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# Design of modular constructed wetland and its effect on rural domestic sewage treatment

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**Abstract:** According to the characteristics of large amount and scattered discharge of domestic sewage in rural residential environment, a rural domestic sewage treatment system based on modular constructed wetland was designed. The wetland is composed of three modules with a treatment scale of 30 m<sup>3</sup>/d. The plants are *Arundo donax* and *Typha*, and three kinds of filter media are selected to fill the substrate. The treatment capacity and treatment effect of the modular constructed wetland were studied through experiments. The results showed that the modular constructed wetland had a good treatment effect on sewage, and the average removal rates of BOD<sub>5</sub>, COD, SS, NH<sub>3</sub>-N, TN and TP were 83.3%, 83.5%, 90.5%, 70%, 66.9% and 68.3%, respectively. The treated water quality can meet the first class standard of water pollutants discharge standard for rural domestic sewage treatment and disposal facilities (DB37/3693-2019) of Shandong Province. The modular constructed wetland can be used to treat rural scattered domestic sewage with strong applicability, flexibility and feasibility.

## 1. Introduction

Rural domestic sewage treatment is one of the key tasks for improving the rural living environment, building beautiful and livable villages, and realizing rural revitalization. Ecological treatment technology should be actively adopted to promote low-cost, low-energy consumption, easy maintenance, high efficiency, and suitable for rural areas. Sewage treatment technology [1]. In 2019, China has 550 million people living in rural areas. According to the per capita domestic water consumption of 83 L·d<sup>-1</sup> and the emission coefficient of 0.8, the total annual discharge of sewage is nearly 13.3 billion m<sup>3</sup> [2]. Rural domestic sewage has the characteristics of large total discharge and scattered discharge, and it is difficult for traditional sewage treatment models to be widely promoted in rural areas. The treatment of rural domestic sewage needs to adopt relevant construction modes and treatment techniques according to local conditions. Modular constructed wetland has the characteristics of flexible operation, treatment effect, simple maintenance and management, and ecological beauty. It treats scattered rural sewage in a targeted manner and has a good application prospect in rural water environment management. There have been a lot of studies on the treatment of rural domestic sewage in constructed wetlands at home and abroad. Wu Xiaoying [3] and others compared the treatment effects of modular fillers on rural domestic sewage and found that modular fillers can better remove ammonia nitrogen, total phosphorus and COD. Zhou Xiang [4] and others



used the grey correlation method to determine the suitable level of constructed wetland construction in each candidate area, and provided an effective method and approach for the suitability evaluation of constructed wetland construction. He Jing [5] and others investigated and analyzed the current situation of domestic sewage treatment in Ningxia rural areas, and found that constructed wetlands accounted for 50%, and put forward suggestions and countermeasures for practical problems. Yee Yong Tan[6] et al. conducted a pilot study on the treatment of manure by the subsurface flow constructed wetland system on the basis of Sarawak's existing constructed wetland domestic sewage treatment system, and verified the feasibility of the CW system as a long-term solution for wastewater management in Sarawak rural areas. Sex has important insights. Most domestic and foreign researches on the treatment effects of constructed wetlands have not focused on the characteristics of domestic sewage treatment in rural areas to establish a low-cost, high-efficiency, applicable and modular wetland system that can be promoted in rural areas.

This article takes the modular constructed wetland designed by the Shandong Institute of Water Resources Research in the Changqing District Irrigation Water-saving Technology Research Center as the research object. The wetland is composed of three modules, and the wetland plants and filter materials are specifically configured. The effluent quality is monitored and analyzed for one year to study the BOD<sub>5</sub>, COD, SS, NH<sub>3</sub>-N, TN, TP treatment capacity of the wetland system on rural domestic sewage, and the influence of seasonal changes on the treatment effect. It can be used in rural areas.

## 2. Materials and Methods

### 2.1. Process flow

The modular constructed wetland adopts a comprehensive water distribution and collection method, with a total area of about 160m<sup>2</sup>, a design hydraulic load of 0.6m<sup>3</sup>/(m<sup>2</sup>.d), and a design treatment flow rate of 30m<sup>3</sup>/d. According to the status quo of rural domestic sewage treatment, in order to reduce project costs and ensure removal capacity, the modular wetland structure includes a total of 6 parts, namely sewage tank, grid pool, regulating tank, vertical flow constructed wetland, first level horizontal subsurface flow constructed wetland, and second Grade horizontal subsurface flow constructed wetland. The process flow chart of the modular constructed wetland system is shown in Figure 1, and the design cross-sectional view is shown in Figure 2.

