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Temporal variation trend and influencing factors of water quality in the Nanchong section of the Jialing River mainstream

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ABSTRACT

In this study, three sampling points located in the Nanchong section of the Jialing River were selected as research objects, and the temporal distribution characteristics and influencing factors of water pollutants in the Nanchong section of the Jialing River mainstream were discussed through monthly sampling analysis of nine monitoring indicators from 2017 to 2021. Gray correlation analysis, Mann–Kendall test, Spearman's correlation analysis, and multivariate statistical analysis were used to analyze the variation trend, time distribution, and differences in water pollutants in different periods. Results show that the water quality in the Nanchong section of the Jialing River mainstream was lightly polluted, and total nitrogen (TN) was the main water pollutant. Except for the concentrations of NH_3–N and TN, the concentrations of pollutants (TP and COD_{Mn}) in the Nanchong section of the Jialing River mainstream decreased. The water quality of the Jialing River was different in time, and the water quality in the rainy season (May–November) was better than that in the dry season (December–April). The concentrations of COD_{Mn}, NH_3–N, TP, and TN in water were lower in the rainy season than in the dry season. The contents of organic matter, nitrogen, and phosphorus nutrients in water in the Jialing River were affected by climate change, rainfall dilution, and other environmental factors. The main sources of pollution were agricultural and rural nonpoint source pollution.

Keywords: Jialing River; Nanchong; Cluster analysis; Time difference; Trend analysis

1. Introduction

Water is the source of all life and is closely related to the environment in which human beings live. Water environmental quality is related to our drinking and other daily life, industrial, and agricultural production, as well as the healthy development of the whole ecological environment. Therefore, water environmental protection is an important pillar to promote social progress and ensure people's health [1,2]. In general, the surface water quality of watersheds is affected by natural and anthropogenic influences. Nonpoint sources such as agricultural runoff and atmospheric deposition, and point sources such as municipal effluents from the villages and mining activities around some tributaries are pollution sources for stream water quality in the watershed. Traditional agricultural practices such as applying manure and chemical fertilizers are frequent in this watershed.

The Jialing River belongs to the Yangtze River system and is the largest tributary of the upper reaches of the Yangtze River. Nanchong, which is located in the northeast of Sichuan Province and the middle reaches of the Jialing River, is the second most populous city in Sichuan Province and an important node connecting the "Belt and Road" and the Yangtze River Economic Belt. The Jialing River is an important drinking water source for most people in Nanchong. The quality of the Jialing River is directly related to the surrounding industrial and agricultural production, the drinking water safety of the people, and the sustainable development

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of the social economy. In recent years, many environmental pollution emergencies have occurred in the Jialing River basin, and the pressure of the water environment is increasing daily. The water quality of the Jialing River basin directly affects the water quality of the Yangtze River basin. Strengthening the monitoring and analysis of water quality in the Jialing River basin and identifying the characteristics, causes, and influencing factors of water quality change in the basin will not only protect the green mountains and clear waters of the Jialing River but also promote the green development of the Yangtze River Economic Belt and better win the battle against pollution.

Many scholars have conducted relevant studies on the water environment in the Jialing River basin, covering the spatial–temporal variation in water quality, water quality simulation and prediction, water environmental capacity, water environmental management, and other aspects. Zhang et al. [3] evaluated the temporal and spatial variation characteristics of water quality in the Guangyuan section of the Jialing River by using a multivariate statistical analysis method. The results showed that the main pollution sources in the Guangyuan section of the Jialing River included domestic sewage, industrial wastewater, agricultural nonpoint sources, livestock and poultry waste, and the main sources of water pollutants were surface runoff and industrial wastewater. Liu et al. [4] evaluated the Chongqing section of the Jialing River trunk stream by using two models of comprehensive pollution index and health risk assessment, and they concluded that the water quality of the Jialing River was generally good but had a high health risk. Meanwhile, they observed no significant difference in the water quality of the suburban area, and the health risk level of the urban area was significantly higher than that of the suburban area. Xia et al. [5] used the fuzzy comprehensive index method to evaluate the water quality monitoring data of four sections in the Hanzhong section of the Jialing River from 2015 to 2019, and the results showed that the water quality of the four sections in the Hanzhong section of the Jialing River was stable and excellent in recent years, which was in line with the water quality target stipulated by the superior. He et al. [6] used a BP neural network model and a comprehensive index evaluation method to evaluate the water quality of the Nanchong section of the Jialing River mainstream, and the results showed that the monitoring index of exceeding the standard of the Jialing River decreased, the trend of change was stable, and the downstream pollution was serious after 2012. However, in the study of the water environment of the Jialing River basin, the water quality status of each study area differed due to the large area and complex water conditions of the basin. The overall water quality change trend, main pollution factors, and pollution sources of the Nanchong section of the basin need further study.

Eutrophication is a common environmental problem in the world. Nitrogen is the main nutrient that limits the growth of algae in freshwater, and its concentration is important for the ecological safety of a lake reservoir water body. Nitrogen pollution can cause environmental problems such as water eutrophication and quality degradation, and it seriously affects the stability of aquatic ecosystems. The three most common forms of nitrogen pollution are ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen, which are usually called the "three nitrogen". Nitrogen-containing compounds in the basin have many sources (e.g., chemical fertilizer and manure, atmospheric nitrogen deposition, domestic sewage, farmland wastewater drainage, and soil organic nitrogen). Different pollution sources are also affected by many factors in the process of migration and transformation (e.g., terrain, hydrological conditions, treatment technology, and precipitation), especially the dispersion, concealment, randomness, difficulty to monitor, and difficulty to quantify nonpoint source pollution. This situation makes the problem of nitrogen pollution in surface water extremely complex. Accordingly, controlling nitrogen inputs is essential to reduce eutrophication and manage ecological quality.

Based on the predecessors, this study takes the Jialing River as the research object. Through the statistical analysis of the monthly monitoring data of three monitoring sections in the Nanchong section of the Jialing River basin from 2016 to 2020, the water quality of the Jialing River is comprehensively evaluated using various variable statistical analysis methods, such as difference comparison, gray correlation analysis (GCA), Spearman's correlation analysis, cluster analysis (CA), discriminant analysis (DA), and Mann–Kendall trend test. By comprehensively understanding and mastering the water quality status, time variation characteristics, and pollution degree of the Nanchong section of the Jialing River, the main influencing factors of the pollution of the river are determined. The research results can provide a certain basis for the water environment treatment of the Nanchong section of the Jialing River basin.

