



Evaluation of water quality and its driving forces in the Shaying River Basin with the grey relational analysis based on combination weighting

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Abstract

The water quality of the Shaying River Basin and even the entire Huai River Basin has been widely concerned. Based on the water quality data acquired in flood and non-flood seasons from 2012 to 2016, the Shaying River Basin was selected as the research object. First, the principal component analysis method was used to identify the main pollution indices. Then, grey relational analysis combined with an analytic hierarchy process and entropy weight method was used to evaluate the water quality of the upper, middle, and lower reaches of the Shaying River Basin, while the single factor evaluation method was used for comparative analysis. Finally, the driving forces of water quality were analyzed and discussed from natural and human aspects. The results show that the main pollutants in the Shaying River Basin are total nitrogen, total phosphorus, and ammonium nitrogen. While the basin is seriously polluted by nitrogen and phosphorus, the spatial and temporal distribution of the pollution varies, although the overall trend toward improving water quality conditions is significant. The midstream region had the poorest water quality, which fluctuated between Classes III and V. The downstream region had generally good water quality, which could be ranked as Class III most of the time. And the upstream region had the best water quality with well-developed ecological conditions; all the water samples were ranked as Class I or II. The water quality improves significantly during the flood season when compared with that in the non-flood season. Seasonal climate variation, non-point source pollution emissions, the release of water from sluices and dams, and water resource management activities are the main reasons for the variations in water quality across the Shaying River Basin.

Keywords Combination weighting · Grey relational analysis · Water quality evaluation · Driving forces · Shaying River Basin

Introduction

The Shaying River is the largest tributary of the Huai River with the most serious water pollution problem. The amount of sewage it receives from 31 cities and towns above the

county level is far beyond its environmental capacity to purify water (Ding et al. 2021). Having a comprehensive evaluation of the water quality in a river along with an accurate grasp of the characteristics of water and environmental pollution can provide an important basis for mitigation, control, and prevention of water pollution in the Shaying River Basin (Hao and Dong 2019). The reliability of the results of an evaluation of water quality depends on the accuracy of monitoring data and use of a scientific evaluation method.

In recent years, many water quality assessment methods have been employed worldwide, each having its advantages and disadvantages. The commonly used methods include the single factor evaluation method (Wang et al. 2016; Deng 2021), comprehensive water quality identification index method (Ning and Li 2020; M. et al. 2021), Nemerow index method (Gao et al. 2017; Zhang et al. 2018), analytic hierarchy process (Xing et al. 2011; Araujo and

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Dias 2021), fuzzy comprehensive evaluation method (Rai et al. 2014; Zhang et al. 2019), artificial neural network method (Wu et al. 2021; Maryam et al. 2021), and grey relational analysis (Liu et al. 2020; Wang et al. 2021a, b, c).

The single factor evaluation method takes the category of the poorest water quality index as the final water quality category, but its evaluation results are generally too conservative (Guo et al. 2019). The comprehensive water quality identification index method can express abundant water quality information, but its evaluation process ignores the important difference of different evaluation indices in the real water environment; in addition, the evaluation results are not intuitive and clear (Zhou and Ma 2017). The calculation process of the Nemerow index method is simple and operable but only considers the average and maximum values of a single factor pollution index, and the maximum weight is too high (Han et al. 2017). The analytic hierarchy process is subjective so that a certain degree of information is lost during the operation of the process (Li et al. 2019). The evaluation results of the fuzzy comprehensive evaluation method are clear, but the assignment of weights is subjective (Fan et al. 2016). The artificial neural network model has strong adaptability, but the model parameters are subjective (Ivana et al. 2021). The traditional grey relational analysis provides a clear idea of current conditions during water quality assessment and involves a relatively small workload, but it cannot give weight to the degree of correlation between various characteristics of river water quality. It does not consider the relationship between evaluation indices and water environmental quality standards and cannot intuitively reflect the degree of pollution related to the comprehensive water quality of different evaluation objects (Ma and Wang 2015). Therefore, it is very important to know how to choose the appropriate evaluation method that will provide the best evaluation results (Deniz et al. 2021).

An index weight serves as an important part of a water quality evaluation. Weight determination methods include both subjective and objective weighting methods (Xie et al. 2020). Subjective weighting can fully account for the opinions of experts, but the evaluation results are limited by being strongly subjective and arbitrary and lacking objectivity and have certain limitations during application (Sutadian et al. 2017). The objective weighting method lacks most subjectivity and is not arbitrary, so that the decision-making or evaluation results have a strong mathematical theoretical basis. However, this weighting method relies too much on objective data, ignoring the importance of expert experience in determining weights; as a result, the calculated results are often unsatisfactory (Jiang et al. 2015).

Based on the above discussion, this paper puts forward a method that employs grey relational analysis with a combined weighting model that was based on analytical hierarchical process with an entropy weight method. This method

can then be applied as an example in the Shaying River Basin. First, principal component analysis was used to determine the main pollution indices of the Shaying River Basin; next, improved grey relational analysis was used to analyze the water quality of different regions in the up-, mid-, and downstream regions of the Shaying River Basin. The single factor evaluation method was selected for comparative analysis to verify the feasibility and effectiveness of the method. Finally, the driving forces of water quality were analyzed and discussed from natural and human aspects. The study provides a basis for making decisions related to the development, management, and protection of the environment in the Shaying River Basin.

Materials and methods

Study area and data

The Shaying River Basin, located in the middle of Henan Province and northwest of Anhui Province, covers 36,651 km² (Fig. 1). The Shaying, the largest tributary of the Huai River, is also a typical gate-controlled river. At present, more than 1,400 large, medium, and small sluices; 19 rubber dams; 405 reservoirs; and 1825 pond dams slow the river's flow in the basin. The area controlled by water conservation projects includes 7000 km², with a water storage capacity of about 2.7 billion m³. The annual precipitation in the basin is distributed unevenly, with June to September providing 50–60% of the annual precipitation (He et al. 2019). Although the control of pollution in the Shaying River Basin is increasing, the long-term trend in water quality is still not optimistic (Yang et al. 2019).

