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RESEARCH ARTICLE

Evaluating surface water quality using water quality index in Beiyun River, China

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Abstract

The Beijing-Tianjin-Hebei urban agglomeration is one of the most water-scarce regions in China, because of the frequent human activities. Water scarcity and pollution have weakened the service functions of water ecosystems and hindered the regional economic development. As the “lifeline” of the economic development of Beijing-Tianjin-Hebei region, the water quality of Beiyun River has been widely concerned. River water quality assessment is one of the most important aspects to enhance water resources management plans. Water quality index (WQI), as one of the most frequently used evaluation tools, was used to comprehensively analyze the water quality in the Beiyun River. Between January 2017 and October 2018, we collected samples from 16 typical sampling sites along the main rivers of the watershed, covering four seasons. Seventeen water quality parameters, including temperature, pH, conductivity, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), total phosphorus (TP), oil, volatile phenol (VP), fluoride, sulfide, surfactant, lead (Pb), copper (Cu), zinc (Zn), and arsenic (As), were used to calculate WQI. The average WQI values of Beiyun River in winter, spring, summer, and autumn were 88.15, 71.70, 78.92, and 90.12, respectively, explaining the water quality was “good” generally. There were significant differences in the spatial distribution of WQI values from Beiyun River, and water quality of upstream and downstream was better than that of midstream. In addition, correlation analysis was applied to explore the correlation between land use types and water quality. Water quality was significant negatively correlated with agriculture land and rural residential land, and a positive relationship between urban land and water quality. Generally, we believe that people’s related activities on different land use are major elements impacting the water quality. Water environment improvement ought to increase the wastewater collection rate and sewage treatment capacity in rural areas, especially in the midstream of the Beiyun River.

Keywords Beijing-Tianjin-Hebei region · Beiyun River · Water quality analysis · Water quality index (WQI) · Land type

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Highlight
- We assessed water quality and its spatiotemporal variations of Beiyun River.
- The water quality of the upstream and downstream was better than that of the midstream.
- Water quality was significant positively correlated with urban land (%).
- Water quality was significant negatively correlated with agriculture land (%) and rural residential land (%).
- Rural life was the main source of water pollution.

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Introduction

As an important part of modern urban ecosystem, urban river plays a significant part in supporting the continuous and healthy development of social economy (Lu et al. 2019). In recent years, rapid development and expansion of cities have led to the structural damage and functional degradation of urban river channels (Chassiot et al. 2019). Industrial production (Taufiq et al. 2019), agricultural activities (Aldrich et al. 2002), aquaculture (Ismail et al. 2017), and storm runoff (Ahmed et al. 2018) cause large amounts of toxic pollutants to discharge into the water. The pollutant load exceeds the water environmental load-bearing capacity, leading to water quality deterioration and aquatic biodiversity reduction. The urban river pollution seriously hinders the sustainable economic and social development and threatens human health (Huang et al. 2019; Liu et al. 2016). Therefore, it is urgent to analyze the water quality of rivers and explore the causes of water quality deterioration to improve water environment.

Assessing the water quality of rivers according to physical, chemical, and biological parameters is the basis of river ecosystem health management (Marmonier et al. 2013; Norris and Thoms 2001). In recent years, various water quality assessment methods served to evaluate underground and surface water quality (Adimalla et al. 2019; Adimalla and Taloor 2020; Chabukdhara et al. 2017; Jha et al. 2015; Sotomayor et al. 2018). As an analysis model, water quality index (WQI) can be applied to integrate various water quality parameters into a dimensionless value that can represent the overall water quality (Adimalla et al. 2018; Alver 2019; Hurley et al. 2012). WQI has been widely used in aquatic ecosystem evaluation since it was proposed by Horton in 1965 (Horton 1965). Williams et al. (2009) averaged biotic index and WQI values to give a bay health index representing ecological conditions, which used to develop and evaluate the spatially explicit index of health in Chesapeake Bay. Hurley et al. (2012) used WQI to characterize drinking source water quality and proved that WQI is a valuable tool to monitor, communicate, and understand surface source water quality. Sener et al. (2017) combined the WQI model and GIS technology to assess water environment of the Aksu River. WQI model was used in these articles, but few articles have analyzed the correlation between land use-related human activities with comprehensive water quality.

The Beiyun River, located in important economic center of northern China, has experienced rapid urbanization and complex river network evolution. As a typical urban river, Beiyun River is under the pressure of slow water flow, serious water pollution, water ecological degradation, and poor self-purification capacity. Therefore, the urgency of improving the water quality of Beiyun River is self-evident. Li et al. (2004) used multivariate statistical methods and GIS to analyze nitrogen and phosphorus pollution in the Beiyun River. Ma et al. (2017) analyzed the distribution and environmental risks of pharmaceutically active compounds in the Beiyun River. These studies are based on single or partial water quality parameters for water quality analysis. Currently, there are no studies on the comprehensive assessment of Beiyun River environment. In addition, effects of land use factors related to anthropogenic activities on water quality are not exactly known. Hence, this study is extremely important for the region. Accordingly, the primary targets of this paper were (1) to use WQI to conduct a comprehensive evaluation of the physical and chemical indicators in the Beiyun River, (2) to clarify the spatiotemporal distribution of the comprehensive water quality, (3) to analyze the relation between land use types and the water quality of the Beiyun River, and (4) to analyze of pollution sources.