2. Materials and methods

2.1. Study area

The Jialing River is the main tributary of the upper reach of the Yangtze River. It originates from Daiwang Mountain at the northern foot of Qinling Mountain, crosses four provinces (municipalities), including Shaanxi, Gansu, Sichuan, and Chongqing, and is eventually fed into the Yangtze River at Chaotianmen District, Chongqing City. The Jialing River mainstream is approximately 1,345 km in length, has a watershed area of about 160,000 km^2, and is second to none among the many tributaries of the Yangtze River [7]. The economic development of the Jialing River watershed is dominated by agriculture [8]. Agriculture is the pillar industry in this area, and it primarily includes food production as well as livestock and poultry breeding [9].

The Nanchong section of the Jialing River mainstream is located in the middle reach of the Jialing River. It enters the region of Nanchong City at Shaxi Town, Langzhong City (county-level city), crosses seven counties (districts) including Langzhong, Nanbu, Yilong, Peng'an, Shunqing, Gaoping, and Jialing, and finally flows into Limian Town, Guang'an City. The Nanchong section of the Jialing River mainstream is about 297.8 km in length and has more than 25 tributaries, approximately 10,000 km^2 of watershed area, and a population that exceeds 5.6 million.

The climate of the Nanchong section of the Jialing River is subtropical monsoon with an average temperature of about 17.1°C. The annual average rainfall is approximately 1,100 mm, and it is mainly concentrated in summer and autumn. The annual sunshine hours range from 1,200 to 1,500 h [10]. The economic development of the Nanchong section of the Jialing River watershed is dominated by agriculture, and the main products include grain, stockbreeding, and fruit [9].

2.2. Data sources

Based on the hydrologic features of the river, three sampling sites located in the Nanchong section of the Jialing River were selected (Fig. 1). Selected sites were sampled every day for 5 y (2017–2021). The water quality data of the Nanchong section of the Jialing River were obtained from the Nanchong Ecological and Environmental Monitoring Central Station of Sichuan Province. Water quality parameters included permanganate index (COD_{Mn}), ammonia nitrogen (NH_3–N), total phosphorus (TP), total nitrogen (TN), dissolved oxygen (DO), pH, water temperature (WT), electrical conductivity (EC), and turbidity (Tu). The meteorological data, including air temperature (AT), precipitation (P), and days of precipitation (DP) were collected from the Nanchong Meteorological Bureau. All mathematical and statistical calculations were performed using Microsoft Office Excel 2010, IBM SPSS Statistics 23.0, and Origin 2018.

2.3. Data preprocessing

2.3.1. Water quality standards and the Comprehensive Pollution Index of Water Quality (CPIWQ)

The environmental quality standards for surface water in China (GB 3838-2002) [11] classified water quality of surface waters into five classes. This standard stipulated that class III water quality was standard for surface water. The corresponding standard limits of water quality parameters are presented in Table 1 as the Environmental Quality Standards for Surface Water of China (GB 3838-2002) [11].

We used these standard limits of water quality parameters to calculate the CPIWQ [12]. The calculation formulas of CPIWQ are as follows:

$$P_{(i)} = \frac{C_{(i)\text{monitor}}}{C_{(S)}} \tag{1}$$

where $P_{(i)}$ represents the CPIWQ value of each water quality parameter during online monitoring. $C_{(i)\text{monitor}}$ represents the online monitoring value of each parameter, and $C_{(S)}$ represents the class III water quality standard for each parameter. This equation was applied to calculate $P_{(i)}$ of COD_{Mn}, NH_3–N, TP, and TN.

For DO, $P_{(\text{DO})}$ was calculated as:

$$P_{(\text{DO})} = \frac{\left|\text{DO}_S - \text{DO}_{\text{monitor}}\right|}{\text{DO}_S - \text{DO}_C} \tag{2}$$

where DO_S represents the saturated dissolved oxygen, $\text{DO}_{\text{monitor}}$ represents the online monitoring value of DO, and DO_C represents the class III water quality standard for DO.

For pH, $P_{(\text{pH})}$ was calculated as:

$$P_{(\text{pH})} = \frac{7.0 - \text{pH}_{\text{monitor}}}{7.0 - \text{pH}_{\text{low}}}, \text{ when pH} < 7 \tag{3}$$

$$P_{(\text{pH})} = \frac{\text{pH}_{\text{monitor}} - 7.0}{\text{pH}_{\text{high}} - 7.0}, \text{ when pH} \geq 7 \tag{4}$$

Table 1
Target standard limits of surface water quality (class III)

WQI	Target standard limits
COD_{Mn} (mg/L)	6.0
NH_3–N (mg/L)	1.0
TP (mg/L)	0.2
TN (mg/L)	1.0
DO (mg/L)	5
pH	6~9

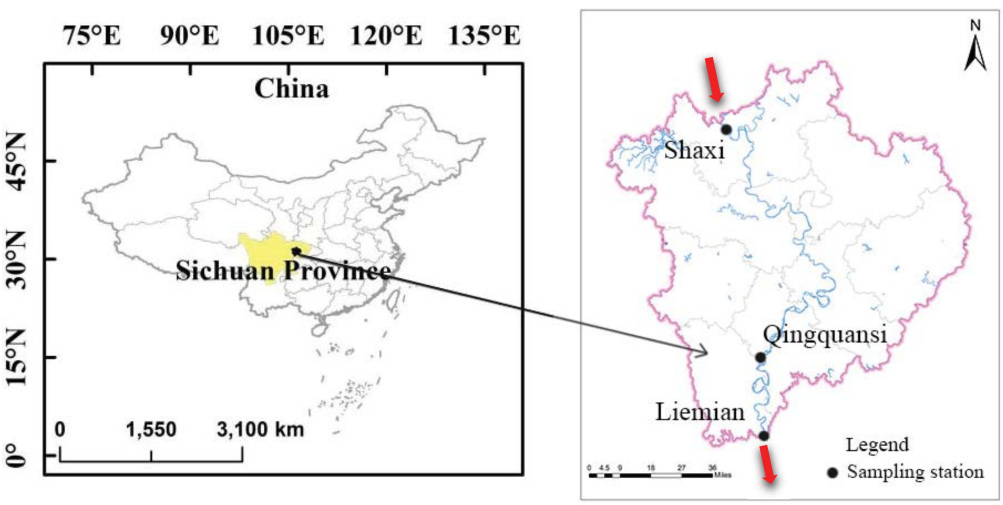

Fig. 1. Distribution of monitoring points in the Nanchong section of the Jialing River.

where $pH_{monitor}$ represents the online monitoring values of pH: pH_{low} and pH_{high} refer to the lower and higher limit of class III water quality standard, respectively.

