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Spatial and Temporal Variation and Trend Analysis of Water Quality in Large Reservoirs in Ji'an City

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Abstract Based on the water quality monitoring data of 5 large reservoirs in Ji'an City, Jiangxi Province from 2015–2021, the temporal and spatial variation characteristics and trends of water quality of the reservoirs were analyzed by single-factor evaluation method and seasonal Kendall test to evaluate the trophic status of the reservoirs and explore the influencing factors of characteristic pollutants. The results showed that: ① the water quality of the reservoirs was good and could meet the water needs of various functions; ② the water quality of the reservoirs had generally changed from bad to good in recent years, indicating that the implementation of "river chief system" has achieved certain results; ③ Kendall test analysis showed that, except for individual projects which showed an upward trend in water quality, other projects showed no obvious change trend or downward trend, indicating that the water quality of the reservoirs is indeed improving; ④ the causes of water pollution in reservoir area were further analyzed by exploring the natural and human factors of the characteristic pollutant total phosphorus. It is recommended to strengthen supervision in the later stage to control point and non-point source pollution.

Keywords Water quality evaluation, Single factor evaluation, Seasonal Kendall test, Large reservoir, Trophic status, Water quality trends

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Water quality evaluation and trend analysis are important links in water resources planning management and protection. The analysis and research on the evolution and trend of surface water quality has been dedicated much efforts by scholars. Luo Da et al.[1] statistically analyzed the evolution trend of water quality based on the water quality monitoring data of Baishi Reservoir in the past 10 years. Chen Xinfo et al.[2] used seasonal Kendall test method to analyze the trend of Huangshui water quality and came to the conclusion that the overall water quality changed from bad to good. Zhuo Haihua et al.[3] compared the variation trend of the Three Gorges reservoir before and during the storage operation period, and concluded that the water quality of the main stream of the Three Gorges Reservoir was good and gradually weakened by the influence of water period and water storage scheduling. Miao Deyu et al.[4] analyzed the change trend of surface water quality in China by analyzing the data of 77 monitoring sections throughout China from 2013–2018. Yang Rongjin et al.[5] used a variety of water quality evaluation and analysis methods, such as principal component analysis and reverse distance weight method, to analyze the water quality pollution of Guanting Reservoir from 2010–2017.

Ji'an City is located in the central and western part of Jiangxi Province, with an area of 25,300 km^2 and a total population of 4.47 million[6]. It is in the middle reaches of Ganjiang River Basin, with Ganjiang River running through from south to north. The city has developed water systems, with 732 large, medium and small rivers (more than 10 km^2). The river network density is 0.4 km/km^2, and the per capita water resources are 4 times the national level[7]. The quality of surface water resources is closely related to industrial and agricultural production, residential water consumption and economic development of a region. At present, the analysis of surface water quality evolution in Ji'an City is occasionally reported. Hou Linli et al.[8] analyzed the variation trend of water quality in Wan'an Reservoir from 2008 to 2018. Wu Rong et al.[9] studied the water quality of Suichuan River by using different water quality evaluation methods. Most of these reports are limited to the water quality analysis of a certain reservoir or a certain river, and lack a comprehensive analysis of water quality of the whole city's surface water resources. As one of the main sources of drinking water, large reservoirs generally have the effects of power generation, flood control, shipping, irrigation, aquaculture, tourism and so on, and are an important part of water resources in a region. In recent years, with the acceleration of industrialization, as well as heavy use of pesticides and fertilizers in agricultural production, and massive discharge of industrial and agricultural wastewater and domestic sewage, the surface water quality of Ji'an City has been affected to a certain extent. By selecting 5 large reservoirs in Ji'an City as representative sites of surface water resources quality in the city, the author studied the changes and trends of water quality in recent years, in order to provide a technical support for water pollution prevention and control, water ecological environment protection and sustainable development and utilization of water resources in Ji'an City.

