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Assessment and Time Trend Analysis on Water Quality in the Qingyi River Basin, China

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Abstract. Eight water quality indexes of five sections (sections of the Luma Bridge, the Gaocun Bridge, Upstream of the Qingni River, Downstream of the Qingni River and the Yunliang River section) of the Qingyi River Basin were screened and converted into four main components by the Principal Component Analysis method. A comprehensive assessment model of water quality in the Qingyi River Basin was established. Water quality of the Qingyi River Basin was assessed from 2000 to 2014. And water quality variation trend was recognized by using Mann-Kendall (M-K) method and Daniel non-parametric test method. The results showed that: from 2000 to 2009, water quality in the section of Qingni River upstream was the best and that in the section of Yunliang River the worst; From 2009 to 2014, water quality in the section of Yunliang River gradually improved and became the best among all the sections, while that in the section of Luma Bridge was the worst; In 15 years, water quality in the section of Yunliang River changed greatly, after 2012, all the sections which participate in the evaluation have eliminated the inferior V class. M-K, Daniel Time Trend Analysis showed the same results, M-K method was more sensitive when the fluctuations occurs, the result was more conservative. The water quality of each section showed a significant downward trend. What was more, water quality of the Qingyi River Basin have been significantly improved.

Key words: water quality assessment, Principal Component Analysis, Time Trend Analysis, Qingyi River Basin

1. Introduction

The Qingyi River Basin is a tributary of the Ying River water system in the upper streams of the Huai River Basin. Its main stream flows through the Xuchang City of Henan Province. Because the shore side sewage is absorbed, the river is seriously polluted. The quality of life of residents and the construction of urban ecological civilization has been seriously affected [1], [2]. It is necessary to carry out the work of water quality evaluation and water quality trend identification at the present stag, for further promote the water pollution control of the Qingyi River Basin during “13th Five-Year Plan”, and achieve the goal which determined by Water Pollution Control Action Plan [3].

It is very important to analysis the factors which are involved in the evaluation, because of the comprehensive evaluation of water quality is the basic work of water environment management. At present, the Index Method, Fuzzy Mathematics Evaluation, Gray System Evaluation, Analytic Hierarchy Process, Artificial Neural Network Evaluation, Water Quality Index and Principal Component Analysis are the common methods for comprehensive water quality evaluation of river in China. Among them, Principal Component Analysis can reduce the variable dimensionality reduction and transform a number of indicators into a few independent indicators, named "Principal Component", which can provide the basis for interpretation for the research conclusion [4]-[7]. Domestic and foreign scholars [8], [9] have achieved good result by using the Principal Component Analysis method for tropical lake, Fen River, Huai River and other comprehensive evaluation of river water quality.

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Mann-Kendall (MK) nonparametric test-based on sequential statistics is part of the statistical model，which has been widely used for water quality Time Trend Analysis because of its data is not disturbed by outliers [10]-[15].The comprehensive evaluation of the water quality of the Qingyi River Basin is still rarely reported. In this paper, the main component analysis method is used to evaluate the water quality of the three main rivers in the Xuchang section of the Qingyi River Basin, the water quality time series from 2000 to 2014 were obtained, the trend of change is identified by the M-K method, and compared the results with the Daniel trend test results, in order to provide the basis for the Qingyi River water pollution control and achieve the Qingyi River water quality improvement objectives.

2. Material and Methods

2.1. Research Object

The Qingyi River originate from the Goucaoyuan, Xinzheng City, flow through the Changge City, the Xuchang County, the Weidu District, the Linying County and the Yanling County, import into the Ying River at the Taocheng gate in the southeast of Yanling County, the total length is 149 kilometers, the basin area is 2362 square kilometers, the main role is to control flood and accept pollutant. The Qingni River, the Yunjiang River are its tributaries. The distribution of water quality monitoring and evaluation section is shown in Fig.1.