CPIWQ of the surface water was calculated as:

$$P = \frac{1}{n}\sum_{i=1}^{n} P_{(i)} \tag{5}$$

where P represents the water quality index. The values of P were divided into five levels, as shown in Table 2.

2.4. Statistical analysis

2.4.1. Difference analysis

The differences in CPIWQ, water quality parameters, and impact factors were analyzed using the statistical software SPSS 23.0. The normality and homoscedasticity of variables were checked using the Shapiro–Wilk and Levene tests, respectively. Normal and normalizable data were compared using one-way ANOVA (with Duncan's multiple range test). The nonparametric tests (with the Kruskal–Wallis H test) were used when the variables were unnormalizable.

2.4.2. Gray correlation analysis

GCA was used to analyze the influence of water quality parameters and impact factors on water quality. The GCA calculation formula are as follows [13]:

$$\Delta_i(j) = \left| \frac{Y_0(j)}{\frac{1}{n}\sum_{j=1}^{n} Y_0(j)} - \frac{X_i(j)}{\frac{1}{n}\sum_{j=1}^{n} X_i(j)} \right| \tag{6}$$

The data sequence of an influencing factor can be defined as follows: i denotes the number of influencing factors, i = 1, 2, …, n. $Y_0(j)$ is the observed characteristic data of CPIWQ (or water quality parameters) Y_0 relative to the jth index, $X_i(j)$ is the observed data of influencing factor X_i relative to the jth index, and j is the index number of Y_0 (or X_i), j = 1, 2, …, n.

The formula for calculating the gray correlation degree (R) is as follows:

$$R_i = \frac{1}{n}\sum_{j=1}^{n} \frac{\min_i \min_j \Delta_i(j) + \xi \max_i \max_j \Delta_i(j)}{\Delta_i(j) + \xi \max_i \max_j \Delta_i(j)} \tag{7}$$

Table 2
Classification of CPIWQ

P	Categories of water quality
≤0.4	Clean water
0.41–0.7	Lightly polluted water
0.71–1.00	Moderately polluted water
1.00–2.00	Heavily polluted water
>2.00	Seriously polluted water

where R_i is the correlation degree of the ith influencing factor with CPIWQ (or water quality parameters), and ξ is the resolution coefficient, which can change the difference between correlation coefficients and is normally 0.5.

2.4.3. Correlation analysis

Spearman's correlation analysis was used to analyze the relationship (r_s) between the water quality parameters and impact factors.

2.4.4. Mann–Kendall test

The Mann–Kendall (MK) trend test is not affected by the actual distribution of the data and is less sensitive to outliers; it is widely used to identify significant trends in hydrological, climatological, meteorological, and water quality data time series [14–17]. The temporal trends of CPIWQ and water quality parameters were analyzed by the MK test in the Nanchong section of the Jialing River mainstream. For a time series $X = \{x_1, x_2, …, x_n\}$, the calculation formulas of the MK test are as follows:

$$\operatorname{sgn}(X_j - X_i) = \begin{cases} 1, & \text{if } X_j > X_i \\ 0, & \text{if } X_j = X_i \\ -1, & \text{if } X_j < X_i \end{cases} \tag{8}$$

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i) \tag{9}$$

where n is the length of the dataset. X_i and X_j indicate the data values at times i and j, respectively. S is the MK temporal trend test statistics. A positive value of S indicates an increasing trend, and a negative value of S indicates a decreasing trend. The temporal trends were considered statistically significant when $P < 0.1$, and all significance levels were tested at $P < 0.05$ and $P < 0.1$ confidence levels.

2.4.5. Cluster analysis

CA is a statistical method that divides a group of subjects into similar groups [18,19]. The basic idea is as follows: each sample is divided into a class, the distance between each group is specified, and the smallest pair is merged into a new kind of clustering; the corresponding calculation is merged into the distance between the new class and other classes and the nearest two types of merger; the step is repeated until all the samples are synthesized into a class [3,20,21]. This method is an important means of data mining at present. In this study, CA was used to summarize the similarities and differences between different months employing Ward's method, and squared Euclidean distances were used as a measure of similarity.

2.4.6. Discriminant analysis

DA is mainly used to classify samples according to the observed sample CA results, distinguish sample points of different categories, verify the correctness of CA results, and identify significant difference indicators of the original data [22–24]. This study adopted stepwise DA and cross-validation method to verify the accuracy [25].

3. Results and discussion

3.1. Basic descriptive statistics of water quality

The descriptive statistics dataset, including minimum values (min), maximum values (max), and mean values (mean), for the water quality, water quality parameters, and impact factors, is presented in Table 3. The monthly CPIWQ value ranged from 0.284 to 0.811, and its mean value was 0.453, which was significantly higher than 0.4 (one-sample test, $P < 0.001$). According to the descriptive statistics for surface water quality by Wang et al. [12], the water quality was lightly polluted in the Nanchong section of the Jialing River mainstream during the study period (Table 2).

