

Study on the Application and Optimization of Domestic Sewage Treatment Demonstration Based on a Novel Biofilter-Constructed Wetland Coupling System

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Abstract

A novel biofilter-constructed wetland coupling system has been applied more than 160 domestic sewage treatment projects in different cities of Zhejiang province, China. The performance of a randomly selected project (flux rate was 27.0 m³/d) based on the coupling system was evaluated in long-term, and the effluent monitoring by big data analysis showed a relatively stable and good water quality. The effluent concentrations of COD_{Cr}, NH_4^+ -N and TP was 37.57 ± 11.17 mg/L, 5.64 ± 1.69 mg/L and 0.82 ± 0.16 mg/L, respectively, which met the first class of "Standards for Discharge of Water Pollutants from Rural Domestic Sewage Treatment Facilities" (DB33/973-2015). The concentrations of effluent TP showed a strong polynomial curve fitting with effluent NH_4^+ -N concentrations ($R^2 = 0.9329$) according to the big data analysis. Besides, the concentrations of effluent COD_{Cr} had a strong positive linear correlation with the concentrations of effluent NH_{Δ}^{+} -N (R² = 0.9297), which increased with the increase of effluent TP concentrations ($R^2 = 0.6957$). Results also showed C/N had stronger correlation with pH ($R^2 = 0.6441$), while the concentration of effluent NH_4^+ -N and effluent TP had weak correlation with pH (R^2 = 0.3348 and R² = 0.4834, respectively). The findings might have very important guiding significance for the future monitoring methods of water effluent quality of treatment facility and the cost reduction of monitoring management. Moreover, a demonstration and experiments were carried out for a contrast study of the enhanced system (b) and original system (a). The removal efficiency of COD_{Cr}, NH₄+-N and TP of the enhanced system (b) was 81.33 %, 90.22 %, and 75.44 %, respectively, which increased by 4.33 %, 9.11 % and 13.77 % respectively compared to the original system (a).

1. Introduction

The pollution of rural domestic sewage has become more and more concerned around the world over the past decade (Zhang et al., 1996; Lutterbeck et al., 2018), especially in developing countries where increasing demand for governance (Sunny et al., 2006; Mohammad et al., 2008). The pollution of rural domestic sewage in China is more complicated due to factors such as its large population base and uneven economic development (Wang et al., 2019; Hong et al., 2019). The large rural population in China results in a huge amount of domestic sewage, and a correspondingly large market. However, the startup of rural domestic sewage treatment is late, and the technologies and process are various, which like anaerobic/aerobic (A/O) (Cui et al., 2016), anaerobic/anoxic/aerobic (A²/O) (Chen et al., 2011; Liu et al., 2013), integrated purification tank (Cui et al., 2016), Membrane Bio-Reactor (MBR) (Kong et al., 2013a), Multi-stage anaerobic biological filter or Multi-soil-layering system (Chen et al., 2013; Song et al., 2018), constructed wetland (Kong et al., 2013b; Wu et al., 2015; Li et al., 2018), and ecological pond/ditch (Ma et al., 2019). However, these technologies have problems such as unstable processing effect, high energy consumption (Xu et al., 2019), large land occupation, high investment, difficult technical management (Cui et al., 2016), and poor compatibility with ecological landscapes, making the applicability and popularization of these technologies are limited. It is urgent to find a new technology with stable

processing effect, economically affordable for investment and operating, simple management and coordination with the surrounding landscape (Cameron et al., 2003; Wu et al., 2013; Lu et al., 2019).

Many countries have their own practical in terms of rural domestic sewage treatment technology. Japan mainly uses the "Johkasou" technology which now introduced into China (Kaneko et al., 1997; Ichinari et al., 2008). The predominant treatment technology around the world are high rate algae pond (Godos et al., 2016; Assis et al., 2017), earthworm filter bed or vermifilter (Moon et al., 2010; Liu et al., 2012; Jiang et al., 2016), and constructed wetland (Vymazal, 2007; Vymazal et al., 2014), etc. All of these countries have different pollution concentrations with China and have rather small population density except Japan. Thus, appropriate treatment technology should be selected based on their actual situation in the country.

