Evaluation of Water Quality and Habitat Quality in the Beiyunhe River Watershed

Jiaxiang Zou\textsuperscript{1,2,a}, Shiyan Wang\textsuperscript{1,2,b}, Chang Liu\textsuperscript{1,2,c}, Zhen Han\textsuperscript{1,2,d}, Bei Zhu\textsuperscript{1,2,e}, Zhi Jiang\textsuperscript{1,2,f}

\textsuperscript{1}State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, Beijing, China; \textsuperscript{2}China Institute of Water Resources and Hydropower Research, Beijing, China; \textsuperscript{a}email: iwhrzjx@163.com; \textsuperscript{c}email: liuch@iwhr.com; \textsuperscript{d}email: zhenhan@iwhr.com; \textsuperscript{e}email: zhubei@iwhr.com; \textsuperscript{f}email: 15810643759@qq.com; \textsuperscript{b}Correspondence: email: wangsy@iwhr.com;

Abstract: The water environmental condition of the Beiyunhe River, a typical urbanized and semi urbanized river in northern China, is under multiple threats. In this research, through site investigation and sampling, the water quality and habitat quality was evaluated by adopting the comprehensive pollution index method and the expert scoring method. The research analysis shows that: the water quality of the upstream of the main stream was better than that of the downstream, the water quality spatial characteristics were that the water quality of the upstream was relatively good, the midstream took the second place and the downstream was the worst; the water quality heterogeneity characteristics of the river was relevant to the characteristics of different rivers upstream and downstream; the result of the general evaluation of the quality of the aquatic habitats was fair, the evaluation scores of all the monitoring points were higher than 80, the comprehensive index of the habitat quality of the main stream was higher than that of each tributary, so the habitat quality of the main stream was relatively good, and there was little difference in the habitat quality of all tributaries; the main factor that affecting the quality of the river aquatic habitats in the Beiyunhe River was that the artificial disturbance of an urbanized and semi urbanized river is strong, causing relatively single river habitat, which is difficult to form complex and diverse habitats. This research can be provided as a basis for river water environment scientific management of the Beiyunhe River.

1. Introduction

Rivers can affect the global biogeochemical cycle as well as provide many valuable ecosystem services for human\textsuperscript{[1]}. However, rivers are easily disturbed by human activities. Among the rivers with the length of more than 1000 km in the world, only 37\% remain free flowing over their entire length. 65\% of the world’s rivers and the aquatic habitats that depend on rivers have been strongly threatened by human activities. The quality of river water is very important to public health\textsuperscript{[2]}. Therefore, river water quality management has been paid much attention to all over the world. Comprehensively evaluation of the water environment quality and overall grasp of the characteristics of water environment pollution in the river watersheds are important basic work for river water quality management.

River habitats are the environment on which aquatic organisms live, which provides the necessary...
conditions for the survival and reproduction of aquatic communities [3], and also an important factor in maintaining river ecological integrity and river health, which plays an important role in material circulation, energy flow and information transfer of water ecosystems and adjacent land ecosystems [4]. With the development of industrialization and urbanization at top speed, rivers have been disturbed and destroyed by human activities in different degrees, resulting in water quality pollution and river habitat destruction, and finally rising up to a series of environmental problems such as the loss of natural functions of rivers and the extinction of biological species [5]. For this purpose, the evaluation research of river habitat quality has been paid wide attention to. Effective identification and diagnosis of the characteristics of water environment habitats of river watersheds are of great practical significance to protect the river water environment condition, serving as an important basis for river management.