For the water quality parameters, the maximum monthly concentrations of COD_{Mn}, NH_3–N, and TP were 4.240, 0.181, and 0.177 mg/L, respectively. The mean concentrations of COD_{Mn}, NH_3–N, and TP were 1.934, 0.124, and 0.040 mg/L, respectively, which were significantly lower than the class III water quality standard (one-sample test, $P < 0.001$) (Table 1). The monthly concentration of DO ranged from 7.139 to 10.895 mg/L, and its mean concentration was 9.058 mg/L, which was significantly higher than the class III water quality standard of 5.0 mg/L (Table 1). The water quality in the Nanchong section of the Jialing River mainstream was weakly alkaline with a pH value ranged from 7.59 to 8.31, which was within the surface water quality standard (Table 1). Unfortunately, TN was the only over-standard in all the water quality parameters. Specifically, the monthly TN concentration of 2.488 mg/L was approximately 1.5 times higher than the class III water quality standard of 1.0 mg/L (Table 1). The mean concentration of TN was 1.335 mg/L, which was significantly higher than the class III water quality standard (one-sample test, $P < 0.001$) (Table 1). In conclusion, nitrogen was still very serious issue in the Nanchong section of the Jialing River mainstream [26]. In general, TN mainly exists in the forms of nitrate nitrogen, nitrite nitrogen, and ammonia nitrogen. The content of nitrite nitrogen is very low and unstable, and easy to be transformed into other forms of nitrogen. Among them, nitrate nitrogen has a high solubility in surface water and can maintain a stable form. It is the main form of nitrogen-containing pollutants in surface water. In this study, TN had the highest contribution to CPIWQ in all the parameters ($R = 0.922$) (Table 4), and the correlation between them was extremely positively significant ($r_s = 0.700$, $P < 0.05$) (Table 5). Meanwhile, the contribution of NH_3–N for CPIWQ was only 0.657 (Table 4). The concentration of NH_3–N was 0.124 mg/L (only about one-tenth of TN concentration), which was consistent with the monitoring results of Huang et al. [27] on nitrogen in the Nanchong section of the Jialing River. In their study, nitrate–nitrogen NH_3^-–N) roughly accounted for 75% of TN concentration, which indicated that non-NH_3–N forms were the majority of nitrogen pollutants in the Nanchong section of the Jialing River mainstream during the study period (mainly nitrate–nitrogen). At present, the composition of nitrogen pollutants is insufficient, and the content and variation characteristics of various forms of nitrogen need to be studied further.

3.2. Temporal variation of water quality

The results of the MK temporal trend test on CPIWQ showed that the water quality deteriorated remarkably (the MK value was 4.860) in the Nanchong section of the Jialing River mainstream (Table 6). The Spearman's correlation analysis results showed that COD_{Mn} (NH_3–N $r_s = 0.578$, TP $r_s = 0.767$, and TN $r_s = 0.676$), NH_3–N (TP $r_s = 0.722$ and TN $r_s = 0.224$), TP (TN $r_s = 0.813$), and TN came from the same source (Table 5), and they were significantly positively correlated with CPIWQ ($P < 0.05$) (Table 5). However, the temporal series trends of the water quality parameters differed. The temporal series trends of NH_3–N (the MK value was 1.658) and TN (the MK value was 2.022) were same as CPIWQ, which presented an upward trend, and TN increased significantly ($P < 0.05$) (Table 6). Fortunately, the temporal series trends of COD_{Mn} (the MK value was −2.220) and TP (the MK value was −1.480) were opposite to CPIWQ, which showed a downward trend (Table 6).

The results of the MK temporal trend test showed that the concentration (or value) of DO (the MK value was 1.403) and pH (the MK value was 0.944) presented an upward trend as same as CPIWQ, NH_3–N, and TN (Table 6). However, DO (CPIWQ $r_s = -0.816$, COD_{Mn} $r_s = -0.651$, NH_3–N $r_s = -0.392$, TP

Table 4
Gray correlation degree (R) between CPIWQ and the water quality parameters (COD_{Mn}, NH_3–N, TP, TN, DO, and pH) in the Nanchong section of the Jialing River mainstream at the different periods

Periods	COD_{Mn}	NH_3–N	TP	TN	DO	pH
Total study period	0.869	0.657	0.809	0.922	0.902	0.912
Period A	0.840	0.587	0.749	0.911	0.889	0.883
Period B	0.747	0.462	0.675	0.803	0.843	0.855

Table 3
Data of water quality and impact factors in the Nanchong section of the Jialing River mainstream during the study period

	CPIWQ	COD_{Mn} (mg/L)	NH_3–N (mg/L)	TP (mg/L)	TN (mg/L)	DO (mg/L)	pH	WT (°C)	EC (ms/cm)	Tu (NTU)	AT (°C)	P (mm)	DP (d)
Min	0.284	1.030	0.069	0.011	0.819	7.139	7.59	10.0	236.4	13.9	6.1	2.5	5.0
Max	0.811	4.240	0.181	0.177	2.488	10.895	8.31	28.8	412.6	254.2	29.5	323.3	27.0
Mean	0.453	1.934	0.124	0.040	1.335	9.058	8.01	18.6	329.6	71.8	18.1	97.7	13.2

Table 5
Spearman's correlation coefficients (r_s) between the water quality parameters and impact factors in the Nanchong section of the Jialing River mainstream during the study period

	CPIWQ	COD_{Mn}	NH_3–N	TP	TN	DO	pH	WT	EC	Tu	AT	P	DP
CPIWQ	1												
COD_{Mn}	0.888**	1											
NH_3–N	0.627*	0.578*	1										
TP	0.821**	0.767**	0.722**	1									
TN	0.700*	0.676*	0.224	0.813**	1								
DO	–0.816**	–0.651*	–0.392	–0.792**	–0.825**	1							
pH	–0.858**	–0.729**	–0.497	–0.907**	–0.888**	0.874**	1						
WT	0.837**	0.697*	0.531	0.809**	0.762**	–0.937**	–0.818**	1					
EC	–0.574	–0.676*	–0.441	–0.627*	–0.531	0.28	0.629*	–0.371	1				
Tu	0.760**	0.753**	0.427	0.694*	0.741**	–0.853**	–0.762**	0.839**	–0.42	1			
AT	0.725**	0.634*	0.378	0.595*	0.636*	–0.867**	–0.615*	0.930**	–0.126	0.839**	1		
P	0.750**	0.634*	0.301	0.669*	0.776**	–0.958**	–0.755**	0.916**	–0.175	0.909**	0.937**	1	
DP	0.490	0.294	0.175	0.347	0.336	–0.685*	–0.531	0.566	–0.007	0.608*	0.545	0.685*	1

Note: * and ** represent the significant level exceeds α = 0.05 and α = 0.01, respectively.