2.2. Research Methods

The data from 5 monitoring sections (the Luma Bridge, the Gaocun Bridge, the upstream and downstream of Qingni River, the Yunliang River section) of the Xuchang City Environmental Monitoring Center in 2000 to 2014were studied. According to the available data, COD_{Mn}, BOD_5, COD, ammonia nitrogen, petroleum, volatile phenol, fluoride, DO were selected as the analysis indicators. The missing values were interpolated by using Spline Interpolation Method, the Quantile-Quantile (Q-Q)graph shows the interpolation effect was good. It should be noted that the upstream and downstream sections of the Qingni River were slightly adjusted by environmental protection agency of the Xuchang City within time series. This study was based on the geographical location and assumes that the adjustment of the cross section does not affect the analysis results.

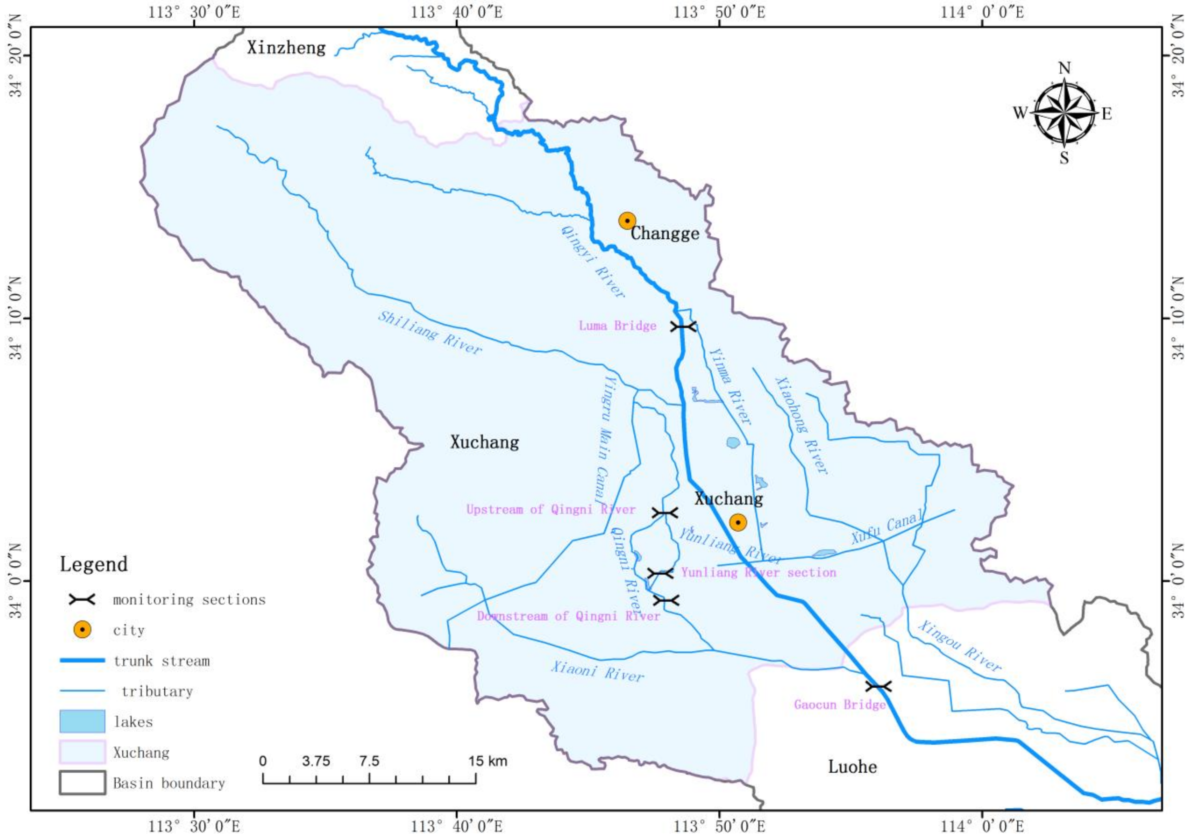

Fig. 1. The geographical location and water quality monitoring section distribution map

According to the data availability, the monthly data of 2006 were selected and the evaluation indicators were further selected by Principal Component Analysis [7]. The indicators and the weight of the principal component have been confirmed. Then, the comprehensive evaluation model of water quality was established. By using this model, the annual data of each section at the time scale were evaluated. Compared with the national standard scoring, water quality level was divided, and the annual water quality in time series was obtained in 2000-2014. The M-K method was used to analyze the trend of water quality [16], and compared the results with the Daniel trend test [17].

