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Temporal and Spatial Distribution Characteristics of Water Quality in Hongya Section of the Qingyi River

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Abstract. Eleven parameters such as pH, dissolved oxygen (DO), permanganate index (COD_{Mn}), ammonia nitrogen (NH_3-N), total phosphorus (TP), total nitrogen (TN), fluoride(F^-), cadmium (Cd), lead (Pb), petroleum and fecal coliform were selected to analyze the main pollution factors and the temporal and spatial distribution characteristics of Hongya Section of the Qingyi River by principal component analysis (PCA) and SPSS software, which based on water monitoring data in the year of 2011, 2013 and 2015. Four principal components were verified through PCA, and the result showed that the change of water quality is the trend of year-on-year deterioration in 2011, 2013 and 2015.The water quality in other seasons was better than that in autumn the water quality in Guidufu Section was better than it was in Muchengzhen Section.

Research Background

Qingyi River is the largest tributary in the downstream of the Dadu River [1], whose length is 276 km and the area is 13,300 km^2. The Hongya section of the Qingyi River flows from Guidufu and out of the Muchengzhen, which has a total length of 58.3km. It is the main source of drinking, industry, and public and irrigation water for residents of Hongya County (Figure 1). So, the analysis of the temporal and spatial characteristics of the water quality for the river is particularly significant.

Fig.1 Geographic location and monitoring section

At present, water quality analysis methods are mainly divided into single-factor evaluation method and multi-factor evaluation method. The single factor method cannot fully reflect the limitations of the water body function [2]. Multi-factor assessment method commonly refers comprehensive assessment method, water quality index method and nemerowan method, etc. These methods have the insufficiency that cannot highlight the pivotal pollution factor when the water quality indicators are increased [3, 4]. The Principal Component Analysis method is based on the idea of dimensionality reduction. On the basis of retaining the original information to the maximum extent, the primary variable is converted into several less comprehensive variables that are the principal components. Then the extracted principal components are used to evaluate each individual. There is unrelated relationship among principal components. It avoids the overlap of information and reflects the main pollution factors, which highlights the advantages of PCA method's objectivity [5, 6]. Therefore, the PCA method is used to analyze the temporal and spatial characteristics of water quality in Hongya Section of the Qingyi River in this paper.

Data and Methods

Sources of Data

This article uses the water quality monitoring data of the entrance section (Guidufu) and exit section (Muchengzhen) of the Qingyi River in 2011, 2013 and 2015. It takes 11 indicators: pH, dissolved oxygen, permanganate index, ammonia nitrogen, total phosphorus, total nitrogen, fluoride, cadmium, lead, petroleum and fecal coliform. These data are divided into groups according to spring (March to May), summer (June to August), autumn (September to November) and winter (December- February) and showed in Table 1.

