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Contamination Assessment and Source Analysis of Urban Waterways Based on Bayesian and Principal Component Analysis—A Case Study of Fenjiang River

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Abstract: Contamination assessment and source analysis of urban waterways are important for the environmental management of water resources. This study applied an improved water quality index (WQI), which was called WQI-DET (water quality index deterioration) to analyze the Fenjiang River's (Foshan City, South China) water quality monitoring data from 2016 to 2021. Between 2016 and 2021, the Fenjiang River had the highest WQI-DET value in 2016. Since then, the water quality has shown a decreasing trend year by year. Then, through Spearman analysis, it was identified that the chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) are the main factors of water quality deterioration. Moreover a Bayesian model was used to analyze and evaluate the main factors. On this basis, relationships between COD, NH_3-N, the natural environment, and human activities were analyzed by principal component analysis. The results showed that NH_3-N has been the main factor affecting the water quality in recent years and there were no significant changes in COD and NH_3-N during the study period. However, COD and NH_3-N showed significant differences in spatial distribution. Meanwhile, human activities contributed 52.3% to the variability in the water quality of the Fenjiang River, and natural factors only 26.8%; factors not considered in this study contributed the remaining 20.9%. Human activities had a more significant impact on the water quality of the Fenjiang River than natural factors.

Keywords: contamination assessment; source analysis; Bayesian; principal component analysis

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1. Introduction

Water is an indispensable resource for urban development. Water resources provide conditions for economic and social development. However, with the rapid socio-economic development, the contamination of rivers is becoming increasingly severe [1]. The water quality of urban waterways is not only affected by natural conditions such as flow rate and precipitation but is also greatly impacted by industrial and agricultural contamination and domestic sewage [2]. It is therefore highly important to monitor and assess the water quality of rivers, study their spatial and temporal distribution characteristics, and analyze the sources of contamination to facilitate the environmental management of water resources and control the water quality of rivers effectively [3,4].

The assessment of water quality and analysis of contamination sources are key points in water research, which are also critical for environmental risk analysis, aquatic environmental protection, and contamination control [5–7]. At present, common water quality assessment methods include the single factor index method, the comprehensive pollution index method [8–10], methods based on multivariate statistics [11,12], methods based on mathematical models [13,14], the water quality index (WQI), etc. Among these, the WQI method has been widely used to analyze the water quality status and water quality trend of lakes and rivers. Different from comparing the evaluation results of various water quality indicators, the WQI converts the combination of multiple physical, chemical, and biological indicators into a single value to reflect the water quality situation, thus providing comprehensive information for evaluating the overall quality of water [15,16]. However, because the different WQI methods have different limitations in different cases [17], the improved WQI method of selecting key indicators helps water managers obtain the water quality status at the lowest cost. Sun et al. [18] established an improved WQI model through principal component analysis (PCA), showing that the improved WQI can better reflect the seasonal change in water quality and reduce the analysis cost. Koçer et al. [19] used PCA to select key indicators to calculate the improved WQI, which was effective in assessing the impact of trout farm wastewater on stream water quality. Yang lie et al. [20] established a WQI model including four major pollution indicators, namely, the five-day biochemical oxygen demand (BOD5), permanganate index (PI), chemical oxygen demand (COD), and dissolved oxygen (DO), to evaluate the water quality of Jinyin Lake in Wuhan and achieved good results. It can be seen that the selection of key indicators of water quality is very important when applying the WQI method. Based on the improved WQI method, a WQI model for a water quality assessment of the Fenjiang River was constructed in this study.

These common water quality assessment methods are adequate for selecting water quality indicators and data statistics. However, uncertain factors in the water quality assessment process have only rarely been systematically considered or not at all. Water quality assessment is extremely sensitive to uncertainties, and it is crucial to fully consider them to obtain accurate results [21]. The uncertainties in water quality assessment are divided into four main categories: uncertainties in model structure, parameters, measurements, and analysis [22]. Compared with the uncertainties in model structure and parameters, the uncertainties in measurement and analysis have less impact on the assessment results [23]. On this basis, the Bayesian model and the generalized likelihood uncertainty estimation method have been used to effectively control the uncertainties in water quality by assessing model structure to a certain extent [24,25]. Considering the uncertainties in water quality assessment, researchers in China have introduced new theoretical methods and proposed assessment methods, such as fuzzy mathematics, grey correlation, and artificial neural networks. These methods take the fuzziness, greyness, and non-linearity of water quality assessment into account and have improved surface water quality assessment, but high numbers of calculations and complex calculations in practical applications represent inevitable problems [26]. In order to solve the problems above, this paper intends to combine the WQI model and the Bayesian method to evaluate the water quality of the Fenjiang River, and further discuss the causes of pollution through principal component analysis, so as to explore a more efficient and accurate method of water quality evaluation and pollution cause analysis.

2. Study Area

The Fenjiang River (Foshan Waterway), see Figure 1, a typical inland river flowing through urban areas in the Pearl River basin, was studied. The Fenjiang River is located between 112°59′14″ E–113°12′52″ E and 22°58′33″ N–23°9′11″ N in the downstream network area of the Pearl River delta. It flows through Chancheng and Nanhai, the two most densely populated and economically populated regions in Foshan. The river starts at the Shakou sluice of the Tanzhou waterway, west to the Shawei Bridge in Guicheng, Nanhai District, and enters the Pingzhou waterway, with a length of 25.5 km. The Shakou and Shiken sluices control the upstream water flux, forming a semi-closed water body. The terrain in the basin is flat with a small drop. The sunshine duration is about 1800 h per year. The average annual temperature ranges between 21.2 and 22.2 °C. The frost-free period is more than 350 days. Precipitation is abundant, and the average annual precipitation is between 1600 and 2000 mm. The total basin area of the Fenjiang River is nearly 265 km². The river network in the basin is crisscrossed and scattered. Industry, mining, and commerce are the main human activities in the catchment. The population density and the risk of river contamination are high. Five automatic water quality monitoring stations have been installed in different sections of the Fenjiang River, i.e., the sections of the Shakou sluice, Jinsha New Town, Renmin Bridge, Hengjiao, and Sanzhou.

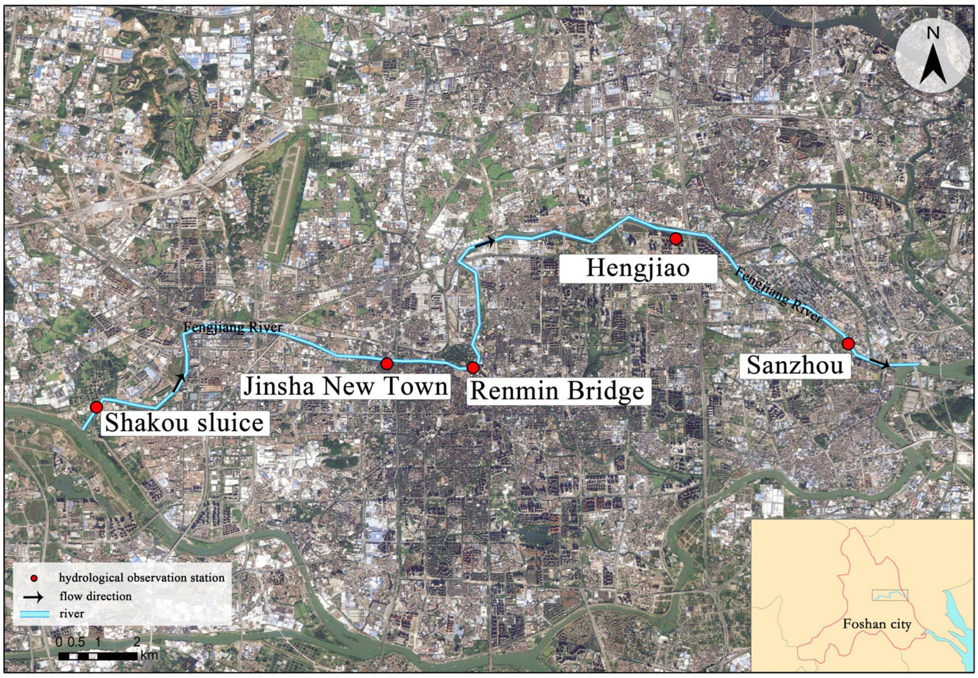


Figure 1. Fenjiang River (Foshan waterway) catchment.