1 Overview of large reservoirs in Ji'an City

The author selected 5 large reservoirs in Ji'an City of Jiangxi Province as the research objects: Wan'an Reservoir, Sheshang Reservoir, Nanche Reservoir, Baiyunshan Reservoir and Laoyingpan Reservoir. Wan'an Reservoir, located in the middle reaches of Ganjiang River, and it is a water conservancy and hydropower cascade project for the comprehensive utilization of Ganjiang River mainstream, with the designed normal water storage level of 100 m, the actual normal water storage level of 96 m, the corresponding storage capacity of 1.116 billion m^3, and the control basin area of 36,900 km^2. Sheshang Reservoir is located in the northwest

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of Ji'an City, the upstream of Lushui River, the first tributary of Ganjiang River, with a catchment area of 427 km^2 and a water surface area of 11.3 km^2, a total storage capacity of 174 million m^3 and an effective storage capacity of 127 million m^3. Nanche Reservoir is located in the middle of Niuhou River, with a normal water storage level of 160 m, a dead water level of 142 m, and a total storage capacity of 153 million m^3. The corresponding water surface area of normal water level is 8.9 km^2 and the storage capacity is 123 million m^3. Nanche Reservoir is developed for the purpose of irrigation, combined with flood control, power generation, and aquaculture. Baiyunshan Reservoir is located in the upper reaches of Futian Water, a tributary of Gujiang River in Ganjiang River system, in Qingyuan District in the west of Ji'an City, with a control basin area of 464 km^2, a total reservoir capacity of 114 million m^3, and a normal water storage level of 180 m. Laoyingpan Reservoir is located in the upstream of Yunting Water, a tributary of Ganjiang River, in Taihe County, southwest Ji'an City. It is a large reservoir with comprehensive utilization efficiency of irrigation and flood control and power generation, with a watershed area of 172 km^2 and a total storage capacity of 107 million m^3. The location and site distribution details of 5 large reservoirs are shown in Fig.1. The 5 reservoirs are located in the main stream of Ganjiang River or on the first and second tributaries of Ganjiang River, and are evenly distributed in Ji'an City. The water quality evaluation and trend analysis of these reservoirs can better reflect the overall situation of water quality in the region.

2 Data sources and methods

All water quality monitoring data were derived from the . Hydrology and Water Resources Monitoring Center of the Middle Reaches of Ganjiang River. The center had established a relatively complete network of water quality monitoring stations in Ji'an City, and began to monitor the water quality of all large reservoirs in the territory in the early 21st century. The length of water quality sequence has a great influence on the evaluation of water quality trend[10], and it is appropriate to be 5–8 years[11]. The author selected the water quality monitoring data from 2015 to 2021. Single factor evaluation method was used to determine the water quality category, and the limit value of Class III water in the *Surface Water Environmental Quality Standard* (GB 3838–2002)[12] was used as the basis to determine whether the water quality was up to standard. The evaluation items were the basic items in GB 3838–2002 (except fecal coliform and total nitrogen). Eutrophication is a phenomenon in which nitrogen, phosphorus and other nutrients are in excess under the action of human activities or natural conditions, resulting in water quality pollution. The total phosphorus, total nitrogen, chlorophyll a, permanganate index and transparency of the project were analyzed, and the trophic status of the reservoirs was evaluated according to the *Technical Regulations for Quality Evaluation of Surface Water Resources* (SL 395–2007)[13]. Seasonal Kendall test was used to analyze water quality change and trend. Seasonal Kendall test[14-16] is a non-parametric test method that only considers the relative arrangement of data, and it is an extension of Mann-Kendall test. It was first proposed by Hirsch et al.[17] in 1982, and the main advantages are that it is not affected by the non-normality of water quality data, seasonal changes, flow correlation, leakage value or less than the detection limit value, etc. According to water quality characteristics and monitoring results, permanganate index (COD_{Mn}), ammonia nitrogen (NH_3-N), 5-day biochemical oxygen demand (BOD_5), total phosphorus (TP) and total nitrogen (TN) were selected as trend analysis items. The author used PWQ Trend 2010 water quality analysis software to carry out Kendall test and analyze the change trend of water quality in each large reservoir. According to the relevant contents of SL 395–2007 water quality change trend analysis, the change trend of water quality in Ji'an City was analyzed.

3 Water quality evaluation and trend analysis

3.1 Single factor evaluation and trophic status evaluation

The results of single factor evaluation and trophic status evaluation of the 5 large reservoirs are shown in Table 1. In summary, the water quality of the 5 large reservoirs from 2015–2021 was good, with water quality categories better than or in line with Class III water standards, and the water quality was up to standard. Except that the trophic state index (EI) of Laoyingpan Reservoir was 57 in 2015, the EI of mild eutrophication was no more than 52 in previous years. In recent years, although slight eutrophication occurred in large reservoirs in Ji'an, the actual state of water quality was closer to mesotrophication ($0 \leqslant EI \leqslant 20$, oligotrophication; $20 < EI \leqslant 50$, mesotrophication; EI>50, eutrophication; $50 < EI \leqslant 60$, mild eutrophication; $60 < EI \leqslant 80$, moderate eutrophication; $80 < EI \leqslant 100$, severe eutrophication). The trophic status of water from 2019 to 2021 was analyzed. In recent 3 years, the trophic status of water quality was mesotrophic, and the water quality showed a trend of improvement.

