Analysis on the evolution trend of water resources and water environment in Xiangjiang River basin

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Abstract: According to the daily flow data collected by three representative hydrological stations in the Xiangjiang River basin which are the Guiyang station in the upstream section, the Hengshan station in the midstream section, and the Xiangtan station in the downstream section, and the water environment data collected from the Hunan Water Resources Bulletin, Mann-Kendal method was used to analyze the changes of the annual average flow of the Xiangjiang River basin in the past 20 years as well as the variation of water environment quality in the whole year, flood season and non-flood season. Based on these analysis, the evolution trend of water resources and water environment in the Xiangjiang River basin is further forecasted. The results show that the annual runoff of the upper reaches of the Xiangjiang River basin tends to be stable, and the runoff of the middle and lower reaches is decreasing. The water quality of the Xiangjiang River basin got deteriorated from 1996 to 2010. A sudden change occurred around 2012, and the water quality of the basin gradually improved.

1 Foreword

Xiangjiang River is an important tributary of the Yangtze River and the mother river of Hunan. Xiangjiang River basin is located in the radiating zone of the Yangtze River Economic Belt and the South China Economic Circle. It is an important grain production base in China^[1]. The climate in the upper reaches of the Xiangjiang River basin is superior to the climate and soil conditions, and is suitable for the growth of special economic crops, such as the prestigious Jiangyong Xiangyou, the citron, the citrus of Xiangnan, the oil tea, the mint of Yongzhou, the tear bamboo of the Lanshan county, and the magnolia of Dao county. The climate in the lower reaches of the basin is mild, with abundant rainfall, abundant light and heat resources, and fertile land. It is suitable for the growth of major crops such as rice, wheat, corn and cotton. However, cities such as Yongzhou, Hengyang, Zhuzhou, Xiangtan and Changsha in the basin are distributed along the Xiangjiang River, and most of the industries such as metallurgy, chemical industry, building materials, light industry, textiles, food processing and machinery in Hunan province are located in the region. In the past two decades, the process of urbanization and the development of industry and agriculture have had a great impact on the water ecological environment of the basin^[2-3]. The protection of water ecological environment is a long-term

and complex system engineering, and is an effective way to improve the ecological environment value of the basin and the coordinated development of regional economic construction^[4]. Therefore, this paper uses Mann-Kendall test method^[5] to analyze the evolution trend of water ecological environment in Xiangjiang River basin in the past 20 years, in order to provide decision-making basis for the development, utilization and protection of water resources in Xiangjiang River basin, as well as the sustainable development of Xiangjiang River basin economy which is of great significance to the improvement of the water ecological environment.

2 Overview of the Xiangjiang River basin

Xiangjiang River is the largest river in Hunan province and the largest tributary of the Dongting Lake water system^[6]. Its annual average flow into the Dongting Lake is 713,108 m³, accounting for 22.4% of the total flow into the Dongting Lake. Its flow changes have a significant impact on the water storage in Dongting Lake^[7]. The length of the main stream of Xiangjiang River is 856km and the area of the Xiangjiang River basin is 94,600km². The tributaries of the Xiangjiang River include Xiaoshui river, Qishui river, Fulingshui river, Zhengshui river, Leishui river, Mishui river, Lushui river, Liuwei river, Laodao river, Liuyang river, Jinshui river, Weishui river,

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etc. which are injected into Dongting Lake at Haohe River located in Yiyang. The water system in the basin is very complicated, which has numerous tributaries. There are 2,157 tributaries of over 5km length, including 124 primary tributaries. The two sides of the main stream of the Xiangjiang River are in the form of asymmetrical feathers. The right bank covers an area of 67,316 km², accounting for 71.2% of the total area of the basin, where the three major tributaries are Xiaoshui river, Leishui river and Mishui river located on the right bank, with watersheds exceeding 10,000km². The left bank covers an area of 27,433 km², accounting for 28.8% of the total area of the basin, where the seven major tributaries with a drainage area of more than 1000 km² are distributed on the left bank, with the largest catchment area is 7155km².(Fig.1)

Figure 1. Xiangjiang River basin water system map

3 Mann-Kendall test method

Mann-Kendall test method is a nonparametric statistical test method. This method does not require the sample to follow a certain distribution, nor is it interfered with a few outliers, and is more suitable for type variables and order variables. The advantage of this method is that not only the calculation is simple, but also the time at which the mutation starts, and the mutation region is indicated. Therefore, it is a commonly used mutation detection method [8-10].