The rural sewage treatment work in Zhejiang Province is at the forefront of China. Rural green revival program in Zhejiang Province named "Demonstration and Regulation in Thousands of Villages" was granted with the UN award in 2018 after transforming a once heavily polluted area of rivers and streams through the local eco-restoration program. A novel biofilter-constructed wetland coupling system serves as a technical support to help win the "Earth Guardian Award" has been utilized in more than 160 projects in Zhejiang Province. Unlike the conventional structure of constructed wetland system, the novel selfventing biofilter-constructed wetland coupling system adopts a upper and lower stacking structure, and the collecting tank is used as a pretreatment unit to adjust the water volume and to achieve the hydrolysis and acidification in the process, while the substrate is calcium-contained gravel which has the capability of enhanced phosphorus removal (Renman et al., 2010; Vohla et al., 2011). Based on the Bernoulli Principle, a series of enhanced oxygen enrichment technologies for self-ventilation pipe network were developed. In the connected pipe network system, there will be an air flow as long as the air density difference existed at different altitudes and the self-ventilation oxygen enrichment of the biological filter would be accomplished, which could effectively improve the pollutant removal effect. The main causes of air density difference were the temperature difference caused by different environment or the change of air density generated by the consumption of a certain component. Besides, the novel biofilterconstructed wetland coupling system adopt stacking structure, and the collecting and distributing water diversion system was set vertically between the upper and lower layers, alternating the system aerobic, anoxic and anaerobic state to achieve a strong removal of TN. Furthermore, comparing with the conventional constructed wetland, the advantages of this technology are low requirement for the land occupation, low operating cost, non-energy consumption when the sewage in self-flow, and stable with remarkable landscape effect, as well as economic and social benefits.

Although the water effluent of novel biofilter-constructed wetland coupling system could meet the first-class standard of Zhejiang Provincial "Water Discharge Standard for Rural Domestic Sewage Treatment Facilities" (DB33/973–2015), however, it could not stably reach higher criterion. Therefore, this study aims to evaluate the performance of multiple engineering projects based on the coupling system, and to optimize the coupling system to achieve a better and stable pollutants removal, expanding its application in the field of micro-polluted surface water as well.

2. Material And Methods

2.1. Process and material

Figure 1 is the structure and flow pattern of the biofilter-constructed wetland coupling system. Figure 1 shows that domestic sewage firstly flows through the grille of the regulating tank, then evenly and vertically enters into the biofilter-constructed wetland coupling system through the water distribution system by the lifting of the pump, and filtered by the upper biofilter unit with the enhanced oxygen enrichment of the self-ventilation pipe network system, and then collected at the bottom to vertical water distribution pipes with holes at the lower part, finally flows in a push-flow mode at the bottom of the constructed wetland, further purified under the synergistic action of the constructed wetland filler, microorganisms and plants, and finally discharged. The air connection for the system are tunnel air diffusion devices buried at the bottom of the biofilter bed, connecting the air inlet pipes, also connecting with vertical air extraction pipe extending out of the fillings top surface to attain air convection and automatic oxygen enrichment of the biofilter bed, improving the pollutant removal efficiency and saving the cost of operation and maintenance.

In this study, a project case with the application of this technology ($27 \text{ m}^3/\text{day}$) was randomly selected and its effluent was monitored and analyzed with continuous big data to evaluate the effluent effect and explore the law of the technology. As shown in Table.1, in order to investigate the engineering effect of this technology, 12 engineering cases ranged from $3 \sim 100 \text{ m}^3/\text{day}$ were selected and its operation effect was monitored by random sampling.

For further improvement of the sewage treatment effect and operation stability of this technology, a pilot-scale comparison (50 m³/day) based on this coupling system was constructed, as shown in Fig. 2. The two sets of biofilter-constructed wetland coupling comparing systems were separated by a partition wall in the middle. Right side, the biofilter was filled with a mixed filter stone for the original system (a), and on the left filled with different fillers for the enhanced system (b).

As shown in Fig. 2, the effective volume of the grille well in the pilot was 1.50 m³, while the volume of the adjusting tank was 36.00 m³. The area of the biological filter bed was 109.20 m2 and the height was 1.20 m, with a density of 30 m²/clumps, placed on the subsurface constructed wetland. The area of the subsurface constructed wetland was 140.2 m² and the height is 1.50 m. The area of uncovered subsurface constructed wetland was planted with a density of 9 Canna /m²; The volume of outlet well was 0.25 m³. The parameters for comparative experimental study of novel biofilter constructed wetland coupling system were the same as kong's (Kong et al., 2013a).