3.2 Analysis results of seasonal Kendall test

According to the water quality monitoring results of 5 large reservoirs from 2015 to 2021, the change process of pollutant concentration was plotted (Fig.2). The concentration of pollutants showed a trend of first increasing and then decreasing, with a maximum value around 2018, indicating that the implementation of "river chief system" in Jiangxi in 2019 achieved certain results. Five water pollution indexes of NH_3-N, COD_{Mn}, BOD_5, TP and TN were selected for analysis. PWQ Trend 2010 water quality analysis software was used to conduct seasonal Kendall test (no flow regulation). The significance of the trend of water quality change should be represented by the significance level α ($\alpha \leqslant 0.01$, the water quality change had highly significant trend; $0.01 < \alpha \leqslant 0.1$, the water quality change had significant trend; $\alpha > 0.1$, the water quality change had no trend), and the results are shown in Table 2. The results of trend test are shown in Table 3. There was no obvious trend change of COD_{Mn} in the 5 large reservoirs, and it can be seen from Fig.2 that the content of COD_{Mn} was about 2.0 mg/L (controlled at a relatively low concentration level), which was lower than the limit of Class II water standard in the *Surface Water Environmental Quality Standard* (GB 3838–2002). In addition to Laoyingpan reservoir which had a rising trend, the other 4 reservoirs had no obvious change trend of BOD_5. The trend of water quality of NH_3-N, TP and TN changed, indicating that the water quality was changing dynamically. The NH_3-N index of Wan'an Reservoir, Sheshang Reservoir and Baiyunshan Reservoir showed a decreasing trend, while that of Nanche Reservoir and Laoyingpan Reservoir showed no obvious change. The TN index of Wanan and Baiyunshan reservoirs showed a downward trend, while that of Nanche and Laoyingpan reservoirs showed no obvious change trend, and that of Shishang Reservoir showed an upward trend. Generally, the water quality of 5 pollutants in the 5 reservoirs basically had no obvious change trend or showed a downward trend, and the water quality was improved.

3.3 Kendall test analysis of storage adjustment

Surface water quality is affected by vegetation, soil, rainfall, runoff and human activities in the basin, and the correlation between storage capacity and concentration can indirectly determine whether the pollutants are point source pollution or non-point source pollution. The concentration of pollutants can be calibrated through storage capacity adjustment, and the influence of storage capacity on water quality can be reflected. Seasonal Kendall test (storage capacity adjustment) was used to analyze the influence of natural factor storage capacity on characteristic pollutants. The correlation between concentration and storage capacity can determine whether the pollutant is from non-point source pollution. Except for TP, the content values of the other 4 indexes were all lower than those of Class II water. The TP content was close to the class III water limit, which should be paid special attention. The residual equation of seasonal Kendall test showed that the TP content of the 5 reservoirs was positively correlated with the storage capacity, indicating that the TP content was affected by non-point source pollution. TP pollutants will be washed by rainwater during rainfall and then merged into water through runoff process. There is no industrial or domestic sewage outlet in the upstream and nearby of the reservoir, so the impact of industrial and domestic point source pollution on the water quality of reservoirs can be excluded, and the pollution source may come from domestic or agricultural non-point source pollution.