Method overview: With a time series X of n sample sizes, construct an order column:

$$S_k = \sum_{i=1}^k r_i \quad (1)$$

$$r_i = \begin{cases} 1 & x_i > x_j \\ 0 & \text{else} \end{cases} \quad j = 1, 2, \dots, i \quad (2)$$

The rank sequence S_k is the cumulative number of the number of values at the i -th time when the value is greater than j . The statistic UF is defined under the assumption that the time series is randomly independent.

$$UF_k = \frac{s_k - E(s_k)}{\sqrt{Var(s_k)}} \quad k = 1, 2, \dots, n \quad (3)$$

Where $UF_1=0$, $E(S_k)$, $Var(S_k)$ is the mean and variance of the cumulative number S_k . When $x_1, x_2, \dots, x_n$ are independent of each other and have the same continuous distribution, they can be calculated by the following formula:

$$E(s_k) = \frac{n(n+1)}{4} \quad (4)$$

$$Var(s_k) = \frac{n(n-1)(2n+5)}{72} \quad (5)$$

UF_i is a standard normal distribution, which is a statistic sequence calculated in time series $x_1, x_2, \dots, x_n$. Given a significance level α , check the normal distribution table, if $|UF_i| > U_\alpha$, it indicates that there is a significant trend in the sequence.

Repeat the above process in time series $x, x_n, x_{n-1}, \dots, x_1$, and make $UB_k = -UF_k, k=n, n-1, \dots, 1, UB_1=0$.

Calculation begins:

(1) Calculate the order column S_k of the sequential time series and calculate UF_k according to the equation.

(2) Calculate the order column S_k of the reverse-order time series, and also calculate UB_k according to the equation.

(3) Given a significance level, such as $\alpha = 0.05$, then the critical value $U_{0.05} = \pm 1.96$.

Analysis of results: If the value of UF_k or UB_k is greater than 0, it indicates that the sequence is increasing; if the value of UF_k or UB_k is less than 0, it indicates that the sequence is decreasing; when the value of UF_k or UB_k exceeds the range of the critical value line $U_{0.05} = \pm 1.96$, the trend of rising or falling is significant. The range exceeding the critical line is determined as the time zone in which the mutation occurs. If there is an intersection point between the two curves of UF_k or UB_k , and the intersection point is between the critical lines, the corresponding time of the intersection point is the mutation start time [11].

4 Analysis of the evolution trend of water resources

The evolution trend of water resources in the Xiangjiang River basin is analyzed by analyzing the interannual variation of annual runoff in the Xiangjiang River basin. The study collected the daily runoff from 1996 to 2016

for the three hydrological stations of the Guiyang station in the upper reaches of the Xiangjiang River basin, the Hengshan station in the middle reaches of the control station, and the Xiangtan station in the downstream section, and calculated the annual average flow series. The specific data is shown in **Table 1**.

Table 1. Annual average flow series of upper-middle and lower-stream rivers in Xiangjiang River basin from 1996 to 2016 Unit: $10^3 \cdot \text{m}^3/\text{s}$