Since December 2012, our research group collected samples in Shaying River Basin twice a year in flood season (July) and non-flood season (December). As of July 2016, a total of nine samples were collected. The layout of sampling points, sampling methods, and sample preservation was performed according to the *Technical Specifications Requirements for Monitoring of Surface Water and Waste Water* (HJ/T91-2002). Sampling points were set along Sha River in the upstream region and along the main stream in the mid- and downstream regions. The specific distribution positions are shown in Fig. 3, which are Zhaopingtai and Baiguishan reservoirs, the Sha River Bridge in Luohe, and sluice gates at Zhoukou, Huaidian, Fuyang, and Yingshang. Field measurements were carried out by HACH HQ 30d and HACH Hydrolab DS5X. The remaining water samples were sent to the water quality monitoring company and tested within 12 h.

Data related to seven water quality indices were selected and included dissolved oxygen (DO), potassium permanganate index (COD_{Mn}), chemical oxygen demand (COD),

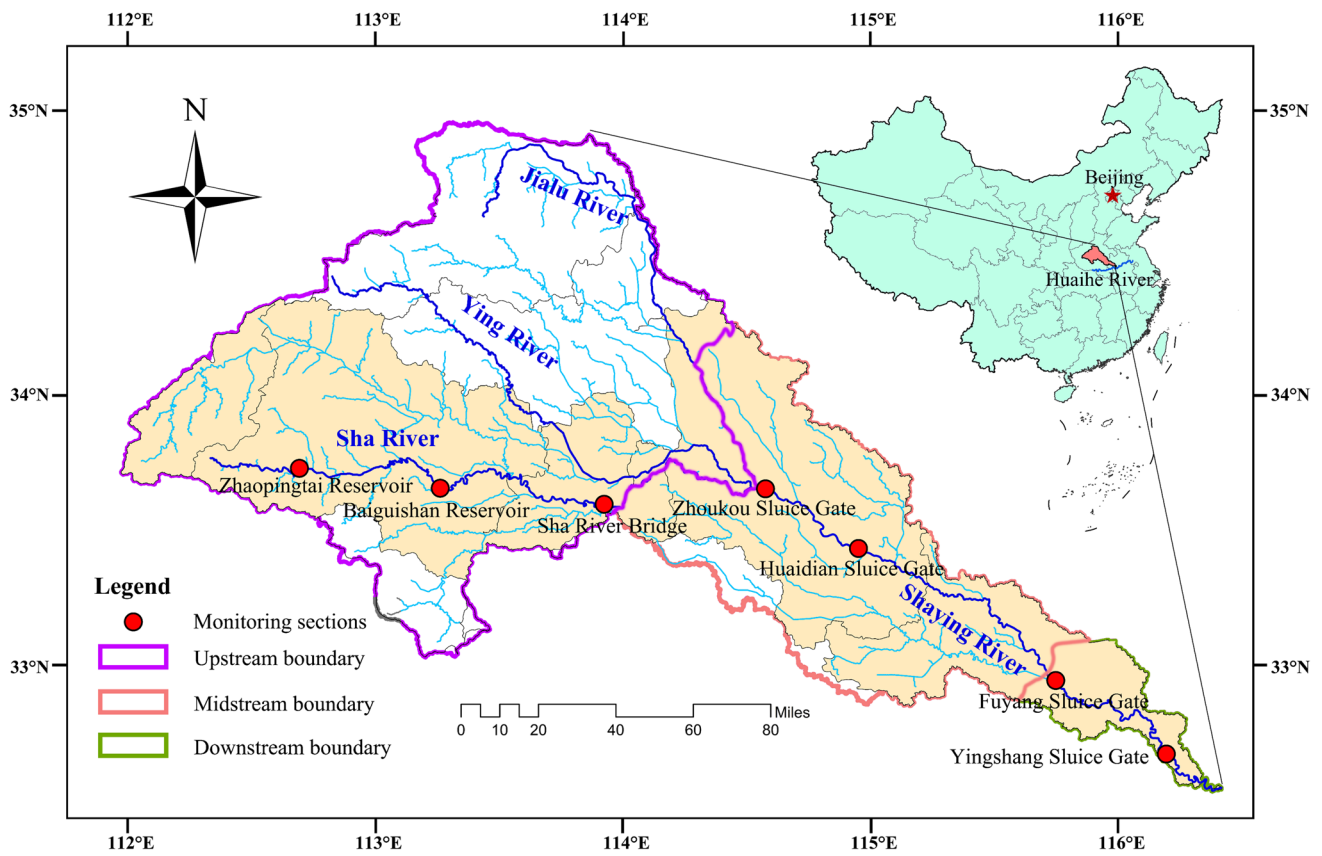


Fig. 1 Upstream, midstream, and downstream divisions of the Shaying River Basin showing the locations of the seven sites for monitoring water quality. An inset map shows the location of the Shaying River Basin within a map of the administrative regions of China

5-day biochemical oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), total phosphorus ($T-P$), and total nitrogen ($T-N$), which can characterize the water quality of Shaying River Basin. The *Environmental Quality Standards for Surface Water* (GB3838-2002) was used as the evaluation standard (Table 1). This study followed the methods of Zuo et al. (2016) as the basis for the division of the upper, middle, and lower reaches of the Shaying River Basin. Zhaoping and Baiguishan reservoirs along with the Sha River Bridge

in Luohe are located in the upper reaches of the basin. The mean values of these three sets of water quality monitoring data were taken as the water quality data of the entire upstream area. Similarly, the Zhoukou and Huaidian sluice gates are located in the middle reaches of the basin, while the Fuyang and Yingshang sluice gates are located in the downstream region of the basin; the data from these sites were averaged as the water quality data representing the middle and downstream regions, respectively.