The data processing of this research was done by SPSS19, DPS data processing system, EXCEL and other software.

3. Results and Discussions

3.1. Water Quality Evaluation Model Based On Principal Component Analysis

The monthly data (the Luma Bridge, the Gaocun Bridge, the Upstream of Qingni River, the downstream of Qingni River, the Yunliang River section) of the Qingyi River in 2006 were selected, the intrinsic link between the indicators (COD_{Mn}, BOD_5, COD, ammonia nitrogen, petroleum, volatile phenol, fluoride, DO) was studied by Principal Component Analysis, and the number of principal components was determined. Indicators were screened and the water quality assessment model was established.

The result showed that: the Kaiser-Meyer-Olkin (KMO) test value was 0.654, indicating the Principal Component Analysis can be carried out. The original index correlation coefficient matrix, the load matrix, the variance contribution rate, the cumulative variance contribution rate, the rotation factor load matrix were calculated. Rotation factor load matrix shows that eight indicators can be divided into five principal components: the first principal component (F1) contains COD_{Mn}, BOD_5, COD, which was reflecting the organic matter content of water; the second principal component (F2) contains the indicators of petroleum, volatile phenol, which can reflect the status of industrial pollution; the third principal component (F3) was the physicochemical index DO; the fourth principal component (F4) was ammonia and nitrogen belongs to eutrophication index; the fifth principal component (F5) contains the indicator fluoride. According to the results in Table 1, the cumulative contribution rate of the first four principal components reached 88.566%, by according to the contribution rate of 70% to 90% as the selection principle [7], select the interpretation data for the first four principal components (including indicators COD_{Mn}, BOD_5, COD, ammonia nitrogen, petroleum, volatile phenol, DO), as the main factor affecting the water quality of the Qingyi River, the water quality assessment model was constructed.

Table. 1 Total variance explained

Ingredient	initial eigenvalue			Extract the sum of squares and loads		
	Sum	Variance %	accumulation %	Sum	Variance %	accumulation %
1	3.766	47.080	47.080	3.766	47.080	47.080
2	1.589	19.867	66.947	1.589	19.867	66.947
3	1.034	12.927	79.873	1.034	12.927	79.873
4	0.695	8.693	88.566	0.695	8.693	88.566
5	0.450	5.619	94.185	0.450	5.619	94.185
6	0.232	2.901	97.086			
7	0.182	2.272	99.358			
8	0.051	0.642	100.000			

$F = 0.3391F_1 + 0.2279F_2 + 0.1528F_3 + 0.1424F_4$ was calculated. That was, integrated water quality evaluation model. Put the average data of each year into the model. The annual water quality evaluation results were calculated. Comprehensive scores are inversely relate to the water quality.

3.2. Water Quality Evaluation Results

Table. 2 Scoring results according to environmental quality standards for surface water

class	1	2	3	4	comprehensive
I	15.78	3.66	-6.20	0.65	5.33
II	17.93	3.95	-4.15	1.23	6.52
III	25.25	5.50	-2.68	2.67	9.78
IV	39.84	9.01	0.19	5.07	16.31
V	56.75	12.88	3.40	7.56	23.78

Based on environmental quality standard for surface water (GB3838-2002)[18], the class limit of indicators (COD_{Mn}, BOD_5, COD, ammonia nitrogen, petroleum, volatile phenol, DO) were obtained, the surface water quality of the national standard score results were obtained (Table 2) when the indicators were brought into model. The results of water quality assessment of each section are shown in Table 3. As shown in the Table 2, Table 3, the lower score means the better water quality.

