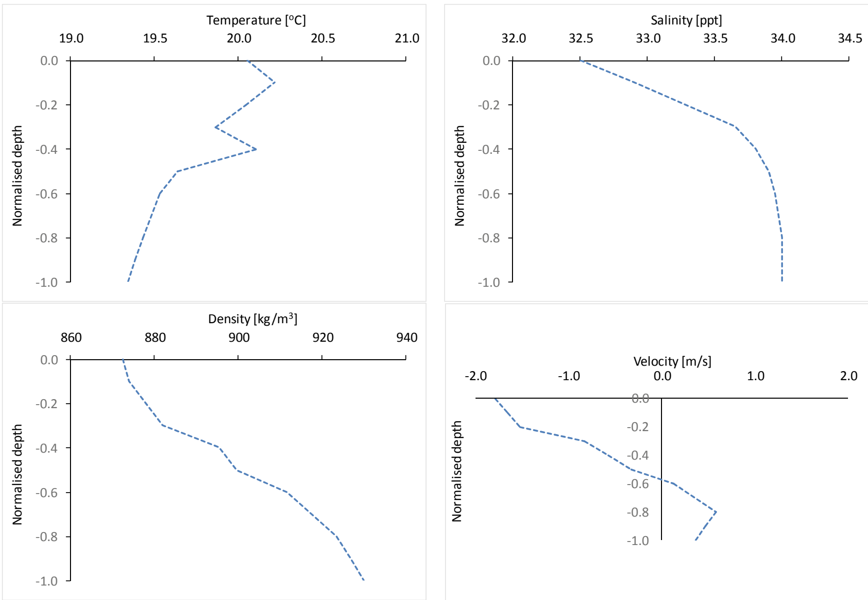


Fig. 3 Tidally averaged water temperature, salinity, density, and velocity profiles with normalized depth, measured at Station 1 during spring-neap tides

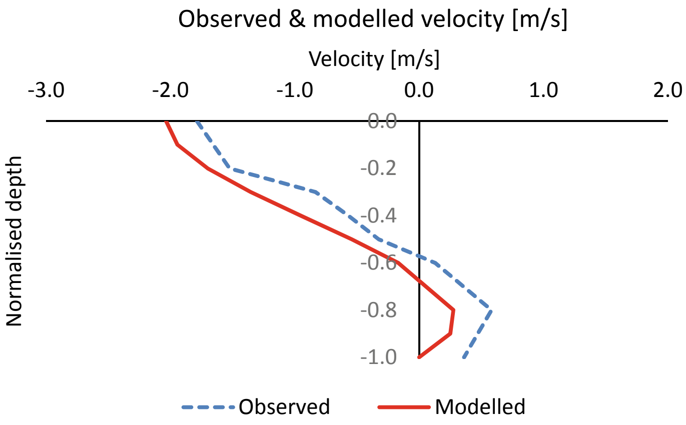


Fig. 4 Comparison of the modeled and observed current profile during spring-neap tides. Model-estimated zero-velocities compare well with the observed data during tide cycle

Model Evaluation

The model was set based on the averaged observations made during the period 7–23 November 2020, covering the spring-neap tides. The residual flow was $U_r = -0.701$ m/s, and the gravitational flow was $U_g = -0.984$ m/s, with a constant of 3.4 m/s. The model fitted well the $r^2 = 0.98$ and $p = 0.000$. Both the gravitational velocity and residual flow are significant for the estuary hydrodynamics, with slight dominance of tides. This residual circulation model can help us understand larval distribution patterns in the Bouregreg Estuary, for example. In general, fish larvae can move directional transport by currents by positioning themselves in the water column. In other words, the distribution patterns are probably related to residual currents at various depths.

4 Conclusions

Hansen and Rattray's classical two-layer model provided an analytical tool that made it possible to quantify fundamental residual circulation in a way that was easier to interpret in model simulations of dispersal and connectivity. Environmental and fisheries management decisions can be predicted using model simulations.

Declaration of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Thoughts on the Treatment of Rural Domestic Sewage

Tian Shao, Lijun Wang, Chaoyan Zhou, and Fan Wan

Abstract Rural revitalization is the only way for Chinese dream of great national renewal, good living environment and perfect infrastructure are the material basis for rural revitalization, and rural sewage treatment is one of the key points to improve rural human settlements. This paper takes the rural sewage treatment of Xiuzhou District as an example summarizes the problems in the process of rural domestic sewage treatment, such as the difficulty of centralized collection, the instability of water quantity, the difficulty in terminal treatment caused by rain and sewage confluence, and the poor operation and maintenance. From the rural domestic sewage treatment in Xiuzhou District to the problems existing in the national rural domestic sewage treatment, puts forward some thoughts and optimization suggestions on rural domestic sewage treatment in the future from the aspects of planning, design, operation and maintenance, monitoring, etc., with a view to playing a certain reference role in the planning and design of rural sewage treatment in the future.

Keywords Rural areas · Domestic sewage · Treatment · Problems · Human settlements · Suggestions

1 Policy Background of Rural Sewage Treatment

With the accelerated development of urbanization, a large number of farmers have left agriculture and poured into cities to participate in the second and third industry activities, since the reform and opening up, which results in a sharp decline in the number of permanent residents, the gradual decline of rural economy, and rural becoming an aging agglomeration area with weak infrastructure and backward economy. Although

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China has entered a moderately society in an all respect and historically solved the problem of absolute poverty, the issue of ‘agriculture, rural areas and farmers’ is still one of the key concerns of the country, which is regarded as one of the key national work priorities in the future proposed by the 20th CPC National Congress and the No. 1 document of the Central Committee in 2023.The demand of rural revitalization for infrastructure and the gradual transfer of national water environment governance from cities to villages will make rural sewage treatment an inevitable trend [1–3].

2 Overview of Rural Sewage Treatment in Xiuzhou District

Xiuzhou is located in the north of Zhejiang Province, one of the lower districts of Jiaxing. It borders Shanghai to the east, Hangzhou to the west, Hangzhou Bay to the south, and Suzhou to the north. It is at the intersection of the three national strategic zones, which are ‘the integrated development of the Yangtze River Delta’, the ‘the Belt and Road’, and ‘the Yangtze River Economic Belt’. Rural sewage treatment is the fundamental demand for regional coordinated development, consolidating the foundation of green development and sustainable economic development. Since Jiaxing is also a granary in northern Zhejiang and a national modern agricultural demonstration area, improving infrastructure construction is the proper meaning of China’s overall planning of urban and rural development, implementation of rural revitalization and solving ‘the three agricultural issues’. As the birthplace of the ‘ten million project’, Zhejiang Province, which is at the forefront of the country in terms of ecological environment governance, continues to do a good job in the typical demonstration of the ‘ten million project’, which is the ardent hope of the whole country for the successful implementation and promotion of the model. Zhejiang Province is precisely aware of the importance of rural sewage treatment for regional coordinated and sustainable development, ‘the three agricultural issues’ solving, and ecological environment improvement, attaches great importance to rural sewage treatment, taking the lead in exploring rural sewage treatment in the province, and the policy documents such as The Regulations on the Administration of Rural Domestic Sewage Treatment Facilities in Zhejiang Province, The Implementation Plan for the Treatment of Agricultural and Rural Pollution in Zhejiang Province, and The Special Action Plan for the Treatment of Rural Domestic Sewage in Jiaxing City (2020–2022) have been issued.