Table 6
Results of the MK temporal trend test of water quality parameters in the Nanchong section of the Jialing River mainstream during the study period

CPIWQ	4.860**
COD_{Mn}	–2.220*
NH_3–N	1.658
TP	–1.480
TN	2.022*
DO	1.403
pH	0.944

Note: * and ** represent the significant level exceeds α = 0.05 and α = 0.01, respectively.

r_s = –0.792, and TN r_s = –0.825) and pH (CPIWQ r_s = –0.858, COD_{Mn} r_s = –0.729, NH_3_N r_s = –0.497, TP r_s = –0.907, and TN r_s = –0.888) were negatively correlated with CPIWQ and other water quality parameters (COD_{Mn}, NH_3–N, TP, and TN) (Table 5). The main pollutants were COD_{Cr}, TP, NH_3–N, COD_{Mn}, BOD_5, and DO in the Nanchong section of the Jialing River watershed [28]. Moreover, the concentration of DO was significantly higher than the class III water quality standard of 5.0 mg/L (one-sample test, $P < 0.001$) (Table 1). However, it was not more than the saturated dissolved oxygen in the Nanchong section of the Jialing River mainstream. The pH value fluctuated within the normal range of surface water quality (6–9). Therefore, the concentration of the main pollutants (except NH_3–N and TN) decreased in the Nanchong section of the Jialing River mainstream.

3.3. Analysis of monthly changes in water quality

Fig. 2 illustrates the monthly trends of CPIWQ and the water quality parameters (COD_{Mn}, NH_3–N, TP, TN, DO, and pH) in the Nanchong section of the Jialing River mainstream during the study period. Fig. 3 shows the monthly trends of the physical factors (TW, EC, and Tu) and impact factors (AT, P, and DP) of water quality. The CPIWQ value was generally stable from January to May. The CPIWQ value increased from June to July and reached the highest value of 0.570 in July. The CPIWQ value showed a downward trend from August to December (Fig. 2a).

The variation trends of COD_{Mn} (Fig. 2b), TP (Fig. 2d), and TN (Fig. 2e) were similar to that of CPIWQ. The concentrations of COD_{Mn}, TP, and TN were generally stable (or slightly fluctuated) from January to June. The concentrations increased from July to August and reached the highest concentrations within the year. The concentrations continued to decrease from September to December. In other words, the concentration of pollutants (COD_{Mn}, TP, and TN) in the river water was high in summer (June to August), decreased in autumn, low in spring and winter, and remained stable. The pollutants (e.g., COD_{Mn}, TP, and TN) in the river water were positively correlated with precipitation (COD_{Mn} r_s = 0.634, TP r_s = 0.669, and TN r_s = 0.776). The maximum monthly concentrations of COD_{Mn}, TP, and TN appeared in the month with the highest precipitation, and the pollutant concentration decreased with precipitation. This feature indicated that the pollutants mainly came from nonpoint sources in the watershed [28], such as the Jialing River mainstream with the lower original water and the water supply mainly from the numerous tributaries in the basin. More than 25 tributaries with approximately 10,000 km^2 of watershed area are situated in the Nanchong section of the Jialing River mainstream [26]. Agricultural runoff, domestic sewage, and livestock pollution are the major pollution sources in this area [28]. The concentrations of nitrogen, phosphorus, and organic pollutants in natural water are lower, and the enriched pollutants in the earth's surface discharge into the river with the surface runoff and increase the concentration of pollutants in the river. Therefore, the surface runoff and the scouring force on the surface increase as precipitation rises, which leads to more surface pollutants entering the river. Thus, a significantly positive correlation was found among the concentrations of