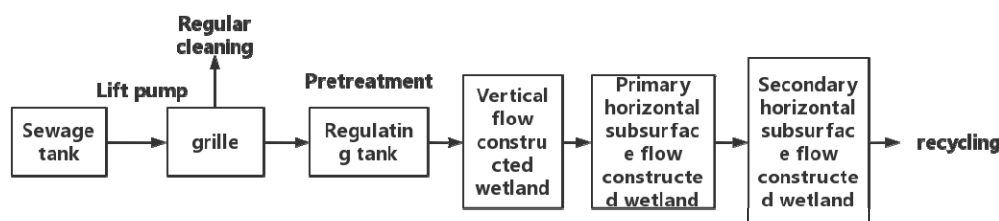
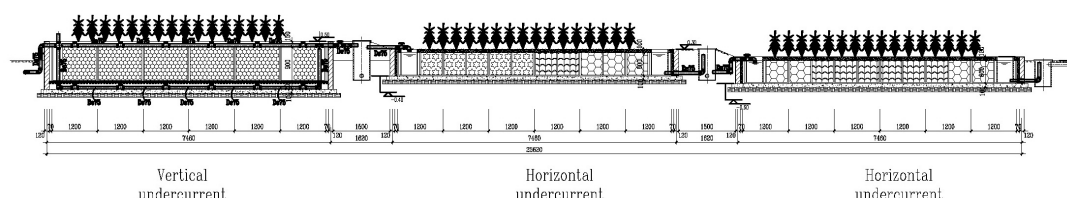


Fig. 1 Process flow chart of modular constructed wetland system



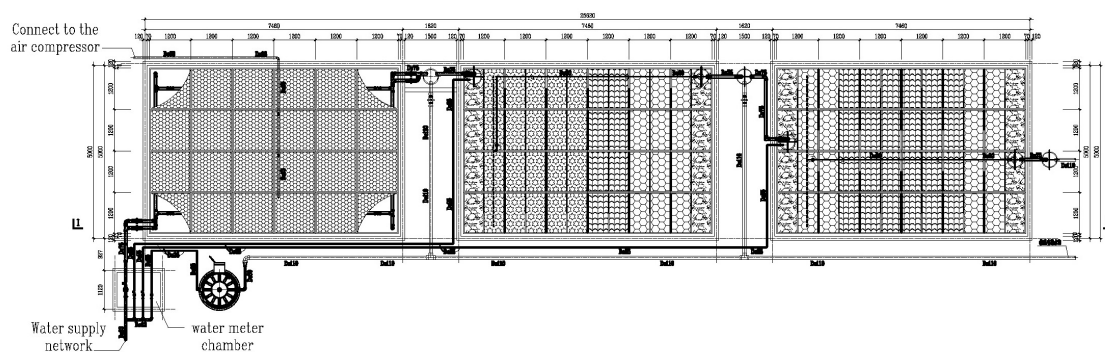


Fig. 2 Sectional view of modular constructed wetland system design

The sewage sources in the modular constructed wetland sewage pond include fish pond wastewater, collected rainwater, and domestic sewage. After testing, the sewage in the sewage tank was roughly maintained within a certain range before the constructed wetland was operated with water. The influent water quality index is shown in Table 1. Sewage is collected in the sewage tank and transported to the grid pool by lifting pumps and pipes. The grid gap is 5mm and the design parameter is  $2.0\text{m} \times 1.0\text{m} \times 1.0\text{m}$ . It mainly intercepts suspended solids in the sewage and prevents blockage of the wetland. Then it flows into the regulating tank, which is a steel concrete structure with a plane area of  $330\text{m}^2$ , a height of 2.5m, and an effective volume of  $660\text{m}^3$ . The influent can be pretreated in the regulating tank, and it has the functions of sedimentation, adjustment of the wetland water intake and water quality. Then it flows into the constructed wetland processing unit. 3 Artificial wetland structural units: vertical flow constructed wetland, covering an area of  $43.2\text{m}^3$  (length  $\times$  width  $\times$  height =  $7.2\text{m} \times 4.8\text{m} \times 1.25\text{m}$ ); first-level horizontal subsurface flow constructed wetland, covering an area of  $27.6\text{m}^3$  (length  $\times$  width  $\times$  height) =  $7.2\text{m} \times 4.8\text{m} \times 0.8\text{m}$ ; second-level horizontal subsurface flow constructed wetland, covering an area of  $27.6\text{m}^3$  (length $\times$ width $\times$ height= $7.2\text{m} \times 4.8\text{m} \times 0.8\text{m}$ ).