2.2. Influent water indexes of the contrast experiment.

The water influent was intermittent in both the biological filter bed system and constructed wetland system, controlled by water level of the adjusting tank. The HRT of the two systems were 18.87 h and 57.54 h, respectively.

2.3. Analysis, sampling, and testing methods

The primary effluent indexes are COD_{Cr} , NH_4^+ -N, and TP. The big data is collected by on-line monitoring equipment every two hours.

3. Results And Discussion

3.1. Big data analysis based on a randomly selected engineering project

More than 160 engineering cases based on the coupling system were applied in different cities of Zhejiang province, and mainly in Kaihua county, which locates in the northwest of Quzhou city. A project using this coupling system was selected and on-line monitoring equipment was added to the effluent section to investigate its long-term effect. The project locates in Xiayu village of Kaihua county, the average influent concentration of COD_{Cr} , NH_4^+ -N and TP of rural domestic sewage in Quzhou city was 113.9 mg/L, 27.27 mg/L, and 3.00 mg/L, respectively, which basically represented the average influent water quality of Kaihua county. The main effluent indexes of the project were continuously observed for nearly 160 days, and data were automatically monitored every four hours. From Fig. 3 effluent concentrations of COD_{Cr} , NH_4^+ -N and TP showed periodic changes, and all of the values were within their standard ranges. Table.2 showed the effluent values of the main parameters of the project, and the effluent concentrations of COD_{Cr} , NH_4^+ -N, and TP were 37.57 \pm 11.17 mg/L, 5.64 \pm 1.69 mg/L, and 0.82 \pm 0.16 mg/L, respectively. On the whole, Fig. 3 showed a relatively stable and good effluent water quality, which met the first level of "Standards for Discharge of Water Pollutants from Rural Domestic Sewage Treatment Facilities" (DB33/973–2015).

It also could be found from Table.2 that the flow rate of the coupling system was $1079.36 \pm 37.79 \text{ m}^3/\text{h}$ (ranges from $25.0 \text{ m}^3/\text{d}$ to $26.8 \text{ m}^3/\text{d}$) during the monitoring period, which approaching the designed parameter ($27.0 \text{ m}^3/\text{d}$). The emergence of the situation that the effluent flow rate was lower than the design flow rate may be related to the gap between the design and the actual situation, leakage or impervious measures in constructed wetland or sewage pipe network, plant transpiration, and other problems.

Figure 4 showed correlations of the main effluent water quality indexes with each other. As shown in Fig. 4(a), the concentrations of effluent COD_{Cr} had a strong positive linear correlation with the concentrations of effluent NH_4^+ -N (R^2 = 0.9297), and increased with the increase of effluent TP concentrations in Fig. 4(c) (R^2 = 0.6957). While in Fig. 4(b), the concentrations of effluent TP showed a strong correlation with effluent NH_4^+ -N concentrations (R^2 = 0.9329). The results showed that there was a strong correlation between different effluent water quality indexes, and if the sample capacity was large enough, the data would be much more accurate. This founding might have very important guiding significance for the

future monitoring methods of effluent water quality of treatment facility and the reduction of monitoring management cost, as well as to ensure the main effluent water indexes meet the standard by a combination of big data analysis and AI technology in ways of early warning and feedback control. In this study, the effluent water index of domestic sewage had stronger regularity, and it was found that the effluent also showed a strong correlation when analyzing other treatment objects such as surface water and other process technologies. This might be the result of complex physical, chemical and biological reactions occurred in different facilities, making it more regular than untreated water.

Few relevant studies and reports were found about effluent water index than the influent in literature. Sun (Sun et al., 2014) found that the indicators including BOD_5 , COD_{Cr} , TN and TP had significant simple linear relationships. And the correlation coefficient of BOD_5 and COD_{Cr} , BOD_5 and TN, BOD_5 and TP, TN, and TP was 0.968, 0.995, 0.823, 0.817, respectively. Besides, some scholars were looking for new methods that can be used for rapid or low-cost simultaneous monitoring of multiple indicators. Wang (Wang et al., 2019) tried to obtain a satisfactory prediction accuracy modelling approach to identify some hard-to-measure variables like COD and TP by selecting flowrate. Lotfi (Lotfi et al., 2019) presented a methodology to model the quality parameters of effluent wastewater and found that the methodology could accurately predict BOD in wastewater. Narendra (Narendra et al., 2019) developed a feedforward artificial neural network model to predict effluent quality parameters through influent characteristics like pH, TSS, BOD, COD, TKN, and TP etc.