The historical data shows that Jiaxing’s surface water environmental quality in the past three years has ranked the last two in Zhejiang Province, and the water quality of the assessment sections above the municipal level still does not meet the standard. At present, more than 40% of rural domestic sewage in Xiuzhou is directly discharged into the river without treatment or simple treatment, which affects the improvement of water environment quality in Xiuzhou District. Rural sewage treatment is an important factor restricting the improvement of the water environment in Xiuzhou District, which is complex, and is in urgent need of comprehensive planning and comprehensive treatment.

The total number of households in Xiuzhou District is 63,651, with a total population of 339,863. At present, the treatment mode of rural sewage entering urban sewage plant accounts for 14%, the mode of sewage treatment station accounts for 35%; the mode of entering the spray weaving mill accounts for 9%; decentralized governance mode accounts for 12%; and 30% have not been treated yet. 470 sewage treatment stations have been built, of which 458 adopt anaerobic-anoxic-aerobic (A/A/O) process, accounting for 97.4%, AAO+ artificial wetland (AWL) process block is adopted, accounting for 1.8%, 3 MBR processes are adopted, accounting for 0.6%,One micro-power + wetland process is adopted, accounting for 0.2%. The effluent of centralized sewage treatment facilities is subject to the first-level standard of *the Discharge Standard of Water Pollutants for Rural Domestic Sewage Treatment Facilities (DB33/973-2015)*, and the operation and maintenance are subject to the second-level standard. The sewage collection pipe network is designed according to the rainwater and sewage separation system: The sewage pipe network collects household toilet sewage, kitchen sewage, and laundry sewage. The collection pipe network and sewage treatment facilities are constructed and operated simultaneously. In line with the basic goal of 'one-time construction, long-term use, and continuous effectiveness' of rural domestic sewage treatment facilities, Xiuzhou District adopts BOT mode for rural domestic sewage treatment, that is, 'unified construction, operation and maintenance, 5-year repurchase, and 10-year operation and maintenance' to achieve the integration of construction, operation and maintenance of rural domestic sewage treatment. All sewage pipe networks, pre-treatment facilities, centralized treatment stations, and decentralized settings are uniformly operated and maintained by a Zhejiang environmental protection company.

The current proportion of agricultural sewage treatment in Xiuzhou District has reached 70%, which is at the forefront of national treatment. However, the sewage treatment facilities that have been implemented have exposed many problems. The investigation of the existing problems of the sewage treatment facilities that have been implemented can provide a good reference for subsequent treatment.

After investigation, the main problems of sewage treatment facilities implemented are as follows:

(1) The scale of sewage treatment facilities is too small, too many sewage treatment stations are set, and the pressure of operation and maintenance is high.

The mode of sewage treatment station in Xiuzhou District accounts for 35%, involving 22,086 households and 470 stations. The scale of the station varies from 2 to 160 m^3/day, of which the scale below 30 m^3/day accounts for up to 75%. The scale of sewage treatment facilities is too small, the operation and maintenance pressure is too large, and the poor operation and maintenance results in poor terminal treatment effect, and the phenomenon of poor effluent quality is widespread.

(2) The too small regulating tank results in the difficulty of balancing the sewage quantity and thus affects the effluent quality.

Since the quality and quantity of rural sewage vary greatly in the day, it is necessary to set up a regulating tank to balance the inflow and ensure the efficiency of sewage treatment. According to the actual investigation, the capacity of the regulating tank in the rural domestic sewage treatment facilities in Xiuzhou District is generally too small to effectively balance the inflow of water at the terminal, resulting in the unsatisfactory sewage treatment effect of the system [4].

(3) The design scale of sewage treatment facilities is different from the actual one.

Because the treatment scale does not fully consider the regional population change, there is a large discrepancy between the design scale of sewage treatment facilities and the actual situation, and the actual daily inflow of some sewage treatment stations is higher than the design flow [5].

(4) Unreasonable type selection of intake pump and lack of grid are common problems.

The sewage treatment scale in Xiuzhou District is generally small, which makes it difficult to select the inlet pump. If the selection of pump station is too small, it will lead to the sensitivity of liquid level change, and the intake pump will start and stop frequently, affecting the pump life. If the pump station is too large, the biochemical reaction time of pollutants will be too short, which will make the treatment effect not ideal. In addition, it is also common that the sewage treatment facilities are lack of grids or the grid setting is unreasonable, which leads to the slag entering the terminal and affects the sewage treatment effect [6, 7].

(5) The construction of constructed wetlands is not standardized, and the operation and maintenance are poor.

The construction of constructed wetlands is not standardized, such as the filling of filter materials is not standardized, the water distribution and collection method is not reasonable, the operation and maintenance of constructed wetlands is poor, the plants are not harvested in time, the filter materials are not dried regularly, and the constructed wetlands are blocked frequently, which seriously affects the wetland treatment efficiency.

(6) Problems such as incomplete access of three water sources, incomplete diversion of rainwater and sewage, and non-standard setting of inspection wells are prominent.

Rural sewage in Xiuzhou District is collected and treated according to the three types of water. Toilet wastewater is connected to the septic tank, kitchen water is connected to the oil separator, and other domestic sewage is directly connected to the pipe network. During the actual construction and operation, problems such as kitchen directly connected to the septic tank, toilet water not connected to the septic tank, oil separator not connected to the terminal and so on occurred, resulting in the terminal water quality is not ideal. The design is not reasonable, resulting in some pipe networks not receiving water, the construction is not reasonable, resulting in frequent pipe network damage and leakage, and incomplete diversion of rainwater and sewage, resulting in severe impact of rainwater on sewage treatment facilities during the flood season, and then the sewage treatment facilities cannot operate normally for a period of time after the flood season. The inspection well is not designed and implemented in strict accordance with the specification, the interval setting is unreasonable, and some inspection well covers are difficult to open, which is not conducive to inspection and maintenance. In addition, some deep inspection wells are not equipped with anti-falling nets.

(7) Unstandardized operation and maintenance are the main factors restricting the effect of sewage treatment.

The operation and maintenance of rural sewage in Xiuzhou District is generally not standardized, which is mainly manifested in clogging of oil separator, untimely cleaning of septic tank, clogging of inspection well, low professional technical level of operation and maintenance personnel, and it is difficult to deal with various problems arising from operation and maintenance. Poor operation and maintenance is one of the main factors restricting the effect of sewage treatment [8].

3 From the Rural Sewage Treatment Problem in Xiuzhou District to the Domestic Rural Sewage Treatment Problem

The problem of rural domestic sewage treatment in Xiuzhou District is also a common problem in rural domestic sewage treatment nationwide. The main problems in rural domestic sewage treatment at present can be summarized as follows:

(1) Design

Due to the insufficient consideration of regional development planning and the lack of detailed investigation of rural basic conditions, it is easy to cause the design to be inconsistent with the actual situation. The sewage treatment station cannot receive water, the pollution load is not fully considered, or the safety margin is too large, which are common problems, resulting in waste of investment, high operating costs, and poor operation effect.