Table .1 Influent water quality of experimental sewage pool

index	BOD <sub>5</sub> mg/L	COD mg/L	SS mg/L	NH <sub>3</sub> -N mg/L	TN mg/L	TP mg/L
content	97.4~127.3	150.3~221.7	111.6~162.7	17.1~26.5	23.2~28.4	0.8~3.9

## 2.2. Selection and configuration of fillers

The matrix filler is equally divided into 4 layers, the first layer is the covering layer, filled with gravel with a particle size of 10-16mm, and the filling thickness is about 150mm. The main function of this layer is to compact the lower layer filter material, stabilize the surface of the constructed wetland, and reduce surface erosion; The second layer is the filter layer, which provides an environment for the growth of plant roots and microorganisms. It is the main area for pollutant treatment. The thickness is about 500mm. The design thickness of the vertical flow constructed wetland unit is about 800mm, and the filter particle size is 0.6~5mm. The third layer is a transition layer, filled with gravel with a particle size of 4-8mm, and a filling thickness of about 100mm, mainly to prevent the filter material with a smaller particle size from blocking the drainage layer and reduce the loss of filter material; Fill the drainage layer with gravel with a particle size of 10-16mm and a thickness of about 50mm to ensure the smooth discharge of the treated sewage.

The modular constructed wetland matrix uses 3 different types of constructed wetland fillers, namely type I filter material, type II filter material, and type III filter material. Type I filter material is a high-efficiency membrane-hanging lightweight filter material, with large porosity, uniform water and air distribution, low abrasion rate, adsorption of the filter material and adhesion of microorganisms at the same time, fast membrane formation, and microbial membranes are not easy to

backwash Falling off is conducive to the rapid hanging of microbes. Type II filter material is a porous ceramic filter material. This filter material has a larger specific surface area, and its irregular pores and gap changes make it have the function of deep filtration or container filtration. Type III filter material has a porous honeycomb shape with a large specific surface area and a porosity of 40%-80%. The surface is tortuous, which can change the flow path of sewage in the gap, so that the reaction time is more sufficient, and the adsorption and water absorption are good. High carbon content, rich in many kinds of oxides.

### 2.3. Selection and cultivation of plants

Wetland plants are selected. Due to the influence of the climate environment, there are fewer plant species to choose from in the construction of artificial wetlands in northern China. Common artificial wetland plants that can meet the construction requirements of northern artificial wetlands include reeds, calamus, cattails, scallions, and scallions Vegetables, water hyacinth, canna, etc. [7]. After screening and comparison, Arundina and Typha were selected as wetland plants, and the planting density was 20 plants/m<sup>2</sup>. Taking into account the plant characteristics and growth characteristics, the typha was planted in the outer circle of the wetland, and the central part was planted. Planting plants in wetlands in June 2019, after that, continue to monitor the growth of plants, and timely replant unsurvived plants to ensure the survival of wetland plants and the good operation of constructed wetlands. Plants in constructed wetland grow well after one month of planting. The average plant height of Arundinacea is 60 ~ 70cm, and the height of cattail is 30 ~ 40cm. The roots of the plant extend into the substrate, the surface of the substrate becomes black and the biofilm is attached, indicating that the wetland plants Already mature, the constructed wetland can be put into operation. Microbial filming adopts the method of inoculating activated sludge. The activated sludge is sourced from the local sewage treatment plant. After cultivation and training of the regulating pond, the film is spread with water.

## 3. Results and discussion

### 3.1. Monitoring results

In July 2019, the wetland plants matured and the constructed wetland functioned well, and the water quality of the inlet and outlet of the system was tested and analyzed. The water quality indicators determined by the test analysis are BOD<sub>5</sub>, COD, SS, NH<sub>3</sub>-N, TN, TP, and the pollutant measurement methods and emission limits are shown in Table 2 [8-10].