Year	Guiyang	Hengshan	Xiangtan	average value
1996	1.25	1.69	2.11	1.68
1997	1.42	2.36	2.76	2.18
1998	0.97	2.15	2.77	1.96
1999	0.77	1.58	1.99	1.45
2000	0.79	1.52	2.19	1.50
2001	0.87	1.59	2.16	1.54
2002	1.43	2.41	3.14	2.33
2003	1.14	1.51	1.97	1.54
2004	1.14	1.12	1.64	1.30
2005	1.25	1.77	2.10	1.71
2006	1.32	2.27	2.42	2.01
2007	0.91	1.79	1.65	1.45
2008	0.85	1.51	1.81	1.39
2009	0.96	1.16	1.55	1.23
2010	1.40	1.76	2.38	1.85
2011	0.67	0.90	1.21	0.93
2012	1.30	1.75	2.25	1.77
2013	1.25	1.74	2.03	1.67
2014	0.90	1.54	1.98	1.47
2015	1.22	2.04	2.37	1.88
2016	1.10	2.21	2.75	2.02

The Mann-Kendall method was used to analyze the annual average flow of rivers in the upper and lower reaches of the Xiangjiang River basin and the entire river basin from 1996 to 2016 and reflect their respective evolution trends. Given a significance level $\alpha = 0.05$, which means that $U_{0.05} = \pm 1.96$. The calculation results are shown in Figures 2 to 5.

Figure 2. MK mutation test of annual average flow in Guiyang Station in the upper reaches of Xiangjiang River basin

Figure 3. MK mutation test of annual average flow rate of Hengshan station in the middle reaches of Xiangjiang River basin

Figure 4. MK mutation test of annual average flow of Xiangtan station in the lower reaches of Xiangjiang River basin

Figure 5. MK mutation test of average annual flow mean value of three hydrological stations in Xiangjiang River basin

According to the UF curve in **Figure 2**, the UF value is less than 0 in 1996-2001, indicating that the runoff in the upper reaches of the Xiangjiang River basin is decreasing during this period. The UF value is greater than 0 in 2002-2006, indicating that the runoff in the upper reaches of the Xiangjiang River basin is increasing during this period. The UF value is close to 0 in 2007-2016, indicating that the runoff in the upper reaches of the Xiangjiang River basin has remained basically

unchanged during this period. In general, since the UF value is less than $U_{0.05}$ and is closer to 0, this indicates that the upstream runoff in the Xiangjiang River basin did not change significantly during the study period.

According to the UF curve in **Figure 3**, the UF curve of the Xiangjiang River basin is basically maintained below 0, which indicates that the overall runoff of the middle reaches in the Xiangjiang River basin is decreasing. According to the position of the intersection of the UF and UB curves, it can be judged that the decline of the runoff in the Xiangjiang River basin is a mutation phenomenon, and this mutation occurred around 1998.

According to the UF curve in **Figure 4**, the UF curve in the lower reaches of the Xiangjiang River basin is similar to that in the middle reaches, and its value is basically maintained below 0. This indicates that the overall runoff of the lower reaches of the Xiangjiang River basin is decreasing. According to the location of the intersection of UF and UB curves, the decline of runoff in the lower reaches of the Xiangjiang River basin is also a mutation phenomenon. This mutation occurred around

1998 and is basically consistent with the situation in the Xiangjiang River basin.

According to the UF curve in **Figure 5**, since 1998, the UF value of the entire river basin has remained below 0, indicating that the overall runoff in the Xiangjiang River basin is decreasing. According to the intersection of the UF and UB curves, 1998 is the point of mutation. This is also consistent with previous conclusions. The overall decline in water volume in the basin is mainly caused by the decline in runoff in the middle and lower reaches.

5 Analysis of the evolution trend of water environment

The analysis of the evolution of water environment is reflected by analyzing the multi-year changes in the proportion of rivers in the II and III water quality. The study collected data on the proportion of rivers in the II and III water quality of the Xiangjiang River from 1996 to 2016. The specific data is shown in **Table 2**. (Data from the Hunan Provincial Water Resources Bulletin)