The planning scheme for sewage discharge into the pipe network, centralized collection and treatment, and decentralized treatment is unreasonable, resulting in increased investment and operation and maintenance costs, and unsatisfactory treatment effect. Because the local domestic sewage treatment is not combined with various plans related to village integration, withdrawal and merger to demonstrate the economic rationality of the discharge into the pipe network, centralized treatment and decentralized treatment, the choice of treatment methods is unreasonable and uneconomical. The setting of centralized treatment scale is too small, resulting in large pressure on operation and maintenance in the later stage and poor operation effect. The centralized treatment scale is set too small, resulting in too many sites, high pressure on operation and maintenance in the later stage, and poor operation effect [9].

(2) Construction

The indoor sewage system is not implemented in strict accordance with the design documents, such as the oil separation tank and septic tank for the classified collection and treatment of three kinds of water, resulting in a large deviation between the actual treatment effect and the design effect.

The construction area of rural sewage collection pipe network is hidden, the construction area is wide, the process supervision is difficult, the quality of construction and materials is poor, and it is easy to cause seepage, which seriously affects the normal operation of the system. It is difficult to find the fault of underground pipe network, the cost of solving it is high, and it is difficult to maintain the source of funds.

(3) Operation and maintenance

The selection of sewage treatment scheme is unreasonable. In order to improve the treatment effect of rural domestic sewage, the constructed wetlands and MBR schemes are adopted. The constructed wetlands need to harvest plants regularly, clean weeds, and turn over the filter material. MBR needs a more refined and professional operation and maintenance team. The operation and maintenance methods of rural sewage are more crude. The operation and maintenance of the constructed wetlands and MBR are generally poor, and the operation effect differs greatly from the design [10].

Lack of high-quality operation and maintenance personnel. The rural sewage treatment facilities needs professional personnel for regular operation and maintenance, such as regular sludge discharge, adjustment of water inflow, and aeration, but the actual operation and maintenance process lacks high-quality professional personnel, which cannot effectively deal with the system failure and keep the system running normally, resulting in a large discrepancy between the actual water output and the design.

It is difficult to control the process due to the lack of simple and effective supervision means for the operation and maintenance management unit and the lag of information. Since the project implementation unit and the operation unit are not the same subject, it is difficult to define the responsible party when the treatment effect is not up to the standard, and it is easy to pass the buck.

4 Suggestions on Future Rural Sewage Treatment

Based on the common problems in rural domestic sewage treatment, the following suggestions are put forward in the future rural domestic sewage treatment.

(1) Reasonably determine the disposal mode and design scale in combination with the upper planning.

In full combination with the relevant local sewage treatment planning, municipal pipe network planning, village distribution planning, land comprehensive renovation planning, etc., reasonably determine the sewage collection volume within the service scope and then determine the sewage treatment mode and design scale. According to the time limit and scale of the planned villages to be removed and merged, the disposal method shall be determined comprehensively: The villages to be removed and merged for more than 5 years shall be temporarily collected and treated by the sewage treatment station, and the villages to be removed and merged for less than 5 years may be considered for decentralized treatment; the planned beautiful rural demonstration site needs to fully consider the impact of tourism and other foreign population and comprehensively determine the sewage treatment scale, and at the same time the sewage treatment facilities can integrate the overall landscape into the beautiful rural planning style.

According to the operation and maintenance situation of the village and the terminal scale, the rural sewage treatment should be treated with MBR and constructed wetland carefully to avoid the poor treatment effect caused by poor operation and maintenance.

(2) Give priority to municipal sewage pipe network treatment.

As the treatment mode of municipal sewage pipe network can ensure the better collection and treatment of sewage without excessive operation and maintenance, the long-term effectiveness of treatment effect, the principle of rural sewage treatment is to give priority to the treatment of municipal sewage pipe network, followed by the centralized collection mode, and finally the decentralized treatment mode.

For the planned new town communities and the population gathering villages in the planned reserved villages that are close to the municipal sewage pipe network, priority should be given to the municipal sewage system for treatment. In principle, the villages within 2 km from the municipal sewage pipe network can be piped. For villages far away from the municipal sewage pipe network but with concentrated population, centralized sewage treatment stations are adopted, and for villages far away from the municipal sewage pipe network and scattered residents, decentralized treatment mode is adopted for treatment.

For the villages that are planned to be merged, the sewage treatment mode shall be determined comprehensively according to their impact on the surrounding environment. In principle, the villages that are merged within 5 years shall be treated by the decentralized treatment mode, and more than 5 years shall be comprehensively determined according to the size of the villages. The villages with population close to the municipal sewage pipe network shall adopt the way of receiving pipes; villages that are far away from the municipal sewage pipe network and are densely populated are collected and treated by building new sewage treatment stations; the villages with scattered population and small water volume shall be treated in a decentralized manner.

(3) Reasonably determine the scale of centralized sewage treatment station.

If centralized sewage treatment station is adopted, combined treatment can be considered, and the scale of sewage treatment station should not be designed too small; otherwise the operation and maintenance pressure in the later stage is large, and the treatment effect is not ideal. In principle, the scale of sewage treatment station should be more than 30 m^3/day.

(4) Determine the domestic sewage treatment process reasonably according to the characteristics of sewage in different areas.

According to the local climate conditions, lifestyle, industry, etc., the characteristics of influent water quality should be analyzed, and the sewage treatment process should be designed to ensure the effect of sewage treatment in different regions and villages.

(5) For the sewage treatment station at the waterlogging point, the regulating tank shall be reasonably set.

For the areas around which waterlogging points are likely to occur due to terrain reasons, the hydraulic impact of rainwater mixing in rainy season on sewage treatment facilities shall be considered in the design of the regulating pond. It is recommended to set up intelligent grid regulating pond and two regulating ponds in areas with conditions to buffer the impact of instantaneous rainstorm on the terminal.

(6) Establish intelligent supervision platform.

An online monitoring system is set for the large-scale centralized sewage treatment station to remotely and real-time monitor and record the operation status of the treatment facilities and water quality data. Through intelligent analysis, the terminal facilities with abnormal operation status can be found in time to improve the operation and maintenance efficiency of the terminal.

For real-time water quality monitoring, from the perspective of cost saving, indicators as simple as possible, and no need for too much artificial operation and maintenance pressure, conductivity is selected to realize real-time monitoring of inlet and outlet water quality, and whether the system operates normally is analyzed according to the conductivity change of inlet and outlet water quality.

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Safety Analysis on Rural Groundwater Pollution in Youyang County

Zhong Pinzhi, Dong Lifei, Zhang Qi, Dong Wenzhuo, and Wang Miao

Abstract With the development of science and technology, modern industrial development has caused severe pollution of drinking water, especially in rural areas, which seriously affects people's health. It has led to water quality pollution in rural areas and seriously affected people's health. According to the 'Sanitary Standards for Drinking Water', the comprehensive evaluation method was used to analyze and study water security in rural areas of Youyang County. The results showed that the total number of colonies in pool 1, 2, 3 was less than the standard value, which was 9, 6, 6 CFU/mL. Total coliforms, *Escherichia coli*, and thermotolerant coliforms were not detected. The chlorine dioxide content was more significant than the traditional value of 0.11, 0.17, and 0.12 mg/L. The groundwater safety evaluation results of the three catchments are safe, and all indicators meet the 'drinking water health standards' index range. The above research provides data to support China in actively promoting urbanization and solving water shortage and pollution problems.