As a typical urbanized and semi urbanized river in northern China, the Beiyunhe River watershed is short of water resources with many hydraulic structures such as river gate dams and rubber dams, which cause great disturbance of human activities. With the large amount of water consumption, and the industrial, agricultural, and domestic wastewater and the reclaimed water discharged into the river, the river water pollution and water ecosystem degradation are obvious [6]. Nowadays, water environment management is gradually changing from traditional pollution control to river watershed water ecosystem health management [7]. For river ecosystem protection and restoration, scientific management of water ecological environment and other fields, it is of great significance to scientifically determine the watershed water ecological health status and to identify the main affecting factors [8-9]. In this paper, by constructing and screening evaluation indexes of water quality and habitat quality of the Beiyunhe River watershed, the current status of the water quality and habitat quality of the Beiyunhe River watershed was evaluated by adopting a comprehensive evaluation method so as to provide technical support for river water environment quality scientific management and river water ecological protection and restoration of the Beiyunhe River.

2. Research Area and Sampling Method

2.1 Overview of the Research Area and Layout of Sampling Points
The Beiyunhe River watershed (115° 49′- 117°14′E, 39°11′- 40°2′N) belongs to Haihe River watershed, involving three areas of Beijing City, Hebei Province and Tianjin City with the drainage area of 6214 km², and the length of the main stream of 186 km, of which the mountainous area is 1000 km² and the plain area is 5214 km². The total population of the watershed is 15.25 million, and there are more than 80 gate dams [10] in the watershed, including 9 gate dams and 5 rubber dams in the main stream alone. With consideration of the characteristics of the Beiyunhe River system, such as complex structure, numerous gate dams, and many factors of water pollution, in order to research the health status of water ecosystem in the Beiyunhe River watershed, and in accordance with the principles of typicality and representativeness, the water ecosystem of the Beiyunhe River watershed was systematically investigated, monitored and sampled in June 2019 with a total of 38 sampling points being set, including 16 points in the main stream and 22 points in the tributaries, covering all the primary tributaries such as Dongshahe River, Nanshahe River, Beishahe River, Tonghuihe River, Liangshuihe River and Bahe River and some secondary tributaries. The content of the investigation and monitoring sampling contains the river hydrological situation, river morphology, river habitats and river water ecology and other factors. At the same time, the river water quality was monitored synchronously.
2.2 Monitoring Sampling and Investigation Methods

2.2.1 Water Quality Monitoring and Sampling Analysis
An EXO-YSI portable multi parameter water quality monitor was used to measure the water quality of sampling points on the site. The monitoring indexes included water temperature (WT), dissolved oxygen (DO), conductivity (Cond), pH value, etc.; in the meanwhile, 2L water samples were collected by polyethylene plastic bottles, placed in a low temperature incubator and taken back to the laboratory within 48 hours for determination of other indexes, including permanganate index (CODMN), biochemical oxygen demand (BOD₅), total suspended solids (TSS), hardness (WH), calcium (Ca), magnesium (Mg), copper (Cu), potassium (K), chromium (Cr), sulfate (SO₄²⁻), chlorine (Cl), phosphate radical (PO₄³⁻), nitrate nitrogen (NO₃⁻), nitrite nitrogen (NO₂⁻), ammonia nitrogen (NH₄⁺-N), total nitrogen (TN), and total phosphorus (TP). The storage, sampling method and determination method of water quality indexes at each sampling point refer to Environmental Quality Standard for Surface Water (GB3838-2002) and Monitoring and Analysis Methods of Water and Wastewater.

2.2.2 Habitat Environmental Quality Data
Referring to the records and evaluation methods in EPA rapid biological evaluation manual of the United States of America, and mirroring the habitat environmental quality evaluation index proposed by Barbour in 1996, combined with the characteristics of the water ecosystem in the Beiyunhe River watershed, ten indexes of the sediment, habitat complexity, V/D combination characteristics, river bank stability, water course change, water quantity, vegetation diversity, water quality, human utilization intensity and river bank land use type were investigated and analyzed by using the field expert scoring method.
3. Research Methods

3.1 Water Quality Comprehensive Pollution Index Method

3.1.1 Index Selection
According to the water quality indexes for evaluation in Environmental Quality Standard for Surface Water (GB3838-2002), and based on the characteristics of the water environment of the Beiyunhe River watershed, the indexes of four categories were selected covering chemical index, oxygen index, nutrient index and metal element index, specifically including 8 indexes: pH value, permanganate index (CODMn), five-day biochemical oxygen demand (BOD5), ammonia nitrogen (NH3-N), total nitrogen (TN), and total phosphorus (TP), copper (Cu) and chromium (sexavalance) (Cr).