3. Methods and Data

3.1. Methods

This study is based on the improved water quality index (WQI-DET). WQI has been widely used in river water quality research. Huang et al. proposed a new method to calculate the WQI, i.e., the WQI-DET [27], based on the comprehensive water quality assessment method of China Surface Water Environmental Quality Standards (GB 3838-2002) shown in Table 1. Compared with the original index, ranging from 0 to 100, the WQI-DET has a broader range from -∞ (extremely poor water quality) to 100 (excellent water quality), which allows clear differentiation between bad and extremely bad water quality conditions to be made. The WQI-DET is calculated according to Equations (1) and (2).

$$WQI_{DET}^{j} = MIN(WQI_{DET_1}^{j}, \dots, WQI_{DET_i}^{j}, WQI_{DET_n}^{j}) \quad (1)$$

$$WQI_{DET_i}^{j} = 100 - MAX(0, \frac{C_{ij} - C_i^{\,I}}{C_i^{\,V} - C_i^{\,I}} \times 100) \quad (2)$$

where, $WQI_{DET_i}^{j}$ is the WQI-DET value of the water quality factor i of the water sample j, C_{ij} is the measured concentration of the water quality factor i of the water sample j, $C_i^{\,I}$ is the class I standard control index of the water quality factor i of the water sample j, $C_i^{\,V}$ is the class V standard control index of the water quality factor i of the water sample j.

Table 1. China Surface Water Environmental Quality Standards.

Water Quality Class	NH_3-N/mg·L^{-1}	COD/mg·L^{-1}	DO/mg·L^{-1}	NTU/FTU
Ⅰ	0.15	15	7.5	15
Ⅱ	0.5	15	6	20
Ⅲ	1	20	5	25
Ⅳ	1.5	30	3	35
Ⅴ	2	40	2	50

As shown in Figure 2, this study was carried out in four stages. First, the water quality monitoring data of Fenjiang River in Foshan City from 2016 to 2021 were calculated by WQI-DET. Then, the Spearman's method was used to analyze the correlation between the single factor WQI-DET of each water quality impact factor and the overall WQI-DET of Fenjiang River. It was found that NH_3-N and COD were significantly negatively correlated with the overall WQI-DET of Fenjiang River. Therefore, NH_3-N and COD were selected in this study to analyze the WQI-DET of the Fenjiang River. After that, the Bayesian model was used to analyze and evaluate the main factors of water quality damage, COD and NH_3-N. On this basis, the relationship between COD, NH_3-N, natural environment, and human activities is analyzed and discussed by principal component analysis. Among them, the natural environmental factors consist of altitude, rainfall, and flow, while the human factors consist of night light intensity, population, sewage treatment plant treatment capacity, sewage treatment plant effluent water quality.

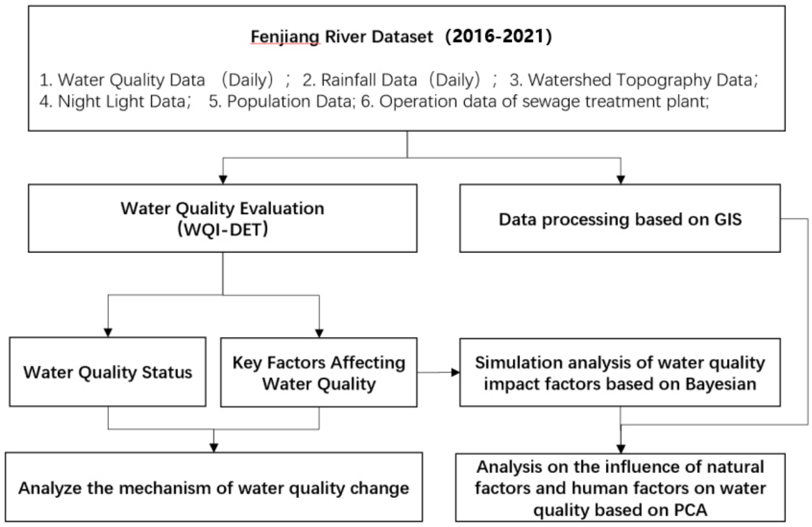


Figure 2. Research roadmap.

3.2. Water Quality Monitoring Data

There are five monitoring sections in Fenjiang River. Each section is sampled six times a day. From 2016 to 2021, it was sampled 65,700 times in total. The monitoring indicators are divided into physical indicators and chemical indicators, including pH, electrical conductivity, water temperature, flow, turbidity, NH_3-N, COD, and DO. Among the indicators monitored this time, NH_3-N, COD, DO, and turbidity are listed in China's surface water environmental quality standards. Thus, NH_3-N, COD, DO, and turbidity were selected as the calculation basis of WQI-DET in this study.

On this basis, the Bayesian model was used to analyze COD and NH_3-N, which were identified as the main factors that deteriorated the water quality. Relationships between COD, NH_3-N, the natural environment, and human activities were analyzed by the principal component analysis. SPSS Statistics 26 was used to analyze correlations between various water quality indicators, and graphs were plotted in Origin 2021.

3.3. Human Social Activity Data

3.3.1. Selection of Human Social Activity Data

With the rapid development of cities and the rapid increase in urban population, the conflict between people and land has become increasingly prominent. This poses a major challenge to the integrated management of regional ecological environment [28,29]. In order to better identify the impact of human social activities on the water quality of urban waterways, this study takes into account the factors of human social activities such as night light intensity, population, and water treatment capacity of sewage treatment plants.

3.3.2. Night Light Intensity

Some studies have shown that the night light intensity is closely related to the regional economic level [30]. Limited by the availability and accuracy of GDP data in the study area, the nighttime light brightness can effectively reflect the level of economic activities in the study area, which is conducive to further research. The project adopts the monthly data of Flint night light from 2016 to 2021 within the research scope, see Figure 3.