Keywords Water safety · Comprehensive evaluation method · Rural · Safety evaluation

1 Introduction

Water is called 'the source of life', one of life's most common substances and an indispensable substance in the growth and development of all animals and plants [1–3]. With the rapid development of the social economy in various countries, many natural resources are consumed, leading to the waste of water resources and water pollution, and the problem of water security is gradually increasing [4]. Under the background of rapid development in China, the rural water security evaluation system and the construction of the corresponding water security system are essential [5].

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On the issue of rural water security, many domestic scholars have carried out many years of research and exploration and accumulated valuable expe-rience. Through analyzing and summarizing the data left by the predeces-sors, Shi and Liu [6] proposed the current water security situation in urban areas, established a sound evaluation system, and discussed the existing problems in the current research. With the rapid development of urbaniza-tion as the research background, Liu and Xu [7] discussed and analyzed the problems and countermeasures in the development process. Through the theory of system coordinated development, Huang et al. [8] established a state-relationship framework as an evaluation model for regional water re-sources security issues. They quantitatively evaluated the region with a var-iable weight-multilayer fuzzy model.

Domestic scholars ignore the analysis of the underlying causes, only pay attention to the surface of the problem, and study the existing security situation. This paper discusses the centralized domestic water Youyang County three groundwater quality monitoring and water quality safety evaluation. According to the test results, the problems of domestic water use in Youyang County were analyzed, and corresponding measures were proposed to improve the sustainable development of rural water resources.

2 Regional General Situation

Youyang County is a small county located on the southeast border of Chongqing, with an area of 5173.2 km^2, as shown in Fig. 1. Youyang County belongs to a humid subtropical climate. Due to altitude and terrain, the overall temperature is low throughout the year. Owing to the large area and complex terrain, the residents in Youyang County are widely distributed, and catchments dominate the water use in most areas.

3 Groundwater Quality Detection

According to groundwater use in rural areas of Youyang County, the water quality areas with daily water supply below 1000 m^3 were measured [9]. The water quality of pool 1, pool two, and pool three from different areas was tested. The reference standard is 'Sanitary Standard for Drinking Water'; the results are shown in Table 1.

The test results show that the indicators of groundwater meet the requirements and can be safely drunk.

Fig. 1 Summary of Youyang County

4 Groundwater Safety Evaluation

According to the above groundwater quality test results, the safety evaluation of groundwater in rural areas of Youyang County was carried out [10]. The standard is 'rural drinking water safety and health evaluation index system'. The evaluation grade is shown in Table 2. The safety evaluation method is a single-factor evaluation method. According to the comparison between the detected groundwater data and the standard, the evaluation results are shown in Table 3. The results show that all the

Table 1 Groundwater quality detection

Order number	Pool 1	Pool 2	Pool 3	Standard
Total number of bacterial colony (CFU/100 mL)	9	6	6	≤ 100
Total coliform group (CFU/100 mL)	No detection	No detection	No detection	Inhibit detection
Oxygen consumption (mg/L)	0.7	1.5	0.9	≤ 3
Visible material by bare eye	No	No	No	No
Free residual chlorine (mg/L)	–	–	–	≥ 0.05
Chlorine dioxide (mg/L)	0.11	0.17	0.12	≥ 0.02

Table 2 Evaluation grade classification

	Meet the level	Result
Water quality test results	Hygienic standard for drinking water (GB5749-2006)	Safety
	Hygienic standard for domestic drinking water guidelines for rural implementation	Basic safe
	Does not meet the above two categories	Insecurity

Table 3 Groundwater safety evaluation results

Catchment number	Hygienic standard for domestic drinking water	Result
Pool 1	Meet	Safety
Pool 2	Meet	Safety
Pool 3	Meet	Safety

indicators meet the 'drinking water health standards', and the water quality safety category in the area is assessed as safe and can be safely drunk.

5 Groundwater Safety Analysis

5.1 Problems

Inadequate water quality monitoring facilities: There are nine water plants and six water supply stations in each area of Youyang County, so the water quality in the areas with relatively concentrated populations is guaranteed and meets the standard of domestic water use. There still needs to be more water quality monitoring methods for areas with more dispersed populations and no stable water resources.

Lack of relevant sewage treatment policies: The lack of relevant sewage treatment policies has led to many factory wastewaters discharged in disorder. The unreasonable use of pesticides and fertilizers makes the water indicators exceed the standard safety indicators, and the water resources are polluted.

Lack of logistical support: According to the development requirements of the new rural construction, the government has carried out a series of 'farmers drinking water' projects, such as building water pipelines for villagers in poor counties. However, many problems still need to be solved, such as untimely maintenance work, insufficient water source detection, and backward technical level.

5.2 Improvement Measures

(1) Government departments should strengthen the management of work for drinking water in rural areas and timely grasp the water quality information of rural drinking water. Create a perfect water quality detection system to ensure continuous water quality detection. Remote real-time detection of water plants and water supply stations ensures that all users can use healthy and safe water sources.
(2) According to the laws and regulations of water resources, adjusting measures to local conditions make up for the gap in rural prevention and control. Cooperate with the administrative law enforcement department to supervise the factory enterprises to ensure the sewage can be safely treated. Strengthen the importance of water resources management in rural areas of China, and improve laws and regulations.
(3) Actively carry out publicity activities such as water resources and environmental protection, and strengthen the villager's concept of 'loving water' and 'saving water.' Continue supervising the maintenance department's work progress and ensure the villagers' average water use at the 'China speed.' Rural water resources management departments should actively formulate corresponding water-saving policies, control drainage volume, and monitor water resources quality in real time. Actively respond to the call of the new rural construction, improve water quality monitoring technology, and escort for Youyang County domestic water.

6 Conclusions

Implementing rural drinking water safety is a health project to implement the scientific concept of development and improve farmers' lives. Based on the comprehensive evaluation method, this paper analyzes and studies the current situation of rural water security in Youyang County. According to the concentration degree of population distribution in Youyang County, water quality monitoring was done in different areas.

The water quality indexes were up to the standard. According to the results of the water quality test, the safety evaluation of groundwater is carried out, and the water quality level is evaluated as excellent. Based on the above results, the problems and solutions for groundwater safety in this area are put forward.

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Safety Evaluation on Water Pollution of Reservoir in Youyang County

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Abstract The green development of reservoirs is a long-term, dynamic and systematic project, an important measure to build rivers and lakes that benefit people's happiness. In order to understand the water pollution situation in rural areas of China. In this paper, the safety problems of reservoirs in rural areas of Youyang are studied and analyzed. The water quality of reservoirs is measured according to the national 'surface water environmental quality standard'. The Xiaoba secondary reservoir safety evaluation in Youyang County uses a single-factor evaluation method. The evaluation results show that the comprehensive qualitative evaluation index of the water quality of Xiaoba secondary reservoir in Youyang County is $P_j = 0.37$, and the water quality grade is excellent. Based on the evaluation results, the corresponding protection measures for the water quality of Youyang County reservoir are put forward, which provides a new idea for the standardized construction of the comprehensive management system for the safe operation of Youyang County reservoir.