Materials and methods

Study area

The Beiyun River lies in North China with a length of 142.7 km and a total drainage area of 6166 km^2 (Fig. 1a). The main terrain of the upstream is mountains and hills with steep slopes, and alluvial plain is the main terrain in the midstream and downstream. Beiyun River is located in a typical warm temperate zone with semi-humid continental monsoon climate. The average annual atmospheric temperature and precipitation are 11 ~ 12 °C and 643 mm, respectively. The soils of this region are classified as cinnamon soil, fluvo-aquic soil, and mountain brown soil. There are many types of rocks in Beiyun River, including various sedimentary rocks, metamorphic rocks and igneous rocks. Most rocks are exposed in the western and northern mountains, and the plain area is widely distributed with quaternary loose sediments. The Beiyun River flows through the three cities of Beijing, Langfang, and Tianjin and finally enters the Haihe River. This river covers the areas with the most concentrated population, the most intensive industry, and the highest urbanization level in Beijing.

Water sampling

Water samples were obtained from sixteen representative state-controlled sections (Fig. 1a) along the Beiyun River in January 2017 (winter), April 2017 (spring), July 2017 (summer), October 2017 (autumn), January 2018 (winter), April 2018 (spring), July 2018 (summer), and October 2018 (autumn), covering the main stream and the primary tributaries within the study area. Collect water samples on sunny days to avoid the impact of heavy rainfall runoff on water quality. Samples were collected from depths of 0.5 m below the water

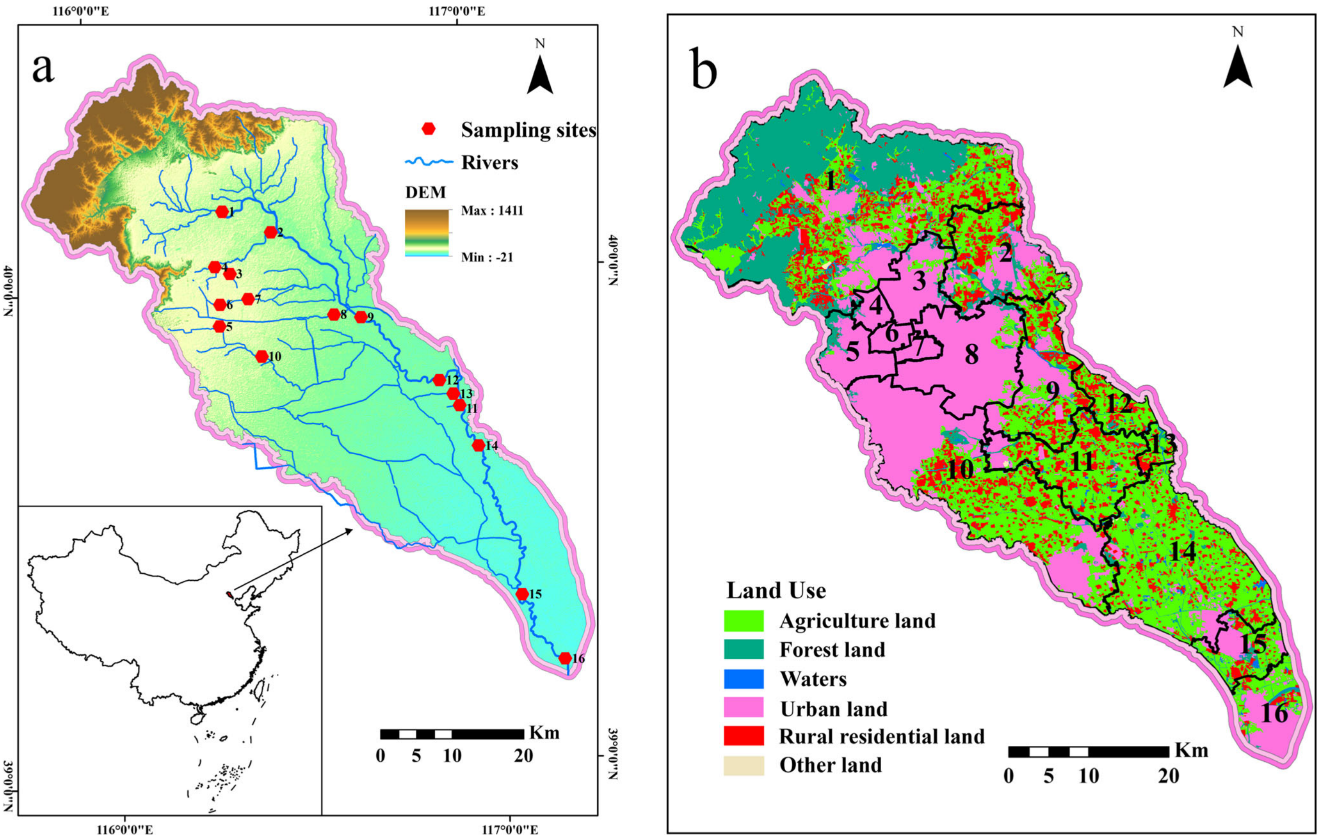

Fig. 1 **a** The water sampling sites, the digital elevation model (DEM), and **b** spatial patterns of land use in the Beiyun River Basin