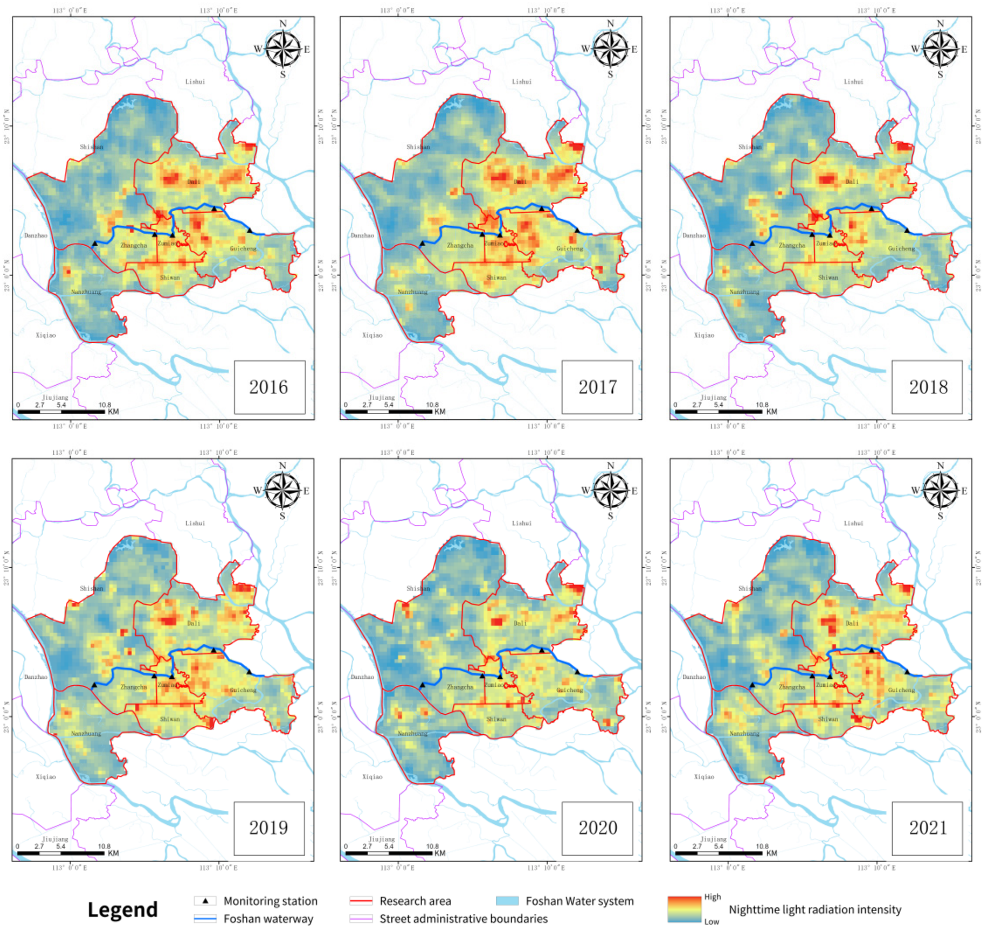


Figure 3. Night light intensity map of Fenjiang River (2016–2021).

3.3.3. Population

The traditional method of statistics of population distribution data through census has some problems such as slow updating speed and long statistical cycle [31]. In addition, the traditional method of taking administrative boundaries as the unit of population statistics cannot reflect the spatial heterogeneity of population distribution [32]. Therefore, some scholars have conducted population spatialization research based on night light data, which can provide new opportunities for more detailed description of the spatial distribution of population in the region [33,34].

The population data of this study are based on the population data in the statistical yearbooks of Foshan City, Nanhai District, and Chancheng District from 2016 to 2021, and then the population data are mapped according to the corresponding pixel intensity of the annual synthetic data of Flint night light. The results are shown in Figure 4.

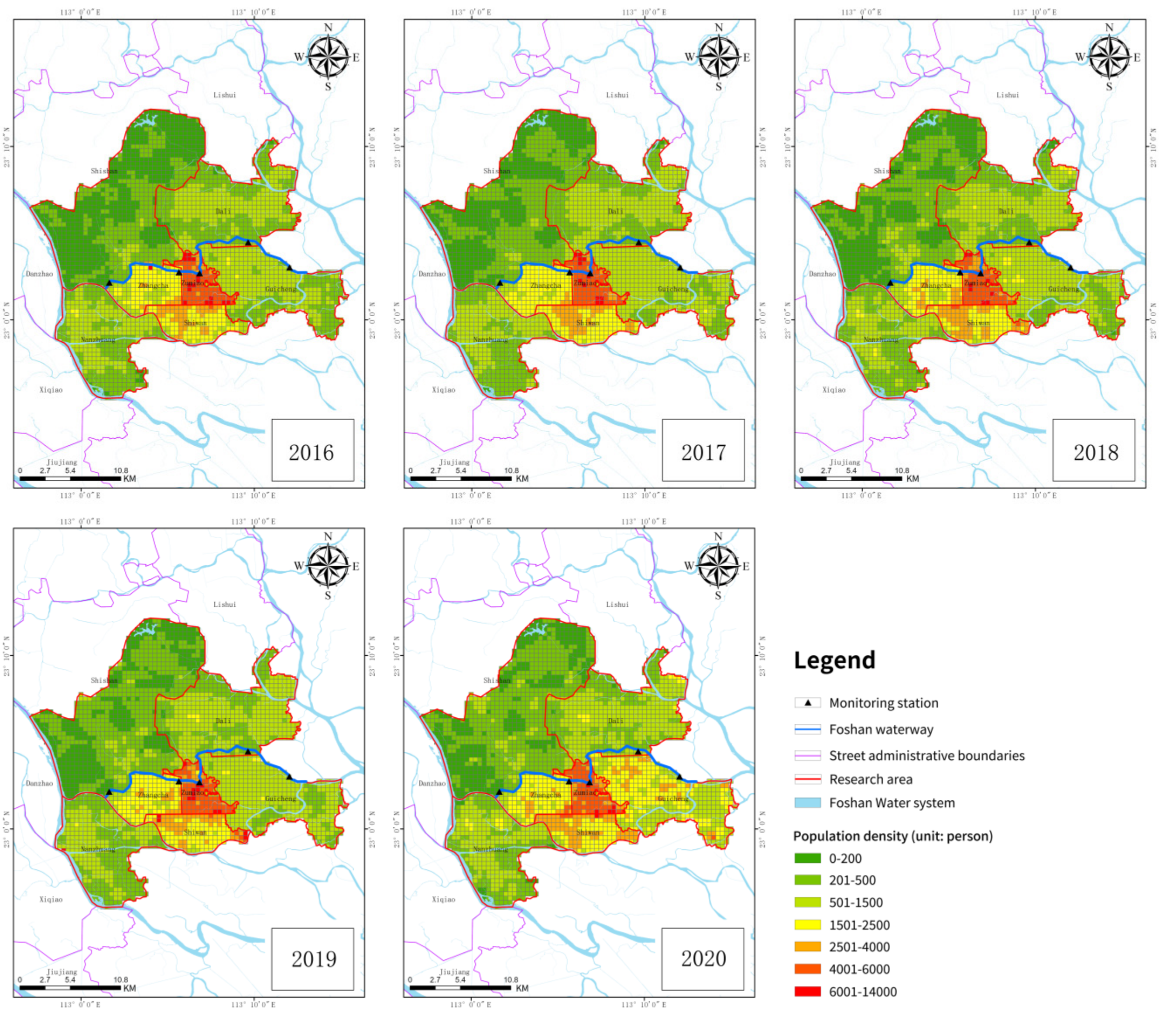


Figure 4. Population density grid of Fenjiang River (2016–2020).

3.3.4. Operation Data of Sewage Treatment Plant

The monthly operation data of 16 sewage treatment plants in the study area were collected from 2016 to 2021, including the treated water volume, COD inlet concentration, COD outlet concentration, COD reduction, NH_3-N inlet concentration, NH_3-N outlet concentration, and NH_3-N reduction.

4. Results

4.1. Overall Water Quality Based on the WQI-DET

The WQI-DET values ranged from −322 to 58.06 between 2016 and 2021 (shown in Table 2), with an average value of −42.60, which is generally poor. The maximum value appeared in the Shakou sluice section, while the minimum value appeared in the Hengjiao section. Spearman correlation analyses were conducted between each water quality variable and WQI-DET values, and the results are shown in Figure 5. All water quality variables significantly correlated with WQI-DET values ($p < 0.05$). WQI-DET values were negatively correlated with turbidity (R = −0.84), NH_3-N (R = −0.44), and COD (R = −0.05). In contrast, they were positively correlated with discharge, DO, pH, and EC, indicating that high values of turbidity, NH_3-N, and COD were the main factors preventing the Fenjiang River's water quality from satisfying environmental standards. Therefore, NH_3-N and COD were selected in this study to analyze the WQI-DET of the Fenjiang River.

Table 2. WQI-DET values of the Fenjiang River from 2016 to 2021.

