Influence of reclaimed water on water quality of urban rivers receiving WWTP effluent in Beijing

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Abstract: As a new type of water source, reclaimed water is used to replenish the landscape water bodies of urban river courses, which can alleviate the problem of insufficient water in river courses. However, due to the large amount of reclaimed water input, the water quality of the downstream river is obviously different from that of the upstream river. In this study, with the recharge of reclaimed water, the water conductivity increased gradually from upstream to downstream of the Wenyu River river, while the pH decreased gradually. In terms of nutrient concentration, TN, NO3-N and NO2-N of river water showed an obvious upward trend from upstream to downstream.

1. Introduction

Due to the serious shortage of water resources and the aggravation of water pollution in northern China, reclaimed water replenishment can alleviate the water shortage in northern rivers to a certain extent and improve the utilization efficiency of water resources, so reclaimed water replenishment has become one of the powerful measures to alleviate the ecological crisis of rivers[1, 2]. However, many studies have shown that recycled water is rich in nitrogen and toxic pollutants[3], which are the key variation factors affecting the water quality of replenished rivers. Ao et al. [4] studied the sediment of a landscape lake replenished with reclaimed water, and the results showed that reclaimed water replenishment significantly increased the risk of eutrophication, and the total nitrogen content of the lake was significantly higher than that of natural water.

In this study, typical reclaimed water replenishing rivers in northern China were selected to analyze the changing trend of nitrogen pollution in reclaimed water replenishing rivers, so as to provide theoretical basis for reclaimed water resource utilization and ecological risk control.

2. General situation of the research region and sampling

Wenyu River originates in Beijing. It is the upper reach of Beijing section of the Beijing-Hangzhou Grand Canal, located in the core area of Beijing, spanning the western ecological zone and the eastern development zone. It is strategically important and known as the "Mother River" of Beijing[5]. Surface water samples were collected from sewage treatment plants of the main stream of Wenyu River and its four tributaries in August 2020, and the information of sampling points was shown in Figure 1. A total of 11 surface water samples (6 surface water samples from the main stream of Wenyu River and 5 outlet of the reclaimed water plant) were collected. Surface water samples are collected with stainless steel water sampler. The water sampler is cleaned with ultrapure water for 3 times before sampling, and the water sample in the sampling area is moistened and washed for 3 times during sampling. Samples used for the physicochemical tests of water quality were placed in brown glass
bottles soaked in acid and cleaned[6].

Figure 1. Study area (sampling sites shown as points) within Wenyu River and the WWTPs connected to the river.

3. Chemical analysis
The conventional physical and chemical indexes of water samples, such as water temperature (T), pH, REDOX potential (ORP), electrical conductivity, etc., were directly measured by using a multi-parameter water quality tester at the sampling site. Chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN) and other indexes were measured according to "Methods for Monitoring and Analysis of Water and Wastewater, Fourth Edition". Chlorophyll a was determined by spectrophotometry (HJ 897-2017). As the direct participants of the nitrogen cycle, ammonia nitrogen, nitrate nitrogen and nitrite nitrogen directly affected the community characteristics and function of functional microorganisms in the nitrogen cycle. The determination was carried out by Najor reagent spectrophotometry (HJ 535-2009), ultraviolet spectrophotometry (HJ/T 346-2007) and spectrophotometry (GB/T 7493-1987), respectively.

4. Results and discussion
According to the PCOA analysis of the physical and chemical properties of the water bodies at the sampling points of Wenyu River and the sewage treatment plant (Figure 3), the water quality of the river sampling points and the recycled water was significantly different. However, due to the large amount of recycled water input, the water quality of the downstream sampling points (A4 and A6) was significantly different from that of the upstream sampling points (Figure 2). The average temperature (28.7°C) was higher than that of reclaimed water (27.2°C). Electrical conductivity (EC) represents the ability of an aqueous solution to conduct current, which is used to monitor the change of dissolved mineral concentration in water. Due to the high ion concentration of reclaimed water [7], the electrical conductivity of reclaimed water in this study area (822.80 μs/cm) was significantly higher than that of river water (598.33 μs/cm). With the input of reclaimed water, the electrical conductivity of the upper
reaches to the lower reaches of Wenyu River gradually increases. The pH range of the water sample is 8.39-9.25, which is weakly alkaline and has good buffering effect [8]. The pH range of the effluent from the reclaimed water plant on each tributary is 7.34-7.88. The pH of Wenyu River water has a downward trend from upstream to downstream, but it is higher than that of the reclaimed water effluent.