Table 1 National water quality standards for seven water quality indices used to identify five classes of surface water quality in China

Indices	Decision symbol	Class I	Class II	Class III	Class IV	Class V
DO	\geq	7.5	6.0	5.0	3.0	2.0
COD_{Mn}	\leq	2.0	4.0	6.0	10.0	15.0
COD	\leq	15.0	15.0	20.0	30.0	40.0
BOD_5	\leq	3.0	3.0	4.0	6.0	10.0
NH_3-N	\leq	0.15	0.5	1.0	1.5	2.0
$T-P$	\leq	0.02	0.1	0.2	0.3	0.4
$T-N$	\leq	0.2	0.5	1.0	1.5	2.0

DO dissolved oxygen, COD_{Mn} potassium permanganate index, COD chemical oxygen demand, BOD_5 5-day biochemical oxygen demand, NH_3-N ammonia nitrogen, $T-P$ total phosphorus, $T-N$ total nitrogen.

Grey relational analysis of combination weighting

Grey relational analysis employs multivariate analysis to determine the degree of mutual influence or comprehensively evaluate the contribution of each index to variations in the data based on the geometric similarity of index factors (Lang et al. 2020). The innovation of the combined weighting grey relational analysis in this paper is to assign weights to the degree of correlation between variables based on the traditional method, so that the weight distribution is more reasonable. The specific calculation process and formula are as discussed below.

Determine the analysis sequence

Standard values corresponding to water quality indices are used as reference sequences, and the actual monitoring results of water quality in each partition are compared as sequences so that:

$$Y_0 = (Y_{01}, Y_{02}, \dots, Y_{0m}) \quad (1)$$

$$Y_i = (Y_{i1}, Y_{i2}, \dots, Y_{im}) \quad (2)$$

where Y_0 is the reference sequence, Y_i is the comparison sequence, $i = 1, \dots, n$, n refers to the number of partitions ($n = 3$ in the present study), and m is the number of indices for water quality assessment ($m = 7$ in this study).

Data dimensionless

In Eq. (3):

$$X_{ik} = \frac{(n+1)Y_{ik}}{\sum_{k=0}^m Y_{ik}} \quad i = 1, 2, \dots, n; k = 1, 2, \dots, m \quad (3)$$

X_{ik} represents the data set after dimensionless processing, and the meanings of other symbols are the same with Eqs. (1) and (2).

Calculation of correlation coefficient

Several comparison sequences X_1, X_2, \dots, X_n exist for a reference sequence X_0 . The correlation coefficient $\xi(X_{ik})$ between each comparison sequence and the reference sequence at each time can be calculated by Eqs. (4) and (5):

$$\xi(X_{ik}) = \frac{\Delta_{min} + \rho \cdot \Delta_{max}}{\Delta_{ik} + \rho \cdot \Delta_{max}} \quad (4)$$

$$\Delta_{ik} = |X_{0k} - X_{ik}| \quad (5)$$

where Δ_{ik} is the absolute value of the difference between the standard and monitoring values of the water quality index at the k^{th} data point, Δ_{min} and Δ_{max} are the minimum and maximum values of the absolute value, respectively, and ρ is the resolution coefficient, generally 0–1, usually 0.5.

Determine the weight of each evaluation index

The analytic hierarchy process (AHP) is a method proposed by Saaty (1977) to study the multi-criteria decision-making process based on the measurement theory of a hierarchical structure (Saha and Paul 2021). The decision-making process of this method involves decomposing the studied problem into a simple hierarchical structure of sub-problems and makes a systematic and independent evaluation of it (Wang et al. 2021a, b, c). The 1–9 scale is used, and the normalized feature vector of the determination matrix is calculated according to the relative importance of each water quality index (Anugrah et al. 2017). After the consistency is passed, the index weight β_k is obtained.

The entropy weight method is an objective weighting method used to determine the weight of each index. Information entropy, as a measure of the degree of system chaos, can be used to determine the index weight in a multi-index evaluation system in addition to measuring the amount of information contained in the data (Yu et al. 2019). After calculating the entropy and normalization of each water quality index, the weight μ_k is obtained.

The combination weighting method effectively combines the advantages of the analytic hierarchy process and entropy weight. In this way, not only the opinions of experts and scholars can be fully considered, but also the basis of authoritative mathematical theory and entropy weight method can be taken into account. In addition, according to the principle of the minimum relative information entropy, the weight is determined and optimized by the Lagrange multiplier method, so that the final weight becomes more reasonable. The calculation formula is shown in Eq. (6):

$$W_{ik} = \sqrt{\beta_k \cdot \mu_k} / \sum_{k=1}^m \sqrt{\beta_k \cdot \mu_k} \quad (6)$$

where W_{ik} is the weight calculated by the combination weighting method, β_k is the weight calculated by analytic hierarchy process, and μ_k is the weight calculated by entropy weight method.

Calculation of the degree of correlation

The degree of correlation refers to the correlation between a comparison and a reference sequence. Equation (7) provides a formula for calculating the correlation. Based on the calculation results, the maximum degree of correlation was considered grey comprehensive value, and the grade

corresponding to grey comprehensive value was selected as the evaluation grade of water samples:

$$\gamma_i = \sum_{k=1}^m [W_{ik} \cdot \xi(X_{ik})] \tag{7}$$

Calculation of comprehensive scores

According to *Environmental Quality Standards for Surface Water* (GB3838-2002) in China, linear interpolation was used to assign the scores to the water quality evaluation indices of the Shaying River Basin. The calculation method of the evaluation index scores is shown in Eq. (8), and the detailed evaluation criteria are shown in Table 2:

$$I_{wq} = \sum_{k=1}^m W_{ik} \cdot S \tag{8}$$

where I_{wq} is the comprehensive score of water quality evaluation index, W_{ik} is the weight calculated by combination weighting, and S is the score corresponding to each water quality index in Table 2.