Figure 5(a)-(d) was the correlations between pH and effluent COD_{Cr} , NH_4^+ -N, TP, C/N.As shown in Fig. 5, C/N showed a stronger correlation with pH (R^2 = 0.6441), while the concentrations of effluent NH_4^+ -N and effluent TP had weak correlation with pH, and the correlation coefficient of which was R^2 = 0.3348 and R^2 = 0.4834, respectively. It could be seen from Fig. 5 (d) that the pH decreased with the increase of C/N when the effluent C/N was less than 8.5, thus a method might be derived to fast monitor and control the effluent quality indexes. Moreover, if the amount of data sample was big enough, the effluent C/N could be used as a more accurate indicator, and the effluent C/N could be indirectly reflected by the change of easily monitored pH value, making the influent C/N could be changed quickly according to the effluent requirements, or the effluent water quality could be improved by fast feedback and the changing of HRT.

Although the project based on the coupling system achieved good and stable effluent water quality, it was only a randomly selected case, and could not represent the entire application effects of the coupling system. Therefore, it was necessary to study more cases and to summarize the actual project effluent effects of this coupling system.

3.2. Study on the pollutant removal in 12 different randomly selected engineering cases

As shown in Table.1, in order to better understand the actual engineering effect and existing problems of the technology more comprehensively, 12 engineering cases with different scales (3-100 m³/d) were randomly selected for the comparative study of pollutant removal effect.

According to investigation conducted our group in year 2015, the average concentration of COD_{Cr} , NH_4^+ -N and TP in the influent of Zhejiang Province (except Ningbo) was 186.35 mg/L, 30.33 mg/L and 4.06 mg/L, respectively, and the average C/N of Zhejiang Province was 6.14, which was beneficial to biological nitrogen and phosphorus removal. The 12 engineering cases in this study mainly located in Quzhou City and Wenzhou city, where contains many mountainous areas. And its average influent concentration of COD_{Cr} , NH_4^+ -N and TP was 171.73 mg/L, 22.14 mg/L and 3.20 mg/L respectively, which was lower than the average values of Zhejiang Province. Besides, there were significant differences among these cities (P < 0.05). Result showed that the topography and economic development level of mountainous areas had greater impact on the influent water quality.

The data of the study case in Fig. 6 showed that the effluent concentrations of COD_{Cr}, NH₄⁺-N and TP in the 12 selected projects were 31.23 mg/L, 9.27 mg/L and 0.97 mg/L, respectively, and the removal efficiencys were 81.81%, 58.13% and 69.69%, respectively. Compared with other research results (Lu et al., 2015; Lu et al., 2016), these data were not ideal. However, results of this study reflected the effect of practical engineering application, while other studies were on the bench-scale or pilot-scale. Result of the investigation taken in 2015 found that the average COD_{Cr}, NH₄⁺-N and TP effluent concentration of Zhejiang Province was 35.62 mg/L, 10.90 mg/L and 1.55 mg/L, respectively. Which means the main effluent indexes of the coupling system were better than that of in Zhejiang Province, and had relatively good treatment effect. Zhejiang rural domestic sewage treatment facilities were required to implemented the Rural Domestic Sewage Treatment Facilities Water Pollutant Discharge Standard (DB33/973-2015) since 2015, in which the effluent COD_{Cr} concentration specified in the first level is 60 mg/L, while the NH_4^+ -N concentration is 15 mg/L, and the TP concentration is 2 mg/L. The coupling system could mostly reach the requirement based on the data from previous practical engineering applications but the exceptions of 9# facility with the effluent COD_{Cr} concentration of 69.08 mg/L, 4#, 6#, 8# and 9# facility with effluent NH_4^+ -N concentration, and 4#, 6# facility with effluent TP concentration all exceeded the first level. It should be noted that for the 6# facility with continuous monitoring equipment introduced above, its NH4+- N and TP exceeding standards in this sampling test, which might be related to factors such as the operation phase of the system and the different monitoring time. Therefore, the effluent water quality and stability of practical engineering cases need to be further improved, and the technical process need to be optimized to achieve a stable effluent water quality.

3.3. Comparative study on the treatment of COD_{Cr} , NH_4^+ -N and TP in demonstration based on the optimized coupling system.

