Simulation of water quality data for advanced treatment of domestic sewage in constructed wetlands

Yuelei Wang, Yancheng Han*, Xinyue Zhou, Panbo Fang and Sihan Chen

Department of hydraulic engineering, School of Water Conservancy and Environment, Univ. of Jinan, Jinan 250022, China

*Corresponding author’s e-mail: stu_hanyc@ujn.edu.cn

Abstract. With the gradual maturity of sewage treatment technology, constructed wetlands are increasingly employed to treat sewage. In residential areas where people live, there are concentrated sewage discharges. Therefore, the author proposes constructing several small movable constructed wetlands in the community to treat domestic sewage in the community. A 40 cm×40 cm model was established to simulate the removal effect of pollutants. The influent concentrations of simulated COD, NH4+-N, NO3-, TP are 96.01 mg/L, 18.23 mg/L, 14.13 mg/L, 3.00 mg/L, respectively, and the outlet concentrations are 18.25 mg/L, 5.51 mg/L, 3.12 mg/L, 0.32 mg/L, the removal efficiency reached 80.99 %, 69.78 %, 77.92 %, 89.33 %, with good simulation effect. It provides a theoretical basis for the construction of constructed wetland.

1. Introduction

1.1 Research background
With the development of society, people pay more and more attention to the recycling and reuse of water resources. As a new type of sewage treatment method, constructed wetland has been investigated by domestic and foreign scholars. Dai Yangye studied the deep purification of sewage from a certain urban sewage treatment plant to make it meet the municipal discharge standard [1]. Wu Lei et al. used multi-level tidal flow constructed wetlands to study typical pollutants in sewage treated by municipal sewage plants, and provided a theoretical basis for the development of tidal flow constructed wetlands [2]. Compared with other sewage treatment technologies, constructed wetlands have the characteristics of low investment, easy construction, low energy consumption, and good sewage treatment effects, which are widely used in urban sewage treatment [3]. The construction of small-scale artificial wetlands in residential areas enables the reuse of treated domestic sewage and can be utilized to community greening construction, thus saving water to a large extent. The construction of small constructed wetland in the residential area is convenient to move. It can be utilized as the greening landscape in the residential area, and it is also convenient for the cleaning and maintenance of the constructed wetland in the later period of use. The author established a small-scale constructed wetland model through the Hydrus, and simulated the effect of its treatment of pollutants in sewage. The results obtained can provide references for the actual establishment of constructed wetlands.

1.2 The water quality situation
The author collected wastewater from a single-family unit building in a community in Shandong, and measured the quality of the influent water in the constructed wetland:
Table 1. Influent water quality during the test

| Project | COD/mg·L⁻¹ | NH₄⁺-N/mg·L⁻¹ | NO₃⁻/mg·L⁻¹ | TP/mg·L⁻¹ |
|---------|------------|----------------|-------------|-----------|
| Range   | 90.71~101.31 | 15.64~20.82    | 11.81~16.45 | 2.78~3.22 |
| Mean value | 96.01      | 18.23          | 14.13       | 3.0       |

2. Wetland construction and simulation
The length × width × height of the small constructed wetland was planned to be 40 cm × 40 cm × 50 cm, and the plants were planted as calamus. The substrate was distributed in the upper 30 cm sandy loam and the lower 20 cm sandy gravel. Several small constructed wetlands were established to conduct meaningful treatment and purification of sewage in the community. Now we will simulate the sewage treatment efficiency of a single constructed wetland through software, so as to provide a theoretical basis for the actual establishment of constructed wetland. Using the Hydrus flow and solute transport module to simulate the pollutant transport process after sewage flowing into the constructed wetland. The size of the model is 40 cm × 40 cm. The time unit of the model is set as day (d) and the duration is 45 d.

2.1. Model selection
The water flow models of constructed wetlands in Hydrus include van Genuchten-Mualem model, Brooks and Corey equation, Kosugi’s logarithmic distribution model and other models. The commonly used VG model is selected without considering the hysteresis of water flow.[4]

2.2. Parameter setting
In the water flow migration module, set the iteration parameters and soil hydrodynamic parameters, as shown in table 2:

| Soil        | Residual moisture content θᵣ/% | Saturated moisture content θₛ/% | α   | n   | Kₛ   |
|-------------|--------------------------------|---------------------------------|-----|-----|------|
| Sandy loam  | 0.065                          | 0.41                            | 0.075 | 1.89 | 106.1 |
| Sand        | 0.045                          | 0.43                            | 0.145 | 2.68 | 712.8 |

In the Hydrus solute transport module, solute transport parameters were set and constructed wetland reaction parameters were set. Default reaction parameters were used in this simulation.