Table 1 Seasonal average data

year	section	season	sequence	pH	DO	COD_{Mn}	NH_3-N	TP	TN	F	Cd	Pb	Petro	Fecal coliform
2011	Guidufu	spring	G1	8.37	8.63	1.40	0.334	0.060	0.653	0.157	0.0005	0.005	0.02	173
		summer	G2	8.27	8.73	1.23	0.706	0.067	0.840	0.164	0.0005	0.005	0.02	287
		autumn	G3	8.00	8.15	1.20	0.298	0.066	0.502	0.092	0.0005	0.005	0.02	230
		winter	G4	8.63	8.79	1.29	0.437	0.071	0.690	0.168	0.0005	0.005	0.03	210
	Muchengzhen	spring	M1	7.55	9.23	1.37	0.133	0.060	0.880	0.127	0.0012	0.017	0.02	8000
		summer	M2	7.42	7.70	1.23	0.118	0.057	0.843	0.225	0.0013	0.020	0.01	8000
		autumn	M3	7.63	7.97	1.50	0.175	0.070	0.930	0.219	0.0013	0.017	0.02	8000
		winter	M4	7.70	10.3	1.22	0.137	0.058	0.937	0.153	0.0011	0.016	0.01	8000
2013	Guidufu	spring	G1	7.80	8.83	1.20	0.321	0.042	0.650	0.098	0.0005	0.005	0.024	5490
		summer	G2	8.27	8.90	0.96	0.210	0.055	0.407	0.103	0.0005	0.005	0.021	833
		autumn	G3	8.20	9.10	1.33	0.332	0.127	0.461	0.111	0.0005	0.021	0.019	620
		winter	G4	7.83	8.93	0.96	0.229	0.052	0.328	0.101	0.0005	0.005	0.022	310
	Muchengzhen	spring	M1	7.93	8.37	1.44	0.091	0.059	1.050	0.125	0.0003	0.001	0.017	8000
		summer	M2	8.07	7.92	2.18	0.043	0.076	0.940	0.136	0.0003	0.001	0.020	8000
		autumn	M3	7.98	7.73	1.59	0.087	0.112	0.850	0.240	0.0003	0.001	0.017	8000
		winter	M4	8.18	10.0	1.56	0.127	0.077	0.933	0.169	0.0018	0.007	0.013	8000
2015	Guidufu	spring	G1	8.20	8.77	1.17	0.095	0.054	0.718	0.197	0.001	0.001	0.02	8000
		summer	G2	7.98	8.47	1.47	0.127	0.121	1.264	0.140	0.001	0.005	0.02	4333
		autumn	G3	7.79	9.07	1.50	0.202	0.076	1.303	0.056	0.002	0.017	0.03	2980
		winter	G4	7.94	8.97	1.66	0.132	0.077	1.076	0.139	0.002	0.010	0.02	5867
	Muchengzhen	spring	M1	8.03	8.31	1.75	0.182	0.069	1.094	0.129	0.001	0.003	0.01	4900
		summer	M2	7.94	7.95	3.00	0.083	0.073	1.002	0.116	0.001	0.003	0.01	3833
		autumn	M3	7.84	8.33	2.23	0.173	0.093	1.106	0.176	0.001	0.004	0.01	3300
		winter	M4	7.75	7.88	1.50	0.097	0.078	0.887	0.168	0.001	0.003	0.01	4367

Method Steps and Calculations

The main steps of the principal component analysis method are as follows: 1) After eliminating the influence of the dimension by normalizing the original data matrix, the correlation analysis of each index is performed to obtain the correlation matrix, which illustrates the degree of correlation among the indexes; 2) The eigenvalue, variance contribution rate and cumulative variance contribution rate of correlation matrix are calculated to determine the number of principal components; 3) The load matrix and the corresponding feature value of the eigenvectors of all principal components are determined to provide a comprehensive expression and calculate the composite score of principal component; 4) Finally, we use professional knowledge to analyze the results [7-9].

Factor Correlation Analysis

DO is a degressive indicator, so the higher the concentration, the better the water quality. The other indicators are incremental indicators. Therefore, the dissolved oxygen is first converted and then normalized in the process of water quality standardization [10]. After standardization, the correlation matrix obtained from SPSS shows in Table 2.

Table 2 Correlation Matrix

	pH	DO	COD_{Mn}	NH_3-N	TP	TN	F^-	Cd	Pb	Petro	Fecal coliform
pH	1.000	-0.186	-0.064	0.485	0.147	-0.306	-0.074	-0.352	-0.460	0.401	-0.531
DO	-0.186	1.000	0.380	-0.211	0.164	0.106	0.359	-0.418	-0.306	-0.204	0.078
COD_{Mn}	-0.064	0.380	1.000	-0.367	0.290	0.525	0.025	-0.079	-0.251	-0.411	0.181
NH_3-N	0.485	-0.211	-0.367	1.000	-0.097	-0.365	-0.143	-0.199	0.045	0.374	-0.693
TP	0.147	0.164	0.290	-0.097	1.000	0.274	0.148	-0.061	0.073	-0.025	-0.074
TN	-0.306	0.106	0.525	-0.365	0.274	1.000	0.110	0.425	0.022	-0.264	0.473
F^-	-0.074	0.359	0.025	-0.143	0.148	0.110	1.000	-0.021	-0.017	-0.466	0.458
Cd	-0.352	-0.418	-0.079	-0.199	-0.061	0.425	-0.021	1.000	0.609	-0.019	0.320
Pb	-0.460	-0.306	-0.251	0.045	0.073	0.022	-0.017	0.609	1.000	-0.005	0.105
Petro	0.401	-0.204	-0.411	0.374	-0.025	-0.264	-0.466	-0.019	-.005	1.000	-0.428
Fecal coliform	-0.531	0.078	0.181	-0.693	-0.074	0.473	0.458	0.320	0.105	-0.428	1.000