interface in the middle width of the flowing water. If the depth of water was < 0.5 m, sampling location is half the depth of the river. The water samples at each station had three replicates collected in prewashed sampling bottles. Aqueous samples were collected following the instructions outlined in the Standard Methods for the Examination of Water and Wastewater published by the Ministry of Ecology and Environment of the People's Republic of China (HJ/T 91-2002, available at: http://www.mee.gov.cn/ywgz/fgbz/bz/). In the process of sampling, the temperature, pH, conductivity, and dissolved oxygen (DO) of the water were measured in situ by YSI Professional plus instrument (Pro Plus) immediately. The collected fresh water samples were filtered with 0.45 μm cellulose membrane and stored at 4 °C for testing. The chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), total phosphorus (TP), oil, volatile phenol (VP), fluoride, sulfide, surfactant, lead (Pb), copper (Cu), zinc (Zn), and arsenic (As) were analyzed based on the Standard Methods for the Examination of Water and Wastewater in China (HJ/T 91—2002). Quality assurance and quality control for the laboratory analysis followed the standard methods in the Standard Methods for the Examination of Water and Wastewater of China (HJ/T 91—2002). While conducting the analysis, blank samples were used at all the monitoring stations to control the accuracy of analyses.

WQI calculations

The water quality parameters from each sampling site were normalized and appointed a weight in the range 1–5 according to its importance to the water body health (Ayvaz and Elçi 2018) (Table S1). These parameters were used to calculate the water quality score and compute WQI value using formula (i) eventually (Xiao et al. 2019).

$$\mathrm{WQI}=\sum\left[W_{\mathrm{i}}\times\frac{C_{\mathrm{i}}}{S_{\mathrm{i}}}\times 100\right] \qquad \text{(i)}$$

where $W_i = w_i/\sum w_i$, w_i represents the weight of a single parameter (Ravikumar et al. 2013); $\sum w_i$ is the total of the all weights; c_i represents the measured concentration of each parameter; s_i represents the drinking water standard in China (China 2006).

The WQI model converted multiple parameters into a single value reflecting the river quality (Jena et al. 2013). Water quality was divided into five grades according to the value of WQI as follows: excellent (< 50), good (50 ~ 100), poor (100

~ 200), very poor (200 ~ 300), and (> 300) unsuitable for drinking.

Statistics of land use types

The DEM of the study area in 30 m resolution was used for identifying flow direction and the outlet of each grid cell. Based on stream networks and topographical features extracted from the DEM, the Beiyun River was delineated into sixteen sub-catchments in ArcMap 10.2 software (ESRI, USA) by using the Hydrology module (Fig. 1b). The land use data in this article is 2016, which is inconsistent with the time of water quality. Field investigation found no significant change in land use types during the study period. In addition, researchers believed that land use has legacy effects on river ecosystems (Allan 2004; Tian et al. 2019). To study and predict the effect on water quality we classified the land use types as follows: (1) agriculture land; (2) forest land; (3) urban land, including residential, commercial, and industrial land; (4) rural residential land; (5) water areas; and (6) other land, as shown in Fig. 1b. Among them, water areas and other land use types occupy a small area and were ignored in subsequent analyses.

Statistical analysis

Significant differences of water quality among seasons were analyzed by one-way analysis of variance (ANOVA) with Tukey post-hoc multiple comparisons, and $P < 0.05$ was considered statistically significant. We analyzed the data on SPSS 22.0 software.

Results and discussion

Water characteristics

Table 1 summarizes the water quality parameters among different seasons in the Beiyun River. We found that most parameters changed greatly over four seasons. While pH, COD, oils, and fluoride values did not vary significantly with the seasons ($P > 0.05$), temperature varied greatly with season. The highest water temperature was observed in summer (29.0 °C), and the lowest water temperature was observed in winter (4.4 °C). The average pH values in four seasons ranged from 8.00 to 8.21, indicating that the water quality was slightly alkaline. The average conductivity in autumn was 3440 μs/cm, which was markedly more than that of other seasons. Autumn is a farming season, and the fertilizers might be transported with surface runoff and discharged into the river leading to higher conductivity (Wang et al. 2013). The highest average DO value in winter was 11.30 mg/L and the lowest average DO value in summer was 8.17 mg/L. This distribution was contrary to that of temperature in four seasons, indicating that temperature has a negligible effect on DO.