2.3. Segmentation of constructed wetland
The author divided the constructed wetland model established, and obtained 121 observation points, numbered from left to right, top to bottom, and established points 49, 85 and 109 as observation points N1 (5,5), N2 (8,8) and N3 (10,10).

2.4. Boundary condition setting
The upper boundary condition of the wetland was set as the atmospheric boundary, and the inlet and outlet were set. The water inlet is set as a constant flow boundary, and the water outlet is set as a free drainage boundary. The other boundaries are zero flux boundaries.

3 Results and analysis
3.1 Simulation and analysis of the removal effect of COD in sewage
Generally, soluble organic matter can be removed through matrix adsorption, plant absorption and microbial degradation and metabolism, while insoluble organic matter can be removed through matrix filtration and sedimentation and plant root interception.
The author has set up three observation points for the constructed wetland, from top to succeeding as N1, N2, N3. It can be observed in Figure 1 that in 0-20 days, sewage enters the constructed wetland and gradually fills up the constructed wetland. When the constructed wetland was running for about 28 days, the COD concentration measured at each observation point reached a stable level, and the effect of the constructed wetland on the removal of COD in sewage reached a relatively stable level. As the observation point N3 is very close to the constructed wetland outlet, considering the error problem in the actual project. The removal efficiency of the position N3 is approximately equal to the actual constructed wetland removal efficiency. The inlet concentration of COD in the sewage is 96.01 mg/L, and the outlet concentration is 18.25 mg/L. The removal efficiency of COD in the constructed wetland reaches 80.99%, with effective removal effect. The removal effect of each observation point is given in table 3:

Table 3. Removal efficiency of COD at each observation point of constructed wetland

|     | N1          | N2           | N3          |
|-----|-------------|--------------|-------------|
| water concentration/mg/L | Effluent concentration/mg/L | Efficiency/% | Effluent concentration/mg/L | Efficiency/% | Effluent concentration/mg/L | Efficiency/% |
| 96.01 | 96.01       | 0.00         | 44.85       | 53.29       | 18.25         | 80.99         |

3.2 Simulation and analysis of removal effect of NH₄⁺-N in sewage

Generally, the nitrogen sources in urban sewage mainly include NH₄⁺-N, NO₃⁻, NO₂⁻, NO₂, and N₂, etc. The removal of nitrogen pollutants in wetlands mainly involves substrate adsorption, precipitation, plant absorption, and nitrification and denitrification by microorganisms. The removal process includes physical reaction, chemical reaction and biological reaction. The removal of pollutants in constructed wetlands is a complex process influenced by multiple factors. As can be seen from Figure 3, the effluent concentration of NH₄⁺-N at each observation point of constructed wetland gradually weakens, but has a definite fluctuation. In about 23 days, the effluent concentration at each observation point reached a relatively stable level.

When the influent concentration of NH₄⁺-N in the constructed wetland was 18.23 mg/L, the effluent concentration of N3 observation point was about 5.51 mg/L, and the removal rate reached 69.78%, showing a respectable removal effect. The removal effect of each observation point is given in table 4:
Figure 3. Effluent concentration of NH$_4^+$-N at each observation point of constructed wetland

Figure 4. Effluent concentration of NH$_4^+$-N at N3 in constructed wetland

Table 4. Removal efficiency of NH$_4^+$-N at each observation point of constructed wetland

| Observation Point | N1 | N2 | N3 |
|------------------|----|----|----|
| Water Concentration (mg/L) | 18.23 | 14.58 | 5.51 |
| Effluent Concentration (mg/L) | 17.93 | 20.02 | 69.78 |
| Efficiency (%) | 1.65 | 5.51 | 69.78 |

3.3 Simulation and analysis of removal effect of NO$_3^-$ in sewage

The removal of NO$_3^-$ in sewage is mainly performed by nitrification and denitrification in the constructed wetland. In the aerobic environment, the aerobic bacteria produce action; in the anaerobic environment, the anaerobic bacteria conduct biochemical reaction, and the removal of NO$_3^-$ is realized under the joint action of aerobic bacteria and anaerobic bacteria. When the concentration of dissolved oxygen in the wetland is greater than 0.2 mg/L, the biological activity of anaerobic bacteria is inhibited, and denitrification is impacted.

