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Water Quality Evaluation of Wenyu River Based on Single Factor Evaluation and Comprehensive Pollution Index Method

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ABSTRACT

Wenyu River is the “mother river” in Beijing. In recent years, the research on the water quality of the Wenyu River has increased gradually. In this paper, the monitoring data at Shahe Reservoir, Lu Tuan Gate, Xin Bao Gate, and Ma Fang sections for each month in 2019 were adopted. The single-factor evaluation method and the comprehensive pollution index method were selected to analyze the current situation of the water quality of Wenyu River in the Chang Ping section and its temporal and spatial variation trend. The single factor evaluation method showed that the dissolved oxygen exceeded the standard seriously in all other months of the year except that the situation was better in May, June, and July. The ammonia nitrogen content reached the highest level in January, followed by a month-by-month decreasing trend. After June, each section basically met the requirements of Class v water quality. The comprehensive pollution index method shows that the water quality of Shahe reservoir varies greatly throughout the year, and it is in grade v for 6 months. The evaluation results of both methods show that the water quality of all sections of Wenyu River in 2019 was mostly in category v.

INTRODUCTION

Wenyu Originating in the southern foothills of the Yan Mountains River, the Wenyu River is the only one of the five major river systems in the city that originates in Beijing and has water all year round. Shahe Reservoir is called Wenyu River. In the lower reaches of Shahe Reservoir, there are mainly Lin Gou River, Qing He River, Dam River, small and medium-sized river confluence through Chaoyang and, Shun Yi District from North Tong Zhou District Gate into North Canal. Wenyu River has more water than the rest of Beijing. In recent years, with the rapid development of Chang Ping District’s economy and the acceleration of urban industrialization, the Wenyu River has gradually become a river with industrial and domestic sewage as its main supply of water. From 2005 to 2006, the sewage treatment rate of Wenyu River was less than 61%. In the survey in 2013, it was found that there were still many direct discharge of sewage. Yang et al. (2015) team found that the non-point source pollution in Changping section of Wenyu River mainly comes from commercial land and transportation land, as well as fertilization of farmland, Yu et al. (2012) systematically analyzed the evolution process of water environmental quality of Wenyu River from 1980 to 2010, and found that the sewage discharged from the centralized treatment facilities became the primary supply source of Wenyu River (70.1%). Additionally, the discharge of factory wastewater and domestic sewage will increase the content of heavy metals in sediments. The leachate produced by garbage stacking contains a large amount of heavy metals such as Cu, Zn, Pb and Cr, which enter rivers through surface runoff or soil runoff, resulting in the increase of heavy metal content in river sediments. Though the heavy metal pollution and potential ecological risk in surface sediments of Changping section of Wenyu River are slight, the water quality of Wenyu River still needs to be paid enough attention to prevent further deterioration.

In recent years, with the development of society and the improvement of people’s living standards, water environment management is extremely urgent. And reasonable water environment management measures need to be formulated according to accurate water quality assessment. However, water environment pollution is affected by many factors at the same time, has a certain complexity. Therefore, the selection of the evaluation method has always been a major problem in the process of water environment management.