Table 1 Mean and standard deviation of water quality parameters among four seasons in Beiyun River

Parameters	Winter Ave.	Spring Ave.	Summer Ave.	Autumn Ave.
Temperature (°C)	4.4 ± 3.1c	16.4 ± 2.3b	29.0 ± 1.5a	17.5 ± 1.8b
pH	8.21 ± 0.40	8.16 ± 0.43	8.00 ± 0.57	8.00 ± 0.45
Conductivity (μs/cm)	860 ± 393b	865 ± 289b	676 ± 285b	3440 ± 3351a
DO (mg/L)	11.30 ± 2.60a	10.02 ± 2.59ab	8.17 ± 4.25b	8.49 ± 3.04b
COD (mg/L)	21.5 ± 11.4	20.3 ± 7.2	24.2 ± 11.6	22.6 ± 14.1
BOD_5 (mg/L)	3.2 ± 2.8ab	2.3 ± 1.5b	3.7 ± 3.2ab	3.9 ± 3.1a
NH_3-N (mg/L)	2.29 ± 4.14a	1.45 ± 2.50b	1.58 ± 2.00b	1.42 ± 1.95b
TP (mg/L)	0.26 ± 0.39b	0.15 ± 0.19d	0.32 ± 0.48a	0.20 ± 0.17c
Oils (mg/L)	0.04 ± 0.14	0.04 ± 0.15	0.02 ± 0.03	0.04 ± 0.09
VP (μg/L)	1.2 ± 1.3b	1.0 ± 0.7b	0.7 ± 0.7b	2.3 ± 31a
Fluoride (mg/L)	0.36 ± 0.22	0.43 ± 0.17	0.39 ± 0.16	0.34 ± 0.15
Sulfide (μg/L)	7 ± 9b	6 ± 5b	11 ± 11a	6 ± 6b
Surfactant (mg/L)	0.10 ± 0.13ab	0.11 ± 0.10a	0.05 ± 0.05b	0.06 ± 0.06b
Pb (μg/L)	1 ± 2a	1 ± 1ab	1 ± 11a	1 ± 1b
Cu (μg/L)	3.9 ± 7.8b	2.0 ± 1.0b	2.8 ± 3.3b	14.8 ± 26.7a
Zn (μg/L)	30 ± 20b	30 ± 30b	60 ± 90a	10 ± 20b
As (μg/L)	1.3 ± 1.7b	1.3 ± 1.1b	2.4 ± 2.9a	1.5 ± 1.2ab

Groups with different letters (a, b, c, and d) are significantly different ($P < 0.05$), and those groups with the same letter are not significantly different at the 5% level.

The average concentrations of BOD_5 in summer and autumn were 3.7 mg/L and 3.9 mg/L, respectively, which were slightly higher than those in spring and winter. The highest average concentrations of NH_3-N was observed in winter (2.29 mg/L), which was dramatically higher than that in spring, summer, and autumn. This may be due to the low biological treatment efficiency of NH_3-N in domestic and industrial wastewater in winter. In addition, extensive use of coal in the winter increases the nitrogen content of the water. The same phenomenon was observed on the distribution of VP concentration, the average concentration in winter (2.3 μg/L) was about 2 ~ 3 times higher than that in other seasons. The average concentration of TP in summer was higher than that in the other three seasons, which was similar to that of sulfide in four seasons. We speculate that the higher temperature in summer increases the release of phosphorus and sulfide in the sediment, which was also reported by Wei and Shao-yong (2014). The average surfactant concentrations in winter and spring were 0.10 and 0.11 mg/L, respectively. Meanwhile, the average concentrations in summer and autumn were 0.05 and 0.06 mg/L, respectively.

Heavy metal concentrations were generally at low level in the Beiyun River. The average concentrations of Pb in winter and summer were slightly higher than those in spring and autumn. The average concentration of Cu in autumn (14.8 μg/L) was observably higher than that in the other three seasons. The trend of variations of Zn concentrations among four seasons was basically consistent with that of As, and the highest average concentrations of those appeared in summer. This may be because heavy metals in the soil enter the river through surface runoffs from heavy rainfall in summer (Liu et al. 2019).

Spatial and temporal distribution of WQI

We calculated the WQI of 16 water samples collected from the Beiyun River basin among four seasons. The average WQI values in winter, spring, summer, and autumn were 88.15, 71.70, 78.92, and 90.12, respectively (Fig. 2a). WQI of autumn and winter were markedly higher than those in spring and summer. The water quality was evaluated as "good" during four seasons based on the WQI classification, which may be attributed to the implementation of Action Plan for Water Pollution Prevention and Control in China. To control point source pollution, the production projects that caused serious pollution to the water environment have been banned by the end of 2016. In addition, the livestock and poultry farms in the forbidden zones of Beiyun River have been closed or relocated to promote rural pollution prevention. These measures effectively control the discharge of pollutants, which is of great significance to the improvement of water quality of the Beiyun River.

During the sampling period, the water quality of "excellent" was dominant, and the proportion reached 44%. Samples with the water quality of "good" accounted for 31%. The "poor" sampling sites accounted for 18%, and 6% samples were at "very poor" level. One percent sample with the water quality of "unsuitable for drinking" was found in four seasons.