From the correlation coefficient matrix, it can be seen that most of the correlation coefficients are more than 0.3, indicating that there is overlap and it has a certain correlation among the index information [11]. It is suitable for principal component analysis.

Extracting Principal Components

According to the correlation coefficient matrix, the eigenvalues, variance contribution rates and cumulative variance contribution rates of each index are extracted, which as follows in Table3.

Table 3 Principal component extraction analysis table

Ingredient	Initial feature value			Extract square and load		
	Eigenvalue	Variance rate	Cumulative rate	total	Variance rate	Cumulative rate
1	3.358	30.532%	30.532%	3.358	30.532%	30.532%
2	2.270	20.633%	51.164%	2.270	20.633%	51.164%
3	1.365	12.413%	63.577%	1.365	12.413%	63.577%
4	1.087	9.879%	73.456%	1.087	9.879%	73.456%
5	0.858	7.797%	81.252%			
6	0.715	6.496%	87.748%			
7	0.595	5.409%	93.158%			
8	0.331	3.010%	96.168%			
9	0.243	2.208%	98.376%			
10	0.097	0.885%	99.261%			
11	0.081	0.739%	100.000%			

When extracting the number of principal components, the first m principal components whose principal component's corresponding eigenvalue is greater than 1 are generally selected. The eigenvalue is an index which representing the influence degree of the principal component. When the eigenvalue is less than 1, it shows the explanatory power of the principal component is less than original variable [12]. Therefore, according to the analysis results, four principal components B_1, B_2, B_3 and B_4 are selected, and the cumulative contribution rate of the four principal components has reached 73.456%. The corresponding principal components can already reflect most of the information of the original index. The load of each factor on each principal component is shown in Table 4.

The study identifies the index with a large absolute value of the correlation coefficient of the principal component as an index significantly related to the principal component. According to the analysis in Table 3 and Table 4, the variance contribution rate of the first principal component B_1 is

30.532%. The load factor of the first principal component is fecal coliform, ammonia nitrogen, permanganate index, total nitrogen, pH and petroleum. It mainly reflects the combined effect of the total number of bacteria, organics, pH, petroleum and nitrogen on water quality. The variance contribution rate of the second principal component B_2 is 20.633%. The loading factor of the second principal component is cadmium, lead and dissolved oxygen. It mainly reflects the combined effect of metal ions and dissolved oxygen concentration on water quality. The variance contribution rate of the third principal component B_3 is 12.413%. The load factor of the third principal component is total phosphorus, which mainly reflects the influence of phosphorus concentration on water quality. The variance contribution rate of the fourth principal component B_4 is 9.879%. The load factor of the fourth principal component is fluoride, which mainly reflects the effect of the fluoride concentration on the water quality.

Table 4 Factor loading matrix

Ingredient / Main component	pH	DO	COD_{Mn}	NH_3-N	TP	TN	F^-	Cd	Pb	Petro	Fecal coliform
B_1	-0.672	0.313	0.512	-0.760	0.158	0.679	0.449	0.365	0.162	-0.670	0.821
B_2	0.377	0.677	0.503	-0.043	0.281	-0.019	0.259	-0.780	-0.774	-0.198	-0.145
B_3	0.245	-0.179	0.474	0.019	0.610	0.535	-0.442	0.258	0.050	0.050	-0.243
B_4	0.134	0.091	-0.206	0.320	0.586	-0.071	0.619	0.061	0.399	-0.112	-0.089

Calculating the Principal Component Score

The four main components B_1, B_2, B_3 and B_4 are recorded in the SPSS software and the feature vectors are obtained by "A_i=B_i/SQRT (λ)" (i=1, 2, 3, 4; λ is the feature value).