In the early days, people evaluated water quality by its sensory properties (i.e. color, smell, turbidity, etc.). Later, with the progress of science and technology, chemical and biological indexes were added as the basis for water quality evaluation, which greatly improved the accuracy of water quality evaluation. At present, the approach for water quality evaluation mainly includes single factor water quality index method, fuzzy mathematics method, comprehensive water quality identification index method, principal component analysis method, etc., but these methods have some shortcomings. The single factor water quality index method is simple to calculate and easy to use, but it is greatly affected by the worst of the selected factors, and there is a certain gap between the evaluation results and the real water quality. The comprehensive water quality identification index method can express abundant water quality information, but it ignores the difference in the importance of different water quality indicators in the evaluation (Wu et al. 2019). The fuzzy mathematics method is subjective in the determination of index weight. TOPSIS is a sorting method approaching ideal points, which is a common and efficient multi-objective decision analysis. In the process of normalization of the multi-objective decision matrix, there are many different methods for data processing, and different data normalization methods will have different impacts on the result (Milani et al. 2005). From the perspective of weights, traditional TOPSIS has a strong subjectivity of index weights, so it is more objective to allocate weights by using the entropy weight method (Liu & Hua 2007). From the perspective of the correlation among the indexes, TOPSIS does not link water quality indicators and their officially defined criteria with each indicator, however, the TOPSIS-based informative weighting and ranking (TIWR) approach can combine the water quality indicators with the relevant standards, and consider the correlation among the indicators by using the importance of the standards through the inter-standard correlation method (Li et al. 2018). The comprehensive pollution index method can compare the water pollution degree of different river sections in space, which is convenient for classification. Index of biotic integrity (BIB) is usually carried out with river bottom fish and benthic animals, and rarely with plankton. In fact, plankton can reproduce rapidly and have a short life cycle and can respond to changes in water quality (Zhu et al. 2018), therefore, based on the IBI, the P-BIB factor analysis method was improved and summarized. Due to slow action and long growth cycle of large invertebrates, they can be indicators of changes in the river water environment, therefore, based on the biological evaluation of IBI, the B-IBI index analysis method was summarized (Yang et al. 2012). Microbial health risk assessment based on indicator bacteria is based on the fact that pathogenic microorganisms pose a threat to human health to a certain extent (Chen et al. 2017). The water quality evaluation based on matter-element analysis is convenient and intuitive, and can comprehensively reflect the water quality (Liu et al. 2019, Bowen et al. 2018). Water quality assessment based on attribute recognition theory of attribute recognition theoretical model can effectively overcome the two common problems of fuzzy classification or unreasonable evaluation, but the subjective confidence is set too high, and through the concept of grey correlation degree analysis in grey system theory, the numerical relationship between subsystems (or factors) in the system can be found (Cai et al. 2019). Principal component analysis (PCA) can cover up some important factors due to the excessive number of related factors. The water pollution index method can collect and summarize the pollutants in the water and comprehensively reflect the water pollution situation in the form of numerical values, and the results are intuitive and accurate. The multivariate analysis technique helps us to determine the water quality status through the physical, chemical, and biological indicators of water. When the multivariate statistical HJ-Biplot method is used for water quality evaluation, the joint representation of physical, chemical, and biological variables of different months in two research fields can be observed simply and clearly on a plane (Carrasco et al. 2019). WQI_{min} model was established by using stepwise multiple linear regression analysis for the water quality index method. The study showed that the WOI_{min} model could effectively evaluate and manage water quality, but the potential risks of algae proliferation were not taken into account in this model.

Difficulties in water quality evaluation:

1. Allocation of multiple index weights. There are often multiple indicators in water quality evaluation, and the problems in the weight allocation of these indicators are that the evaluation results are greatly influenced by the worst or the best factors, the important differences of different water quality indicators are ignored, and the subjectivity is affected.
2. The classification is unreasonable or fuzzy.
3. Some important factors are covered up because of the excessive number of factors. Therefore, water quality evaluation needs us to think from multiple aspects, or through the comparison of a variety of water quality evaluation methods, to get a more reasonable evaluation method.

The interannual variation of water quality in the Wenyu River is influenced by seasonal climate. The runoff from 1982 to 2014 at the hydrological station of the Shahe Gate was simulated based on the Swat model to simulate the hydrological cycle process in the Upper Wenyu River Basin. It is found that in the upper reaches of Wenyu River, the contribution rate of meteorological factors to runoff is 21. According to the analysis of the natural economic situation around Wenyu River, there are a lot of farmland along the river, and the largest source of organic matter in the sediment may be the crop residues such as crop stalks that enter the river with rainfall and runoff. Therefore, the terrigenous organic matter in the sediment will account for a larger proportion. Rivers are seriously affected by non-point source pollution.