Table 2. Table of water quality of Xiangjiang River from 1996 to 2016

Year	The proportion of Grade II and III water quality in the evaluation of river length			Major pollutants in the Xiangjiang River basin
	full year	flood season	Non-flood season	
1996	94.50%	81.50%	80.00%	ammonia nitrogen, arsenide, volatile phenol, COD, BOD ₅ , total mercury, etc.
1997	47.10%	47.90%	54.00%	ammonia nitrogen, volatile phenol, total mercury, etc.
1998	87.23%	91.20%	75.80%	ammonia nitrogen, volatile phenol, heavy metals such as arsenic, mercury and cadmium
1999	54.90%	79.60%	42.20%	total mercury, ammonia nitrogen, total cadmium, volatile phenol, COD, etc.
2000	74.57%	70.00%	62.70%	total mercury, ammonia nitrogen, total arsenide, petroleum, total coliform, etc.
2001	83.56%	87.20%	76.80%	total mercury, ammonia nitrogen, total cadmium, total arsenide, petroleum, etc.
2002	67.54%	70.40%	76.90%	fecal coliform, total phosphorus, ammonia nitrogen, mercury, cadmium, arsenic, volatile phenol, permanganate index, etc.
2003	52.00%	69.40%	34.20%	fecal coliform, total phosphorus, ammonia nitrogen, mercury, hexavalent chromium, cadmium, volatile phenol, permanganate index, etc.
2004	64.19%	66.50%	65.40%	fecal coliform, ammonia nitrogen, cadmium, total phosphorus, volatile phenol, dissolved oxygen, fluoride, permanganate index, etc.
2005	71.60%	75.10%	60.80%	fecal coliform, ammonia nitrogen, cadmium, total phosphorus, volatile phenol, dissolved oxygen, arsenic, permanganate index, petroleum, etc.
2006	54.60%	53.60%	62.20%	fecal coliform, ammonia nitrogen, cadmium, total phosphorus, volatile phenol, dissolved oxygen, arsenic, petroleum, etc.
2007	65.30%	70.30%	62.10%	fecal coliform, ammonia nitrogen, total phosphorus, volatile phenol, dissolved oxygen, petroleum, etc.
2008	68.50%	71.00%	67.70%	fecal coliform, ammonia nitrogen, total phosphorus, volatile phenol, dissolved oxygen, petroleum, etc.
2009	70.80%	72.20%	70.00%	fecal coliform, ammonia nitrogen, total phosphorus, dissolved oxygen, petroleum, etc.
2010	70.30%	70.30%	70.10%	fecal coliform, ammonia nitrogen, total phosphorus, volatile phenol, dissolved oxygen, petroleum, etc.
2011	94.70%	97.80%	89.20%	ammonia nitrogen, petroleum, total phosphorus, dissolved oxygen, etc.
2012	94.30%	93.10%	91.10%	ammonia nitrogen, petroleum, total phosphorus, dissolved oxygen, etc.
2013	98.80%	98.20%	96.90%	ammonia nitrogen, total phosphorus, etc.
2014	98.30%	98.70%	95.70%	ammonia nitrogen, total phosphorus, volatile phenol, petroleum, dissolved oxygen, etc.
2015	98.70%	99.10%	96.60%	ammonia nitrogen, total phosphorus, petroleum, dissolved oxygen, etc.
2016	98.50%	99.40%	95.20%	ammonia nitrogen, total phosphorus, volatile phenol, petroleum, etc.

The Mann-Kendall method was used to analyze the water quality mutations and their respective evolution trends in the three periods of the Xiangjiang River basin during the whole year, the flood season and the non-flood period from 1996 to 2016. Given a significance level $\alpha = 0.05$, $U_{0.05} = \pm 1.96$. The calculation results are shown in Figures 6 to 8.