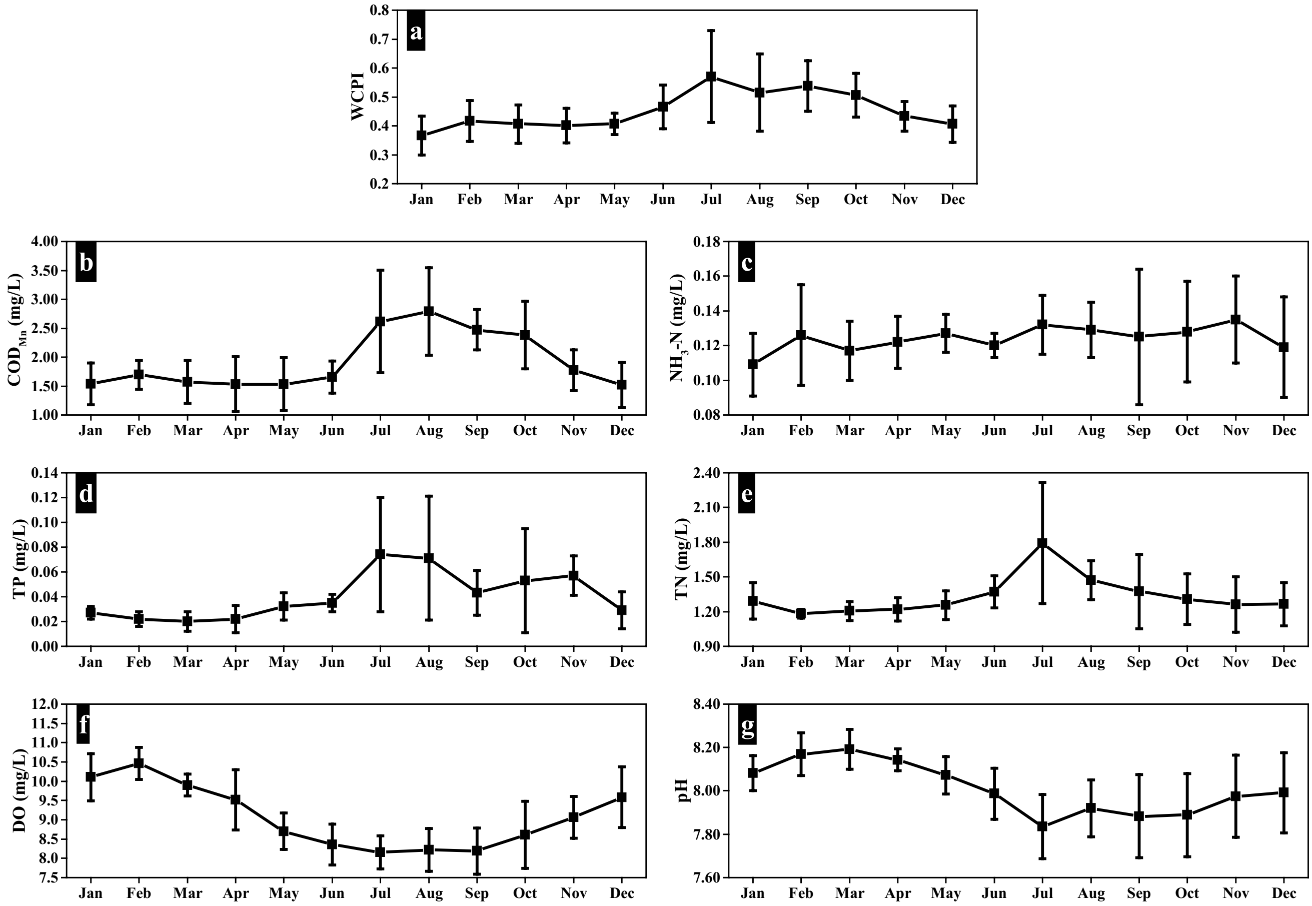

Fig. 2. Monthly trends of the Comprehensive Pollution Index of Water Quality (CPIWQ) values (a) and the concentrations of water quality parameters (permanganate index (COD_{Mn}) (b), ammonia nitrogen (NH_3–N) (c), total phosphorous (TP) (d), total nitrogen (TN) (e), dissolved oxygen (DO) (f), and pH (g)) in the Nanchong section of the Jialing River mainstream during the study period.

COD_{Mn}, TP, TN, and precipitation ($P < 0.05$) in the Nanchong section of the Jialing River mainstream during the study period (Table 5). The concentrations of nitrogen, phosphorus, and organic pollutants were negatively correlated with precipitation in the river water, which was mainly affected by point source pollution. The results suggest that the nitrogen, phosphorus, and organic pollutants of the Jialing River mostly came from domestic and agricultural nonpoint source pollution discharged into the river [7,17,26].

Lower nitrate and ammonium concentrations are remarkable characteristics of nonpoint source pollution [30]. In this study, the mean concentration of NH_3–N (0.124 mg/L) was significantly lower than the class I water quality standard of 0.15 mg/L (one-sample test, $P < 0.001$) in the Nanchong section of the Jialing River mainstream during the study period. The correlation among NH_3–N, COD_{Mn}, and TP was significantly positive ($P < 0.05$). However, the monthly variation trend of NH_3–N was different from that of COD_{Mn}, TP, and TN. The concentration of NH_3–N was stable within the year, with only small fluctuations in February, May, July, and November (Fig. 2c). NH_3–N was positively correlated with precipitation ($r_s = 0.301$, $P = 0.342$). These results suggest that the concentration of NH_3–N was affected by point and nonpoint sources in the Nanchong section of the Jialing River mainstream during the study period.

DO and pH showed the trend of an initial increase, followed by a subsequent decrease and then an increase, and the lowest concentration (or value) of DO and pH appeared in July. The Spearman's correlation analysis results showed that DO and pH were negatively correlated with WT, P, and DP. First, the activities of the aquatic organisms (or organic matter) increase with the rise in WT; then, biological processes such as photosynthesis, respiration, and remineralization of organic matter consume DO and release CO_2; finally, DO and pH decreases [29,31,32]. In addition, the more precipitation and the longer precipitation process lead to the discharge of a mass of pollutants (e.g., nitrogen, phosphorus, and organic pollutants) into the river through surface runoff, which provides sufficient nutrients for the mass reproduction of the aquatic organisms [29,33].

3.4. Cluster analysis of water quality

The temporal dendrogram was analyzed by CA of the water quality in the Nanchong section of the Jialing River mainstream during the study period, as shown in Fig. 4.