MATERIALS AND METHODS

In 2019, data on pH, nh3-n2, COD, and DO was collected in four sections of Wenyu River Shahe Reservoir, Ma Fang, Lu Tuan Gate, and Xin Bao Gate for each month. In this paper, the water quality of Wenyu River is evaluated by a single factor evaluation method and a comprehensive index evaluation method.

Water quality of rivers is affected by rainfall and runoff, and climate change and land use change will affect runoff. Yang et al. (2018) showed that in Changping section of Wenyu River, the contribution of climate change to runoff change was much greater than that of land use change. Therefore, when we study the change of water quality of Wenyu River in one year, we focus on observing the change of water quality from the seasonal change. In recent years, the water quality of Wenyu River has improved because the water quality of Wenyu River has been inferior for a long time. To better understand the water quality of Wenyu River, in this paper, the water quality of the Wenyu River is investigated in four sections: reservoir, Ma Fang, Lu Tuan Gate, and Xin Bao Gate. To avoid accidental factors, the above four sections are sampled every month. The data are shown in Fig. 1.

Methodology: The idea of the single-factor index method is to select the worst index in the series of water quality indexes and use the index calculated by the index as the standard to evaluate the water quality grade. The single factor evaluation method only focuses on one index, which can reflect the water quality index, but only one water quality factor is considered, which cannot reflect the water quality of the river comprehensively.

Water quality indicators can be divided into general water quality assessment factors and special water quality assessment factors (for example: DO, pH).

1. General water quality evaluation factor:

$$S_{i,j} = C_{i,j}/C_{s,j} \quad ...(1)$$

$S_{i,j}$: Standard Index; $C_{i,j}$: The measured value of evaluation factor i in j section, ml/L: $C_{i,j}$: Standard limit of i。

2. Special water quality evaluation factor:
   How to work out pH:

$$PH_j \leq 7.0$$

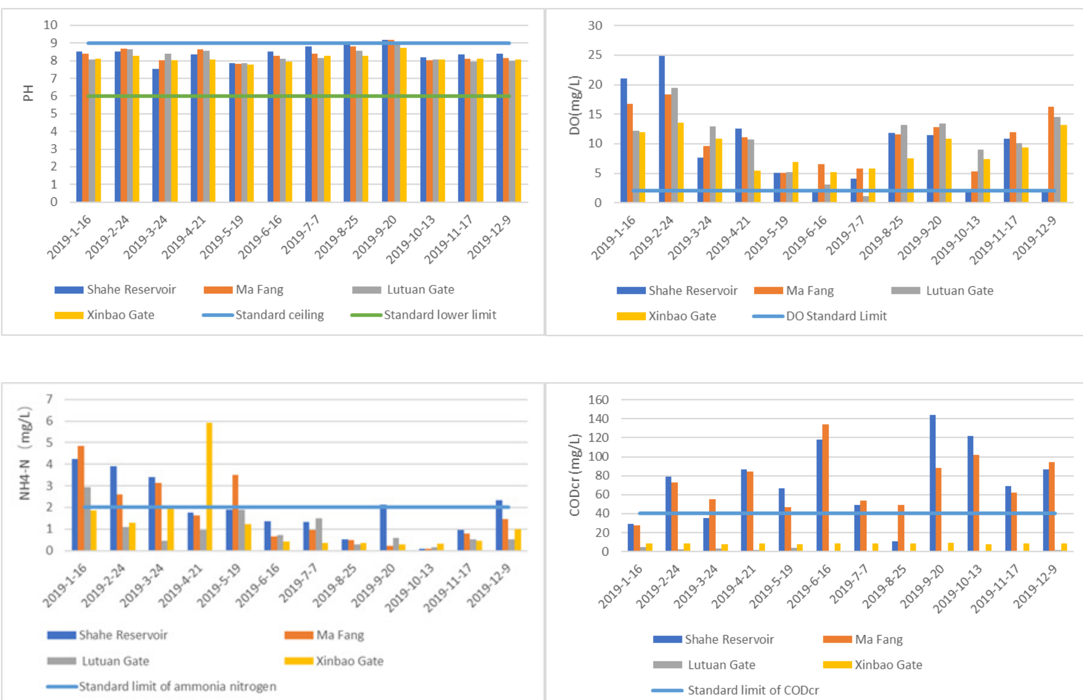

Fig. 1: Measured results of water quality objectives.