Figure 6. MK mutation test of the proportion of the II and III water quality in river in the full year

Figure 7. MK mutation test for the proportion of the II and III water quality in river in the flood season

Figure 8. MK mutation test for the proportion of the II and III water quality in river in the non-flood season

According to the UF curve of the whole year of Figure 6, the UF value from 1996 to the end of 2010 is maintained below 0, indicating that the water quality of the Xiangjiang River basin is deteriorating during the 14-year period. During this period, due to urban

construction, mining, farmland irrigation, etc. a large number of industrial sewage, agricultural water withdrawal and domestic garbage discharge, resulting in serious pollution of heavy metals in the Xiangjiang River basin, fecal coliform, volatile phenol, ammonia nitrogen, total phosphorus and chemical aerobic. The indicators such as quantity exceeded the standard, the aquatic biodiversity decreased, the water environment quality of the Xiangjiang River basin was poor, and the ecological environment was threatened. Since 2011, the UF value is greater than 0, and the water quality of Xiangjiang River has improved. The UF line and the UB line intersect at a significant level of 0.05 in 2012, and the intersection point exists in the 1.96 confidence interval. This indicates that the improvement of the water quality in Xiangjiang River is a sudden phenomenon. Since the end of 2012, the water quality of the Xiangjiang River has gradually improved.

According to the UF curve of the flood season in Figure 7 and the UF curve of the non-flood period in Figure 8, the UF values of both of them remained below 0 at the end of 1996 to the end of 2010, indicating that the water quality of the Xiangjiang River basin showed a deteriorating trend during the 14-year period. According to the location of the intersection of UF and UB curves, the improvement of water quality in Xiangjiang River is a mutation phenomenon. Specifically, the water quality mutation in the flood season started in 2014, and the water quality mutation in the non-flood period started in 2011.

According to Figures 6 to 8, combined with the MK test of three periods, the long dashed line in the figure indicates that the critical value is positive or negative 1.96, which means that the test with a significance level of 95%, and the UF or UB with an absolute value greater than 1.96 indicates that the trend is significant. In each period of approximately 17 years, the water quality growth trend exceeded the critical level of 0.05 critical line. This indicates that the rising trend of water quality in the Xiangjiang River basin in recent years is very significant. The water quality improvement projects in the basin have achieved initial results, and the water ecological environment in the Xiangjiang River basin is constantly improving. Exploring the cause, we find that Hunan Province has adopted many methods to control the Xiangjiang River. On September 27, 2012, Hunan Province officially passed the “Regulations on the Protection of Xiangjiang River in Hunan Province”, which marked the first comprehensive local regulations on the protection of river basins in China; in 2013, Hunan launched the “No.1 Key Project” for the implementation of Xiangjiang River protection and treatment. It plans to implement three “three-year action plans” and the implementation of five key tasks, focusing on strengthening river management, strengthening water resources security, and strengthening water resources management. In the end, it will achieve the overall goal of “mountain clear, shore green, river smooth, water net”, and urge the people of the province to pay more attention to, work harder and more effectively protect the mother

river of Xiangjiang. It can also be seen from the MK test chart that the “Xiangjiang No.1 Key Project” has achieved great success and the water environment quality of the Xiangjiang River basin has been greatly improved.

6 Conclusion

In this paper, the MK mutation test method was used to analyze the annual runoff data of the Xiangjiang River basin in the past 20 years and the trend data of the II and III water quality. The results show that the annual runoff of the upper reaches of the Xiangjiang River basin tends to be stable and the scope of change is small. The runoff of rivers in the middle and lower reaches is declining, and this decline in runoff is a sudden phenomenon, which occurred around 1998. The water quality of the Xiangjiang River basin has been deteriorating throughout the 14-year period from 1996 to 2010, and the water quality is poor. Since 2011, the water quality of the basin has been continuously improved. This water quality improvement is also a sudden phenomenon, which occurred around 2012. In recent years, the improvement trend of water quality in the Xiangjiang River basin is very significant.

In the future, for the protection of water resources and water environment in the Xiangjiang River basin, it is still necessary to continue to strengthen the control and treatment of watershed pollution^[12]. On the one hand, it is necessary to optimize and adjust the local industrial structure, develop clean energy, and reduce emissions of pollutants in industrial and agricultural production; on the other hand, it is necessary to strengthen the system management of water environmental protection, and the various departments and industries involved in water environmental protection. To unify, build an integrated model for comprehensive improvement of the water environment in the Xiangjiang River basin, and realize unified planning and comprehensive management of the Xiangjiang River basin.

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