Single factor evaluation

A single factor evaluation selects the index factor with the poorest water quality in the index to represent the water pollution category of the entire section of a river basin (Li et al. 2020). The determination of major pollution indices in the study area needs to compare the measured concentration of the index to standard limit Class III. The multiple exceeding the Class III water quality standard is exceeding multiple ratio. The index with the largest exceeding multiple ratio is the main pollution (Shi et al. 2021). This method follows the principle of “from inferior to superior” and can intuitively reflect the pollution situation. However, the poorest water quality index is selected as the final evaluation result when using this method, which can only unilaterally represent the degree of pollution for certain pollutants that affect water quality and cannot fully reflect the main pollution indices in surface water.

Principal component analysis

Principal component analysis uses a small number of seemingly irrelevant new variables to reflect the original variables and solves the problem of providing an optimal comprehensive simplification of multivariate data by sorting and classifying new variables (Zhou et al. 2020). The principle is based on the characteristic value greater than 1 or cumulative variance percentage is greater than 85%, and the number of main components is determined (Samira et al. 2020). It adopts the idea of dimension reduction, so that each final principal component can reflect most of the variation of the original data and overcomes the subjective arbitrariness of

Table 2 Water quality assessment scoring standard of the Shaying River Basin

Pollution indices	Scores										
	100	90	80	70	60	50	40	30	20	10	0
DO	≥ 7.5	[7, 7.5)	[6, 7)	[5.3, 6)	[4.5, 5.3)	[3.7, 4.5)	[3, 3.7)	[2.2, 3)	[1.5, 2.2)	[0.8, 1.5)	(0, 0.8)
COD _{Mn}	(0, 1)	[1, 2)	[2, 3)	[3, 4)	[4, 6)	[6, 8)	[8, 10)	[10, 12)	[12, 14)	[14, 15)	≥ 15
COD	(0, 10)	[10, 15)	[15, 18)	[18, 20)	[20, 23)	[23, 26)	[26, 30)	[30, 33)	[33, 36)	[36, 40)	≥ 40
BOD ₅	(0, 2)	[2, 3)	[3, 3.5)	[3.5, 4)	[4, 5)	[5, 6)	[6, 7)	[7, 8)	[8, 9)	[9, 10)	≥ 10
NH ₃ -N	(0, 0.01)	[0.01, 0.05)	[0.05, 0.1)	[0.1, 0.2)	[0.2, 0.3)	[0.3, 0.4)	[0.4, 0.5)	[0.5, 0.75)	[0.75, 1)	[1, 1.25)	≥ 1.25
T-P	(0, 0.01)	[0.01, 0.02)	[0.02, 0.05)	[0.05, 0.1)	[0.1, 0.15)	[0.15, 0.2)	[0.2, 0.25)	[0.25, 0.3)	[0.3, 0.35)	[0.35, 0.4)	≥ 0.4
T-N	(0, 0.1)	[0.1, 0.2)	[0.2, 0.35)	[0.35, 0.5)	[0.5, 0.75)	[0.75, 1)	[1, 1.25)	[1.25, 1.5)	[1.5, 1.75)	[1.75, 2)	≥ 2

DO dissolved oxygen, COD_{Mn} potassium permanganate index, COD chemical oxygen demand, BOD₅ 5-day biochemical oxygen demand, NH₃-N ammonia nitrogen, T-P total phosphorus, T-N total nitrogen.

the traditional method. Therefore, it is widely used in water quality evaluation and water quality index selection (Liu et al. 2015; Guo et al. 2019; Wang et al. 2021a, b, c; Yang et al. 2021).

Results

Results of principal component analysis

The extraction results of principal component analysis in different regions of the upper, middle, and lower reaches of the Shaying River Basin are shown in Table 3. It can be seen that the cumulative contribution of the first three principal components in the Shaying River Basin reached 87.13%, 86.68%, and 89.48%, respectively, meeting the principle of extraction of cumulative percentage greater than 85%. In addition, through the principal component load matrix, it can be seen that total nitrogen (T-N), total phosphorus (T-P), and ammonium nitrogen (NH₃-N) are the three pollution indices with the largest loads. The higher the cumulative percentage is, the stronger the representation of all indices (Yilmaz and Ozelik 2018). Therefore, the subsequent water quality analysis is mainly carried out around these three indices.

Results of an interannual water quality assessment in the Shaying River Basin

The changes in concentration and comprehensive scores of T-N, T-P, and NH₃-N indices are shown in Fig. 2. The water quality analysis results of the improved grey relational

analysis and single factor evaluation method are shown in Table 4. The results show that the water quality in each division of the Shaying River Basin varies markedly. The upstream region had the best water quality with well-developed ecological conditions; all the water samples were ranked as Class I or II. The midstream region had the poorest water quality, which fluctuated between Classes III and V; nitrogen and phosphorus pollution here was very serious. Total nitrogen exceeded the Class III water quality standard by 5 times or more in the non-flood season from 2012 to 2015, while T-P and NH₃-N pollution were relatively minimal; the water quality fluctuated around the Class III water standard. The downstream region had generally good water quality, which could be ranked as Class III most of the time; nevertheless, T-N pollution was still serious and exceeded the Class III water quality standard about 2–3 times. In addition, the fact that T-P exceeded standard for the first time in 2016 may have been caused by serious phosphorus pollution in the upper and middle reaches of the non-flood season in 2015. Nitrogen and phosphorus pollution can cause water eutrophication. A large number of aquatic organisms die due to hypoxia, and the ecological balance is destroyed.

According to *China Ecological Environment Status Bulletin 2020*, among the 1614 river water quality monitoring sections, Classes I to III water quality sections account for 87.4%. In contrast, the water quality of the Shaying River Basin is poor, but a significant trend toward improving water quality conditions was observed over time. The main reason for the improvement of water quality in the Shaying River Basin is that with the strengthening of the water environment governance and the successive operation of completed sewage treatment plants, the pollutant emissions have decreased year by year.