Section	Shakou Sluice	Jinsha New Town	Renmin Bridge	Hengjiao	Sanzhou
2016	−278.89	17.39	−60.01	−26.26	−69.55
2017	40.38	/	−60.01	−20.78	−122.09
2018	30.43	/	1.56	−322.50	−66.92
2019	−5.68	−64.76	−11.16	−64.21	−24.62
2020	38.19	6.20	−28.43	−16.62	0.33
2021	58.06	−88.82	−33.06	−30.52	−10.77
Average	−19.59	−32.50	−31.85	−80.15	−48.94
Maximum	58.06	17.39	1.56	−16.62	0.33
Minimum	−278.89	−88.82	−60.01	−322.50	−122.09

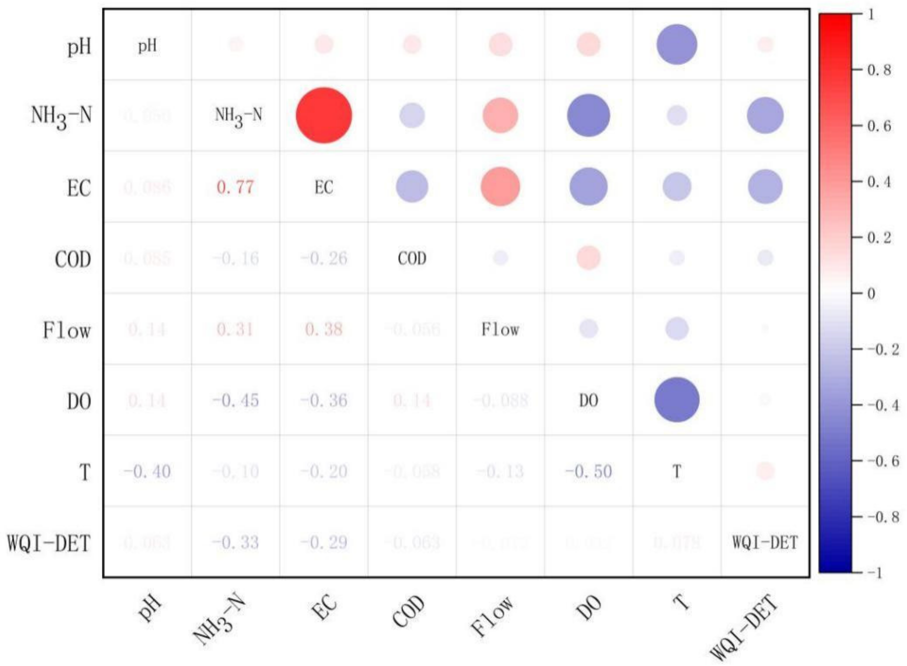
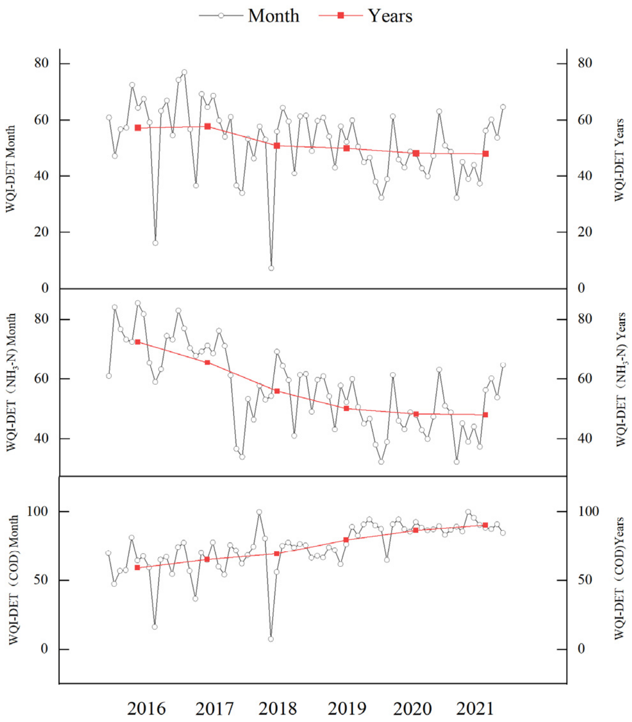


Figure 5. Correlation matrix between the WQI-DET and various water quality variables.

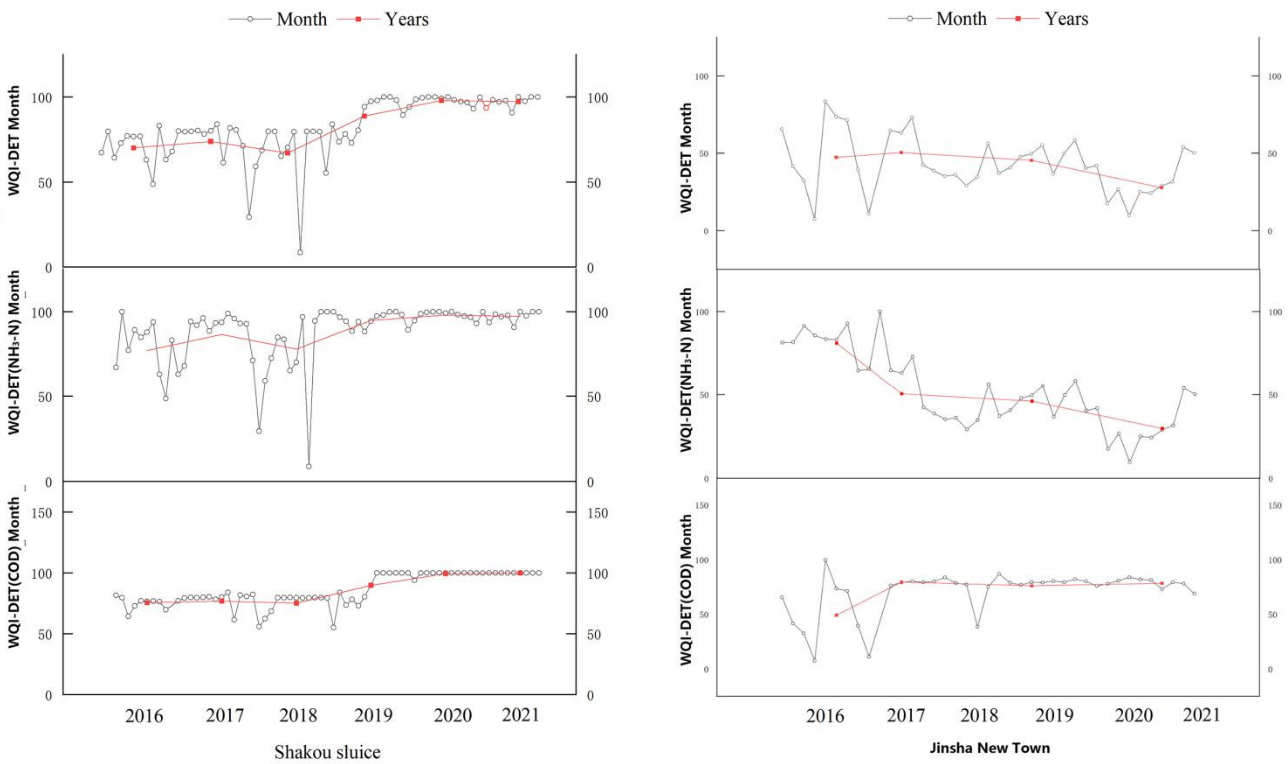
4.2. Interannual Evolution of Water Quality