3.1.2 Evaluation Method
The comprehensive pollution index method is a relative pollution index based on the single factor pollution index method, comprehensively considering of each pollution index, so it not only inherits the simple algorithm but also avoids the singleness of the single factor pollution index to obtain the pollution degree of water body by considering the influence of multiple chemical factors of the characterizing water quality index [11]. The calculation formula is as follows:

\[ P = \frac{1}{\sum_{i=1}^{m} P_i} \]

For the calculation of pH value, the calculation formula is as follows:

\[ P_i = \begin{cases} \frac{C - 7.0}{8.5 - 7.0} & (\text{pH} \geq 7.0) \\ \frac{7.0 - C}{7.0 - 6.5} & (\text{pH} \leq 7.0) \end{cases} \]

In the above formula, \( P_i \) refers to the single pollution index of index \( i \), \( i = 1, 2, \ldots, m \), \( m \) is the total number of water sample monitoring indexes; \( C_i \) is the measured concentration of index \( i \); \( S_i \) is the standard concentration of index \( i \); and \( P \) means the comprehensive pollution index.

3.1.3 Evaluation and Grading Standards
According to the surface water functional areas in Beijing City, Arcgis10.4 was used to analyze the spatial superposition of monitoring sampling points and water functions to determine the water quality targets of each sampling point. It can be seen that 10 of the 38 evaluation points were located in Class IV water quality target area, and the rest were located at Class V (Table 1). On the basis of the limit values of Class IV and V water quality standards in Environmental Quality Standard for Surface Water GB3838-2002, the standard value of comprehensive pollution index of water quality at each point was determined.

### Table 1 Water Quality Target of Each Sampling Point

| Sampling point | Water quality target | Sampling point | Water quality target | Sampling point | Water quality target | Sampling point | Water quality target | Sampling point | Water quality target |
|----------------|----------------------|----------------|----------------------|----------------|----------------------|----------------|----------------------|----------------|----------------------|
| s1             | IV                   | s9             | V                    | s17            | V                    | s25            | V                    | s33            | V                    |
| s2             | IV                   | s10            | V                    | s18            | IV                   | s26            | V                    | s34            | V                    |
| s3             | IV                   | s11            | V                    | s19            | IV                   | s27            | V                    | s35            | V                    |
| s4             | IV                   | s12            | V                    | s20            | V                    | s28            | V                    | s36            | V                    |
| s5             | IV                   | s13            | V                    | s21            | V                    | s29            | V                    | s37            | V                    |
| s6             | IV                   | s14            | IV                   | s22            | V                    | s30            | V                    | s38            | V                    |
| s7             | IV                   | s15            | V                    | s23            | V                    | s31            | V                    |                |                      |

According to the grading method of comprehensive pollution index, the water quality grading of
monitoring points was analyzed (Table 2) referring to the relevant literature [12]. The comprehensive index of all monitoring points exceeded 0.4, of which 6 monitoring points belonged to slight pollution, accounting for 16%, 10 belonged to moderate pollution, accounting for 26%, 21 belonged to heavy pollution, accounting for 55%, and 1 belonged to serious pollution, which was No.b86 located in the north of Xinggezhuang Village, Daxing District. It can be seen that the overall water quality of the Beiyunhe River watershed was poor, mainly because the current volume of runoff of the Beiyunhe River was mainly sewage and reclaimed water, and the natural runoff was accounted for a relatively small proportion (about 30%). The water volume and flow of the river in non-flood seasons were small, which is not conducive to the convective diffusion and dissolution of pollutants in the river.