The results of single factor evaluation show that in addition to the fact that the upstream pollution indices in June 2016 reached Class III water standards, most of the other regions could be ranked as Classes IV and V, which indicate lower water quality. The evaluation results of the two methods provided obviously different results. This difference stems from the single factor evaluation, which regards the poorest single water quality index results as the overall evaluation results, while the improved grey relational analysis method is more reasonable because it allocates the weight of various pollution index, providing more objective and accurate evaluation results.

Results of annual water quality assessments in the Shaying River Basin

The spatial distribution of pollution concentration obtained by inverse distance weighted interpolation along the Sha River tributary and Shaying River main stream (yellow area in Fig. 1) is shown in Fig. 3. The goal was to study the

Table 3 Principal components and related parameters of upper, middle, and lower reaches of the Shaying River Basin

Basin division	Parameter	Principal components		
		1	2	3
Upstream	Eigenvalue	2.40	1.50	1.34
	Variance proportion (%)	39.93	24.92	22.29
	Cumulative percentage (%)	39.93	64.85	87.13
	Maximum load pollution index	T-N	NH ₃ -N	T-P
Midstream	Eigenvalue	2.39	1.63	1.18
	Variance proportion (%)	39.87	27.22	19.59
	Cumulative percentage (%)	39.87	67.09	86.68
	Maximum load pollution index	T-N	T-P	NH ₃ -N
Downstream	Eigenvalue	2.55	1.81	1.00
	Variance proportion (%)	42.53	30.23	16.72
	Cumulative percentage (%)	42.53	72.76	89.48
	Maximum load pollution index	T-P	T-N	NH ₃ -N

NH₃-N ammonia nitrogen, T-N total nitrogen, T-P total phosphorus.

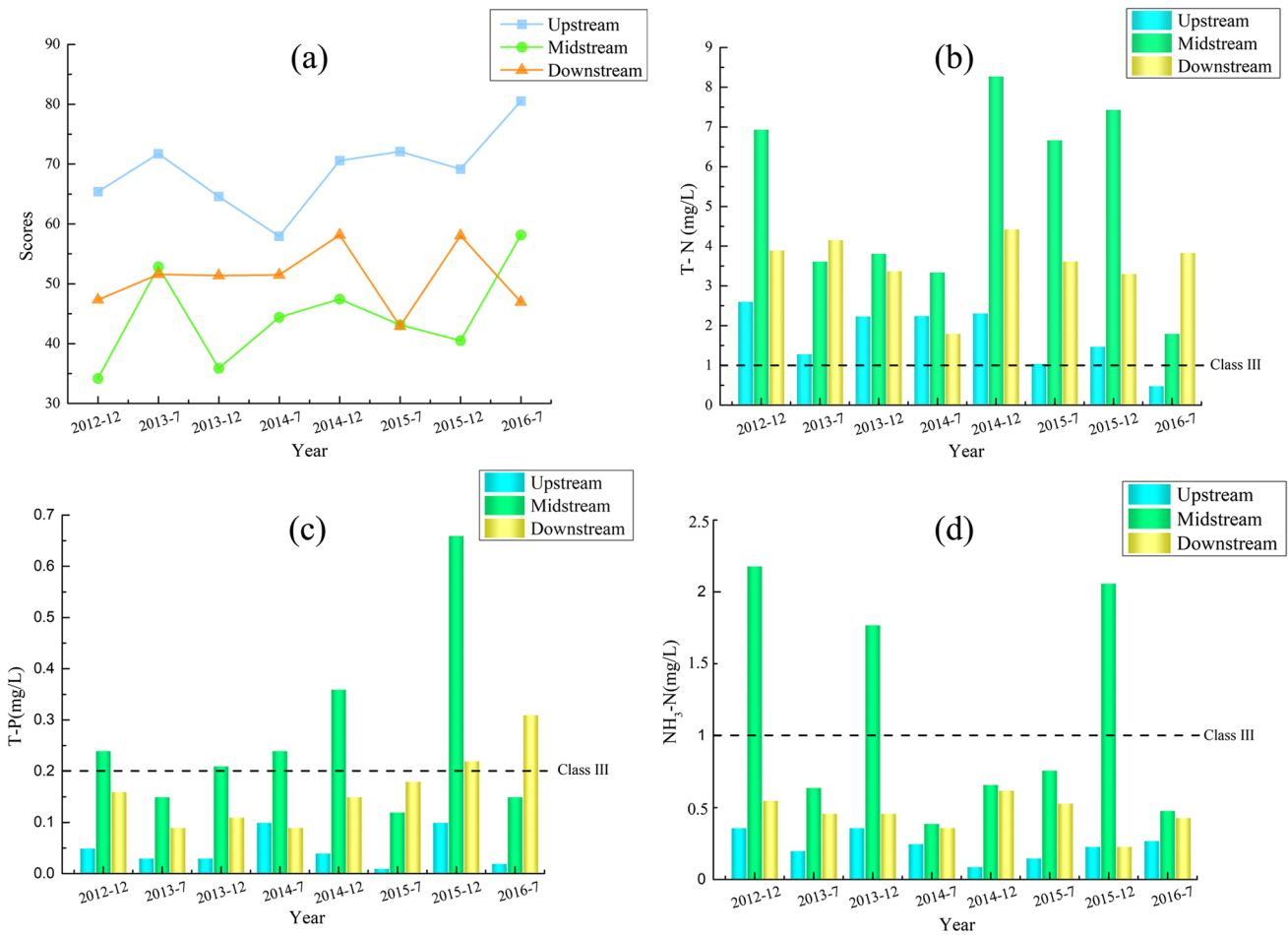


Fig. 2 a Comprehensive scores and changes in the concentrations of water quality indices; b T-N, total nitrogen; c T-P, total phosphorus; d NH₃-N, ammonia nitrogen

variations in water quality between flood and non-flood seasons in a year by taking data collected in July and December 2015 as examples. The results show that the spatial distribution of the concentrations of pollutants and the related indices within a year were roughly the same as that between years; pollution was extremely serious in the midstream, less serious in the downstream region, with the upstream region having the best water quality. The reason is that the upstream region represented by Zhaopingtai Reservoir and Baiguishan Reservoir is the hub project for comprehensive treatment of Shaying River Basin, which combines water, irrigation, and other functions, and away from the sewage outlet. Therefore, the water environment protection in this region is the top priority. In addition, according to the land use data provided by the Resource and Environmental Science and Data Center (<https://www.resdc.cn>), the proportion of forest land and grassland in the upstream region is relatively high, about 15%. The mid- and downstream regions are mainly dry land and urban land, which are greatly affected by agricultural activities, surrounding industries, and urban domestic

sewage. And the area of forest land and grass is relatively low, about 1.3%, not conducive to the improvement of water environment.