Table .2 Indexes and methods of detecting water quality

Detection Indicator	Class I Standard of Water Pollutant Discharge Standard for Rural Domestic Sewage Treatment and Disposal Facilities (DB37/3693-2019)	Emission standard for pollutants from urban sewage treatment plants (GB 18918-2002), class I b standard	Class I Standard of Integrated Waste water Discharge Standard GB 8978-1996	assay method
BOD <sub>5</sub>	-	20	20	Dilution and inoculation method
COD	60	60	60	potassium dichromate method
SS	20	20	20	gravimetric method
NH <sub>3</sub> -N	8 (15)	8(15)	15	Nessler's reagent spectrophotometry
TN	20	20	-	Oxidation of potassium persulfate
TP	1.5	1	-	Molybdenum-antimony spectrophotometry

Note: The value outside brackets of ammonia nitrogen index is the control index when the water temperature is > 12°C, and the value in brackets is the control index when the water temperature is ≤12°C.

### 3.2. Analysis and discussion

From July, 2019 to June, 2020, water quality testing was conducted for one year, sampling was conducted once a month, and 12 groups of testing data were measured. Average removal rates of BOD<sub>5</sub>, COD, SS, NH<sub>3</sub>-N, TN and TP by modular constructed wetland are 83.3%, 83.5%, 90.5%, 70%, 66.9% and 68.3%, respectively, and average effluent concentrations are 19.1mg/L, 29.8mg/L and 12.8 mg/L. The effluent quality meets the first-class standard of Discharge Standard of Water Pollutants for Rural Domestic Sewage Treatment and Disposal Facilities (DB37/3693-2019), and the treatment effect is shown in Figure 3-8.