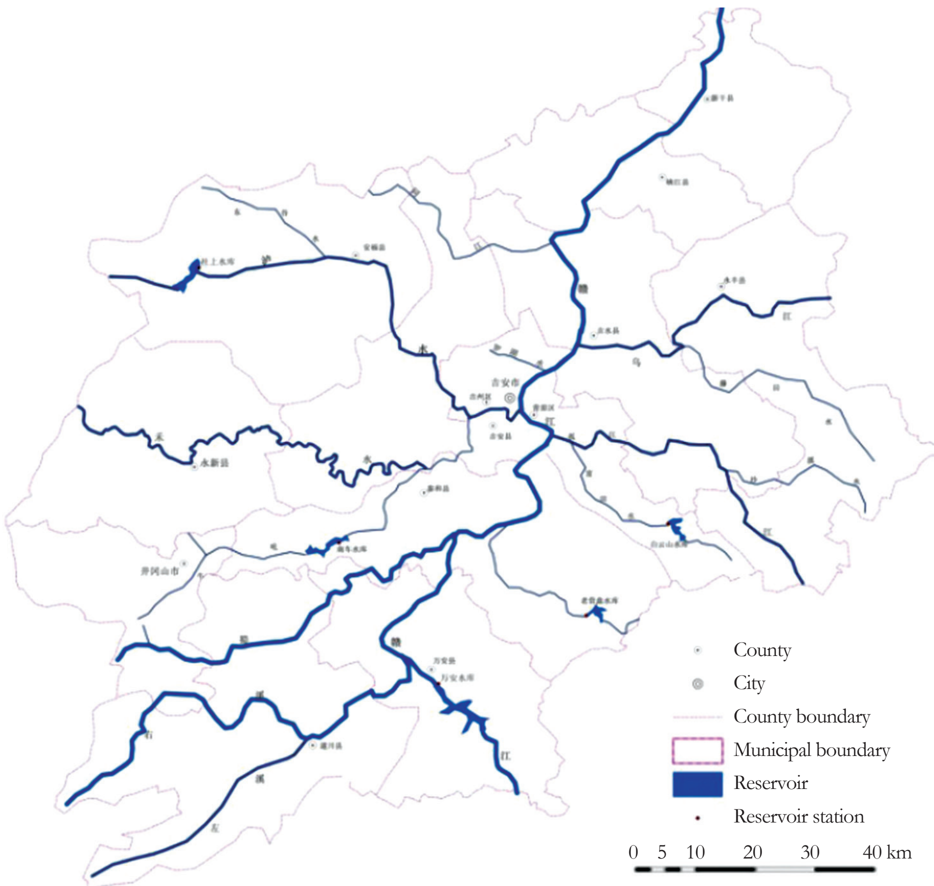

Fig.1 Distribution of main water systems and large reservoirs in Ji'an City

3.4 Trend analysis of regional water quality in Ji'an City

As shown in Fig.1, the 5 large reservoirs selected are located on the main stream and the first or second level tributaries of Ganjiang River, evenly distributed on all water systems in Ji'an City. According to the relevant contents of *Technical Regulations for Quality Evaluation of Surface Water Resources* (SL 395–2007), the trend of regional water quality in Ji'an City was analyzed. In terms of NH_3-N and TP, the TUP_m of water quality station with rising trend was