By comparing the concentrations and distributions of pollutants in flood and non-flood seasons, it was found that the concentrations were significantly higher in non-flood season than that in flood season, especially in the middle and lower reaches. Pollutant levels were higher in the non-flood season for the following three reasons. First, the increase of flow during floods dilutes the concentration of pollutants in the river and accelerates their migration and transformation. Second, winter wheat is sown in Henan Province from October to November, when unabsorbed nitrogen and phosphorus fertilizer in the field will be discharged into the river network; this is also an important cause of excessive nitrogen and phosphorus loading in the river during the non-flood season. In addition, Qi et al. (2017) showed that large numbers of aquatic plants begin to die in November; these decomposing aquatic plants release large amounts of nutrients, increasing the nitrogen and phosphorus loads in river

Table 4 Water quality evaluation results based on improved grey relational analysis and single factor evaluation

Year	Basin division	Results of improved grey relational analysis						Results of single factor evaluation			
		Grey relativity					Grey comprehensive value	Water quality classification	Exceeding multiple ratio	Main pollution indices	Water quality classification
		Class I	Class II	Class III	Class IV	Class V					
2012.12	Upstream	0.813	0.788	0.622	0.546	0.619	0.813	Class I	1.61	T-N	Class V
	Midstream	0.443	0.466	0.480	0.615	0.682	0.682	Class V	5.94	T-N	Class V
	Downstream	0.620	0.655	0.685	0.656	0.644	0.685	Class III	2.90	T-N	Class V
2013.7	Upstream	0.821	0.789	0.567	0.548	0.527	0.821	Class I	0.29	T-N	Class IV
	Midstream	0.496	0.481	0.618	0.570	0.473	0.618	Class III	2.62	T-N	Class V
	Downstream	0.571	0.479	0.659	0.455	0.417	0.659	Class III	3.16	T-N	Class V
2013.12	Upstream	0.781	0.714	0.607	0.513	0.576	0.781	Class I	1.24	T-N	Class V
	Midstream	0.424	0.381	0.462	0.577	0.617	0.617	Class V	5.82	T-N	Class V
	Downstream	0.627	0.550	0.706	0.529	0.552	0.706	Class III	2.38	T-N	Class V
2014.7	Upstream	0.756	0.763	0.538	0.618	0.518	0.763	Class II	1.25	T-N	Class V
	Midstream	0.581	0.556	0.467	0.650	0.545	0.650	Class IV	2.35	T-N	Class V
	Downstream	0.743	0.666	0.573	0.727	0.601	0.743	Class I	0.80	T-N	Class V
2014.12	Upstream	0.812	0.806	0.612	0.588	0.567	0.812	Class I	1.32	T-N	Class V
	Midstream	0.410	0.409	0.510	0.631	0.589	0.631	Class IV	7.28	T-N	Class V
	Downstream	0.540	0.545	0.709	0.683	0.569	0.709	Class III	3.43	T-N	Class V
2015.7	Upstream	0.773	0.779	0.612	0.512	0.531	0.779	Class II	0.05	T-N	Class IV
	Midstream	0.414	0.388	0.561	0.499	0.465	0.561	Class III	5.67	T-N	Class V
	Downstream	0.452	0.432	0.644	0.564	0.533	0.644	Class III	2.62	T-N	Class V
2015.12	Upstream	0.793	0.760	0.705	0.658	0.581	0.793	Class I	0.48	T-N	Class IV
	Midstream	0.407	0.373	0.370	0.417	0.423	0.423	Class V	6.44	T-N	Class V
	Downstream	0.678	0.661	0.616	0.631	0.531	0.678	Class I	2.31	T-N	Class V
2016.7	Upstream	0.722	0.732	0.612	0.603	0.433	0.732	Class II	—	—	Class III
	Midstream	0.482	0.467	0.653	0.737	0.560	0.737	Class IV	0.80	T-N	Class V
	Downstream	0.387	0.402	0.496	0.564	0.534	0.564	Class IV	2.84	T-N	Class V

water. At the same time, relatively few aquatic organisms thrive during the period, weakening the ability of the water to self-purify and further aggravating the problems created by excessive amounts of pollutants.

Discussion

The discussion of the driving forces affecting water quality in the Shaying River Basin was carried out by reviewing two aspects: natural factors (including climate change) and human activities (emissions of non-point source pollutants, the sluice and dam flood control method, and management of water resources).

Driving forces of natural factors

The correlations between rainfall, temperature, and T-N were analyzed in view of the serious pollution in the midstream of the Shaying River Basin including excessive

T-N, by taking the midstream region as an example (Fig. 4). The results show that the T-N concentration decreased with increasing rainfall. This is because precipitation is the main factor generated by the runoff. With the increase of precipitation, streamflow increases and the concentration of pollutants is diluted. The T-N concentration presents a trend of “first increasing and then decreasing” with the increase of temperature, which may be related to the growth of microorganisms and algae in the basin. On the one hand, air temperature is closely related to water temperature; when the temperature is low, the microorganisms and the algae are not active, so the utilization rate of nitrogen is low. Further, as the temperature rises, the nitrogen in the sediment is released, so that the T-N concentration is slowly increased. On the other hand, when the temperature continues to rise, the biological activity of microorganisms and algae is restored and the metabolism is constantly enhanced; then, the nitrogen in the basin is reduced due to utilization.