$$SPH_j = \frac{7.0-PH_j}{7.0-PH_{sd}} \quad \ldots(2)$$

$$PH_j \leq 7.0$$

$$SPH_j = (PH_j - 7.0)/(PH_{sn} - 7.0) \quad \ldots(3)$$

PH_j: Measured value of PH; SPH_j: Standard Index; PH_{sn}: Upper limit of Ph in evaluation criteria; PH_{sd}: Lower limit of Ph in evaluation criteria.

How to work out DO:

When $DO_j \geq DO_s$

$$S_{DO,j} = \;/DO_f - DO_j\;/\,/(DO_f - DO_s) \quad \ldots(4)$$

When $DOj < DOs$

$$S_{DO,j} = 10 - 9DO_j/DOs_s \quad \ldots(5)$$

$S_{DO,j,}$ is the standard exponent of DO; DO_f is Saturation dissolved oxygen concentration under water temperature and air pressure, $mg.L^{-1}$ Rentenformel (Germany): $DO_f = 468/(31.6 + t)$, t means temperature, °C; DO_j is the measured value of dissolved oxygen at Point j, $mg.L^{-1}$; DO_s Standard limit for evaluation of dissolved oxygen, $mg.L^{-1}$.

The comprehensive pollution index method is to obtain the comprehensive pollution index of the water body and to grade the water quality according to the standard of water quality classification. The formula is:

$$P = \frac{1}{n}\sum_{i=1}^{n} P_i \quad \ldots(6)$$

Table 1: Water quality assessment indicators and standard classification

Indicators	I	II	III	IV	V
pH	6.5	7.5	7.5	8.5	9
COD/(mg/L)	15	15	20	30	40
DO/(mg/L)	7.5	6	5	3	2
NH_4^+N/(mg/L)	0.15	0.5	1	1.5	2

P is the comprehensive pollution index, P_i single factor evaluation method for calculating the value of I index.

Case Study

Because the water quality of Wenyu River is in the category of v for a long time, the water quality of Wenyu River was sampled in 2019 in accordance with the water quality standard of surface water (gb3838-12002) as shown in Table 1. The single factor evaluation method and the comprehensive pollution index method were used.

RESULTS AND DISCUSSION

Results of Single Factor Analysis

According to the division of the functional zone objects of surface water environment in the "surface water environment standard" (GB 3838-2002), the single factor index analysis of the above-mentioned four sections of Wenyu River was

Fig. 2: Single-factor index.

carried out with the standard of type v water. Insert the data from Fig.1 into equations (1), (2), (3), (4), and (5) to get Fig. 2.

Since the single-factor evaluation method only selects the results of one evaluation factor as the evaluation index, therefore, in the single-factor evaluation, it cannot reflect the comprehensive water quality of the river, but for the evaluation factor, you can see how far it's gone. According to the calculation, the DO of the 4 sections reached the V Type Water Standard most of the time, but the DO of Lu Tuan Gate exceeded the standard in July, and the water quality was poor V type water. In the whole year, the CODCR indexes of each section generally exceeded the standard, which indicated that the Wenyu River was seriously polluted. In the treatment of the Wenyu River, we should strengthen the treatment of sewage, strictly in accordance with the national comprehensive sewage discharge standards. In the first half of 2019, the phenomenon of ammonia nitrogen exceeding the standard was common in all sections. After June, except for a small amount of ammonia nitrogen exceeding the standard in Shahe Reservoir, the other sections basically met the standard of V type water. The single factor index of ammonia nitrogen showed an obvious difference between the first half-year and the second half-year. While the Wenyu River pH showed a long-term stability in the V Water Standard, and not too large fluctuations.