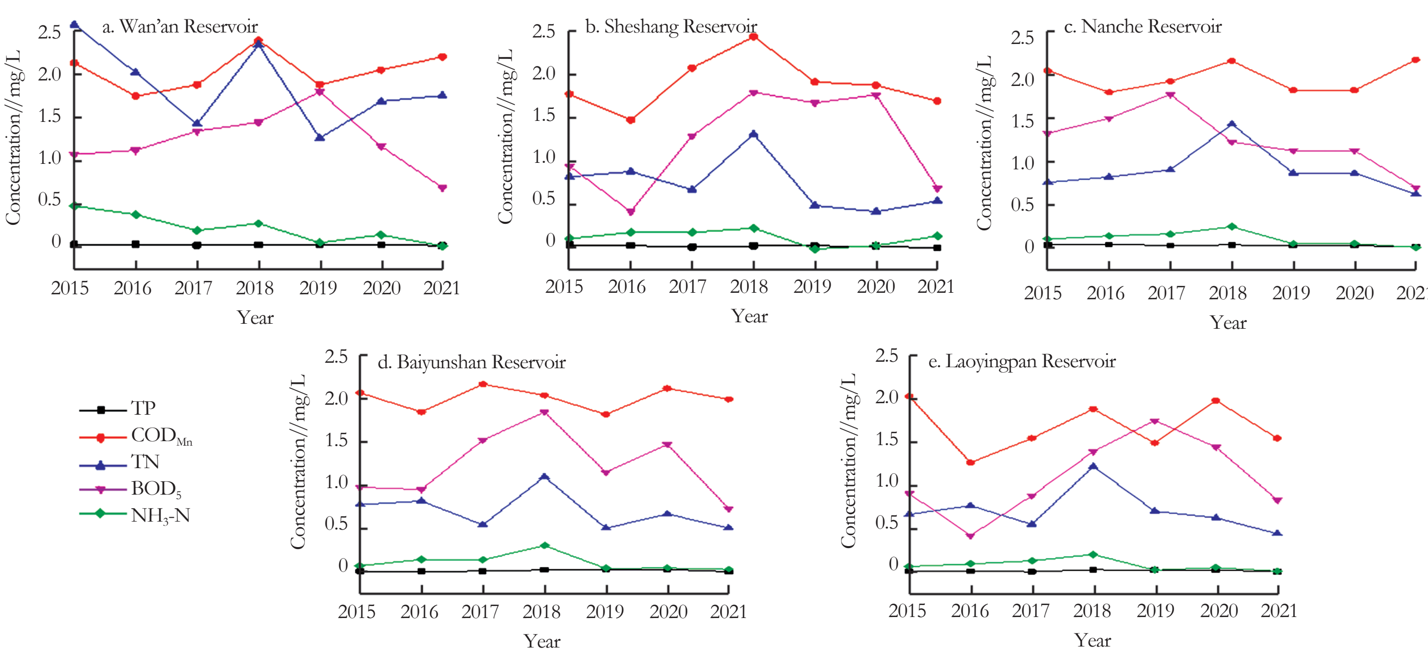

Fig.2 Change process of pollutant concentration

Table 1 Single factor evaluation and trophic status evaluation

Name of reservoir	Item	2015	2016	2017	2018	2019	2020	2021
Wan'an Reservoir	Water quality category	III	III	III	III	III	III	III
	EI	51	48	49	52	49	50	48
	Trophic state	Mild eutrophication	Mesotrophication	Mesotrophication	Mild eutrophication	Mesotrophication	Mesotrophication	Mesotrophication
Sheshang Reservoir	Water quality category	III	III	II	III	III	III	II
	EI	45	41	49	52	42	44	44
	Trophic state	Mesotrophication	Mesotrophication	Mesotrophication	Mild eutrophication	Mesotrophication	Mesotrophication	Mesotrophication
Nanche Reservoir	Water quality category	III	III	II	III	III	III	II
	EI	43	51	52	47	41	44	46
	Trophic state	Mesotrophication	Mild eutrophication	Mild eutrophication	Mesotrophication	Mesotrophication	Mesotrophication	Mesotrophication
Baiyunshan Reservoir	Water quality category	II	II	III	III	III	III	II
	EI	44	51	49	52	44	47	45
	Trophic state	Mesotrophication	Mild eutrophication	Mesotrophication	Mild eutrophication	Mesotrophication	Mesotrophication	Mesotrophication
Laoyingpan Reservoir	Water quality category	II	II	II	III	III	III	II
	EI	57	40	39	52	44	43	45
	Trophic state	Mild eutrophication	Mesotrophication	Mesotrophication	Mild eutrophication	Mesotrophication	Mesotrophication	Mesotrophication

Table 2 Kendall test analysis of water quality change trend

Name of reservoir	Item	Median concentration//mg/L	Concentration trend	Change rate %	Significance level α//%
Wan'an Reservoir	NH_3-N	0.23	−0.07	−28.50	0.00
	COD_{Mn}	1.95	0.00	0.00	100
	BOD_5	1.10	−0.06	−5.30	49.67
	TP	0.05	0.00	−1.63	0.06
	TN	1.72	−0.12	−7.27	4.26
Sheshang Reservoir	NH_3-N	0.15	−0.02	−16.23	3.88
	COD_{Mn}	1.85	0.01	0.54	81.98
	BOD_5	1.00	0.00	0.00	93.95
	TP	0.04	0.00	−11.43	0.52
	TN	1.02	0.17	17.10	0.04
Nanche Reservoir	NH_3-N	0.13	−0.02	−14.17	12.98
	COD_{Mn}	2.00	0.00	0.00	93.90
	BOD_5	1.25	−0.03	−2.33	70.41
	TP	0.03	0.00	−9.54	1.92
	TN	0.77	0.00	0.16	100
Baiyunshan Reservoir	NH_3-N	0.12	−0.02	−16.53	9.76
	COD_{Mn}	2.00	0.00	0.00	93.90
	BOD_5	1.00	−0.03	−3.25	64.70
	TP	0.03	0.00	0.00	93.95
	TN	0.72	−0.05	−6.89	3.50
Laoyingpan Reservoir	NH_3-N	0.09	−0.01	−9.22	25.73
	COD_{Mn}	1.45	0.00	−0.23	100
	BOD_5	1.05	0.10	9.52	6.91
	TP	0.02	0.00	1.88	81.98
	TN	0.66	−0.03	−4.76	32.90

