Analysis of the trend change in water quality and its influencing factors in Changsha section of the Xiangjiang River

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Abstract. Based on the measured water quality data of national control stations in Changsha city of Xiangjiang River from 2016 to 2019, the principal component analysis method was used to evaluate the water quality at each section. The annual trends in concentrations of ammonia nitrogen and total phosphorus were analysed and the influencing factors were explored. The results show that the water quality of the tributaries of the Xiangjiang River was worse than that of the main stream. The average score of the principal component of Shengli section is the highest, which is 4.412. This suggests that the water quality is poor, where the main pollution sources are domestic sewage and agricultural discharge. From 2016 to 2019, the concentrations of ammonia nitrogen and total phosphorus in each tributary showed a downward trend. The variations of the water quality in each year were mainly affected by rainfall, e.g., the water quality concentration in the dry season was higher than that in the flood season.

1. Introduction
The Xiangjiang River, which is the largest river in Hunan Province, has a total length of 856 km, an area of 9.46×10^4 km^2 and an average annual runoff of 7.22×10^10 m^3. It provides water resources for domestic usage, industrial production, agricultural irrigation, fishery, shipping, etc., and plays a vital role in the social and economic development of coastal urban agglomeration [1]. The water environment of the Xiangjiang River has always been the focus of people's attention. For example, WU Li made the analysis of water quality of Lenshuitan section in Yongzhou section of the Xiangjiang River, and found that there is a significant relationship between water quality and hydrometeorology [2]. Cheng Mingxia applied the seasonal Mann Kendall test and found that the heavy metal pollution was mainly affected by the flow change and historical discharge [3]. Peng Yahui found that energy consumption and heavy metal emissions of Changsha-Zhuzhou-Xiangtan Urban Agglomeration were significantly positive driving factors [4]. Yuan Xiao found that the concentration of pollutants in the Xiangjiang River is closely related to water level [5]. In water quality evaluation, many scholars usually have used the principal component analysis method. For example, Yu Dongsheng investigated the water quality on the West Bank of Taihu Lake, and found that ammonia nitrogen and chemical oxygen demand were the main
driving factors of water pollution, and the spatial distribution of water pollution gradually decreased from the north to the south [6]. Han Shuang studied the water quality of Dahuofang reservoir and found that concentrations of total nitrogen in the basin exceeded the standard value seriously, which was mainly affected by agricultural non-point source pollution [7]. Yang Pan studied the water quality of the main stream of the Yangtze River, and found that the water quality of the main stream of the Yangtze River was better than that of the middle and lower reaches, and the water quality of the middle and lower reaches was deteriorating [8]. Therefore, in this paper, seven national control sections in Changsha city of the Xiangjiang River are taken as the study area, and the principal component analysis method is used to evaluate the water quality, analyze the trend of water quality change, and explore the influencing factors of changes in water quality, so as to provide a scientific basis for the protection and management of water environment of the Xiangjiang River.

2. Materials and methods

2.1. Overview of the study area
In this paper, the monitoring data of ammonia nitrogen (NH₃-N), total phosphorus (TP), permanganate index (CODₘₙₐ₃ᵦ), five day biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD) at seven national control sections, i.e., namely Zhaoshan, Jinjiang estuary, Juzizhou, Sanjiaozhou, Laodao estuary, Shengli and Zhangshugang from 2016 to 2019 were taken as the research area to evaluate and analyze the changes in water quality. The locations of the water quality monitoring stations are shown in Figure 1. Zhaoshan, Juzizhou and zhangshugang are the national control sections in the main stream of the Xiangjiang River, reflecting the water quality characteristics of the main stream of Xiangjiang River. Jinjiang estuary, Sanjiaozhou, Laodao estuary and Shengli are the national control sections of Jinjiang River, Liuyang River, Laodao River and Weishui River respectively, reflecting the water quality characteristics of the tributaries of the Xiangjiang River Basin. Therefore, the variation in water quality at the seven national control sections can basically reflect the variation in water environment of the Xiangjiang River in Changsha city.

![Figure 1. The locations of water quality monitoring sites](image)

2.2. Evaluation and analysis method
Principal component analysis adopts the idea of dimension reduction to simplify multiple variables, from which potential categories can be summarized. Variables with strong correlation can be classified into one category, while variables with weak correlation belong to different categories [9]. Compared with the commonly used single factor evaluation method, principal component analysis method can
more comprehensively analyse the relative pollution degree and pollution sources of water body through pollutant load and comprehensive score.