Table. 3 Assessment results of water quality in each section of the Qingyi River Basinin 2000 - 2014

Date	Luma Bridge		Gaocun Bridge		Upstream of Qingni River		Downstream of Qingni River		Yunliang River section	
	Score	class	Score	class	Score	class	Score	class	Score	class
2000	201.53	InferiorV	163.68	InferiorV	49.69	InferiorV	91.24	InferiorV	251.43	InferiorV
2001	157.31	InferiorV	139.25	InferiorV	56.95	InferiorV	207.75	InferiorV	373.49	InferiorV
2002	130.02	InferiorV	98.03	InferiorV	65.78	InferiorV	202.24	InferiorV	404.91	InferiorV
2003	87.24	InferiorV	63.67	InferiorV	21.90	V	65.44	InferiorV	258.66	InferiorV
2004	109.08	InferiorV	35.84	InferiorV	17.80	V	66.89	InferiorV	127.26	InferiorV
2005	20.77	V	28.89	InferiorV	15.13	IV	54.89	InferiorV	30.98	InferiorV
2006	31.13	InferiorV	20.48	V	20.10	V	29.14	InferiorV	58.64	InferiorV
2007	25.65	InferiorV	27.99	InferiorV	21.53	V	13.85	IV	46.53	InferiorV
2008	28.01	InferiorV	28.27	InferiorV	17.55	V	39.62	InferiorV	24.74	InferiorV
2009	22.87	V	26.41	InferiorV	13.40	IV	83.17	InferiorV	14.95	IV
2010	19.41	V	20.01	V	15.06	IV	15.06	IV	14.95	IV
2011	28.07	InferiorV	21.44	V	13.77	IV	34.89	InferiorV	15.73	IV
2012	18.95	V	16.05	IV	14.75	IV	16.11	IV	13.93	IV
2013	16.50	V	18.42	V	16.09	IV	14.70	IV	10.06	IV
2014	15.86	IV	17.17	V	15.90	IV	18.32	V	10.75	IV

Note: The inferior Ⅴ class is worse than the Ⅴ class.

3.3. Time Series Trend Test

M-K, Daniel trend test results in Table 4.

Table. 4 Trend test results for integrated score of each section of the qingyi river basin in m-k and daniel methods

Test Method	Luma bridge	Gaocun bridge	Upstream of Qingni River	downstream of Qingni River	Yunliang Riversection
M-K statistic	-2.53**	-3.32**	-1.11	-1.27	-2.52**
Trend	decline	decline	--	--	decline
Daniel statistic	-0.90**	-0.943**	-0.77*	-0.76*	-0.95**
Trend	decline	decline	decline	decline	decline

Note: "*" and "**" indicate that the value passed the significant level of α = 0.05 and 0.01, respectively.

3.4. Result Analysis

a. Trend Analysis and the Time Variation of Water Quality in Each Section

The Yunliang River section: The worst comprehensive score was 23.8 times higher than the class Ⅳ score, reaching 404.91 in 2002, which was the maximum value in the entire basin during the time series. The minimum value appeared in 2013, up to class IV standards. Since 2003, the score began to decline, the water quality was improved, the declined fluctuation in 2005 was the largest, it fell by 75.6% than the last year; the water quality reached class Ⅳ in 2009. The results of time trend analysis were significantly decreased by using the test of the M-K and Daniel trend test, and the water quality had been significantly improved.

The Upstream of Qingni river: Comprehensive score of water quality was 6 times higher than class Ⅲ,reaching 65.78 in 2002. Although the water quality reached Class IV in 2009but still did not meet the functional zoning requirements. The water quality from inferior class Ⅴ to class Ⅴ in 2003, the score fell by 67% during the year. The result of M-K trend test showed that the change of water quality was not significant, and did not passed by using the test of α_1=0.1. Daniel trend test result showed that the comprehensive score was significantly decreased by using α_1=0.05 significant level. The water quality in the upstream of the Qingni River had a small change in time series.