Table 5 Feature Vectors Values

Ingredient / Feature Vector	pH	DO	COD_{Mn}	NH_3-N	TP	TN	F^-	Cd	Pb	Petro	Fecal coliform
A_1	-0.37	0.17	0.28	-0.41	0.09	0.37	0.25	0.2	0.09	-0.37	0.45
A_2	0.25	0.45	0.33	-0.03	0.19	-0.01	0.17	-0.52	-0.51	-0.13	-0.1
A_3	0.21	-0.15	0.41	0.02	0.52	0.46	-0.38	0.22	0.04	0.22	-0.21
A_4	0.13	0.09	-0.2	0.31	0.56	-0.07	0.59	0.06	0.38	-0.11	-0.09

According to the eigenvectors, the linear equations of each principal component can be expressed as follows:

$$z_1 = -0.37x_1 + 0.17x_2 + 0.28x_3 - 0.41x_4 + 0.09x_5 + 0.37x_6 + 0.25x_7 + 0.2x_8 + 0.09x_9 - 0.37x_{10} + 0.45x_{11}. \quad (1)$$

$$z_2 = 0.25x_1 + 0.45x_2 + 0.33x_3 - 0.03x_4 + 0.19x_5 - 0.01x_6 + 0.17x_7 - 0.52x_8 - 0.51x_9 - 0.13x_{10} - 0.1x_{11}. \quad (2)$$

$$z_3 = 0.21x_1 - 0.15x_2 + 0.41x_3 + 0.02x_4 + 0.52x_5 + 0.46x_6 - 0.38x_7 + 0.22x_8 + 0.04x_9 + 0.22x_{10} - 0.21x_{11}. \quad (3)$$

$$z_4 = 0.13x_1 + 0.09x_2 - 0.2x_3 + 0.31x_4 + 0.56x_5 - 0.07x_6 + 0.59x_7 + 0.06x_8 + 0.38x_9 - 0.11x_{10} - 0.09x_{11}. \quad (4)$$

In the above formula, z_1, z_2, z_3, z_4 represent the scores of the four principal components; x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11} respectively represent pH, dissolved oxygen, permanganate index, ammonia nitrogen, total phosphorus, total nitrogen, fluoride, cadmium, lead, petroleum and fecal coliform. The scores of each principal component can be obtained by bringing the standardized data into the above equation. The integration of the product of the score of each principal component and the variance contribution rate is the comprehensive score of each principal component. The score is higher; the water pollution is more serious. These main component score, main component composite score and rank are shown in Table 6.

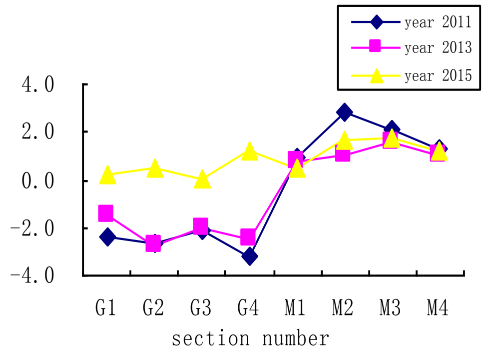
Table 6 Main component score, main component comprehensive score and rank