3. Results and discussions

3.1. Analysis on pollutant characteristics of each section

Based on the principal component analysis of the annual average values of water quality indicators at each section from 2016 to 2019, the relative pollution degree and main pollution factors of water quality of each section were explored. In order to test the applicability of principal components, KMO (Kaiser Meyer Olkin) and Bartlett (Bartlett test of sphericity) tests are needed for the relevant data. In general, when KMO is greater than 0.5, it is suitable for factor analysis, and when Bartlett test value is less than 0.05, it is suitable for principal component analysis [10]. As shown in Table 1, KMO and Bartlett values in 2016-2019 meet the requirement of principal component analysis.

| Test index | 2016 | 2017 | 2018 | 2019 |
|------------|------|------|------|------|
| KMO        | 0.526| 0.517| 0.674| 0.642|
| Bartlett   | 0.002| 0.000| 0.000| 0.003|

As shown in Table 2, according to the principle for selecting the number of principal components, two principal components with eigenvalues greater than 1 were extracted from five water quality indicators in 2016, and the cumulative contribution ratio of the two principal components was 92.26%. From 2017 to 2019, one principal component was performed for five water quality indicators, and the contribution rates were 88.34%, 88.28% and 79.54%, respectively, indicating that the information contained in the original indicators can be well explained. In 2016, NH3-N, TP, CODMn and COD were the main loads in the first principal component, and BOD5 was the main load in the second principal component. In 2017-2019, NH3-N, TP, CODMn, COD and BOD5 were the main loads, so the pollution sources might be domestic sewage and agricultural sources. From the perspective of water quality driving, river water quality is affected by natural factors and human activities. Among them, natural factors include rainfall, runoff, temperature, etc., while human activities include industrial wastewater, domestic sewage, fertilizer use, livestock and poultry breeding, etc. [11]. In wet season, due to the large amount of rainfall, the accumulated agricultural pollutants and domestic sewage larger than the treating ability of Sewage plants are being flushed into the river by surface runoff, resulting in the increase of water pollutant concentrations. In the dry season, due to the small amount of rainfall, slow flow rate and low self-purification capacity of water body, pollutants are detained, which aggravates the pollution load of water body.
According to the comprehensive score of principal components at each section from 2016 to 2019 (Table 3), the water quality of tributaries of the Xiangjiang River is worse than that of the main stream. The average score of principal components at Shengli section is the highest, which is 4.412, suggesting that the water quality is relatively poor. This may be due to the flat terrain in the middle and lower reaches of Weishui River, the slow flow, the difficulty of pollutant convection and diffusion, and the relatively developed aquaculture industry in Ningxiang city in the basin, which also makes the water quality worse, together with the relatively serious agricultural non-point source pollution. The average score of Sanjiaozhou and Laodao estuary is 2 and 3 respectively, which may be due to the developed urbanization, dense population, large domestic sewage discharge and heavy river pollution. The water quality of the main stem is good, and the average score of Zhaoshan section is -4.435, indicating that the water quality of the Xiangjiang River at the confluence of Xiangtan and Changsha sections is good.

| Monitoring section | 2016  | 2017  | 2018  | 2019  | Average |
|--------------------|-------|-------|-------|-------|---------|
|                    | F     | Rank  | F     | Rank  | F       | Rank  | F     | Rank  |
| Zhaoshan           | -2.905 | 6    | -4.891 | 6    | -5.049 | 7    | -4.893 | 7    | -4.435 | 7    |
| Jinjiang estuary   | 0.170  | 4    | -1.033 | 4    | 0.309  | 4    | 0.371  | 4    | -0.046 | 4    |
| Juzizhou           | -3.010 | 7    | -4.932 | 7    | -4.307 | 6    | -4.12  | 6    | -4.165 | 6    |
| Sanjiaozhou        | 4.143  | 1    | 5.165  | 2    | 3.845  | 2    | 3.789  | 2    | 4.235  | 2    |
| Laodao estuary     | 1.848  | 2    | 2.634  | 3    | 2.421  | 3    | 3.430  | 3    | 2.583  | 3    |
| Shengli            | 1.675  | 3    | 3.566  | 1    | 6.302  | 1    | 4.304  | 1    | 4.142  | 1    |
| Zhangshugang       | -1.921 | 5    | -2.309 | 5    | -3.521 | 5    | -2.589 | 5    | -2.585 | 5    |