Table 2 Grading Standard of Water Quality Comprehensive Pollution Index Method

| P value range | ≤0.20 | 0.21-0.40 | 0.41-0.7 | 0.71-1.00 | 1.01-2.0 | ≥2.0 |
|---------------|-------|-----------|----------|-----------|----------|------|
| Grading       | Good  | Relatively good | Slight pollution | Moderate pollution | Heavy pollution | Serious pollution |

3.2 Habitat Quality Evaluation Method

3.2.1 Grading Evaluation of Each Index

Each index was divided into four classes: good (16-20), Relatively good (11-15), fair (6-10) and poor (0-5), with 20 scores for each index and 200 scores for the total. In order to eliminate the deviation of different investigators in the evaluation standard, all the investigation points were evaluated by the same person. Finally, the score of each point was counted and analyzed to construct the habitat quality evaluation index system of the Beiyunhe River watershed. The higher the point score, the better the habitat quality.

3.2.2 Evaluation Grading Standard

Combined with the actual scoring of aquatic habitat quality in the Beiyunhe River watershed, the evaluation standard of the habitat quality was graded according to the natural interruption method (Table 3) into total five grades, namely good (> 150), Relatively good (120~150), fair (90~120), Relatively poor (60~90) and poor (≤ 60) [13]. The aquatic habitat quality comprehensive index was calculated according to the cumulative summation of aquatic habitat quality rapid evaluation scores so as to evaluate the river aquatic habitat quality in the watershed.

Table 3 Grading Standard for River Habitat Quality Evaluation

| Evaluation Grade | Distribution probability | Score range |
|------------------|--------------------------|-------------|
| Good             | <25%                     | >150        |
| Relatively good  | 25%~40%                  | 120~150     |
| Fair             | 40%~55%                  | 90~120      |
| About poor       | 55%~70%                  | 60~90       |
| Poor             | >70%                     | ≤60         |

4. Results and Discussion

4.1 Water Quality Evaluation Results and Analysis

The comprehensive pollution indexes of 16 monitoring points of the main stream were mapped and analyzed according to the sequence from upstream to downstream (Figure 2). Generally, the upstream water quality of the main stream was better than that of the downstream. This situation is relevant to the distribution of Beijing sewage treatment plants mainly in the midstream and downstream. In the meanwhile, the downstream water volume was reduced compared with the upstream due to the water diversion caused by Yunchaohue River diversion and Qinglongwanhe River diversion, resulting in the downstream water quality being relatively poor. Therein, the relatively poor water quality evaluation result of point s5 in the upstream was mainly due to the fact that the point was near to the inflow point
of Lingouhe River, which as a primary tributary of Wenyuhe River, has relatively poor water quality; The monitoring result of point s21 in the midstream was relatively good, because this point was located in Tongzhou Grand Canal Forest Park, where the riparian vegetation coverage was high, the river water surface was wide, the riverine wetland was developed, and the overall water ecosystem was in good condition.

In order to better analyze the spatial distribution of water quality evaluation results in the watershed, the spatial interpolation analysis was conducted on the comprehensive pollution indexes of water quality at all monitoring points by using the Kriging spatial interpolation method of Arcgis10.4 software. It can be seen clearly from Figure 3 that the water quality in the upstream of the watershed was obviously better than that in the midstream and downstream, which is consistent with the spatial characteristics of water quality in the main stream. Specifically speaking, there was less human disturbance and larger river water volume on the upstream of the Beiyunhe River, meanwhile, the upstream water was mainly natural runoffs with low comprehensive pollution index; the water quality evaluation results of the upstream of Fenghe River, Dalonghe River and Liangshuihe River in the midstream were relatively poor, because here was the downstream of the Beiyunhe River flowing through Beijing urban area, where many sewage treatment plants were distributed and many industrial pollution sources were located, therein, Liangshuihe River watershed was not only the watershed of industrial gathering, but also the watershed with more direct discharge environmental enterprises; with small population density, the downstream of the watershed was dominated by the agricultural non-point source pollution, however, the runoff of the downstream was reduced and the self purification ability of the water body was insufficient, which led to the relatively poor comprehensive evaluation results of the downstream water quality.