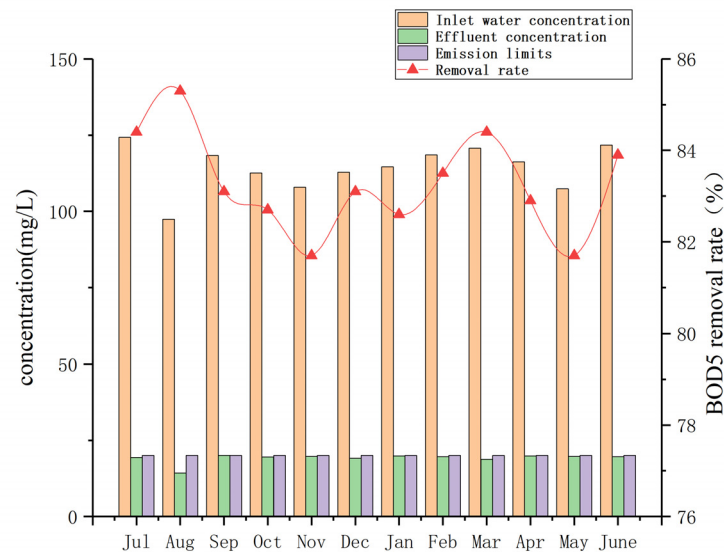


Fig.3 Treatment effect of modular wetland BOD<sub>5</sub>

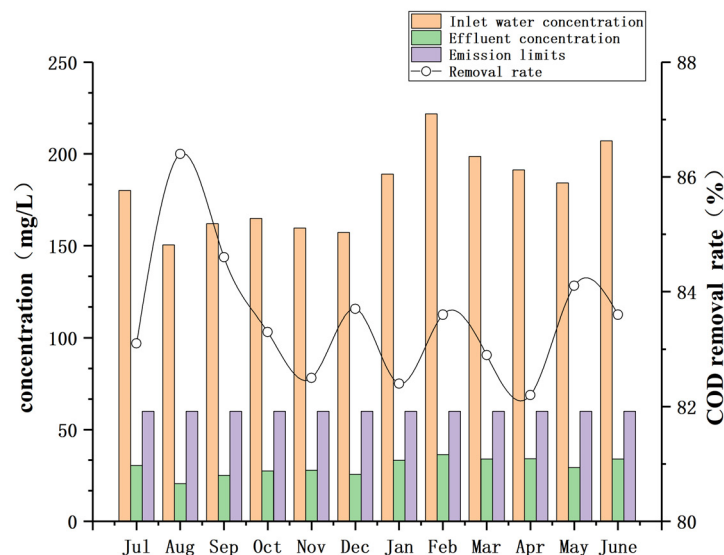


Fig. 4 COD treatment effect of modular wetland

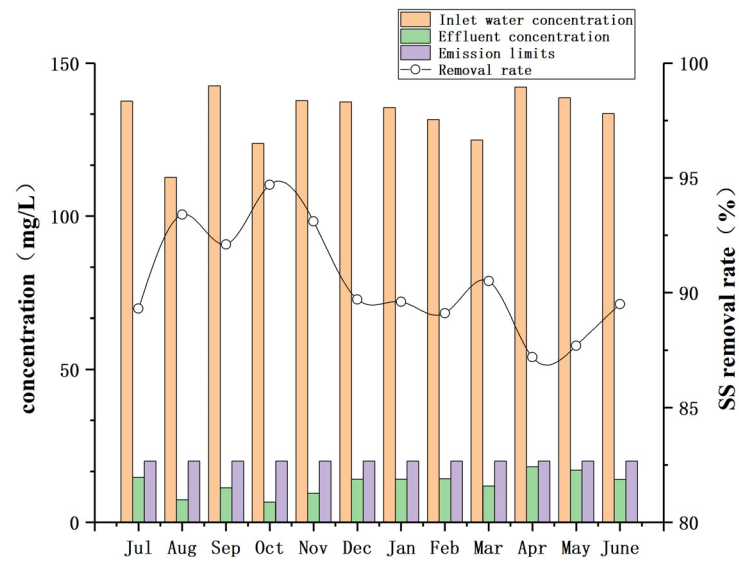
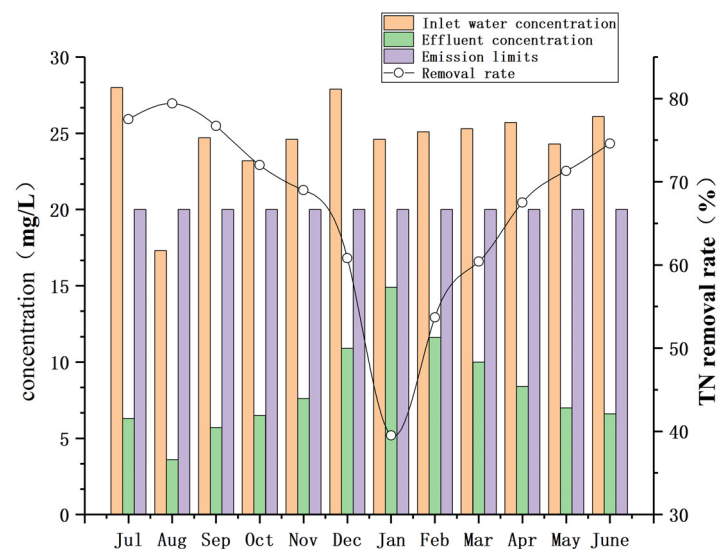