The Downstream of Qingni river: The maximum appeared in 2001, comprehensive score of water quality was 12.7 times higher than class Ⅳ, belongs to the inferior class Ⅴ water quality. Water quality was improved significantly in 2003, the score fell by 67%. After 2010, water quality reaching class Ⅳ which had been met the requirements of functional zoning. M-K trend test result showed that the comprehensive score did not pass the test ofα_1=0.1 significant level, the downward trend was not significant. Daniel trend test result showed that the comprehensive score passed the test of α_1=0.05 significant level, decreased significantly. M-K method was more sensitive to data fluctuation, the result was more conservative .The test result was more realistic by using Daniel trend test.

The Luma Bridge: The maximum appeared in 2000, the water quality was ranked in the inferior class Ⅴ,reaching 201.53. Since 2000, the score had declined year by year. In 2005, the score fell by 81%,it was the largest decline, the water quality from inferior Ⅴto Ⅴ class. The comprehensive score declined to the bottom in 2014, and the water quality was climbed to the peak. The results of M-K and Daniel trend test showed that the water quality was improved significantly, the decreasing amplitude of comprehensive score was significantly, and passed the test of α_1=0.1 significant level.

The Gaocun Bridge: The maximum appeared in 2000, the comprehensive score of water quality was163.68. The lowest score appeared in 2012, and the water quality was climbed to the peak. The score fell by 44% in 2004,which was the largest amplitude reduction. The result of M-K trend test showed that the water quality improved significantly, the decreasing amplitude of comprehensive score was significantly,and passed the test of α_1=0.01 significant level.

b. Analysis on Water Quality Variation

In 2000-2005, the comprehensive score of the Yunliang River section was above the others sections, the Luma Bridge ranked the second. The pollution level in the downstream of Qingni River was at a moderate level. In 2006-2008, the pollution of five monitoring sections from light to heavy were the Yunliang River, the upstream of Qingni River, the downstream of Qingni River, the Luma Bridge and the Gaocun Bridge. During the time series, the improved effect of water quality of the Yunliang River and the Qingni River were obvious.

In 2000-2005, the change of score between the downstream of Qingni River and the Yunliang River section was coincided, the water quality is mainly affected by the Yunliang River; From 2006 to 2014, the water quality fluctuation of the downstream of Qingni River was more intense, the water quality of the Yunliang River section improved significantly and the change was stable, the water quality of the upstream of Qingni River was better and stable, so the main pollution source of the Qingni River was located in the downstream of Qingni River.

In 2000 to 2014, the trend of water quality change between the Gaocunqiao and the Luma Bridge was basically same between each other in the Qingyi River, which was not affected by the Qingni River. Domestic sewage absorption, industrial wastewater discharge, were the main headwaters of the Qingyi River Basin. In 2001, some project had been taken place in the Xuchang City, river dredging work was carried out, garbage, weeds in the Qingyi Riverwere cleared, the river had been dredged. In 2003-2004, the paper-making, leather and other industries of which have pollution were remediated, hundreds of enterprises were closed down. Since 2007, further environment comprehensive improvement of urban river have been taken place in the Xuchang City, hundreds of sewage outfall were closed [2].

In conclusion, by comprehensive managed the industrial structure, environmental infrastructure, small watershed and new pollution resources in the Xuchang City in the Qingyi River Basin, water quality has been improved greatly since 10th Five-year Plan.

4. Conclusions

(1)During the period of 2000 to 2014, the peak of water quality comprehensive score of the Luma bridge, the Gaocun bridge, the upstream and the downstream section of Qingni River, the Yunliang River were appeared in 2000-2003；Compared with the highest score, the lowest point decreased by 80% to 97%, appeared in 2009 - 2014, the water quality of each section was significantly improved in 2003 to 2005, and then the inferior class V water quality was eliminated in 2012.

(2)The result of the M-K method is more sensitive when the data fluctuation, the result is more conservative and basically consistent with the result by using Daniel test. Overall, the holistic water quality of the Qingyi River basin in 2000 to 2014 was significantly improved.Among them, the treatment effects of the Yunliang River and the Qingni River were the most obvious in time series.

5. Acknowledgment

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6. References

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