As mentioned above, a demonstration comparison system based on this coupling system was conducted (Fig. 2) in order to further improve the sewage treatment effect and operation stability of this technology. Figure 7 showed the long operation and removal of COD_{Cr} , NH_4^+ -N and TP by the two contrast coupling

systems. The system-b represents the enhanced system (b) while the system-a stands for the original system (a).

As can be seen from Fig. 7, the variation of COD_{Cr} of influent water was relatively large, which from 350 mg/L at the beginning to below 50 mg/L, then suddenly rose to about 400 mg/L on the 30th day; And gradually declined after the 45th day, lower than 100 mg/L. Compared with the original system (a), the enhanced system (b) had lower effluent COD_{Cr} concentration. Especially during the period when the influent COD_{Cr} concentration fluctuates sharply. For example, the effluent COD_{Cr} concentration of the enhanced system (b) was lower and more stable from the 20th to the 70th day, and the maximum difference of removal efficiency was more than 50%. Figure 7 also showed that the temperature increases with time, and the COD_{Cr} removal efficiencys of the two coupled contrast systems were increasing. On the whole, as shown in Table.3, the average COD_{Cr} concentration in the influent was 152.81 ± 130.33 mg/L, while the COD_{Cr} concentrations in the effluent of the original system (a) and the enhanced system (b) were 23.63 ± 13.89 mg/L and 20.22 ± 13.37 mg/L, respectively. Vymazal (Vymazal ., 2019) evaluated 17 HFCWs operated for more than 20 years and revealed that the removal efficiency of these systems amounted to 82.9% for COD, while in this study, the average removal efficiencys of COD_{Cr} in the original system (a) and the enhanced system (b) was 77.00% and 81.33%, respectively. The removal efficiency of COD_{Cr} in the enhanced system (b) was higher than that in the original system (a), which rose by 4.33%.

The fluctuation of influent NH₄⁺-N was also large during the study period. Figure 7 showed that the concentration range of influent NH_4^+ -N was 11.10-58.00 mg/L, and the effluent NH_4^+ -N concentration of the two coupled systems is relatively low and stable in the first 30 days. With the continuous increase of influent NH_4^+ -N concentration (up to 58.00 mg/L) from 30 to 45 days, the effluent NH_4^+ -N concentration of the two coupled systems showed an upward trend, and the effluent NH₄+-N concentration of the enhanced system (b) was significantly lower than that of the original system (a) (P < 0.05). On the 53rd day, the removal efficiency of NH_4^+ -N in the original system (a) reached the lowest 27.08%, while that in the enhanced system (b) was close to 80.00%, showing strong stability. In summary, the average $NH_{\Delta}^{+}-N$ concentration of the original system (a) and the enhanced system (b) was 5.93 ± 5.29 mg/L and 2.70 ± 2.49 mg/L, respectively. The average removal efficiency was 81.11% and 90.22%, respectively. That is to say, the removal efficiency of NH₄⁺-N by the enhanced system (b) was 9.11% higher than that of the original system (a). Yasinta (Yasinta et al., 2020) found the aerated saturated vertical up-flow constructed wetland achieves a high (more than 85%) removal of NH₄⁺-N, while the new coupling system had a much higher removal efficiency with nonexternal power assisted aeration process. Different substrates exhibit different adsorption characteristics. Khalifa (Khalifa et al., 2020) found in their research that some traditional used media could boost the pollutants removal capacity of polystyrene foam. Results showed that the removal of NH₄⁺-N increased from 66 to 78%, while a better removal effect was obtained in this study without adding polystyrene foam.

It could be seen from Fig. 7 that the removal effect of TP by the two coupled systems was also very different. Although the influent TP concentration varied considerably, most of the effluent concentrations of the enhanced system (b) were less than 1.00 mg/L. On the whole, the effluent TP concentration of the enhanced system (b) was significantly lower than that of the original system (a) (P < 0.05), which maintained a relatively stable TP removal efficiency. The average TP concentration of the original system (a) and the enhanced system (b) was 1.66 ± 0.73 mg/L and 1.09 ± 0.62 mg/L, respectively. The average removal efficiency was 61.67% and 75.44% respectively. That is to say, the removal efficiency of TP by the enhanced system (b) was 13.77% higher than that of the original system (a).