The water quality exhibited distinct seasonal variation with the best water quality in spring, followed by summer, winter, and autumn. We found that the conductivity of water in autumn is significantly higher than in other seasons, which indicates that the river has large amounts of salts in autumn (Bouaroudj et al. 2019). This may be a consequence of an exogenous contribution caused by thrusting and leaching from surrounding farmlands. Agricultural activities (cultivation, fertilization, and irrigation) are frequent in autumn, and the traditional flooding irrigation has resulted in the loss of soil nutrients (Borin et al. 2016). Therefore, agricultural non-point sources have a greater impact on river water quality in autumn. In winter, as the temperature of the Beiyun River

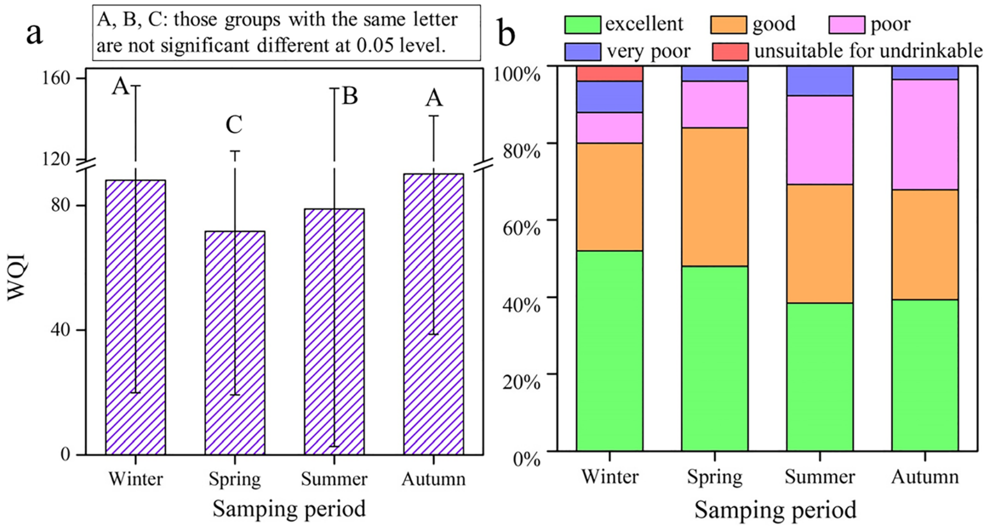

Fig. 2 **a** Distributions of WQI values among four seasons of Beiyun River; **b** proportion of different water quality grades in four seasons