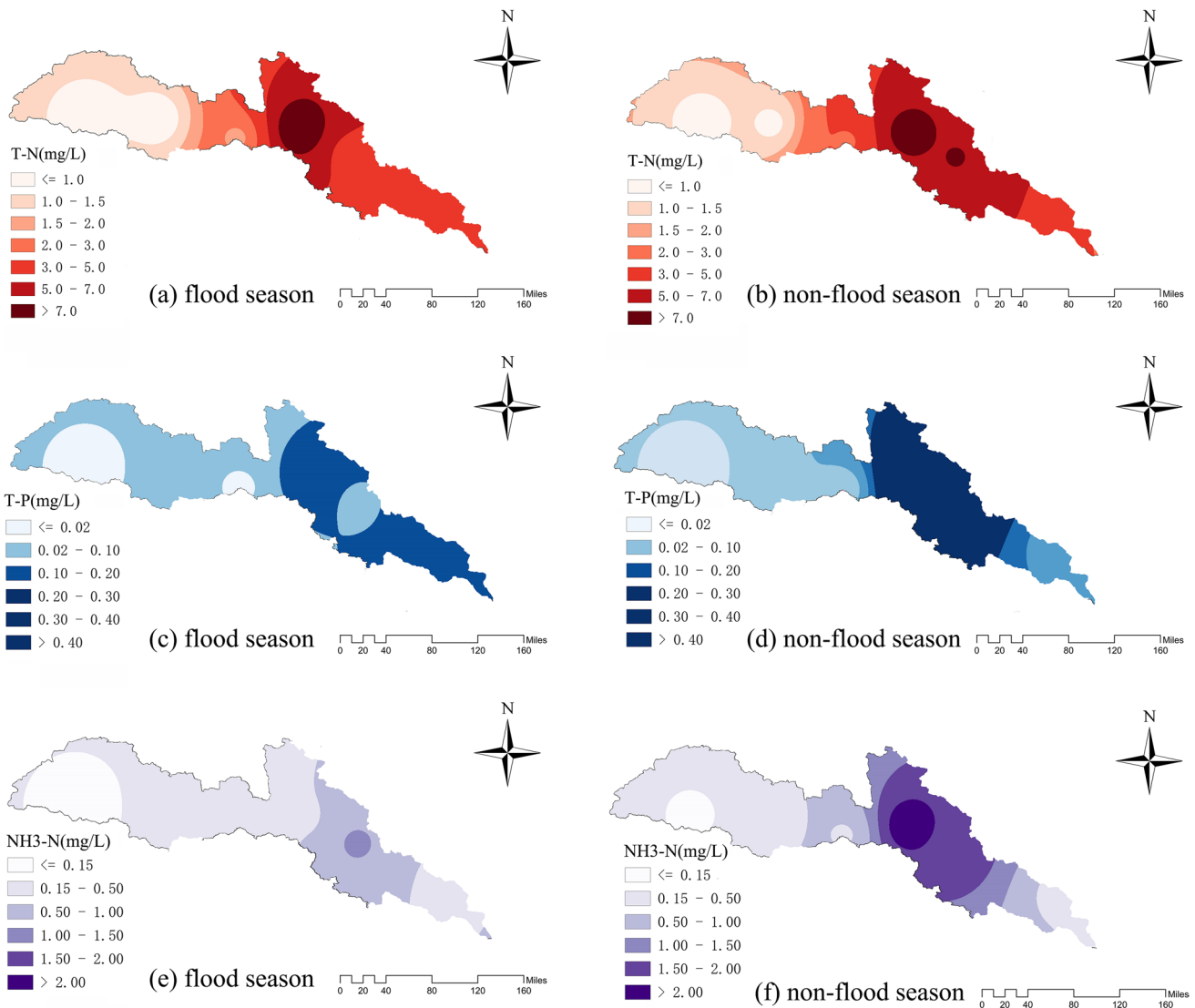


Fig. 3 Regional distribution of pollutant concentrations for monitored sections along Sha River tributaries and main streams of the Shaying River in flood (a, c, e) and non-flood (b, d, f) seasons in 2015; a, b T-N, total nitrogen; c, d T-P, total phosphorus; e, f NH₃-N