Table.3 shown the 6 months continuous monitor data of effluent water indexes derived from the officially authorized testing agency. The effluent monitor results of the two comparison systems showed that the effluent COD_{Cr} , NH_4^+ -N and TP of the demonstration project reached the first level of "Standards for Discharge of Water Pollutants from Rural Domestic Sewage Treatment Facilities" (DB33/973–2015). It could be found from Fig. 7 and Table.3 that the comparison system showed better removal efficiency compared with the other one, although the influent fluctuated unregularly. And the comparison system had great superiority on the removal of NH_4^+ -N and TP than that of the original system.

4. Conclusion

The performance of engineering case of randomly selected projects and a contrast optimization demonstration based on a novel biofilter-constructed wetland coupling system was investigated.

- 1) The effluent monitoring of a project (flux rate was 27.0 m3/d) by big data analysis showed a relatively stable and good water quality. The effluent concentrations of COD_{Cr} , NH_4^+ -N and TP was 37.57 ± 11.17 mg/L, 5.64 ± 1.69 mg/L and 0.82 ± 0.16 mg/L, respectively, which met the first class of "Standards for Discharge of Water Pollutants from Rural Domestic Sewage Treatment Facilities" (DB33/973–2015).
- 2) The concentrations of effluent TP showed a strong polynomial curve fitting with effluent NH_4^+ -N concentrations (R^2 = 0.9329) according to the large data analysis. The concentrations of effluent COD_{Cr} had a strong positive linear correlation with the concentrations of effluent NH_4^+ -N (R^2 = 0.9297), which increased with the increase of effluent TP concentrations (R^2 = 0.6957). The results may have very important guiding significance for the future monitoring methods of water effluent quality of treatment facility and the cost reduction of monitoring management, as well as early warning and feedback control.
- 3) The average removal efficiency for COD_{Cr} , NH_4^+ -N and TP by other 12 projects investigated was 77.52%, 58.93% and 61.01%, respectively; The removal of COD_{Cr} , NH_4^+ -N and TP of the enhanced system of the contrast demonstration was 81.33 %, 90.22 %, and 75.44 %, respectively, and which increased by 4.33 %, 9.11 % and 13.77 % respectively when compared with the original system.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Authors' contributions

Xiaomin Wang and Lingwei Kong had the idea for the article, Xiaomin Wang, Yunli Liu and Yi Zhang performed the literature search and data analysis, and Wenqing Shi, Yunli Liu, Yifan Yang, Lingwei Kong and Yi Zhang drafted and/or critically revised the work. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

All data generated or analysed during this study are included in this published article.

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Tables

Table.1 Information summary of randomly selected engineering case

Item	Project name	Operation From	Treatment Scale	HRT
		(year)	(m^3/d)	(d)
1#	Shifan	2015	33	3
2#	Yangkengkou-1	2014	16	3
3#	Yangkengkou-2	2014	25	3
4#	Xiajia	2014	36	3
5#	Yaojia	2014	36	3
6#	Xiayu	2014	27	3
7#	Zhongfanshangyou	2015	11	3
8#	Chenjia	2014	21	3
9#	Yangjiashan	2014	3	3
10#	Jincun	2011	50	3
11#	Nanyangcun	2014	100	3
12#	Wanlicun	2014	40	3

Table.2 The effluent values of the main parameters of the project

Item	Variety Range	Average Value
рН	6.45~6.57	6.51±0.04
COD _{Cr} (mg/L)	12.70~54.11	37.57±11.17
NH ₄ ⁺ -N (mg/L)	2.09~8.99	5.64±1.69
TP (mg/L)	0.63~1.10	0.82±0.16
C/N	5.65~11.34	6.67±0.64
Flow rate (m3/h)	1022.61~1166.58	1079.36±37.79

Table.3 The water quality of two contrast systems

Item	Inf.of water	Eff.of original-(a)	Eff.of enhanced-(b)
	mg/L	mg/L	mg/L
CODCr	152.81±130.33	23.63±13.89	20.22±13.37
NH4+-N	36.76±13.46	5.93±5.29	2.70±2.49
TP	4.63±1.37	1.66±0.73	1.09±0.62