year	section	sequence	F1	F2	F3	F4	F	No.
2011	Guidufu	G1	-2.409	0.645	-0.132	0.178	-60.131	8
		G2	-2.636	0.522	-0.130	-1.993	-91.021	3
		G3	-2.120	0.427	-0.430	-0.483	-66.038	7
		G4	-3.233	0.730	0.388	0.897	-69.976	6
	Muchengzhen	M1	0.988	-2.347	-4.275	-0.538	-76.638	5
		M2	2.809	-1.204	-2.233	1.262	45.664	18
		M3	2.094	-0.923	-0.963	1.270	45.479	17
		M4	1.339	-2.496	-0.746	-0.101	-20.892	11
2013	Guidufu	G1	-1.521	-0.724	-0.952	-1.465	-87.658	4
		G2	-2.717	-0.139	-0.806	-0.718	-102.910	2
		G3	-2.034	-0.592	1.353	2.276	-35.033	9
		G4	-2.455	-0.587	-1.253	-0.965	-112.154	1
	Muchengzhen	M1	0.784	0.802	-0.457	-1.408	20.911	14
		M2	1.070	1.962	0.478	-1.151	67.722	21
		M3	1.580	2.392	-0.490	1.603	107.358	24
		M4	1.055	-1.422	0.553	0.188	11.594	13
2015	Guidufu	G1	0.223	0.284	-1.523	-0.222	-8.444	12
		G2	0.518	0.561	2.146	0.660	-34.964	20
		G3	0.072	-3.036	2.702	-0.817	60.543	10
		G4	1.238	-1.394	1.114	-0.102	21.883	15
	Muchengzhen	M1	0.461	0.704	0.491	-0.800	26.794	16
		M2	1.697	2.094	1.400	-1.477	97.795	22
		M3	1.719	1.970	0.742	0.468	106.954	23
		M4	1.191	1.011	-0.680	-0.039	48.401	19

Results Analysis

Analysis of the Trend of Each Principal Component Change

According to Table 6, the scores of the main components in year 2011, 2013 and 2015 are shown from figure 2 to figure 5.



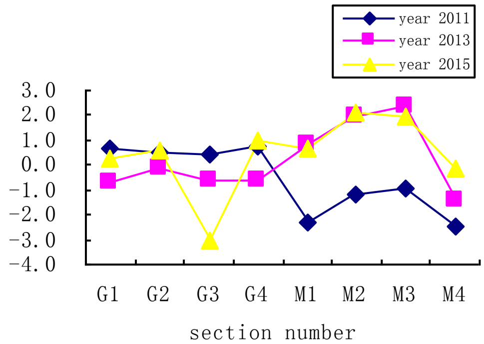
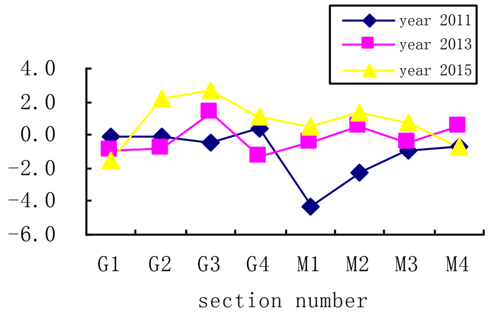


Fig. 2 the score of the first principal component F1 **Fig. 3** the score of the second principal component F2



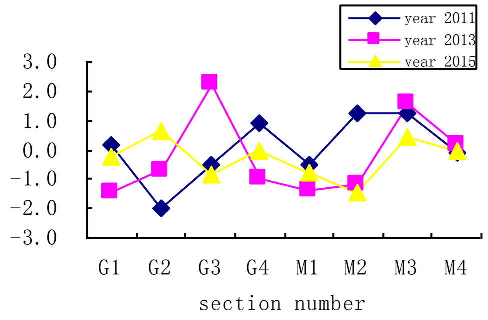


Fig. 4 the score of the third principal component F3 **Fig. 5** the score of the forth principal component F4

According to the principle of low-priority in water quality, the first principal component score shows an increasing trend during the year 2011, 2013, and 2015 from figure 2 to figure 5, that is, the combined effects of the load factor of the first principal component pH, fecal coliforms, petroleum, permanganate index and nitrogen on water quality have increased year by year. According to actual monitoring data, there has been a significant increase on the concentrations of total nitrogen and permanganate index in 2015, which compared to 2011 and 2013. So it can be concluded that total nitrogen and organic matter have been the main influencing factors, and the effect has gradually increased during three years. The change trend of the score of the second principal component is the same as the first principal component. The composite score in year 2015 is significantly higher than that in year 2013, and the score in year 2013 is higher than that in year 2011, that is, the effect of the load factor of the second principal component that cadmium, lead and dissolved oxygen on the water quality has increased year by year. The inter-annual variation in the score of the third principal component is relatively consistent, and the effect of the load factor TP is not changed significantly. The inter-annual change in the score of the fourth principal component shows a decreasing trend year by year, and the effect of the load factor fluoride gradually decreases.