Keywords Single factor evaluation · Reservoir · Evaluation of safety

1 Introduction

Youyang County is located in the upper reaches of the Yangtze River, in Wuyi Mountain's hinterland. Surrounded by mountains and undulating terrain, Youyang County is rich in water resources. However, due to geographical and temporal constraints, water security in Youyang County has been threatened [1, 2]. Recently, the Chinese government has attached great importance to water source environmental protection.

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Adopt a series of engineering and management measures to protect the water safety of urban and rural residents [3–5]. At the same time, some experts and scholars have also begun to study the safety evaluation of drinking water. Through the analysis and summary of the data left by the predecessors, Shi and Liu [6] proposed the current situation of water security in urban areas and established a set of the evaluation system to analyze the existing problems. Bao [7] analyzed the current situation of China's water security by constructing an evaluation index system and using the method of 'single index quantification-multi-criterion integration-multi-type synthesis' Liu and Xu [8] and Li and Cao [9], and others took the rapid development of urbanization as the research background and discussed and analyzed the problems and countermeasures in the development process. The focus of the above research and analysis is mainly on the city, and there are still some defects in the study of water security in rural areas.

This paper analyzes and studies the current situation of water security in rural areas of Youyang County. On this basis, how to improve the safety of rural water use in Youyang County is of great significance to the construction of water resources security and sustainable development.

2 Overview of Regional Reservoirs

According to the field investigation of the research group, Youyang County is rich in water resources. A total of 9 water plants and 6 water supply stations were built. The construction of water conservancy facilities makes most villages have water to drink. The reservoirs in Youyang County include Xiaoba II Reservoir, Shengli Reservoir, Youchou Reservoir, Longtan Reservoir, Dongqing Reservoir, Liangfeng Reservoir, Longsha Reservoir, Zaomu Reservoir and Zhongling Reservoir. Xiaoba secondary reservoir has the largest water capacity and is the main reservoir in Youyang area. The basic situation of reservoir resources in Youyang County is shown in Table 1.

Table 1 Reservoir situation in Youyang County

Name	Normal storage/10,000 m^3	Aggregate storage capacity/10,000 m^3
Xiaoba II Reservoir	1100	1300
Shengli Reservoir	1045	1235
Youchou Reservoir	1200	1350
Longtan Reservoir	727	1125
Dongqing Reservoir	30	45
Liangfeng Reservoir	40	57
Longsha Reservoir	120	160
Zaomu Reservoir	124.5	129.7
Zhongling Reservoir	32.5	49.1

3 Reservoir Safety Evaluation Method

In this paper, the single-factor evaluation method is used to evaluate the safety of reservoir water quality. The 'surface water environmental quality standard' was used as the water quality evaluation standard. According to the results of single-factor evaluation, the comprehensive qualitative evaluation index P_j of water quality was determined (excellent: $P_j < 0.59$; good: $0.59 \leq P_j < 0.74$; general: $0.74 \leq P_j < 1.00$; difference: $1.00 \leq P_j < 3.50$; range: $3.50 \leq P_j$).

According to the following formulas (1), (2), and (3), the single-factor index *Pi*, the comprehensive pollution index *P*, and the comprehensive qualitative evaluation index *Pj* of water quality are calculated, and the water quality of the water source area is qualitatively described according to the water quality level.

$$P_i = \frac{C_i}{S_{oi}} \tag{1}$$

$$P = \sum_{i=1}^{n} P_i \tag{2}$$

$$P_j = \sqrt{\frac{1}{2}\left[\left(\max \frac{C_i}{S_{oi}}\right)^2 + \left(\frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_{oi}}\right)^2\right]} \tag{3}$$

C_i—The annual average concentration value of the evaluation factor, mg/L.

S_{oi}—The standard value of evaluation factor, mg/L.

n—Number of monitoring items of drinking water sources.

P_j—Comprehensive qualitative evaluation index of water quality of drinking water sources.

Environmental quality index *Pi* is a dimensionless number. It is the degree of water pollution by the pollutant. The larger the index, the lower the quality of the single index [10].

4 Reservoir Safety Evaluation of Youyang County

The water quality of Xiaoba II Reservoir in Youyang County is tested. Combined with the single-factor evaluation method, the test results of each factor are analyzed. The calculation process is as follows (the calculation of each single-factor index takes the calculation process of PH, DO, and CODMN as an example).

$$\text{PH} : P_i = \frac{C_i}{S_{oi}} = \frac{7.62}{6} = 1.3$$

$$\text{DO}: P_i = \frac{C_i}{S_{oi}} = \frac{9.56}{7.5} = 1.3$$

$$\text{CODMN}: P_i = \frac{C_i}{S_{oi}} = \frac{1.1}{2} = 0.6 \quad P_j = \sqrt{\frac{1}{2}\left[\left(\max \frac{C_i}{S_{oi}}\right)^2 + \left(\frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_{oi}}\right)^2\right]}$$

$$P_j = \sqrt{\frac{1}{2}\left[\left(\max \frac{C_i}{S_{oi}}\right)^2 + \left(\frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_{oi}}\right)^2\right]}$$
$$= \sqrt{\frac{1}{2}\left[(1.3 + 2.3)^2 + \left(\frac{1}{24}\sum_{1}^{24} 1.3 + \cdots + 2.3\right)^2\right]} = 0.37$$

5 Evaluation Results

The single-factor evaluation results of water source of Xiaoba secondary reservoir in Youyang County show that comprehensive qualitative evaluation index of water quality $P_j = 0.37 < 0.59$. Water quality level is excellent. All indexes reached the third standard of 'surface water environmental quality standard'. The water quality grade meets the requirements of class II, including 20 class I evaluation factors, 1 class II evaluation factor, and 5 items below the standard limit. The comprehensive qualitative evaluation index of water quality is 0.37. The statistical results are shown in Table 2.

Table 2 Classification of water quality grade categories

Name	Category	Evaluation factor
Youyang County reservoir	I	pH, DO, CODMN, Cu, Zn, Fluoride, Se, As, Hg, Cd, Cr^{6+}, Pb, cyanide, Volatile phenols, Petroleum, Anionic surfactants, sulfide
	II	Permanganate index, N, P, Fecal coliforms
	Standard limits	Sulfate, chloride, nitrate, Fe, Mn

6 Protective Measures

(1) Strengthen reservoir boundary management: Reservoir boundary management is also an important part of the safe operation of the reservoir. The local government should be based on existing water resources laws and regulations. Prevent the surrounding people from planting and mining in the reservoir protection area, threaten the water quality safety of the reservoir, and make up for the rural prevention and control gap.
(2) Establish and improve the water quality detection system: Relevant government departments should strengthen the detection and management of drinking water in rural areas. Ensure 24 h to grasp the water quality information, as well as the dynamic information of microorganisms, pollutants and other information. Create a perfect water quality detection system for real-time detection. Remote detection of each water plant and water supply station should also be carried out to ensure the comprehensive and continuous water quality detection.
(3) Reservoir health protection: The reservoir area must be cleaned before impoundment, and the garbage and other pollutants in the reservoir area should be transported out of the reservoir as far as possible to ensure that the water quality in the reservoir area is in good condition. If garbage continues to be piled up on the bank, it will have an extremely adverse impact on the health of people around the bank. Therefore, the construction of sewage treatment sites and garbage disposal sites should be completed.