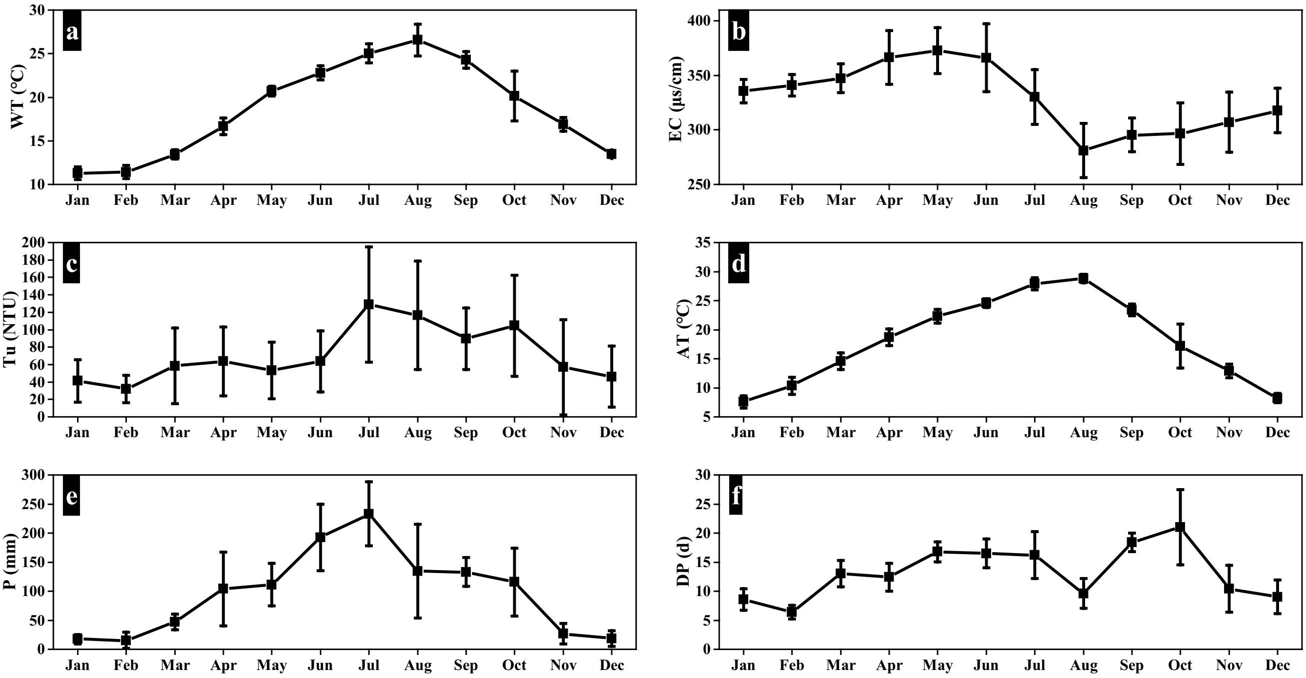

Fig. 3. Monthly trends of water temperature (WT) (a), electrical conductivity (EC) (b), turbidity (Tu) (c), air temperature (AT) (d), precipitation (e), and days of precipitation (DP) (f) in the Nanchong section of the Jialing River mainstream during the study period.

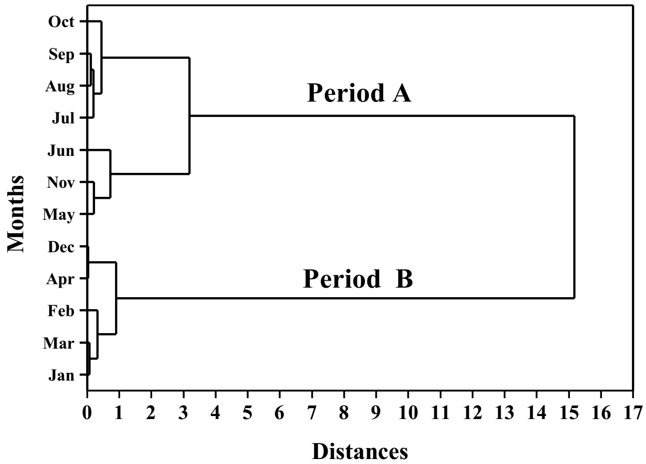

Fig. 4. Cluster dendrogram of monitoring time series in the Nanchong section of the Jialing River mainstream during the study period.

This grouping was carried out based on similarities in the water quality parameters. The months were divided into two periods in the Nanchong section of the Jialing River mainstream. Period A (wet season) consisted of seven months, including May to November, while Period B (dry season) consisted of five months, which covered January to April and December (Fig. 4). DA was used to verify the correctness of CA results, and the temporal DA function in this study had the strong discriminant ability and good reliability and validity ($P < 0.001$).

Fig. 5 shows the differences in CPIWQ, water quality parameters, and impact factors between Period A and Period B in the Nanchong section of the Jialing River mainstream during the study period. The CPIWQ value in Period A (0.491) was significantly higher than that in Period B ($\chi^2 = 10.832$, $P = 0.001$). In terms of water quality parameters and impact factors, the concentrations (or values) of COD_{Mn}, NH_3–N, TP, TN, WT, Tu, AT, P, and DP in Period A were higher than those in Period B, and only the difference in NH_3–N was insignificant ($F = 2.061$, $P = 0.156$) between Period A and Period B. On the contrary, DO, pH, and EC in Period A were significantly lower than those in Period B ($P < 0.05$). So far, these parameters (except NH_3–N) appear to be the primary source of temporal variations in water quality. The temporal distribution of ammonia nitrogen concentration differed between the rainy and dry seasons. The main reason is that part of the ammonia nitrogen from rainfall leaching is absorbed and trapped by the soil when it passes through the soil, while the rest of the ammonia nitrogen and the ammonia nitrogen re-released from the soil infiltrate into the water [34].

These correlations among various water quality parameters can be explained in terms of climatic and hydrological characteristics associated with the period. The water temperature reflects the atmospheric temperature, and this parameter presents the most significant difference between the two periods. The contents of P and DP in Period A (rainy season) were significantly higher than those in Period B (dry season), and Tu can also be interpreted as an increase in the amount of erosion material and urban runoff expected during rainfall (rainy season).

The content of DO is negatively correlated with water temperature, microbial quantity, nitrogen pollution, and

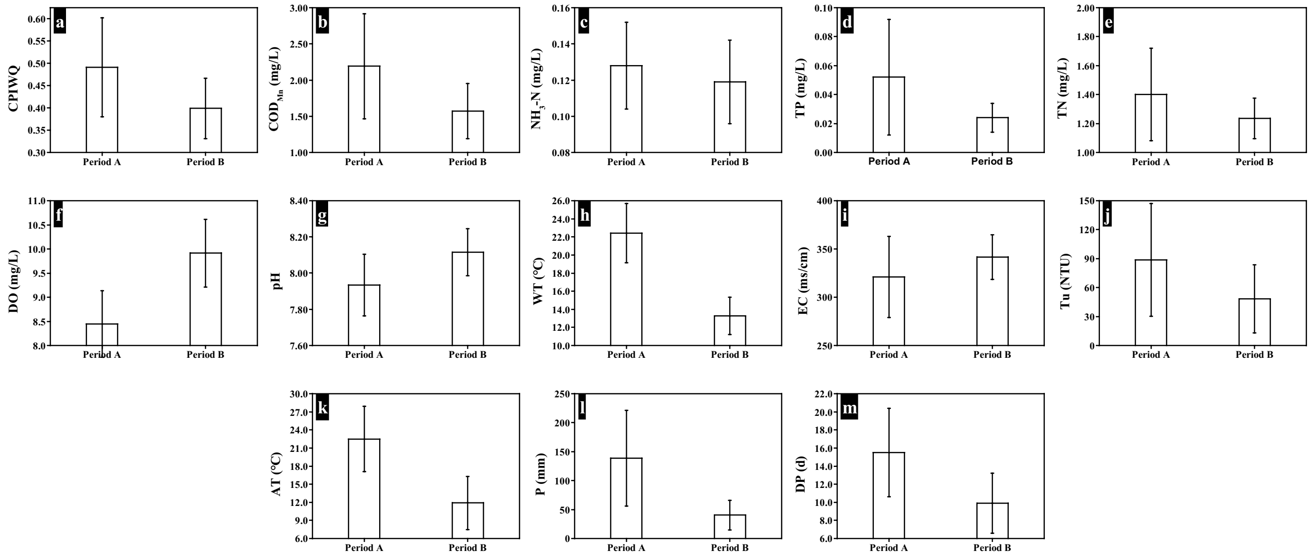

Fig. 5. Temporal variations in the Nanchong section of the Jialing River mainstream during the study period. (a) Comprehensive Pollution Index of Water Quality (CPIWQ), (b) permanganate index (COD_{Mn}), (c) ammonia nitrogen (NH_3–N), (d) total phosphorous (TP), (e) total nitrogen (TN), (f) dissolved oxygen (DO), (g) pH, (h) water temperature (WT), (i) electrical conductivity (EC), (j) turbidity (Tu), (k) air temperature (AT), (l) precipitation (P), and (m) days of precipitation (DP).