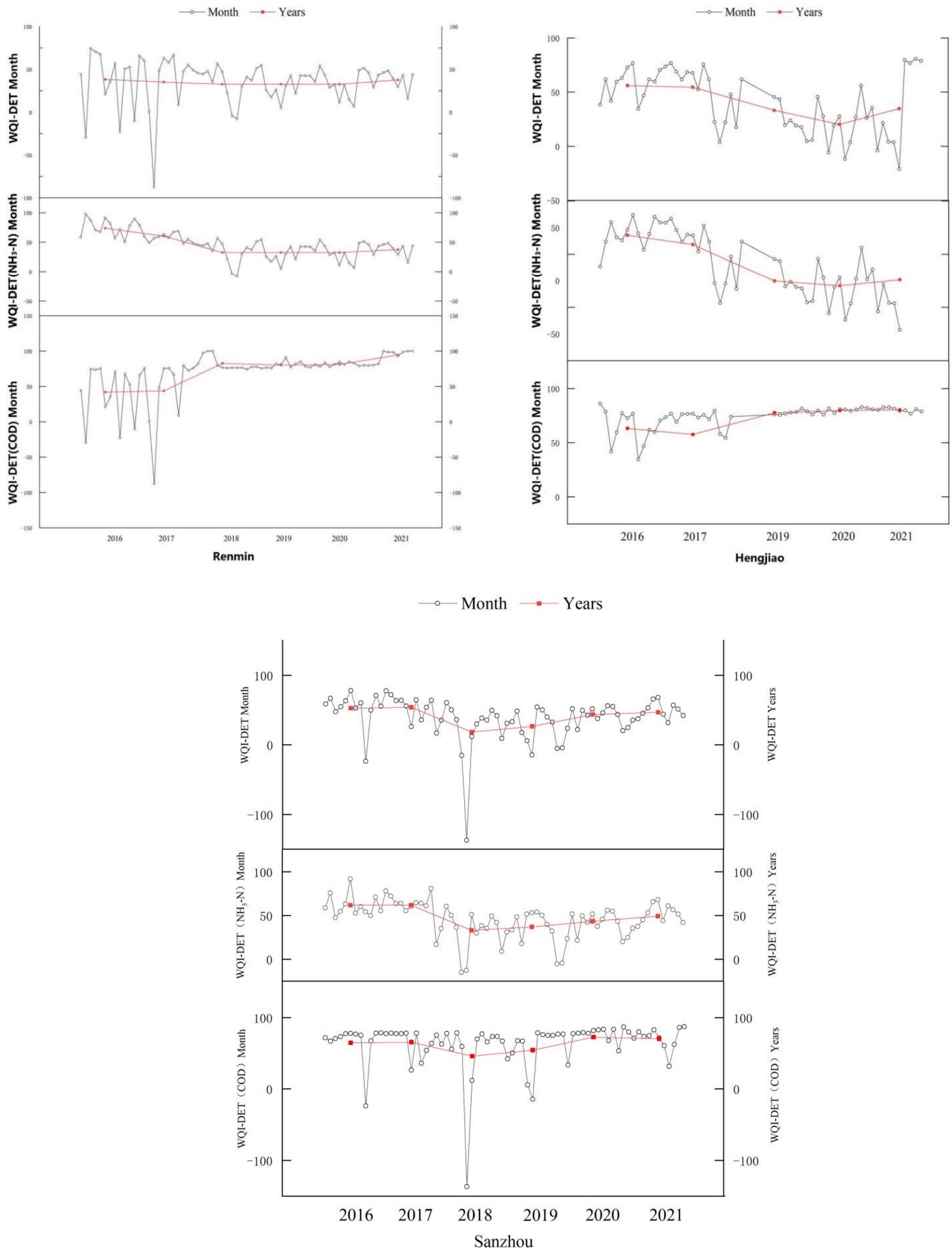
The variation in the WQI-DET in the Fenjiang River from 2016 to 2021 is shown in Figure 6a. The WQI-DET (NH_3-N) and WQI-DET (COD) showed contrasting patterns. The

WQI-DET (NH_3-N) showed an overall decreasing trend, with the highest value of 85.42 in 2016 and the lowest value of 32.26 in 2021. The WQI-DET (COD) showed an increasing trend, with the lowest value of 7.26 in 2018 increasing to 100 in 2021. The average value in the study period was 74.23. In contrast, the impact of NH_3-N on the deterioration of the water quality in the Fenjiang River from 2016 to 2021 was greater than that of COD.

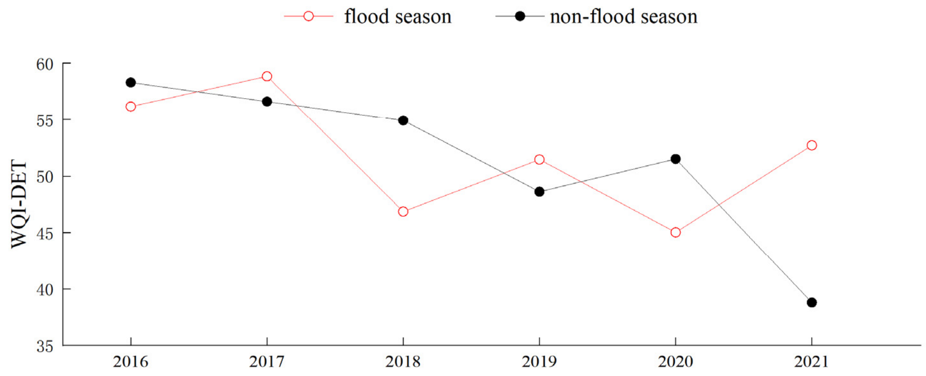


(**a**)

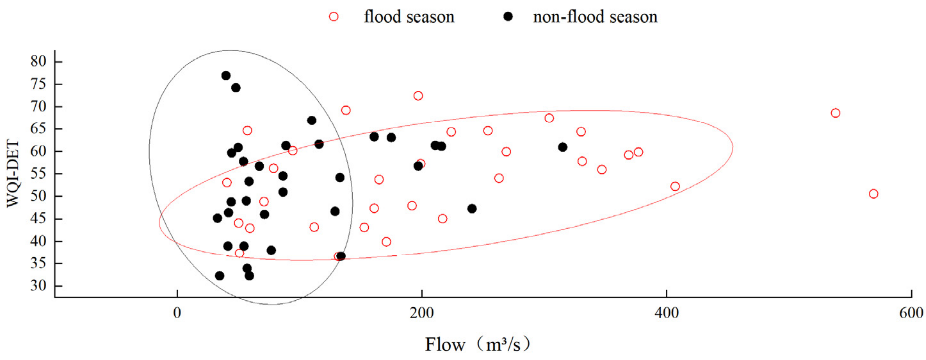



Month
Years
WQI-DET Month
WQI-DET(NH₃-N) Month
WQI-DET(COD) Month
2016
2017
2018
2019
2020
2021
Renmin
Hengjiao
WQI-DET Years
WQI-DET（NH₃-N）Month
WQI-DET（NH₃-N）Years
WQI-DET（COD）Month
WQI-DET（COD）Years
Sanzhou

(**b**)



(**c**)



(**d**)

Figure 6. (**a**) Variation in the WQI-DET of the Fenjiang River from 2016 to 2021. (**b**) Variation trend of the WQI-DET of Fenjiang River sections from 2016 to 2021. (**c**) Variation in the WQI-DET of Fenjiang River from 2016 to 2021 by flood season. (**d**) Variation in the WQI-DET of Fenjiang River from 2016 to 2021 by flood season.