7 Conclusions

(1) The water quality safety of reservoirs in this area was evaluated by single-factor evaluation method. Water quality comprehensive qualitative evaluation index $P_j = 0.37$, excellent water quality, and safe to drink.
(2) The evaluation of reservoir safety in rural areas of Youyang County is realized, which provides reference for local reservoir safety protection measures.

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Accurate Traceability of Pollutants in Zhoucheng River Channel in Liyang

Qiuyue Tang, Wei Tang, Jinglong Du, Yangyang Tang, and Chen Xu

Abstract River and lake water environment governance and enhancement have become the focus of high-quality development. The premise of accurate pollution control is to precisely trace the source. Targeting the outstanding problems of rivers, implementing "one river, one policy," strengthening supervision and management, and enhancing the pertinence and operability are the important tasks that need to be solved at this stage of river water environment improvement and remediation. The Zhoucheng River is located in the third-tier protection zone of the Taihu Lake Basin, and its water environmental protection is the focus of its renovation. In order to systematically carry out the Zhoucheng River water environment renovation to meet the standards, the Zhoucheng River water environment pollution comprehensive traceability, classifying and establishing a long-term mechanism as the main task, based on the investigation and analysis of the current state of the water environment quality to clarify the Zhoucheng River pollution status and causes, and further propose water quality management measures to meet the standards in a targeted manner. Through comprehensive evaluation of water quality, identification of main pollution factors and evaluation of main water quality indexes, etc., know that the water quality of the main stream of Zhoucheng River gradually deteriorates from upstream to downstream, and its main pollution factor is ammonia nitrogen, followed by total phosphorus and finally permanganate index. Besides, the main polluted section of the main stream of Zhoucheng River is located in the upstream section and the middle and downstream (Zhoucheng Settlement section).

Keywords Water quality assessment · Precise traceability · Pollutants

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1 Introduction

In order to improve the ecological environment of rivers and achieve the goal of harmonious coexistence of people and water, the country has applied the concept of civilized city construction to river regulation, and the restoration and protection of river environment cannot be delayed. Prevention and control of pollution has been elevated to a major decision deployment in China [1–3]. In August 2019, General Secretary Xi first put forward the requirement of "accurately control pollution, scientifically control pollution, and control pollution according to the law" at the Central Economic Conference, and the report of the 20th Party Congress emphasized that the treatment and improvement of water in rivers and lakes have become the focus of high-quality development [4–6]. The premise of precise pollution control is to trace the source accurately. Targeting the outstanding problems of rivers, starting from the actual situation of different regions, different rivers and lakes, coordinating upstream and downstream, left and right banks, implementing " one river one policy," strengthening supervision and management, enhancing the pertinence and operability, are important tasks at this stage of river water environment improvement and remediation urgently need to be addressed [7–10].

Jiangsu Liyang Zhoucheng River is located in the downstream of the former Song Reservoir, starting from Jinfeng Green Channel in the north, south to Southern Cement Company, with a total length of 10.4 km, and intersecting with Daxi River and ZhuYu River at the bordering of Shezhu Town, Nandu Town, and Tianmu Lake Town at the end of the river, and finally merging into ZhuYu River and Daxi River, the quality of Zhoucheng River directly affects the water environment of ZhuYu River and Daxi River. In recent years, all departments and townships in Liyang City have been cooperating to promote the various pollution control measures, and the main water quality indexes of Zhoucheng River in Liyang have been improved, but there is still a certain gap from the stable water quality of Class III. Therefore, the improvement and treatment of water environment of Zhoucheng River cannot be delayed.

In order to systematically carry out the Zhoucheng River water environment renovation to meet the standards, the Zhoucheng River water environment pollution comprehensively trace the source, classifying and establishing a long-term mechanism as the main task, based on the investigation and analysis of the current state of the water environment quality to clarify the Zhoucheng River pollution status and causes, and further propose water quality management measures to meet the standards in a targeted manner.

2 Materials and Methods

2.1 Study Area

Liyang is located at the junction of Jiangsu, Zhejiang, and Anhui provinces in the southwest of Yangtze River Delta, at latitude 31°09′–31°41′N, longitude 119°08′–119°36′E, adjacent to Yixing in the east, Gaochun and Lishui in the west, Guangde and Langxi in the south, Jurong and Jintan in the north, with a length of 59.06 km from north to south and a width of 45.14 km from east to west. The total land area is 1535.87 km^2. A total of 104 national highway passes through the territory, Ning-Hang Expressway, Yang-Li Expressway, and Ning-Hang High-speed Railway cross the whole territory, and the shipping rivers such as Danjin-Li Cao River, South River, and Wu-Tai Canal are connected to the water transportation network in south Jiangsu, which has initially formed a transportation network with high-grade highway as the main skeleton and water and land together, with convenient transportation. The Zhoucheng River starts from the Qian Song Reservoir and runs through Shezhu Town, flowing from south to north, and is the main river for water diversion, drainage, and navigation in the hilly area of the territory, and is located within the third-level protected area of Taihu Lake Basin.

Zhoucheng River (Shezhu section, including overflow river) is located in the downstream of Qian Song Reservoir, from Jinfeng Green Channel in the north to Southern Cement Company in the south, with a total length of 10.4 km, bottom height of 0.5 m (Wusong height), bottom width of 20 m, river mouth width of 70 m, at the end of the river Shezhu, Nandu Town, Tianmuhu Town bordering Daxi River, Zhu Yu River, Zhoucheng River has three tributaries which are Zhu Zhuang River, Xidian River, and Daxi Reservoir West Main Canal. Jiangsu Province surface water environmental function zone: Zhoucheng River is mainly for industrial and agricultural water, requiring water quality up to standards Class III (Fig. 1).

2.2 Model Description

Single-factor evaluation method: This paper adopts the single-factor evaluation method, i.e., comparing the concentration of each parameter with the evaluation standard of the corresponding section, based on whether the ratio exceeds 1 to evaluate whether the river water body meets the corresponding water quality standards, and determine the water quality category of the evaluation index, and will use the worst water quality category as the results of the comprehensive evaluation of water quality [11].