overall water quality. Water with a low DO content indicates a high degree of pollution. Among them, water temperature plays a major role in DO content, and the DO content is lower when the temperature is higher. Under the influence of rainfall, pH increases with the rise in rainfall, water is abundant, and the wastewater entering the river through surface runoff is diluted to a certain extent. Evaporation will lead to an increase in salinity concentration, and the ions present will become more concentrated as the water level decreases, which results in higher EC levels. As a result, Period B > Period A. On the other hand, rainfall will increase water volume and level and decrease EC.

The concentrations of COD_{Mn}, NH_3–N, TP, and TN in the water showed a trend of Period A > Period B, which was similar to the study of Wang et al. [35], which found that the contents of organic matter and nitrogen and phosphorus nutrients in the water of the Jialing River basin were jointly affected by climate change, rainfall dilution, and other environmental factors. In general, the self-purification capacity of the water body in the wet season is stronger than that in the dry and normal seasons. According to the study of Xiao [36] and Huang [37], the pollutants mainly come from nonpoint source pollution when the concentration of pollutants in the wet season is higher than that in the dry season. On the contrary, the pollutants mainly come from point source pollution when the concentration of pollutants is high in the dry season. Previous studies showed that the concentration of major pollutants in the Jialing River mainstream in the wet season is higher than that in the dry season, which means that the pollution in this area is mainly from nonpoint source pollution. The main reason why the wet season is higher than the dry season is that the precipitation in the wet season increases, which scours the nutrients accumulated in the soil and may also impact the sediment at the bottom of the river; thus, the nutrients in the sediment that has been precipitated are released again. It may also be due to the large inflow of exogenous pollution sources (major tributaries of the Jialing River), which accelerate the flow rate and increase the flow rate of all tributaries of the Jialing River in the wet season. A large amount of them flows into the Jialing River, which results in the decline in the water quality of the Jialing River.

The analysis of the second national pollution source survey data in Nanchong City shows that agricultural and rural nonpoint source pollution is the main feature and is very obvious. Agricultural and rural sources accounts for more than 77% of NH_3–N emissions in Nanchong City [26]. Among the agricultural and rural pollution sources, rural domestic pollution sources are the main sources, among which the ammonia nitrogen from rural domestic sources accounts for 73.49% of the total amount of agriculture and rural areas, the emission from livestock and poultry breeding accounts for 16.36%, and the pollution from farmland accounts for 10.15% [26]. Therefore, the control of rural and agricultural nonpoint source pollution is the key to improve water quality, especially the rural domestic pollution sources. Nanchong has a large population density and a low urbanization rate, a large rural population, and a high density. The rural domestic sewage treatment rate is less than 15%, and the utilization rate of recycled water is only 1.12%. Therefore, the nitrogen pollution of the surface water in the Nanchong section of the Jialing River basin can be prevented and controlled by strengthening the management of agricultural wastewater and improving the drainage network of agricultural wastewater, anti-seepage treatment of the surface drainage ditch, and rational application of nitrogen fertilizer.

4. Conclusion

(1) The water quality in the Nanchong section of the Jialing River mainstream was weakly alkaline, but only TN exceeded the class III standard among all the water quality

parameters. The results of CPIWQ showed that the water quality of the studied area was slightly polluted, and the mean value of its CPIWQ was 0.453. The main influencing factor of the eutrophication status of the Nanchong section of the Jialing River was nitrogen nutrients, and nitrate nitrogen (non-ammonia nitrogen) was the main nitrogen pollutant. The CPIWQ value and the concentrations of pollutants (COD_{Mn}, TP, and TN) were higher in summer (June to August), decreased in autumn, were lower in spring and winter, and remained stable. The concentration of NH_3–N remained stable for 1 y. DO and pH showed a trend of first increasing, then decreasing, and finally increasing within 1 y.

(2) The results of the MK time trend test showed that the water quality of the Nanchong section of the Jialing River trunk stream deteriorated significantly (MK = 4.860). However, the temporal series trends of COD_{Mn} (the MK value was −2.220) and TP (the MK value was −1.480) showed a downward trend. The concentration of TN main pollutants showed a significant upward trend ($P < 0.05$). Reducing TN concentration is an important goal of Nanchong City in the future to reduce the risk of eutrophication of the Jialing River.

(3) Water pollutants in the Nanchong section of the Jialing River basin had obvious time difference characteristics. CA divided the 12 months into two periods, and the water quality in the rainy season (May–November) was better than that in the dry season (December–April). Agricultural and rural nonpoint source pollution were the main sources of water pollution in this basin. The concentrations of COD_{Mn}, NH_3–N, TP, and TN in the water showed a trend of Period A > Period B. The contents of organic matter, nitrogen, and phosphorus nutrients in the water in the Jialing River basin were affected by climate change, rainfall dilution, and other environmental factors.

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Availability of data and materials

The datasets used during the current study are available from the corresponding author upon reasonable request.

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Author contributions

H.J.H. (Senior Engineer) and Y.F.Q (M.D) wrote and revised the manuscript. J.X. (M.D) made significant contributions to data acquisition, analysis, and interpretation. H.J.Z. (M.D) helped organize the manuscript data. Y.X. (M.D) and J.H. (Senior Engineer) made key changes to important academic content and were responsible for the final revision.

Conflict of interest

The authors declare that they have no conflict of interest.

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