![Figure 2](image2.png)

**Figure 2 Figure of Water Quality Comprehensive Pollution Indexes of Monitoring Points in the Main Stream**

**Figure 3 Spatial Distribution Map of Water Quality Comprehensive Pollution Indexes**

Generally speaking, the water quality of the Beiyunhe River watershed was affected by many factors. From the perspective of the main stream and tributaries, the water quality of the tributaries was worse than that of the main stream, because the catchment area of the main stream was larger and the water volume was larger; from the analysis of the spatial relationship between the upstream and downstream, the water quality of the upstream was relatively good, followed by the midstream, and the downstream was the worst. The reason is that the upstream was mainly the mountain section of the river mainly with natural runoffs of good water quality, while, the midstream and downstream flowed through the urban area, absorbing a large number of domestic sewage and reclaimed water after treatment by sewage treatment plants. At the same time, urban non-point source and agricultural non-point source pollution were increasingly emerging, leading to the relatively poor water quality in the midstream and downstream of the Beiyunhe River watershed.
4.2 Habitat Quality Evaluation Results and Analysis

The results show that the overall evaluation result of aquatic habitat quality in the Beiyunhe River watershed was fair, and the evaluation scores of all monitoring points were more than 80, only the evaluation of point s13 was relatively poor, the evaluation of 30 points was fair, accounting for 79%, and 7 points were evaluated relatively good, accounting for 18%. Point s13 was located in the urban section of Bahe River dominated by a single artificial hard habitat, with the sediment of less gravel and pebbles, and relatively thin sediment on the river bottom. Its V/D combination characteristics and vegetation diversity were relatively single. Affected by all above factors, the evaluation of the point was relatively poor. In addition, among the 11 sampling points of which the scores exceeded (included) 120, 7 were located in the main stream area, accounting for 64%. It can be seen that the habitat quality of the main stream of the Beiyunhe River was higher than that of the tributaries, and the habitat environment quality was relatively good.

According to the results of habitat quality evaluation in different sections of the upstream and downstream of the main stream (Figure 4), the habitat quality of the upstream was better than that of the downstream, and the upstream area maintained a relatively good natural state. Therein, the river course where the point s5 in the upstream located had more volume of runoff, diverse habitats, and many kinds of vegetation on both sides of the floodplain wetlands, therefore the habitat environment quality was relatively good; the habitat quality between point s23 and point s27 showed an increasing trend, because this section was located in the Beiyunhe River section of Beijing Grand Canal Forest Park, where the riparian vegetation coverage was relatively high and the human disturbance was relatively small. Moreover, by the ways such as river ecological restoration, ecological corridor construction and beach ecological protection, the habitat quality conditions were made relatively good.

In order to analyze the spatial distribution characteristics of the habitat quality evaluation comprehensive indexes of the Beiyunhe River watershed, the Kriging interpolation method of Arcgis10.4 software was used for spatial interpolation to obtain the spatial distribution map of the habitat quality comprehensive indexes of the Beiyunhe River watershed (Figure 5). It can be seen that the habitat quality of the tributaries of the Beiyunhe River had no significant difference, and the habitat quality evaluation of the mountainous area in the upstream of the northwest was relatively good. Except for the area of 20 km around the Beijing Grand Canal Forest Park, the main evaluation results in the midstream and downstream were fair. Based on the analysis of habitat quality evaluation and environmental conditions of the river sections where the habitats were located, the main factors affecting the quality of aquatic habitats of Beiyunhe River were artificial disturbance such as river hardening in urbanized and semi urbanized river sections, causing regular sections, relatively single habitats, and relatively thin sediment of river bottom mainly composed of domestic sludge of the river sections. It is difficult for them as a single river environment to form complex and diverse biological habitats. The ability of the habitats to resist external interference was relatively weak. When disturbed, the self-healing time was relatively long, and the ecological stability was relatively poor, which made the ability of them to maintain the structure and function of water ecosystem relatively weak. Therefore, it is suggested that the research from the perspective of aquatic habitat complexity-ecological diversity system coupling should be carried out so as to protect and restore the aquatic habitats of urbanized and semi urbanized rivers.
5. Conclusions
1. The spatial heterogeneity of water quality evaluation results was relatively large; the water quality of tributaries was worse than that of the main stream; the water quality of the upstream was relatively good, the midstream took the second place, and the downstream was worse; the increasingly apparent urban and rural non-point source pollution was the main factor leading to the poor water quality in the midstream and downstream of the river.