According to Figure 6b, the interannual trend in water quality differed between sections of the Fenjiang River. The distribution range of the WQI-DET in the Shakou sluice section was 8.65–100, with an average value of 81.91. The lowest WQI-DET occurred in 2018, followed by an increasing trend, indicating that upstream water quality improved between 2018 and 2021. In the Jinsha New Town section, the WQI-DET ranged from 7 to 83.47, with an average value of 42.83. The highest WQI-DET was found in 2017, and the water quality deteriorated after that. The range of the WQI-DET in the Renmin Bridge section was −87.61 to 74.64, with an average value of 34.73. The WQI-DET values in the Renmin Bridge section increased from 2016 to 2021, and the change was relatively stable. The overall water quality in the Renmin Bridge section was worse than that of the Shakou sluice and Jinsha New Tows sections. The WQI-DET in the Hengjiao section ranged from −21.06 to 79.76, with an average value of 38.97. The changes in water quality in the Hengjiao section could be divided into three stages: an increasing trend during 2016, a decreasing trend from 2016 to 2020, and an increasing trend from 2020 to 2021. The range of the WQI-DET in the Sanzhou section was −136.84 to 78.01, with an average of 38.8. This change could be divided into two stages: a decreasing trend from 2016 to 2018, and an increasing trend from 2018 to 2021.

Fenjiang River is located in a subtropical zone, so the impact of the flood season on water quality change should be considered. It can be seen from Figure 6c,d that the WQI-DET variation range of river water quality in the flood season was 45.03~58.82, and the average value was 53.15; The variation range of the WQI of river water quality in the non-flood season was 38.79~58.29, with an average value of 51.45. The Mann–Whitney U-test showed that there was no significant difference between the two groups.

4.3. Spatial Differences and Evolution of Water Quality

In terms of spatial distribution, the highest WQI-DET values of the Fenjiang River were in the Shakou sluice section, with an average value of 82.5, and the lowest was in the Renmin Bridge section, with an average value of 36.04 (Table 3). The water quality of the Shakou sluice section was relatively stable (Figure 7) because the section is located at the inlet of the Fenjiang River, with a large water volume and few human impacts. Since 2016, external sources have seriously affected the water quality of the Jinsha New Town section. The WQI-DET data points of the Renmin Bridge section were widely scattered compared to other sections. This section received not only polluted water from upstream, but also contamination from the surrounding area. The water quality of the Fenjiang River diminished in the order: Shakou sluice section > Jinsha New Town section > Sanzhou section > Hengjiao section > Renmin Bridge section. In the respective order, the water quality index decreased from the upstream to the midstream sections, the water quality of the monitoring points in the urban section decreased significantly, and the water quality index increased and tended to be stable from the midstream to the downstream sections. We speculated that this trend was related to patterns of human activities.

Table 3. Summary statistics of WQI values of the sections of the Fenjiang River.

Section	Shakou Sluice	Jinsha New Town	Renmin Bridge	Hengjiao	Sanzhou
Maximum	100	100	100	91.18	94.21
Minimum	−198.6	−82.92	−298.4	−239.2	−203.65
Average	82.5	40.04	36.04	37.54	36.88

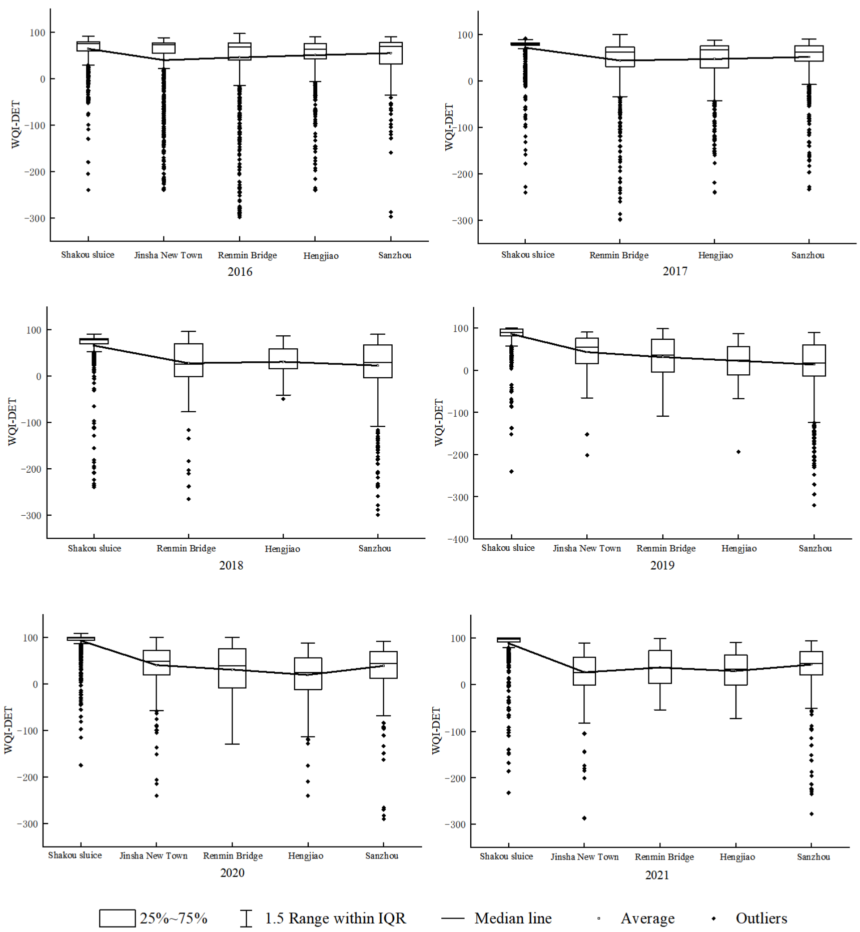


Figure 7. Spatial patterns of the WQI-DET in the sections of the Fenjiang River (2016~2021).

4.4. Bayesian Analysis of COD and NH_3-N Contamination Levels

To further analyze the levels and variations of COD and NH_3-N in the Fenjiang River, Bayesian statistics was used to evaluate the reliable range of COD and NH_3-N in the whole river basin during the study period. The concentrations of NH_3-N and COD in the Fenjiang River basin were normally distributed ($p > 0.05$). According to sample calculation, values of $\mu = 73.881$ and $\sigma = 17.566$ in the density function equation of the COD distribution of the monitoring samples were obtained. Based on these values, a Bayesian model was established (all calculations were carried out with PyMC 4.0), and the results are shown in Figure 8.

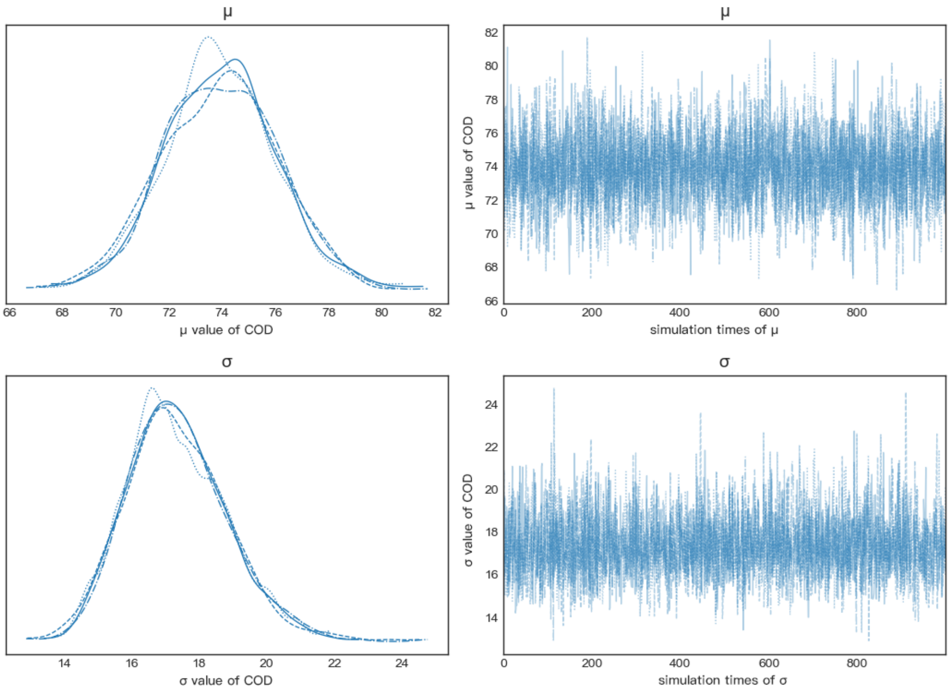


Figure 8. Bayesian analysis of COD.