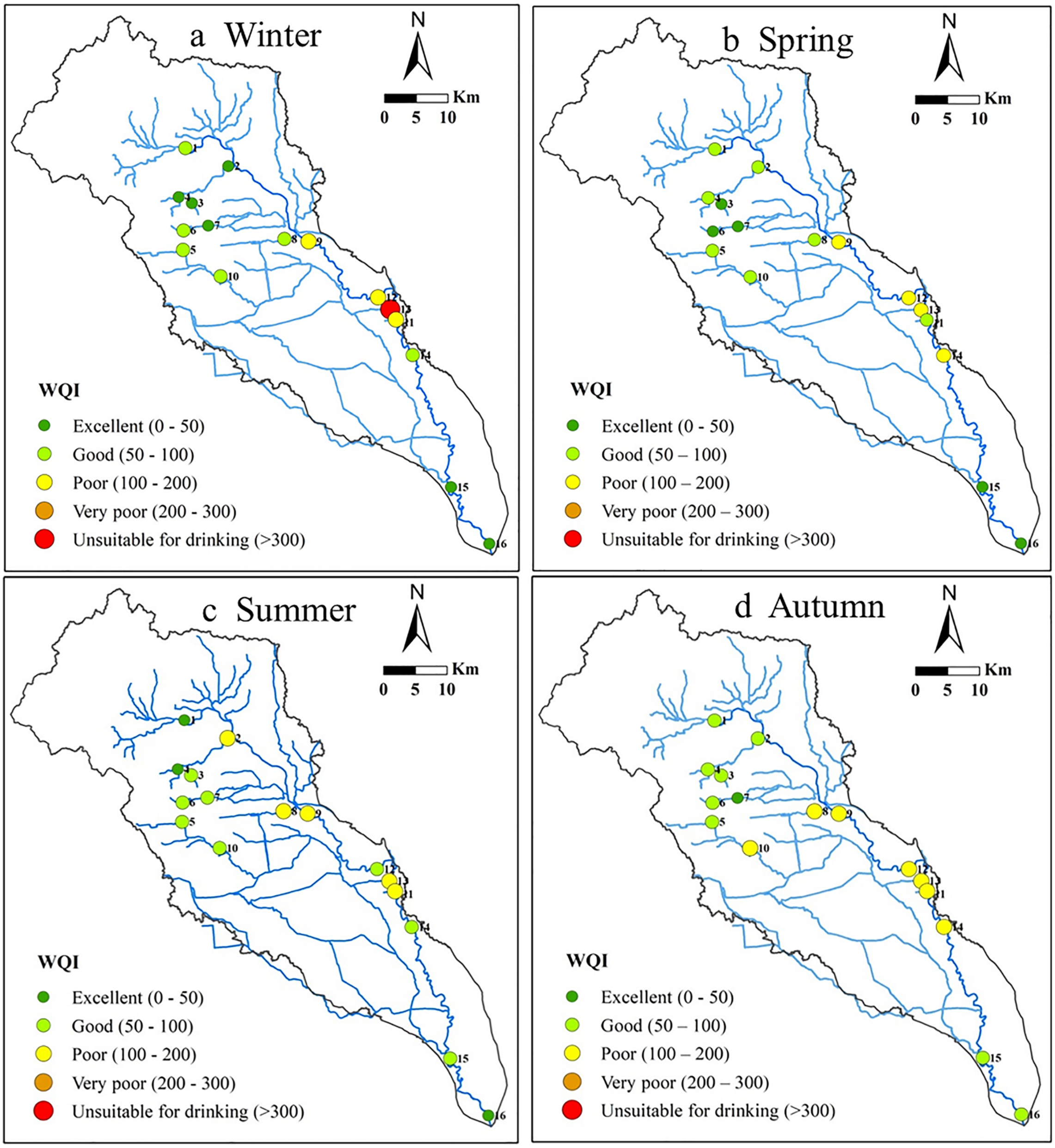

Fig. 3 The spatial distribution of WQI in winter (**a**), spring (**b**), summer (**c**), and autumn (**d**) in the Beiyun River

decreases, the DO content increased. However, the value of NH_3-N is the largest in winter. The lower runoff and flow velocity of river during the winter (dry season) is not conducive to the dilution and diffusion of pollutants, resulting in worse water quality in winter. In addition, the activity of microorganisms is suppressed in winter, resulting in low self-purification ability of the river (Zhai et al. 2020). Water quality varies with seasons related to various water quality parameters, which was complex and had no clear conclusions (Sun et al. 2015).

Figure 3 provides that the spatial distribution of water quality in the Beiyun River had certain regularity. In general, the water quality of the upstream and downstream was better than that of the middle reaches. This is likely because the agriculture land areas and rural residential land areas in the midstream section were larger than those in the upstream and downstream sections. The characteristics of sewage water in rural areas are scattered, difficult to collect, and have high pollution load. In addition, our investigation found that direct discharge of livestock wastewater and domestic sewage in rural areas still exists, posing a serious threat to the river water quality. Dai et al. (2015) found that 60% of the pharmaceuticals and personal care products (PPCPs) burden in the Beiyun River was from freshly discharged untreated sewage. The land use type is the primary factor influencing seasonal changes in water quality of the Beiyun River basin.

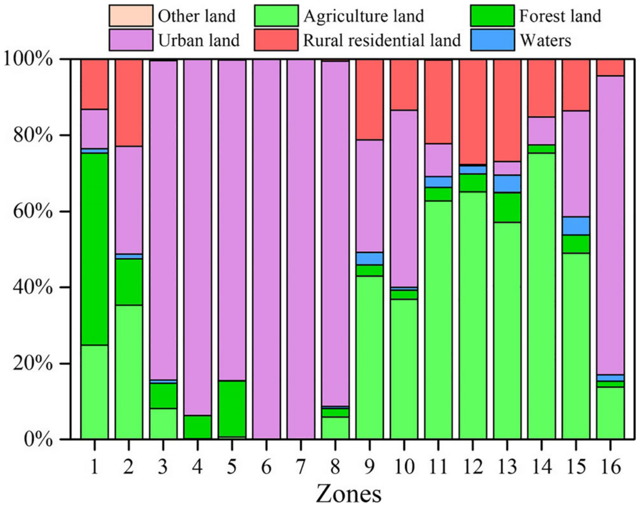

Fig. 4 Proportion of different land uses of 16 catchment zones of the Beiyun River

The findings were consistent with previous papers (Gu et al. 2017) and indicated that WQI could be used to assess integrated water quality in watersheds. The WQI model uses simple results to represent the overall situation of multiple indicators, providing strong support for water quality management (Pesce and Wunderlin 2000; Wu et al. 2018).

Impact of land use types on river water quality

Figure 4 displays the proportion of land use types in the 16 watershed areas in the Beiyun River basin. We could see that the proportion of various land use in the 16 watershed areas varied significantly. Urban land accounted for more than 75% of the area in zones 3, 4, 5, 6, 7, 8, and 16, and the proportion in zones 6 and 7 was 100%. The rural residential and agriculture lands with unbalance distribution were mainly concentrated in the upstream and midstream of the Beiyun River. Overall, the proportion of forest land in the Beiyun River basin is relatively small (9.33%), and the proportion of forest land in the 16 sites varies greatly, reaching 50.49% in zone 1, but less than 15% in other zones.

The relevance between land use types with WQI of 16 sampling sites in the Beiyun River among four seasons was analyzed by linear regression method. From Fig. 5, we could conclude that the area ratio of agriculture land and rural residential land in winter, spring, and summer was positively correlated with the value of WQI. However, the area ratio of urban land in winter, spring, and summer was negatively correlated with the value of WQI. The fitting results showed that the correlation between the proportion of land use types and water quality was not obvious in autumn.