Figures

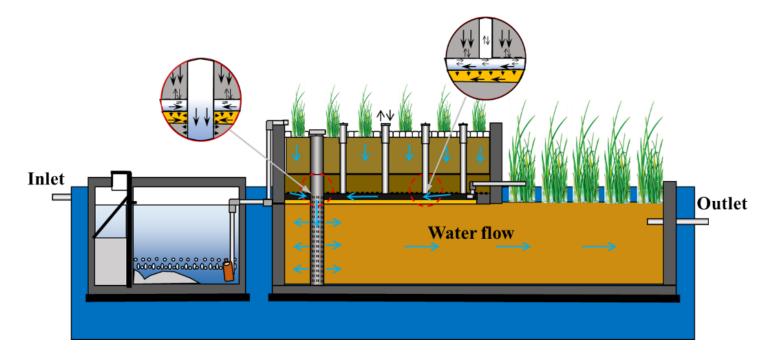


Figure 1

The schematic and water flow of the novel biofilter-constructed wetland coupling system

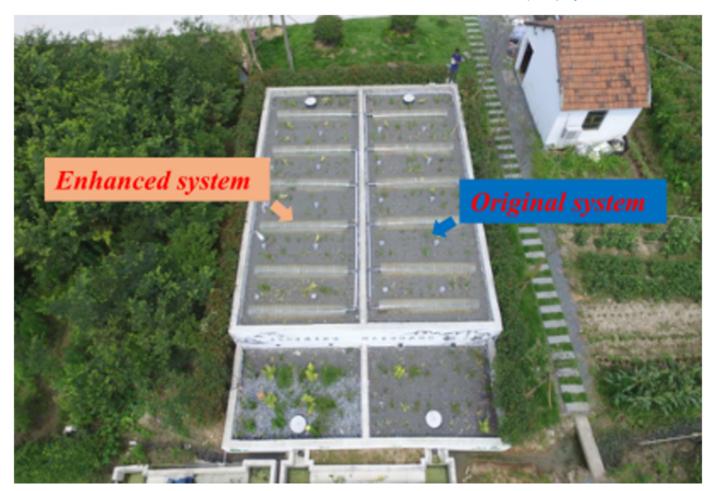


Figure 2

The comparative demonstration based on the coupling system

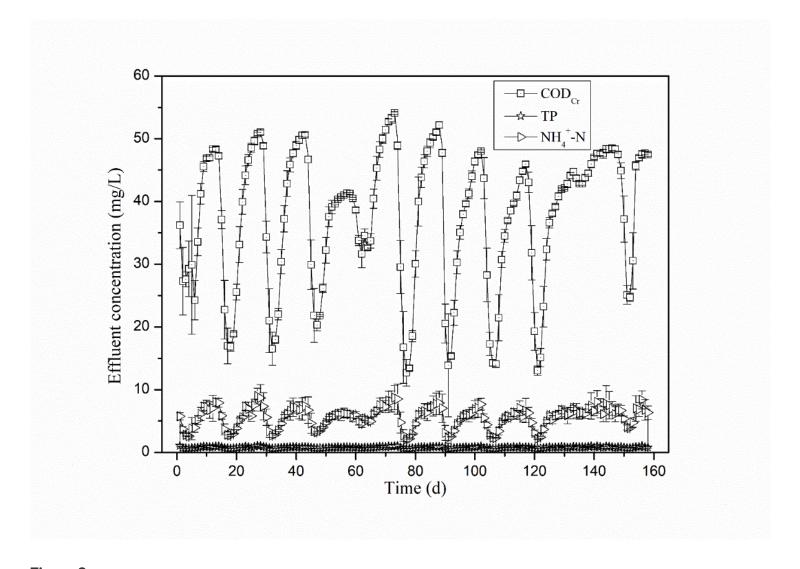


Figure 3

Variation of the effluent of former project based on the novel coupling system

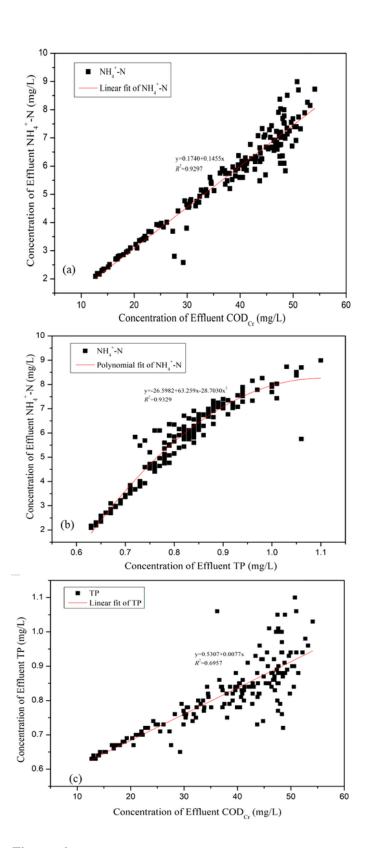


Figure 4

Correlations between the main effluent water quality indexes