The joint probability distribution diagram of the parameters was then plotted. According to Figure 9, there was no correlation between the parameters μ and σ, indicating that these two parameters are independent of each other. Figure 9 on the right shows the highest posterior density (HDP) of the posterior distributed μ and σ, with a 94% probability when the mean is between 70 and 78 and a 94% probability when the standard deviation is between 15 and 20.

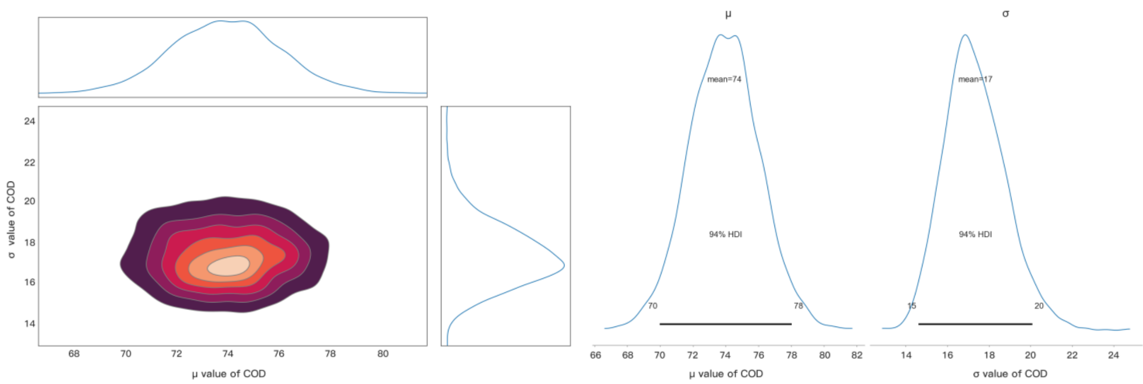


Figure 9. Joint probability distribution diagram of the parameters of COD.

Similarly, a Bayesian model of NH_3-N was established and the results are shown in Figure 10. According to sample calculation, the mean value of NH_3-N was 57.029, and the standard deviation was 13.783.

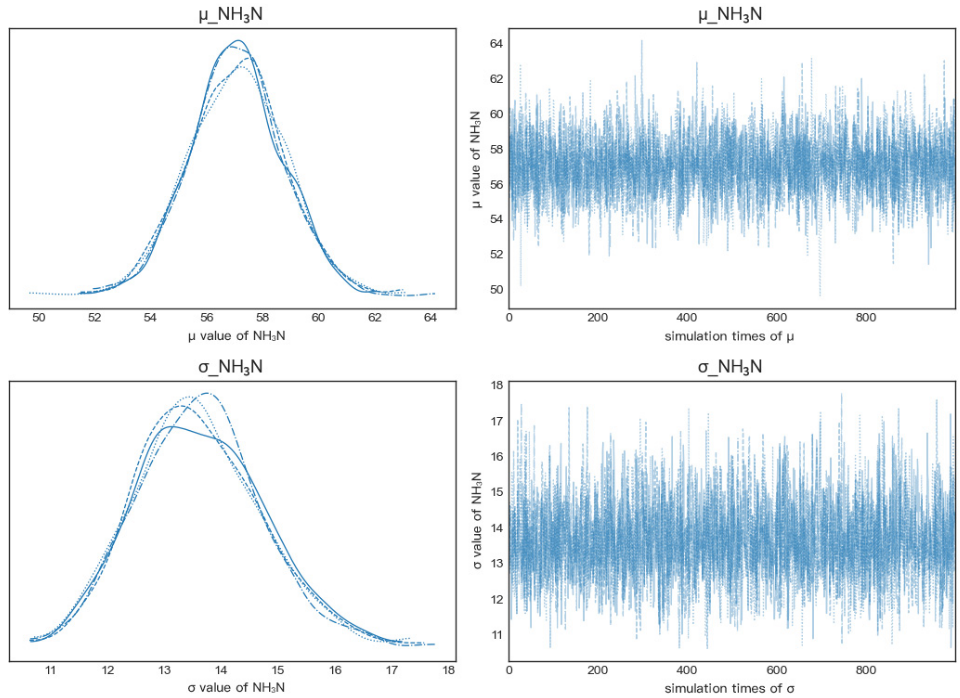


Figure 10. Bayesian analysis of NH_3-N.

Figure 11 (left side) shows the joint probability distribution of the normal distribution parameters of NH_3-N. There was no correlation between the parameters μ and σ. Accordingly, these two parameters are independent of each other. Figure 11 (right side) shows the highest posterior density (HDP) of the posterior distributed μ and σ, with a 94% probability when the mean is between 54 and 60 and a 94% probability when the standard deviation is between 12 and 16.

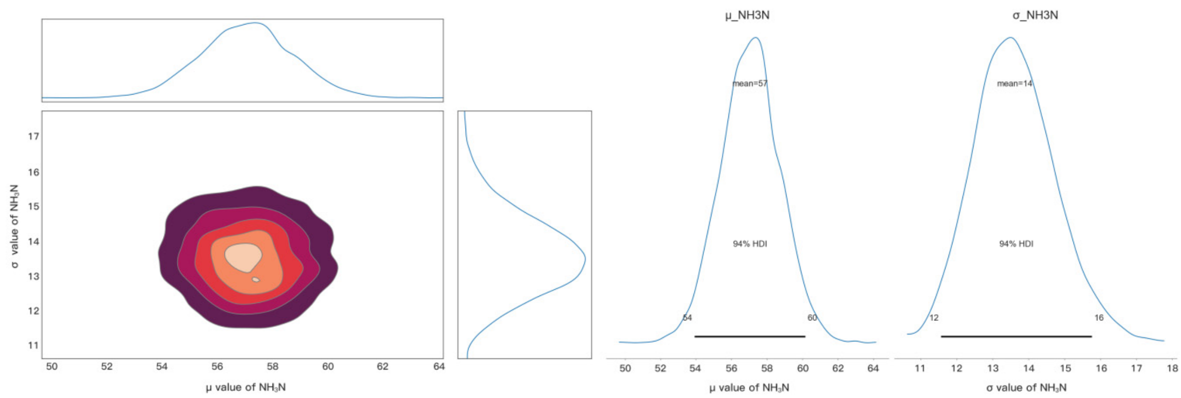


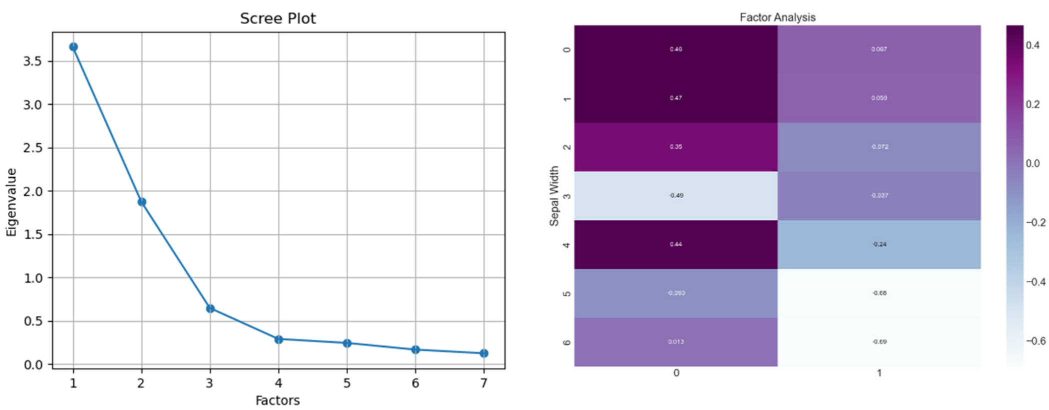
Figure 11. Joint probability distribution diagram of the parameters of NH_3-N.