Fig. 5 Treatment effect of SS in modular wetland

Fig. 6  $\text{NH}_3\text{-N}$  treatment effect of modular wetland

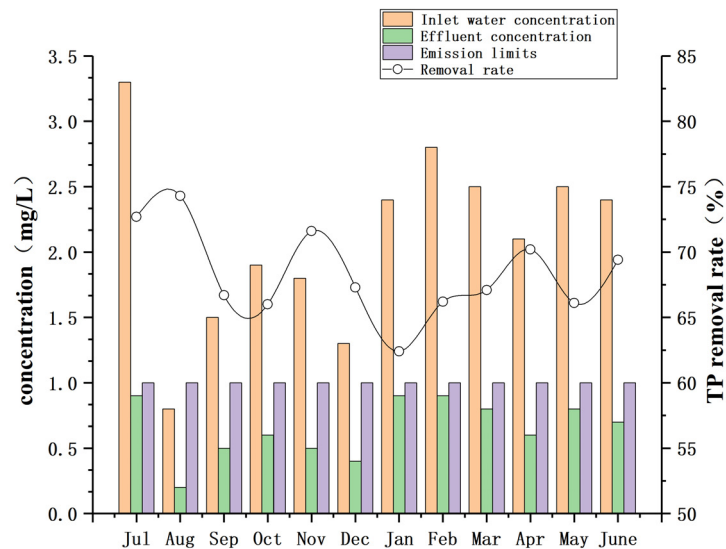


Fig. 7 TN treatment effect of modular wetland

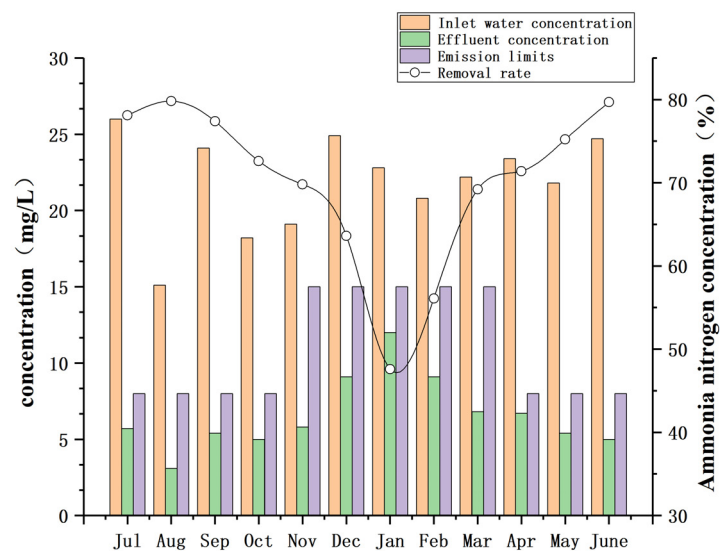


Fig.8 TP treatment effect of modular wetland

#### 4. Recycling

According to the test results, the effluent quality of the sewage treated by the wetland system meets the first level standard of the "Rural Domestic Sewage Treatment and Disposal Facilities Water Pollutant Discharge Standard" (DB37/3693-2019). The effluent quality is good and the treated sewage can be directly discharged in the rural water environment or recycling, it not only reduces the pollution of the rural water environment, but also protects the rural water resources and realizes the rational use of water resources.

For the treatment of the effluent of the modular constructed wetland, it is mainly used as irrigation water and flushing water. The quality of the treated sewage conforms to the "Water Quality of Urban Sewage Recycling Farmland Irrigation Water" GB 20922-2007 [11], and can be used for farmland irrigation. In addition, this research designed a circulating toilet flushing system by connecting the effluent from the wetland to the toilet. The toilet sewage passes through the septic tank pretreatment facility, using the principle of anaerobic fermentation and static separation. Under the action of gravity,



the large particulate matter in the sewage settles or floats, and at the same time, the organic matter is partially degraded and pretreated by anaerobic fermentation. The effluent enters the modular constructed wetland treatment unit. After the wetland treatment, the effluent reaches the domestic miscellaneous water standard, and can be recycled for toilet flushing, achieving reclaimed water reuse and water saving effect. The process flow chart of reclaimed toilet water reuse is shown in Figure 9.

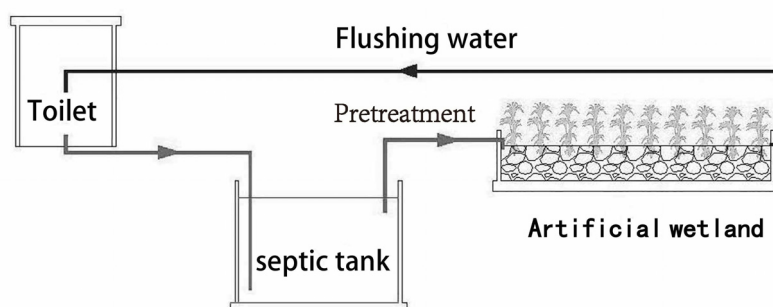


Fig.9 Process flow chart of toilet water reuse

## 5. Conclusion

1) Monitoring data shows that the average removal rate of BOD<sub>5</sub>, COD, SS, NH<sub>3</sub>-N, TN, and TP is 83.3%, 83.5%, 90.5%, 70%, 66.9%, and 68.3% of the modular constructed wetland. With high removal capacity, the effluent quality meets the first-level standard of "Water Pollutant Discharge Standard for Rural Domestic Sewage Treatment and Disposal Facilities" (DB37/3693-2019).

2) For northern rural areas, temperature is the main factor affecting the treatment of rural domestic sewage in the constructed wetland. Experimental data shows that the annual water effluent indicators of the modular constructed wetland are all qualified, and the seasonal and temperature changes affect NH<sub>3</sub>-N, TN removal has a great impact. The NH<sub>3</sub>-N removal rate is 36.2%, and the TN removal rate is 41.8%. In winter, it is especially important to take good measures to keep the wetland in heat.

4) The modular constructed wetland can be used for rural domestic sewage treatment in North China. The scale of the wetland needs to be changed according to the actual sewage flow. It has strong applicability and feasibility. The treated sewage can be used as irrigation water for farmland and flushing water, or directly discharged into the rural water environment. In addition, the modular constructed wetland can add different treatment modules, such as A<sub>2</sub>O, MBR and other treatment units to meet higher water quality requirements.

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