From Fig. 2 to Fig. 5, it can also be concluded that the first principal component and the third principal component scores are significantly higher in Guidufu than that in Muchengzhen. In addition, the second principal component and the fourth principal component have little change in both sections. Therefore the effect of the first principal component loading factor that pH, fecal coliform, petroleum, permanganate index, nitrogen and the first principal component loading factor total phosphorus on the water quality is greater in Muchengzhen than that in Guidufu. Other factors changes are not obvious.

Analysis of the Change of Principal Component Composite Score

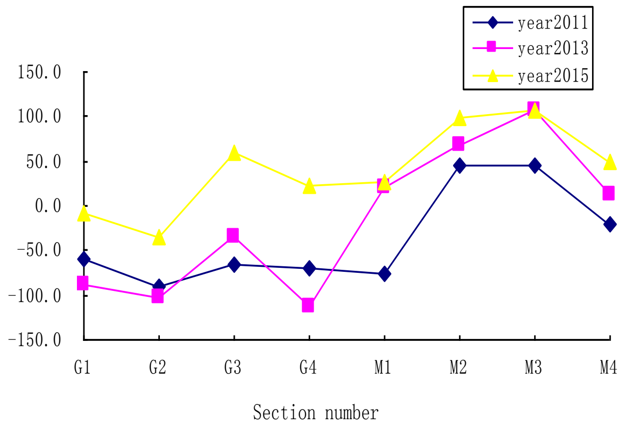


Fig. 6 Principal component composite scores for year 2011, 2013 and 2015

The composite scores of the principal components for year 2011, 2013 and 2015 can be obtained and show in figure 6. It shows that the annual comprehensive water quality in 2011 is better than that in 2013, and the water quality in 2013 is better than that in 2015, that is, water quality tends to deteriorate gradually. Combined with the analysis of each principal component score, we can know that the source of the deterioration of water quality is the change of the concentration of organic matter, total nitrogen, heavy metals and dissolved oxygen in the water.

According to a survey of industrial and mining enterprises along the Qingyi River valley in Hongya County in 2015, during the “Twelfth Five-Year Plan” period (year 2011-2015), Hongya County is a restricted development area, however there are still many violations in the settlement of enterprises. The disorder of pollution control is very severe. Most wood processing companies, brick-making enterprises and wine-making enterprises in Hongya County have no environmental assessment procedures and no pollution control facilities. Wastewater is discharged directly into the river and causes pollution. During the “Twelfth Five-Year Plan” period, Hongya County has been experienced rapid economic growth and urbanization acceleration process significantly. The discharge of domestic sewage is continuously rising to cause the increasingly serious treatment of domestic pollution sources. There has been a problem with the operation of the original urban sewage treatment plant and sewage collection rate has not met the target of 85% of the Sichuan Provincial Environmental Protection Agency by 2015. In addition, the Liujiang Wastewater Treatment Plant, Yuping Wastewater Treatment Station and Dongyue Wastewater Treatment Station have all been out of service for years due to imperfect pipe networks. Township sewage cannot be properly collected and treated, and it is directly discharged into water bodies, resulting in high concentration of organic and nitrogen content in water. The construction of large-scale aquaculture in Hongya County is excessive and dense and has been increasing year by year. There are no effective pollution prevention and control measures. Especially during the wet season, livestock husbandry wastewater overflows and leaks into the water with rain, causing the nitrogen content of the water to increase. The effect of heavy metal ions of cadmium and lead in the water has a process of enrichment over time, showing a trend of increasing year by year. The above reasons all lead to the deterioration of the inter-annual change of water quality in the Hongya section of the Qingyi River.