The relation between land use types with water quality was significant in natural or semi-natural watersheds. However, socio-economic activities in urban areas would affect the response of water quality to land use types (Hong et al. 2009). Many articles showed that agriculture land has a bad effect on river water quality (Bu et al. 2014; Lee et al. 2009). This study discovered that agriculture land was inversely associated with water quality in winter and spring, which was consistent with the previous conclusion. This might be related to fertilization activities during farming. Excessive application of chemical fertilizers could directly or indirectly affect the content of nitrogen, phosphorus, and other elements in rivers (Huang et al. 2017).

Figure 5 also illustrated that the ratio of rural residential land was positively correlated with WQI, especially during winter and spring. It indicated that the rural residential land had adverse effects on the quality of river water. This was mainly due to rural sewage treatment facilities were inadequate and the sewage treatment capacity was poor (Neal et al. 2005). Meanwhile, we found that the coverage of rural sewage collection pipe network was limited in the process of field investigation. It was regrettable that part of the rural domestic sewage without treatment would be discharged directly into the river, which severely degraded river ecological services functions and damaged river ecosystems.

Nevertheless, the water quality was better when the ratio of urban land is large, especially in winter and spring. Sewage water in urban district of Beijing was collected and treated entirely, and the effluent from the sewage treatment plant was an important source of Beiyun River. Reclaimed water could dilute the concentration of pollutants and improve water quality of Beiyun River (Mano et al. 2017). In addition, the relocation of industrial enterprises in Beijing effectively reduced industrial pollution on the water quality of the Beiyun River.

The proportion of forest land area in the Beiyun River was small, so the correlation with water quality was not obvious in the four seasons. Additionally, we found that the relationship between water quality with land use was obvious during the dry seasons (winter, spring), but not obvious in the rainy seasons (summer, autumn). This might be related to the rainwater runoff during the rainy season which impacts on river water quality that was highly uncertain (Old et al. 2003). Factors such as the underlying surface (Hollis and Ovenden 1983; Niyogi et al. 2010), rainfall intensity (Zhang et al. 2019), slope (von Freyberg et al. 2014), and soil properties (Beck et al. 2011) all affect the quality of rainfall.

The effect of land use types on water quality was caused by human's agricultural production and social activities. Water quality environment was directly affected by the sewage collection rate and sewage treatment capacity of the river basin. Therefore, we were able to forecast the river water quality by measuring the scale of land use in the basin.