3.2. Changes in annual values of pollutant concentrations

The analysis shows that the water quality of the tributaries of the Xiangjiang River is worse than that of the main stem. The annual changes of NH$_3$-N and TP concentrations in tributaries are analyzed, as shown in Figure 2. From 2016 to 2017, the concentrations of NH$_3$-N and TP at Sanjiaozhou section fluctuated intensively and exceeded the grade five value intermittently. In April 2016, concentrations of NH$_3$-N reached the highest value of 3.29 mg/L, which was inferior to class V standard. In February 2017, concentrations of TP reached the highest value of 0.38 mg/L and this may be due to the unreasonable management of urban and rural sewage treatment facilities in the basin, and the low environmental carrying capacity and low basic flow discharge in the tributaries with high urbanization level. After March 2018, concentrations of NH$_3$-N and TP decreased significantly, and were above the class III standard, which was due to the substantial reduction of domestic sewage discharge. The upgrading and reconstruction of sewage treatment plants in the basin caused the improvement in water quality. Concentrations of NH$_3$-N and TP in Shengli section of Weishui River in 2016 were in class III except for an obvious increase in April. In 2017, concentrations of NH$_3$-N and TP exceeded the standard level of class V seriously, especially in November when the concentrations of NH$_3$-N and TP were 6.35 mg/L and 0.78 mg/L respectively, far exceeding the class V standard. After April 2018, concentrations of NH$_3$-N and TP improved significantly, and basically remained at class III standard every month. This was due to the building and upgrading of the sewage treatment plants in Wangcheng and Ningxiang counties, and the implementation of zero growth action of chemical fertilizer and large-scale breeding. The water quality of Jinjiang River is good, and concentrations of NH$_3$-N and TP in 2016-2019 are basically below the class III standard, except for a high value of NH$_3$-N concentration of 2.05 mg/L in April 2018, which is inferior to the class V standard. Concentrations of NH$_3$-N and TP in Laodao River exceeded the standard seriously in March 2018, which were 1.92 mg/L and 0.32 mg/L respectively, both of which were in class V standard. This may be due to the excessive discharge of industrial and domestic sewage and insufficient treatment capacity. Concentrations of NH$_3$-N and TP decreased significantly from then on, which may be due to the building of the new sewage treatment plants and the expansion of pipe networks in the sub-basins. Overall, concentrations of NH$_3$-N and TP in each tributary showed a downward trend from 2016 to 2019.
3.3. Changes in monthly values of pollutant concentrations

The trend in monthly mean values of NH$_3$-N and TP concentrations in each tributary section from 2016 to 2019 was analysed (Figure 3). The concentration of NH$_3$-N in Jinjiang estuary was basically remained at class III standard from January to August, then the NH$_3$-N concentration decreased significantly from September to December, which was maintained at class II standard. Concentrations of TP were maintained at class II standard generally, where the values fluctuated in the range between 0.1 mg/L and 0.6 mg/L. The water quality of Sanjiaozhou section fluctuated significantly, which was mainly affected by rainfall. The pollutant concentrations were low in flood season and high in dry season. The lowest NH$_3$-N concentration was 0.41 mg/L in July and the highest was 2.11 mg/L in February. Concentrations of NH$_3$-N and TP in Laodao estuary showed the similar trend, and they were stable in class III standard from January to April to December. The higher concentration of water quality from February to March may partly be due to lower flow discharge and weaker water quality dilution and transport capacity in dry season. Concentrations of NH$_3$-N at Shengli were lowest in the summer season, and the water quality was better from May to August, which was in class II standard. Concentrations of NH$_3$-N in November was 1.9 mg/L, which exceeded class IV standard. The concentration of TP was at class III except for 0.28 mg/L in November. Water quality in the flood season was better than that in the dry season at this regions.

Figure 3. Annual variation of NH$_3$-N and TP
4. Conclusion
This study performed the principal component analysis and trend analysis of the water quality monitoring data at seven national controlled sections in Changsha section of the Xiangjiang River using data from 2016 to 2019. The results showed that the water quality of tributaries in Changsha city of the Xiangjiang River is worse than that of the main stem. The comprehensive score of the principal component at Shengli station was the highest, indicating that the water quality of Weishui river is relatively poor, and the main pollution sources are domestic sewage and agricultural discharge. During 2016 to 2019, concentrations of NH$_3$-N and TP in all tributaries showed a downward trend, and the water quality improved significantly since 2018. The interannual variation of pollutant concentration was greatly affected by rainfall, and the water quality concentration was higher in the dry season than that in the wet season, it may be caused by the larger pollutant output loads compared to the weak environmental carrying capacity because of the low basic flow discharge in dry season.

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