It can also be concluded from Figure 6 that the water quality of Guidufu section is obviously better than Muchengzhen, that is, water quality gradually deteriorates with the direction of water flow. According to the scores of the main components of the section, the variation of water quality along the river mainly comes from the influence of pH, fecal coliform, petroleum, permanganate index, nitrogen and phosphorus.

Guidufu Section is the entrance section of Qingyi River in Hongya County, and the section of Muchengzhen is the exit section. The Hongya Section of Qingyi River passes through the main urban areas and townships of Hongya County. It absorbs the domestic sewage of the residents along the river, the drainage of industrial enterprises, the aquaculture wastewater and the agricultural water to generate the high concentration of pollutants, especially in organic matter, nitrogen, phosphorus and bacteria, which made the water quality of the exit section worse.

It can be obtained from Figure 6 that the water quality of the Hongya section of the Qingyi River shows a certain degree of seasonality during the year, the water quality is the worst in the autumn and has improved in the winter. The precipitation in the Qingyi River basin is abundant. The months of July-September (summer and autumn) are the flood period and has heavy rainstorms most of the time that the rainfall accounts for 60% of the annual rainfall. The months of December-February (winter) are the dry period and the rainfall accounts for 4% of the annual rainfall [13]. Hongya County is a large agricultural county with more than 70% of agricultural population. Agricultural non-point source pollution contributes significantly during the flood period water, because of ground pollutants are brought into river with the sour of heavy rainfall [14]. Even if the water volume and dilution effect increases, but the pollutants still show in high concentration in the wet period. And in summer and autumn, the dissolved oxygen concentration decreases along with the water temperature rise [15], leading the water quality is relatively poor. During the dry period, the water flow is small and the flow velocity is slow, leading the sediment settles fast. In the process of sedimentation, the organics, nitrogen, phosphorus and other pollutants are adsorbed into water and settled together, which reduces the concentration of pollutants in the water. In addition, the temperature is low in the winter and the dissolved oxygen concentration is abundant, which improves water quality. The above reasons have caused the water quality is worst in autumn during the year for Hongya section of the Qingyi River.

Conclusion

The paper uses the principal component analysis method to process the water quality monitoring data of the entrance section (Guidufu) and exit section (Muchengzhen) of the Hongya section of Qingyi River in 2011, 2013 and 2015. The main pollution factors, spatial and temporal distribution characteristics of water quality in the section of the river are analyzed and discussed.

(1) Main components of 11 water quality indicators (PH, dissolved oxygen, permanganate index, ammonia nitrogen, total phosphorus, total nitrogen, fluoride, septum, lead, petroleum and fecal coliform) are analyzed in the Hongya section of the Qingyi River, four principal components are extracted. The variance contribution rate of the first principal component B1 is 30.532%. The first principal component loading factor is fecal coliform, ammonia nitrogen, permanganate index, total nitrogen, pH and petroleum. The second principal component B2 has a variance contribution rate of 20.633%, and the second principal component load factor is cadmium, lead and dissolved oxygen. The variance contribution rate of the third principal component B3 is 12.413%, and the third principal component load factor is total phosphorus. The variance contribution rate of the fourth principal component B4 is 9.879%, and the fourth principal component load factor is fluoride.

(2) Acorrding the analysis of the temporal and spatial characteristics of water quality in the Hongya section of the Qingyi River, the annual water quality in 2011, 2013 and 2015 shows a trend of deteriorating year by year on the timescales. It is mainly due to the change of the concentration of organics, total nitrogen, heavy metals and dissolved oxygen; which has certain seasonality during the year, the worst water quality in the autumn and improved winter water quality. On the spatial scale, the water quality in the section of Muchengzhen is worse than that of Guidufu. The water quality deterioration in the section is mainly due to the increase of organics, nitrogen, phosphorus and bacteria in the total number.

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