In this paper, we choose permanganate index, ammonia nitrogen, and total phosphorus as evaluation indexes. This method is the most simple operation water quality evaluation methods, which is mostly used currently, and it can directly understand

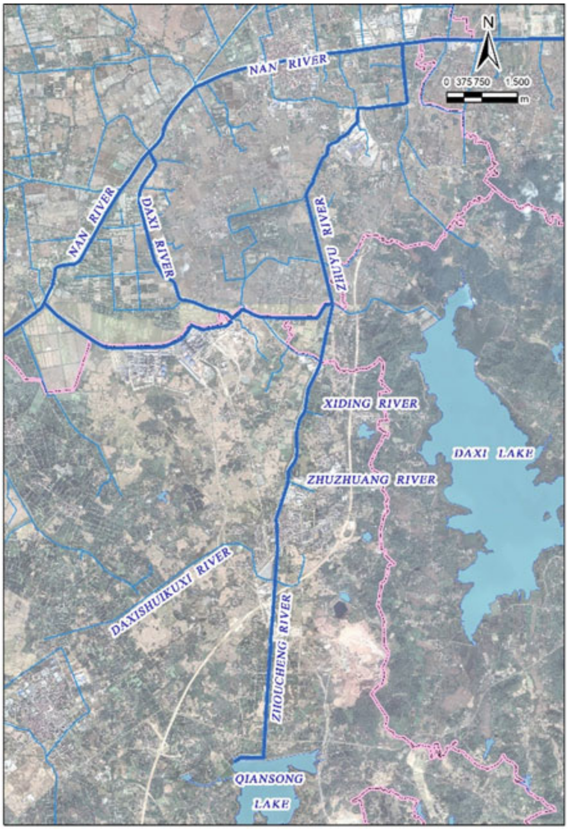

Fig. 1 Distribution of intersecting rivers and confluent tributaries of the Zhoucheng River

the relationship between water quality conditions and evaluation standards, to find the main pollution factors.

$$Pi = Ci/Si \tag{1}$$

Description: Pi indicates the single index of water quality evaluation factor. Ci indicates the average value of the measured concentration of evaluation factor (mg/L). Si indicates the evaluation standard value of evaluation factor (mg/L), which is determined according to the monitoring of the functional area to which Zhoucheng River belongs and the Surface Water Environmental Quality Standard (GB3838-2002).

WQI Modeling: **WQI modelling** improved and developed Pesce and Wunderlin model, and WQI is mostly used for water quality assessment of watershed rivers and lakes in recent years, etc. [12, 13].

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} Ci\,Pi}{\sum_{i=1}^{n} Pi} \tag{2}$$

n is the number of water quality indicators involved in the calculation, *Ci* and *Pi* are the normalized value and weight of variable *i*. *Ci* value reference "Surface Water Environmental Quality Standard" (GB 3838-2002), it is divided into 11 levels from 0 to 100 to assign a value, and the minimum and maximum value of Pi are 1 and 4, respectively. WQI values range from 0 to 100, the higher score indicates the better water quality. Water quality conditions according to WQI value is divided into five levels: poor ($0 \le \mathrm{WQI} \le 25$), average ($25 < \mathrm{WQI} \le 50$), medium ($50 < \mathrm{WQI} \le 70$), good ($70 < \mathrm{WQI} \le 90$), and excellent ($\mathrm{WQI} > 90$). The WQI values were calculated by CODMn, NH3-N, TP, and other indicators.

3 Result and Discussion

3.1 Comprehensive Evaluation of Water Quality in Zhoucheng River

Using the WQI comprehensive index method to comprehensively evaluate the water quality of the Zhoucheng River, we can find from Table 1 that the water quality of the Zhoucheng River is at a medium to poor level, and the overall spatial distribution of the water quality in the Zhoucheng River basin shows a trend of gradual deterioration from upstream to downstream. Therefore, the water pollution tracing and river management work of the Zhoucheng River cannot be delayed.

Table 1 WQI value of each sampling point of Zhoucheng River

Sampling point		WQI	Current water quality
Mainstream	W1	62.5	Medium
	W2	41.25	Average
	W3	41.25	Average
	W4	41.25	Average
	W7	35	Average
	W8	23.75	Poor
	W11	20	Poor
Tributary	W5	41.25	Average
	W6	20	Poor
	W9	23.75	Poor
	W10	35	Average

3.2 Major Pollution Factors Identification

According to the test results, combined with Tables 2 and 3, except W1, all monitoring points permanganate index exceeds III water standard, but the single index is not large; except W6, W7, W8, W9, other points ammonia nitrogen, total phosphorus are up to III water standard, in the exceeded points, the single index value of ammonia nitrogen is larger, and the degree of exceedance is greater. In summary, the main pollution factor of Zhoucheng River is ammonia nitrogen, followed by total phosphorus, while the next is permanganate index.

Table 2 Water quality of the main stream and tributaries of the Zhoucheng River

Point no		Permanganate index (mg/L)	Single index (III Class)	Ammonia nitrogen (mg/L)	Single index (III class)	Total phosphorus (mg/L)	Single index (III class)
Main stream	W1	4.3	0.72	0.259	0.259	0.03	0.15
	W2	6.7	1.12	0.652	0.652	0.1	0.50
	W3	6.3	1.05	0.624	0.624	0.13	0.65
	W4	6.4	1.07	0.669	0.669	0.11	0.55
	W7	6.9	1.15	0.909	0.909	0.15	0.75
	W8	6.4	1.07	1.77	1.77	0.22	1.10
	W11	8.0	1.33	1.93	1.93	0.23	1.15
Tributary	W5	7.5	1.25	0.212	0.212	0.10	0.48
	W6	7.1	1.18	7.295	7.295	0.36	1.78
	W9	6.4	1.07	1.590	1.590	0.21	1.05
	W10	7.2	1.20	0.784	0.784	0.16	0.80

Table 3 Water quality of the Zhoucheng River outfall

Point no	Permanganate index (mg/L)	Single index (III class)	Ammonia nitrogen (mg/L)	Single index (III class)	Total phosphorus (mg/L)	Single index (III class)
PK1	4.8	0.80	0.169	0.169	0.05	0.25
PK11	6.3	1.05	10.200	**10.2**	1.68	**8.4**
PK12	6.3	1.04	5.045	**5.045**	0.54	**2.7**
PK22	6.4	1.06	1.415	1.415	0.17	0.85

Permanganate index is defined as Chemical oxygen demand measured with Potassium permanganate solution as oxidant
Single index (III class) is defined as the water environment quality is Level 3
Ammonia nitrogen (mg/L) is defined as the combined nitrogen present in the form of ammonia or ammonium ions

3.3 Evaluation of the Main Water Quality Indicators of the Zhoucheng River

According to the change of permanganate index along the main stream of Zhoucheng River in Fig. 2, it can be seen that: in the upstream section, the permanganate index of the Zhoucheng River water quality is 4.3 mg/L, which meets the standard of Class III water, and then the permanganate index rises sharply and exceeds the standard of Class III water at W2, reaching 6.7 mg/L; then the permanganate index remains stable until the middle and downstream section of Zhoucheng Township at W8, which slightly exceeds the standard of Class III water; after that, the permanganate index rose greatly again and reached 8 mg/L at W8 in the downstream section. Looking at the whole process changes, the permanganate index rose greatly twice in the upstream and downstream, so it can be seen that the pollution input of permanganate index in Zhoucheng River mainly comes from the upstream and downstream sections (aquaculture concentration area).