The average concentration of chlorophyll (Chla) in Wenyu River was 19.64 μg/L, and the highest concentration was 36.90 μg/L, while the effluent concentration of reclaimed water plants was all lower than 1 μg/L. Dissolved oxygen (DO) concentration also showed a similar trend, and the DO concentration in river water was higher than that in the effluent of reclaimed water plant. The TSS concentration of the effluent from the reclaimed water plant was lower (1-2 mg/L), and the TSS concentration of other rivers (5-34 mg/L) was higher than that of the effluent from the reclaimed water plant except that the TSS concentration at sampling points A1 and A3 was higher due to the interference of human activities. Total organic carbon (TOC) and total dissolved organic carbon (DOC) concentrations did not change significantly in the range of 2.9-4.1 mg/L and 2.1-3.4 mg/L, respectively.

The total nitrogen (TN) concentration ranged from 2.24 mg/L to 6.20 mg/L from the upper reaches to the lower reaches of Wenyu River, and the effluent concentration of the reclaimed water plant was higher than that of the river as a whole, mainly because the reclaimed water containing nitrogen entered the main channel through tributaries, leading to the increase of the total nitrogen concentration in water samples. The trend of nitrate nitrogen (NO\textsubscript{3}-N) concentration was similar to that of TN. The concentration of ammonia nitrogen (NH\textsubscript{3}-N) and nitrite nitrogen (NO\textsubscript{2}-N) in river water is higher than that in reclaimed water. On the whole, the river NO\textsubscript{3}-N value (2.67 mg/L on average) was higher than the NH\textsubscript{3}-N value (0.88 mg/L on average), and the TN, NO\textsubscript{3}-N and NO\textsubscript{2}-N of the river showed an obvious upward trend from upstream to downstream. The total phosphorus (TP) concentration in the river ranged from 0.20 mg/L to 0.61 mg/L, which was higher than the effluent concentration of reclaimed water. Pearson correlation showed (Figure. 4) that there was a high positive correlation between TN and NO\textsubscript{3}-N (R=0.917, P<0.01), had a high positive correlation with NO\textsubscript{2}-N (R=0.812, P<0.05). There was also a high correlation between suspended particulate matter and total phosphorus (R=0.830, P<0.05), and was correlated with dissolved organic carbon (DOC) (R=0.833, P<0.05). In addition, the concentration of dissolved oxygen (DO) was also positively correlated with TOC and DOC.
Figure. 2 Physical and chemical properties of water bodies at the sampling points of Wenyu River and sewage treatment plant. The small figure on the left shows the average concentration of physical and chemical indexes in the sampling points of Wenyu River and the sewage treatment plant. The red represents the sampling points of Wenyu River and the green represents the sampling points of reclaimed water in the sewage treatment plant.
Figure. 3 PCOA analysis of physical and chemical properties of water bodies in Wenyu River and sewage treatment plant sampling points

Figure. 4 Pearson correlation among environmental parameters of river water samples. The size of the circle indicates the degree of correlation, and the color gradient bars indicate positive and negative correlations (blue is positive and red is negative).

5. Conclusion
Due to the large amount of recycled water input, the water quality of the downstream sampling points was significantly different from that of the upstream sampling points not affected by sewage treatment.
plants. The river in the study area was weakly alkaline, and the average temperature (28.7°C) was higher than that of the recycled water (27.2°C). The electrical conductivity of reclaimed water (822.80 μS/cm) in this study area is significantly higher than that of river water (598.33 μS/cm), but with the input of reclaimed water, the electrical conductivity of the upper reaches of Wenyu River to the lower reaches has a gradually increasing trend. The pH of the effluent from the upstream to the downstream has a downward trend, but it is higher than that of the effluent from the reclaimed water plant. The average concentration of chlorophyll (Chla) was 19.64 μg/L, and the highest concentration was 36.90 μg/L, while the effluent concentration of reclaimed water plants was less than 1 μg/L. The total nitrogen (TN) concentration ranged from 2.24 mg/L to 6.20 mg/L, and increased gradually from the upper to the lower reaches of Wenyu River. The value of NO3-N was higher than that of NH3-N, and the TN, NO3-N and NO2-N showed an obvious upward trend from the upper to the lower reaches of Wenyu River.

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