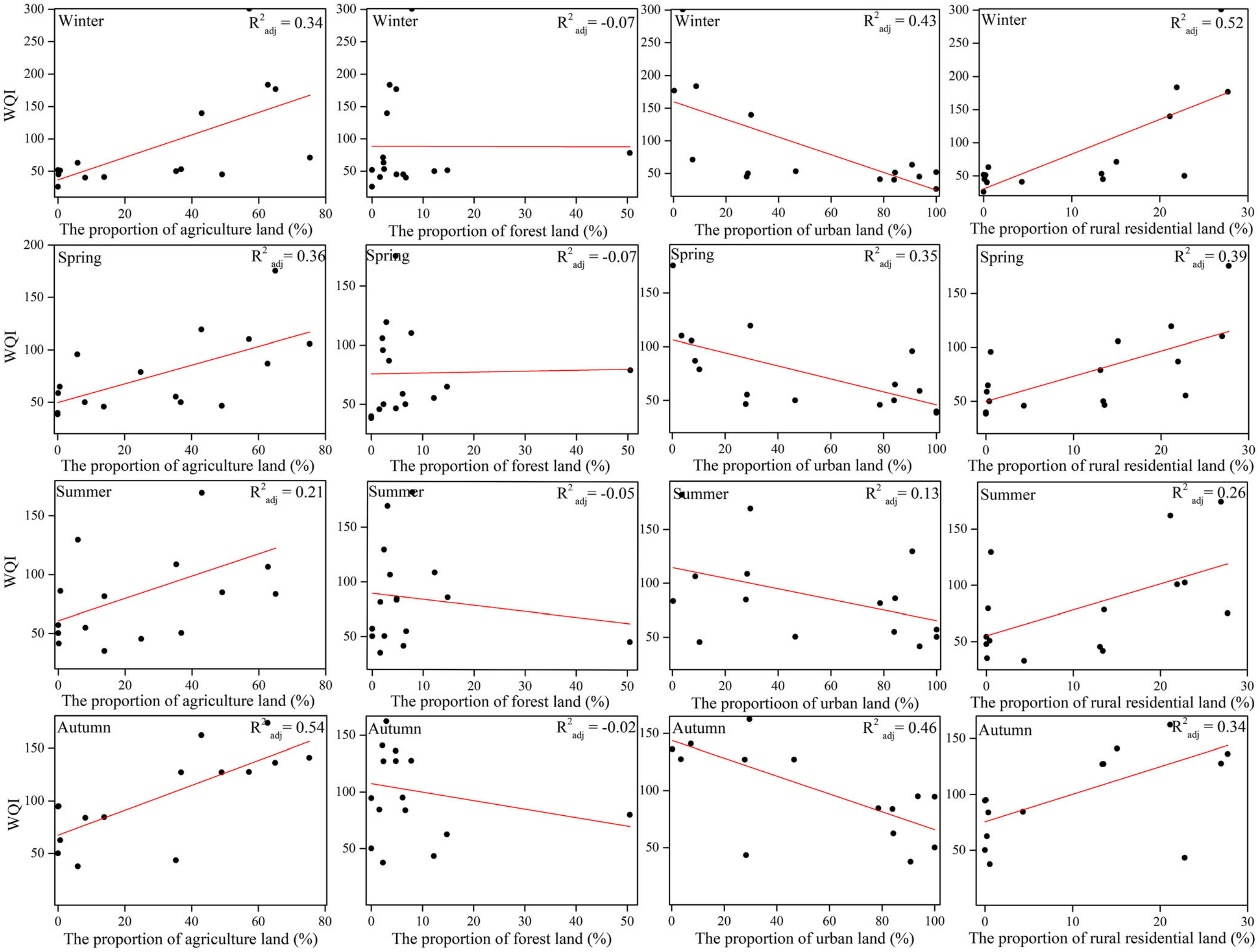

Fig. 5 Relevance between land use types with WQI in winter, spring, summer, and autumn

Analysis of pollutant sources

Principal component analysis (PCA) can be used to identify the sources of pollutants. The Kaiser-Meyer-Olkin (KMO) value and the Barlett test value were 0.59 and 0 respectively, indicating the data in this study were suitable for PCA analysis. PCA method indicated that 17 pollution parameters could be distributed into five principal components (PCs), potentially suggesting the input of different pollutants from different sources as shown in Table 2.

PCA indicated that conductivity, COD, BOD_5, NH_3-N, TP, Oils, VP, and Cu had high loadings on first principal component (PC1), and they are derived from the waters emitted from the sewage treatment plant, agricultural production, and industry including chemical plants, catering industry, and machinery industry (Liu et al. 2020). Second component (PC2) explained that 20.25% of the total variance on which fluoride, Pb, and Zn were positively and largely influential. These elements were mainly from anthropogenic activities, such as mineral processing and smelting (Zhao et al. 2018). Third component (PC3) was responsible for 13.25% of the variance with high loadings of pH and sulfide. Sulfide in the Beiyun River may come from soil or atmospheric deposition. As had high loadings in fourth component (PC4), which comes from the waters emitted from industrial production. Overall, we think that domestic sewage and industrial wastewater are important factors affecting the water quality in Beiyun River.

Conclusions

This study used the WQI to comprehensively evaluate water quality of 16 sites from the Beiyun River basin in four seasons. The data indicated that most of water quality parameters (with the exception of pH, COD, fluoride, and oil) in the Beiyun River varied greatly with seasons. Water quality in the Beiyun River was generally “good” during sampling period based on the WQI classification. The water quality changed significantly along the Beiyun River, and the water quality in the upstream and downstream was generally better

Table 2 The factor loadings of substances

	PC1	PC2	PC3	PC4
Cumulative (%)	39.73	59.98	73.26	79.76
Temperature	−0.097	**−0.735**	0.267	−0.244
pH	**−0.615**	−0.122	**0.545**	0.217
Conductivity	**0.675**	0.436	0.201	−0.324
DO	**−0.624**	−0.154	0.100	0.344
COD	**0.849**	0.151	−0.125	0.340
BOD_5	**0.852**	−0.017	−0.075	0.172
NH_3-N	**0.875**	0.279	−0.034	−0.257
TP	**0.919**	−0.084	0.010	−0.020
Oils	**0.700**	−0.397	0.442	−0.095
VP	**0.878**	−0.250	0.020	−0.005
Fluoride	−0.244	**0.639**	0.439	0.418
Sulfide	0.471	−0.386	**0.565**	0.269
Surfactant	0.383	0.317	**−0.753**	0.220
Pb	0.334	**0.802**	0.362	0.073
Cu	**0.663**	−0.362	0.426	0.093
Zn	0.081	**0.851**	0.349	−0.024
As	0.463	−0.436	−0.326	**0.503**

Bold typeface, strong correlation coefficient

than that in the middle reaches. Additionally, the water quality exhibited distinct seasonal variation with the best water quality in spring, followed by summer, winter, and autumn.

We examined the influence of land use on WQI in the Beiyun River. The result demonstrated that agriculture land and rural residential land had adverse effects on water quality, while the proportion of urban land had positive correlation on water quality. The impact of living activities of rural residents on water quality should be noticed. According to the research results, improvement of sewage collection rate and treatment capacity and appropriate amount of fertilizer are the basis of water quality improvement. We believe that our research contributes effective suggestions for governance and protection of Beiyun River.

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Compliance with ethical standards

Conflict of interest We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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