4.5. COD and NH_3-N Source Analysis Based on the Principal Component Analysis (PCA)

To further analyze the source of contaminants in the Fenjiang River, principal component analysis (PCA) was used to analyze the variables upstream water quality, precipitation, flow rate, population, night light, treatment capacity of sewage treatment plants, and effluent concentration. The eigenvalues and contributions of these seven variables were calculated (Table 4). The seven variables could be expressed by two principal components, see Figure 12. Component 1 reflected the incoming water quality, population density, economic situation, effluent concentration of the sewage plants, and treatment capacity of the sewage plants. This component contributed 52.3% of the total, and the associated variables represented the impacts of human activities. Component 2 reflected the flow rate and precipitation in the Fenjiang River basin, contributing 26.8% of the total variance. The variables associated with this component represented the impact of natural factors.

Table 4. Principal component analysis of the factors affecting water quality.

Principal Component	Variance Contribution (%)	Cumulative Variance Contribution (%)	Upstream Water Quality	Population Density	Economic Situation	Effluent Concentration of Sewage Plants	Treatment Capacity of Sewage Plants	Flow Rate	Precipitation
1	0.523	0.523	0.464	0.467	0.346	−0.494	0.441	−0.093	−0.675
2	0.268	0.791	0.067	0.059	−0.072	−0.037	−0.239	0.013	−0.687
3	0.092	0.883							
4	0.041	0.924							
5	0.035	0.959							
6	0.024	0.983							
7	0.017	1.000							



(**a**) (**b**)

Figure 12. (**a**) Eigenvalues of Factors. (**b**) Result of Factor Analysis.

5. Discussion

5.1. Why Is NH_3-N the Main Factor Affecting Water Quality Recently?

Our analysis found that the water quality variables of the Fenjiang River were significantly correlated with the WQI-DET values ($p < 0.05$). The WQI-DET values were negatively correlated with NH_3-N (R = −0.44) and COD (R = −0.05), indicating that the high values of NH_3-N, and COD were the main factors preventing the Fenjiang River water quality from meeting environmental standards. This phenomenon is similar to the situation of rivers of the same type flowing through densely populated cities in China. For example, Li Xiaoyu et al. [35] found that NH_3-N and COD were the main pollution indicators of the urban waterways in the Tongzhou District of Beijing before 2016, and their values were relatively high before 2016 and decreased significantly after 2016.

Our analysis found that during 2016-2021, the water quality of the Fenjiang River showed an obvious improvement during 2016-2017 and a gradual downward trend during 2018-2021. This downward trend was mainly caused by NH_3-N. The question is, where does the NH_3-N come from? As we know, NH_3-N in water mainly comes from the decomposition products of nitrogen-containing organic matter in domestic sewage by microorganisms. The Fenjiang River flows through the central area of the built-up area of Foshan City. The NH_3-N index at the inlet of the upstream water (Shakou section) is in a good trend during the study period. However, after entering the second monitoring section (Jinsha New Town section), the NH_3-N index continues to decline, which is closely related to the continuous increase in the population scale in this area during the study period. Future studies will focus on how NH_3-N enters urban waterway water through human activities and provide ideas for urban waterway water treatment.

5.2. Is the Water Quality of the Fenjiang River Getting Better or Worse?

Through the analysis of COD and NH_3-N in the Fenjiang River based on Bayes, it was found that the COD and NH_3-N indexes followed the normal distribution during the study period, with the average value of COD in the range from 70 to 78 and the average value of NH_3-N in the range from 54 to 60. From this perspective, there were no significant changes in COD and NH_3-N during the study period.

However, in the spatial distribution, COD and NH_3-N showed significant differences. The water quality of the Fenjiang River diminished in this order: Shakou sluice section > Jinsha New Town section > Sanzhou section > Hengjiao section > Renmin Bridge section. In the same order, the water quality index decreased from the upstream to the midstream sections, the water quality of the monitoring points in the urban section decreased significantly, and the water quality index increased and tended to be stable from the midstream to the downstream sections, which was significantly related to human activities.

Although this study does not reflect that the water quality of the Fenjiang River has improved significantly during the study period, if we trace the study back more than 20 years ago, we find that the current water quality of the Fenjiang River has improved significantly and is stable compared with 20 years ago. Wei Junting [36] studied another river (Yayao River) from Foshan City and found that the annual average of NH_3-N increased from 2.11 mg/L in 1991 to 12.96 mg/L in 2003. Our analysis found that since 2016, the annual average of NH_3-N in the Fenjiang River has been stable between 0.8 and 1.12 mg/L, and it is only 10% of that in Yayao River 20 years ago. This shows that the water quality of the Fenjiang River is at a better level at present, and at the same time, it supports the economic and social development of Foshan City. The water quality has remained stable and good, which is obviously inseparable from the local government's efforts to improve water environment treatment in recent years.

5.3. What Can Be Done to Help Improve the Water Quality of Fenjiang River?

As mentioned above, the water quality of the Fenjiang River is stable at a good level, but there was still a risk of water quality deterioration during the study period. Between 2016–2021, the Fenjiang River had the highest WQI-DET value in 2017. Since then, the water quality showed the risk of declining. The interannual water quality trends differed between river sections, which was related to natural factors and human impacts. From the analysis of PCA, this study found that human activities contributed 52.3% to variability in the water quality of the Fen River, and natural factors only 26.8%. Human activities play a decisive role in changes in water quality. Therefore, in order to prevent the Fenjiang River from falling into the water quality crisis of urban development again, changes in the human society should play a more active role. In terms of the reduction of NH_3-N, the main pollution factor of the Fenjiang River, the local government needs to give full consideration to the treatment of the NH_3-N source, including zero direct discharge of domestic sewage, zero direct discharge of industrial park sewage, and non-point source pollution treatment [35,36].

6. Conclusions

In this study, more than 65,700 water quality sampling data from five monitoring sections of the Fenjiang River from 2016 to 2021 were collected and sorted. The water quality of the Fenjiang River was evaluated and analyzed by using the improved comprehensive water quality identification index method (WQI-DET), Bayesian model, and principal component analysis, and the pollution factors affecting the water quality were identified. At the same time, it was preliminarily identified that the pollution factors were mainly from human activities.

In this study, through the calculation and analysis of WQI-DET, it was found that the main factors of water quality damage in the Fenjiang River are COD and NH_3-N. Further analysis shows that the interannual characteristic distribution of COD and NH_3-N fluctuates, with different trends. Among them, WQI-DET (NH_3-N) shows a downward trend and WQI-DET (COD) shows an upward trend. In the distribution of spatial evolution characteristics, the water quality index decreases from the upstream to the middle reaches, the water quality of the monitoring points in the built-up section decreases obviously, and the water quality index rises from the middle reaches to the downstream and tends to be stable.

In this study, the overall analysis of COD and NH_3-N was carried out through the establishment of Bayesian models. It was found that the COD and NH_3-N indexes of the Fenjiang River basically follow the normal distribution during the study period, the average value of COD is in the range of 70 to 78, and the average value of NH_3-N is in the range of 54 to 60.

Finally, through the principal component analysis (PCA) of the causes of COD and NH_3-N pollutants in the Fenjiang River, it was found that the factors reflecting the impact of human activities contribute 52.3% of the total, and the factors reflecting the impact of natural factors contribute 26.8% of the total. Human activities play a decisive role in the water quality.

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