0, and the TDN_m of water quality station with decreasing trend was 0.6. As for NH_3-N and TP, $TUP_m < TDN_m$ indicated that the indexes were improved. As for COD_{Mn}, $TUP_m=TDN_m=0$ indicated there was no change. As for TN, $TUP_m=0.2$ and $TDN_m=0.4$ indicated that the index was improved. Although the BOD_5 index had a worsening trend, the absolute value of content was not high. As shown in Fig.2, the individual water quality categories of each monitoring value were below Class I water (the standard limit value of Class I water is 3 mg/L). The overall upward trend index $WQTI_{UP}$ was 0.08 and the downward trend index $WQTI_{DN}$ was 0.28, $WQTI_{UP} < WQTI_{DN}$, indicating that the water quality in Ji'an City has improved in recent 7 years.

4 Conclusions and suggestions

(1) Water quality evaluation. The water quality of reservoir was evaluated using single factor and trophic status. The results showed that the 5 large reservoirs in Ji'an City had good water quality, and their water quality categories from 2015−2021 were all better than or in line with Class III water standards (total nitrogen and fecal coliform did not participate in the evaluation), meeting the water quality requirements as a centralized drinking water source, and satisfying other water needs such as fishery waters, irrigation water, and swimming areas. In recent years, the trophic status showed mesotrophication and mild eutrophication. Generally, the water quality of reservoirs is good and can meet the water demand, but the trophic status should be strengthened to avoid increasing the degree of eutrophication.

(2) Water quality trend change. From 2015−2021, the water quality of the 5 large reservoirs in Ji'an City generally showed a trend of turning from bad to good, and the concentration of pollutants reached a maximum around 2018, indicating that the "three red lines" supervision of water resources and the implementation of "river chief system" have achieved certain results. Seasonal Kendall test analysis results demonstrated that except that the BOD_5 index of Laoyingpan Reservoir and the TN index of Sheshang Reservoir of water quality change showed an upward trend, other projects showed no obvious change trend or downward trend, indicating that the water quality of reservoirs has a trend of improvement. By analyzing the trend of regional water quality in Ji'an City, the comprehensive index of downward trend was greater than that of upward trend, indicating that the overall water quality in Ji'an City has improved in recent years.

(3) Influencing factors of TP pollution.

Table 3 Trend change of major pollutant indexes of water quality

Name of reservoir	NH_3-N	COD_{Mn}	BOD_5	TP	TN
Wan'an Reservoir	Highly significant reduction	No obvious upward or downward trend	No obvious upward or downward trend	Highly significant reduction	Significant reduction
Sheshang Reservoir	Significant reduction	No obvious upward or downward trend	No obvious upward or downward trend	Highly significant reduction	Highly significant increase
Nanche Reservoir	No obvious upward or downward trend	No obvious upward or downward trend	No obvious upward or downward trend	Significant reduction	No obvious upward or downward trend
Baiyunshan Reservoir	Significant reduction	No obvious upward or downward trend	No obvious upward or downward trend	No obvious upward or downward trend	Significant reduction
Laoyingpan Reservoir	No obvious upward or downward trend	No obvious upward or downward trend	Significant increase	No obvious upward or downward trend	No obvious upward or downward trend

As a project index to determine the category of water quality, TP pollution should be paid more attention. On the one hand, TP mainly comes from non-point source pollution caused by rain erosion and soil erosion around the reservoir area. On the other hand, because Ji'an is dominated by agriculture and the industry is underdeveloped, the TP pollution comes from human influence such as the use of agricultural fertilizers and domestic sewage around the reservoir area.

In short, the analysis of water quality of the 5 large reservoirs shows that the water quality of the reservoirs is good and can meet the water demand, and the water quality has a trend of improvement in recent years. However, we should also pay attention to control the influence of human factors. On the one hand, we should strengthen the monitoring of the trophic status of reservoirs, so as not to aggravate the degree of eutrophication. On the other hand, to control the influence of TP on the water quality of reservoir area, it is necessary to control the pollution of point source and non-point source in the later stage. It is also necessary to strengthen supervision and departmental linkage, pay close attention to the implementation of responsibilities, optimize the industrial structure, and strengthen the maintenance and restoration of water bodies.

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