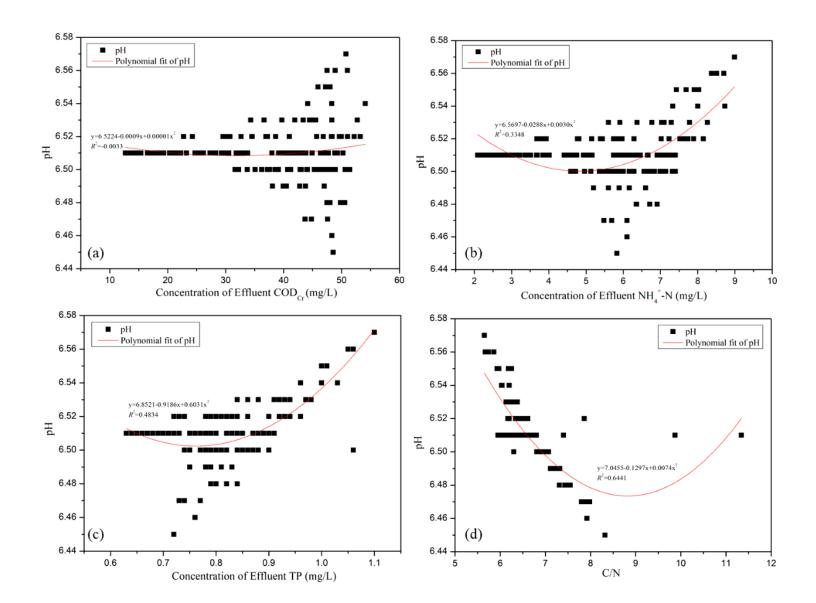
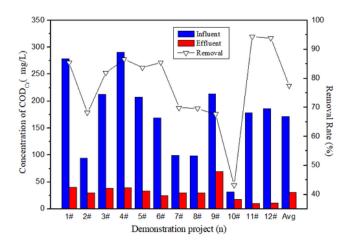
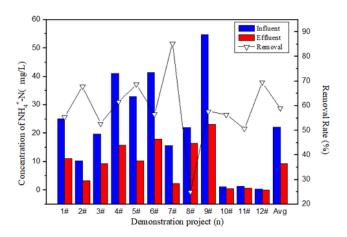


Figure 5

Correlations between pH and effluent CODCr, NH4+-N, TP, C/N





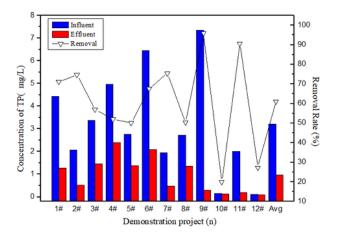


Figure 6

Treatment performance of the novel biofilter-constructed wetland system

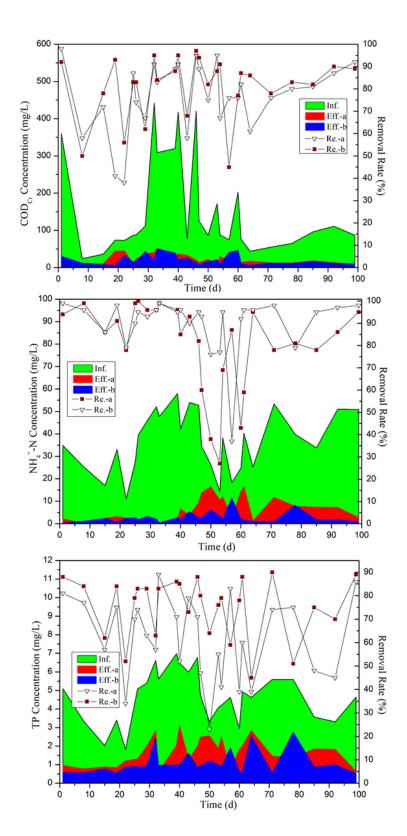


Figure 7

Removal of CODCr, NH4+-N and TP by the two contrast coupling systems (The system-b represents the enhanced system, while the system-a stands for the original system)