Results of Composite Pollution Index Analysis

The single factor analysis method lays too much emphasis on the influence of single factor, and the evaluation of river water quality is not comprehensive enough. In order to reflect the water quality of the river in a more comprehensive way, on the basis of single factor analysis, this paper adopts the comprehensive pollution method to distinguish the water quality of Wenyu River. The results are shown in Fig. 3.

In summer (June, July and August), the water quality of each sampling section experienced a process of gradual deterioration and gradual improvement. Beijing has entered flood season in summer, and the water quality of rivers has gradually deteriorated, reaching the worst of the year. And after the end of the flood season, the water quality gradually improved. Compared with the other three sections, the water quality of Shahe Reservoir is usually worse. But in the flood season, Lutuan gate water quality deterioration is the most obvious. The water quality of each section basically belongs to class V water, and the fluctuation range is small with time.

CONCLUSIONS

1. Combining single factor and comprehensive pollution index method, it is found that the water quality of Shahe Reservoir is poor and belongs to the Inferior v water body.
2. Beijing has a temperate monsoon, it is hot and rainy in summer while cold and dry in winter .Rainy summers increase the runoff of rivers. However, because Wenyu River has been polluted for a long time, part of nitrogen, phosphorus and inorganic gel metal may eventually settle in the bottom mud. In the flood season, due to heavy rainfall, not on the basis of non-point source pollution, but also accompanied by the release of endogenous pollution, this makes the water quality of the river in the summer flood season when coming an obvious deterioration. After the flood season, the river water quality improved under the river's self-regulation ability.
3. In the single-factor evaluation, it was found that the single-factor index of ammonia nitrogen in Wenyu river exceeded the standard in the first half of the year and the second half of the year, especially in January, February and March. It may be that the low temperature

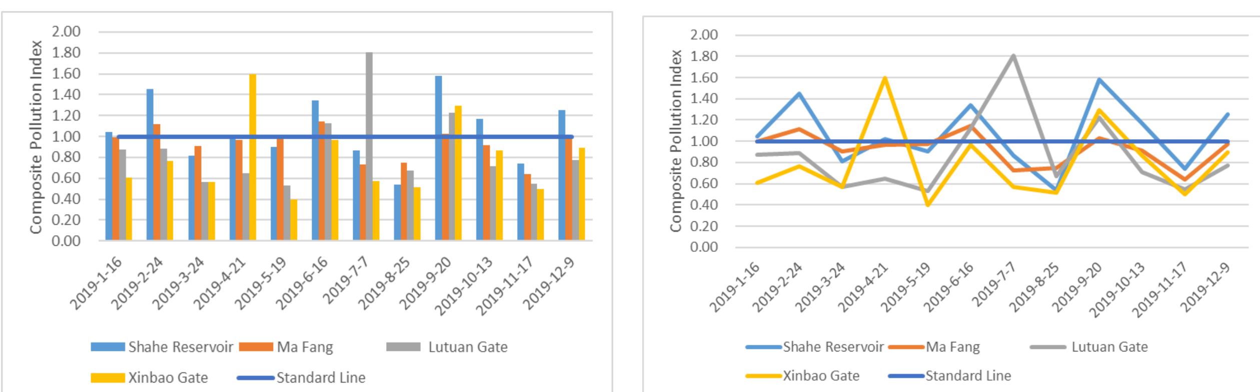

Fig. 3: Composite Index.

in Beijing at this time caused high ammonia nitrogen. The low temperature not only affected the growth rate and activity of nitrifying bacteria but also affected the speed and efficiency of denitrification. The nitrification reaction will decrease when the temperature is lower than 15°C, which caused the ammonia nitrogen levels to go off the charts.

4. The water quality of the Wenyu River varies with seasons, and the water quality monitoring indexes are affected by temperature and rainfall. In the treatment of the Wenyu River, we must first understand the causes of water quality changes to take proper measures.

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