2. The overall evaluation of the aquatic habitat quality of the Beiyunhe River watershed was fair; the habitat quality of the main stream was higher than that of the tributaries, and the habitat environment quality was good; the main reasons affecting the habitat quality of the Beiyunhe River were the single habitat structure and the relatively large artificial disturbance such as the barrier of gate dams.

Acknowledgments
This research was funded by the Major Science and Technology Program for Water Pollution Control and Treatment (2018ZX07111003), IWHR Research & Development Support Program (WE0163A052018, WE0163A042018, WE0145B422019), Program for Innovative Research Team of IWHR (WE0145B592017).

References
[1] C. Zhao, N. Shao, S. Yang, et al. (2019) Integrated assessment of ecosystem health using multiple indicator species. Ecological Engineering, 157-168.
[2] Luo, Z.; Zuo, Q.; Shao, Q. (2018 )A new framework for assessing river ecosystem health with consideration of human service demand. Sci. Total Environ. 640, 442–453.
[3] Wenqi, P. (2018) Research on river and lake health assessment indicators, standards and methods. J. China Institute Water Res. Hydropower Res. 16, 394–404.
[4] Xia, T.; Zhu, W.; Xin, P.; Li, L. (2010) Assessment of urban stream morphology: An integrated index and modelling system. Environ. Monitoring Assess. 167, 447–460.
[5] Wang, T.; Liu, S.; Qian, X.; Shimizu, T.; Dente, S. M. R.; Hashimoto, S.; Nakajima, J. (2017) Assessment of the municipal water cycle in China. Sci. Total Environ. 607, 761–770.
[6] Zhang, F.; Liu, J.; Yang, Z. (2015) Health evaluation of urban rivers and lakes ecosystem—taking Beijing “six seas” as an example. Acta Ecologica Sinica .11, 227–235.
[7] Li, W.; Qiu, L.; Chen, X.; Huang, Q. (2011) Assessment model for river ecology health based on Set Pair Analysis and Variable Fuzzy Set. J. Hydraulic Eng. 42(7), 775–782.
[8] Gangfu, S.; Bing, S. (2012) Improvement of “scatter degree” method and its application in evaluating river ecosystem health. *Yingyong Shengtai Xuebao, 23*(7), 163–168.

[9] Song, Y.; Song, X.; Shao, G.; Hu, T. (2020) Effects of Land Use on Stream Water Quality in the Rapidly Urbanized Areas: A Multiscale Analysis. *Water, 12*(4), 1123.

[10] Gu, X.; Xu, Z.; Liu, L.; Yin, W.; Wang, M. (2018) Health Assessment of the stream ecosystem in the north canal river basin, Beijing, China. *Environ. Sci, 39*(6): 2576–2587. 

[11] Pan, G.; Xu, Y.; Yu, Z.; Song, S.; Zhang, Y. (2015) Analysis of river health variation under the background of urbanization based on entropy weight and matter-element model: a case study in Huzhou City in the Yangtze River Delta, China. *Environ. Res. 139*, 31–35.

[12] Zhao, Y.; Yang, Z. (2005) A preliminary study on the health assessment of urban river ecosystem. *Adv. Water Sci. 3*, 349–355.

[13] Zhang, Y.; Jiang, Y.; etc. (2009) Health assessment of water ecosystems in key river basins in China. Science Press: Beijing, China.