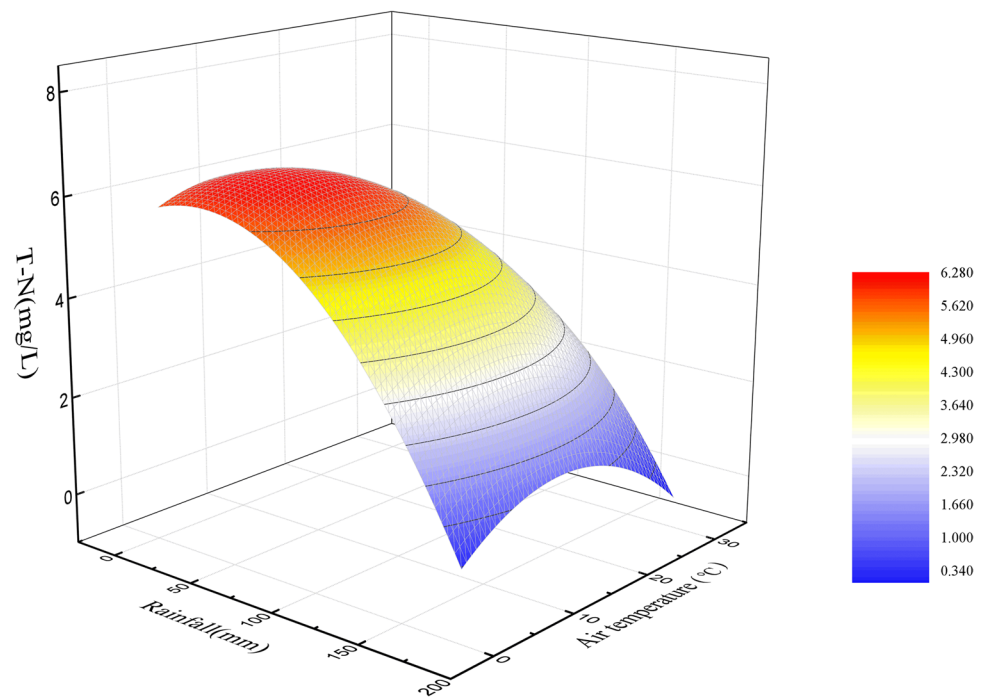
Human driving factors

Emissions of non-point source pollution

Henan Province is a major grain-producing province in China, and the Shaying River Basin is the core area of grain production in Henan Province, with agricultural non-point source pollution becoming a more and more prominent problem. The middle reaches of the river basin have experienced very serious nitrogen and phosphorus pollution; however, a statistical analysis of the use of fertilizer in this region found it to be extremely low. Only about 35% and 15% of nitrogen and phosphorus fertilizers were being used on the farmland, respectively. A large amount of unused fertilizer eventually flows into rivers. Moreover,

with a large area of arable land, livestock and poultry breeding industry has become a more common practice in the region. Various livestock and poultry utilization rate of protein was very low, 50% to 70% of nitrogen in feed was discharged into the environment with feces, and the utilization rate of phosphorus was not more than 50%. A large amount of fish feces in addition to some organic fertilizer are discharged into the river, which will lead to excessive nitrogen and phosphorus in the river. In addition, coal mining, non-ferrous metals, papermaking, nitrogen fertilizer, and other key water pollutant emission industries have a large share, and the total amount of sewage and wastewater is large, which also causes serious pollution of the water environment.

Fig. 4 Relationship between T-N and both temperature and rainfall in the Shaying River Basin



Sluice and dam scheduling method

Many sluice gates and reservoirs have been built in the Shaying River Basin; these play an extremely important role in flood control, power generation, and navigation and in providing water for potable water, irrigation, and aquaculture. However, this type of construction and water management in the Shaying River Basin has also changed the habitat of the reservoir area and downstream rivers, resulting in a series of problems such as noise, hydrological problems, and modification of the water environment and aquatic ecology (Wei et al. 2009; Alcayaga et al. 2019; Anan and Li 2021). Therefore, it was necessary to establish a reasonable series of sluices and dams for water management (Zhang et al. 2010; Luo et al. 2015; Ni et al. 2018; Chong and Lai 2021). Since 2009, our research group has taken Huaidian Sluice Gate in Shaying River Basin as the object to carry out the research on the regulation ability of sluice and dam on water quality and quantity of polluted rivers. On this basis, the water environment monitoring of Shaying River and Huai River mainstream is carried out continuously, and the joint use of multiple sluices and dams in the Shaying River Basin to analyze water quantity, quality, and aquatic ecology is being studied (Li and Zuo 2012; Zuo and Li 2013a, b; Chen et al. 2014; Li and Zuo 2014). This is a very necessary and meaningful work. At the same time, many scholars at home and abroad are also carrying out the related work of joint scheduling of multiple sluices and dams (Won et al. 2020; Frediani et al. 2020; Getirana et al. 2020; Liang et al. 2021), optimizing the scheduling scheme of sluices

and dams, maintaining a good water ecological environment system, and realizing a new win–win situation of harmony between human and water among environmental benefits, economic benefits, and social benefits of the basin.

Water resource management

Water resources management efforts in Shaying River Basin have experienced a series of problems such as faint boundaries of water management authority and responsibility, insufficient infrastructure, and a need to improve the management techniques. And this water resources management mode in exchange for economic benefits at the expense of an ecological environment has not been fundamentally solved. However, the local government is working to continuously strengthen the formulation and effective implementation of a standardized water resources management system as well as promoting actively the implementation of infrastructure. In addition, the new idea of “water saving priority, spatial balance, system governance, and doing things with both hands” is being implemented. Based on the promotion of environmental protection and restoration planning, non-point source pollution emissions will be reduced, which is conducive to harmony between human. This will allow land managers to fundamentally realize real-time monitoring and management modernization of the entire process of water resources use and sewage discharge, the intensive and economically efficient use of water resources, the protection of the environment, and the comprehensive management of watershed.

Conclusion

Based on a comprehensive evaluation of water quality monitoring data of the Shaying River Basin from 2012 to 2016, the interannual and annual laws of water quality were analyzed, and the driving forces of the current status of water quality are discussed from natural and humanistic aspects. The main conclusions are as follows.

- i. The main pollutants in the Shaying River Basin are T-N, T-P, and NH₃-N. The spatial distribution of water quality varies widely within the basin. The middle reaches have experienced the most serious pollution, followed by the downstream region, while the water quality in the upstream region is better. Overall, the trend of water quality is optimistic.
- ii. The water quality of the Shaying River Basin in the flood season is better than that in the non-flood season, which is closely related to the differences of climatic characteristics, agricultural planting, and the survival of aquatic plants in different periods.
- iii. Compared with the single factor evaluation method, the grey relational analysis method based on combination weighting can objectively reflect the actual situation of water body.
- iv. There are many driving forces leading to the changes in water quality in the Shaying River Basin. The study only briefly expounds the seasonal variations in climate, the discharge of non-point source pollution, the water release patterns from sluices and dams, and the management of water resources.
- v. From the results of the analysis, it is necessary to strengthen the remediation of nitrogen and phosphorus pollution in the basin in the future, especially for the middle and lower reaches, which have experienced heavy pollution. Land managers need to continuously improve the purification capacity for urban point source pollution, strengthen the strict monitoring and control of industrial wastewater release, and appropriately manage the withdrawal of agricultural water. Continuous regulation of aquaculture, reasonable control of aquaculture density, and reduction of the water self-purification load should all be improved in the future.

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Data availability All data generated or analyzed during this study are described in this published article. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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