As shown in Fig. 3, the changes of ammonia nitrogen along the main stream of Zhoucheng River, it can be seen that in the upstream section, the ammonia nitrogen in the incoming water of Zhoucheng River is 0.259 mg/L, which meets the standard of Class III water, then until the middle and lower reaches of W7, the ammonia nitrogen rises slowly to 0.909 mg/L; between W7 and W8 in the middle and lower reaches, the ammonia nitrogen rises significantly, reaching 1.77 mg/L at W8, which exceeds the standard of Class III water; then it rises slowly to 1.93 mg/L at W11. Throughout the whole change process of ammonia nitrogen, there is a significant increase in the middle and downstream section of Zhoucheng Town, so it is known

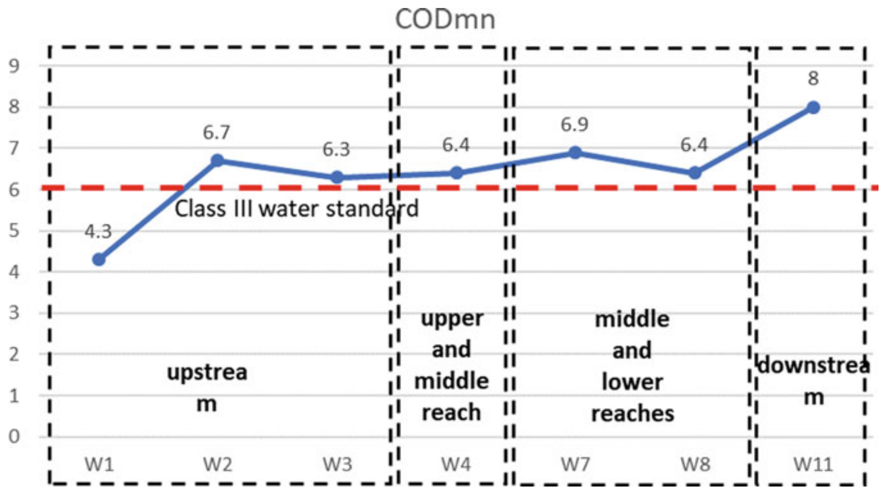

Fig. 2 Changes of permanganate index along the main stream of Zhoucheng River

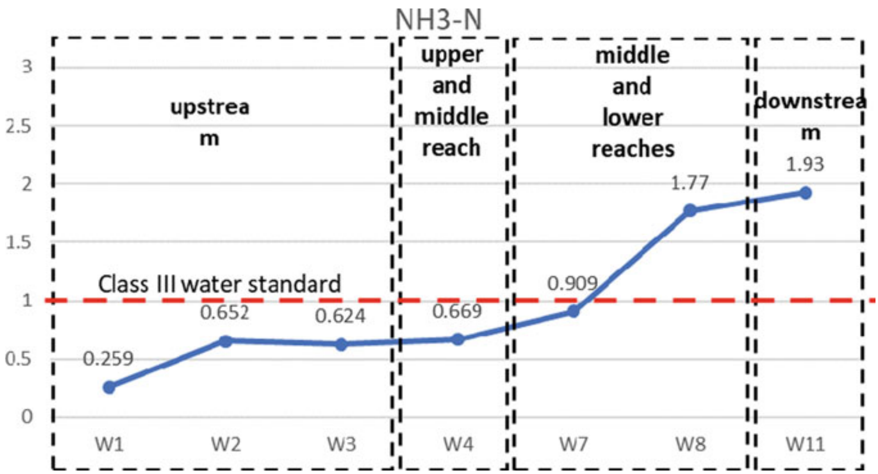

Fig. 3 Changes of ammonia nitrogen along the main stream of Zhoucheng River

that the ammonia nitrogen pollution in Zhoucheng River mainly comes from the middle and downstream section of Zhoucheng Town.

From Fig. 4, the changes of total phosphorus along the main stream of Zhoucheng River can be seen: from W1 to W7, although there is a relatively large increase in total phosphorus, but none of them exceed the III water standard; between W7 and W8, total phosphorus rises significantly, reaching 0.22 mg/L at W8, exceeding the III water standard; finally it slowly rises to 0.23 mg/L at W11. Looking at the changes of total phosphorus throughout the whole course, the key to exceed the standard is the input of total phosphorus pollutants in the middle and lower reaches of the Zhoucheng catchment.

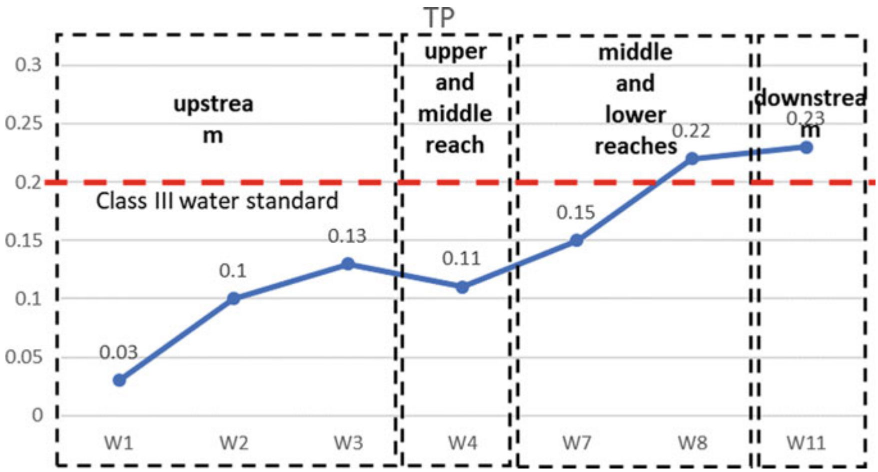

Fig. 4 Changes in total phosphorus along the main stream of Zhoucheng River

4 Conclusion

Through the above comprehensive evaluation of water quality, identification of main pollution factors, and evaluation of main water quality indicators, it is concluded that the water quality of the main stream of Zhoucheng River gradually deteriorates from upstream to downstream, and its main pollution factor is ammonia nitrogen, followed by total phosphorus and finally permanganate index. And, the main polluted section of the main stream of Zhoucheng River is located in the upstream section and the middle and downstream (Zhoucheng settlement section). At the same time, through the analysis of the impact of Zhoucheng River tributaries and coastal outfalls on its water quality, it was further concluded that ammonia nitrogen and total phosphorus exceeded the standard mainly in the middle and lower reaches of Zhoucheng Township, and permanganate index exceeded the standard mainly in the upper and lower reaches of Zhoucheng River. Based on the above analysis, combined with the distribution characteristics of regional pollution sources, the spatial distribution characteristics of water quality changes in the Zhoucheng River, and the water quality of discharge outlets, it is concluded that the following problems mainly exist in the prevention and control of pollution sources in the Zhoucheng River. First, the middle and lower reaches of the Zhoucheng Township section exists rain and sewage mixed flow, and the continuous input of pollutants from both sides of the river has become the most important reason for the deterioration of the water quality of the Zhoucheng River; second, the pollutants input from the shrimp farming ponds on both sides of the upper and lower reaches affect the water quality of the Zhoucheng River; third, the fertilizers and pesticides brought by agricultural planting on both sides of the upper and lower reaches enter the water body of the Zhoucheng River with surface runoff; fourth is the impact of enterprise wharf drainage and ship disturbance.

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