The inlet concentration of the simulated NO$_3^-$ was 14.13 mg/L, and the outlet concentration of the observation point N3 was 3.12 mg/L, with a removal efficiency of 77.92% and a respectable removal effect. As the reactions of NH$_4^+$-N and NO$_3^-$ are affected by both aerobic and anaerobic bacteria, the simulation results have slight fluctuations. The removal effect of each observation point is given in table 5:

Figure 5. Effluent concentration of NO$_3^-$ at each observation point of constructed wetland

Figure 6. Effluent concentration of NO$_3^-$ at N3 in constructed wetland.
Table 5. Removal efficiency of NO$_3^-$ at each observation point of constructed wetland

|       | N1             | N2             | N3             |
|-------|----------------|----------------|----------------|
| water |                |                |                |
| mg/L  |                |                |                |
| 14.13 | 13.87          | 8.54           | 3.12           |
| Effluent concentration/mg/L | 1.84 | 39.56 | 77.92 |
| Efficiency/% | 3.4 Simulation and analysis of TP removal effect in sewage

The removal of phosphorus in constructed wetlands is mainly through physical removal and chemical precipitation. The physical removal process of phosphorus is mainly the process of solid phosphorus being intercepted by the substrate and then precipitated to achieve the removal of phosphorus. Chemical removal occurs mainly in soil and substrate, which are the main part of phosphorus removal in constructed wetlands. Through the chemical reaction of phosphorus with metal ions in the matrix, insoluble phosphate is set up to achieve the effect of phosphorus removal [5].

Through the simulation, it can be seen that the constructed wetland have a relatively good effect on the removal of phosphorus. At the inlet concentration of 3.00 mg/L and the outlet concentration of 0.32 mg/L, the phosphorus removal rate reaches 89.33 %, which meets the national standard and the effluent concentration of phosphorus is less than 1 mg/L. The removal effect of each observation point is shown in Table 6:

Table 6. Removal efficiency of TP at each observation point of constructed wetland

|       | N1             | N2             | N3             |
|-------|----------------|----------------|----------------|
| water |                |                |                |
| mg/L  |                |                |                |
| 3.00  | 3.04           | 0.81           | 0.32           |
| Effluent concentration/mg/L | 0.00 | 73.00 | 89.33 |
| Efficiency/% | 0.65 | 0.75 | 0.85 |

Figure 7. Effluent concentration of TP at each observation point of constructed wetland.

Figure 8. Effluent concentration of TP at N3 in constructed wetland.

4 Conclusion

(1) Through the establishment of the Hydrus constructed wetland model, the numerical simulation method was used to simulate the removal effect of COD, NH$_4^+$-N, NO$_3^-$ and TP in sewage in the establishment of a small constructed wetland in residential areas. When the inlet concentration of COD, NH$_4^+$-N, NO$_3^-$ and TP is 96.01 mg/L, 18.23 mg/L, 14.13 mg/L and 3.00 mg/L, the outlet concentrations are 18.25 mg/L, 5.51 mg/L, 3.12 mg/L and 0.32 mg/L, respectively, the removal efficiency reaches
80.99 %, 69.78 %, 77.92 % and 89.33 %, showing a good simulation effect. So this idea has certain maneuverability.

(2) Before the establishment of constructed wetland, the experimental results can be predicted through numerical simulation, which, to a certain extent, can reduce the failure of the experiment and provide a reference for the experiment, which has certain practical significance.

References

[1] Dai, Y.Y., (2018) Operation effect analysis of advanced treatment by constructed wetland for secondary effluent in a municipal wastewater treatment plant. J. Water Purification Technology., 37: 96-100.

[2] Wu, L., Yang, Y.Z., Ding, D.J., Zhao, L., Cheng, G., (2017) Characteristics of typical pollutants removal from reject water of municipal wastewater treatment plant using a multi-stage tidal flow constructed wetland. J. Technology of Water Treatment., 43: 99-104.

[3] Ma, S.H., Liu, C.L., (2007) The application of constructed wetland in urban sewage treatment project. J. Coastal Enterprises and Science & Technology., 08: 33-35.

[4] Zhang, W., Zhao, X.N., Gao, X.D., Wu, P.T., Pan, D.L., Song, X.L., Yang, S.W., Yao, J., (2019) Numerical simulation of soil water infiltration under rainwater collection and infiltration systems based on HYDRUS-2D. J. Agricultural Research in the Arid Areas., 37: 78-85.

[5] Li, L.H., Li, H., Zhang, P.W., Wang, Q.W., (2019) Phosphorus removal and recovery technology for rural domestic wastewater. J. China Rural Water and Hydropower., 12: 99-104.