Spatiotemporal characteristics of the water quality in the Jinsha River Basin (Panzhihua, China)

Yan Yang, Xing Huang, Xiaohua Zhu, Yiyang Zhou, Liuqing Zhang, Yiming Zhang and Guobiao Zhou

ABSTRACT

Spatiotemporal changes in the water quality index are important measures with which to analyze water quality. Fifteen water quality indices at the Longdong, Luoguo, and Jinjiang stations in the Panzhihua Section of the Jinsha River Basin from 2016 to 2018 were analyzed using cluster analysis (CA), discriminant analysis (DA), independent sample t-test and correlation analysis. The results of CA showed that the months can be divided into the following groups based on the similarities in the water quality characteristics: group 1 (dry season), January-April and December; group 2 (flood season), August-September; and group 3 (flat season), May-July and October-November. In group 1 the river is remarkably polluted. The main parameters that distinguish the spatial differences are pH level, chemical oxygen demand, chlorophyll a, fecal coliforms, and electrical conductivity. All sections of the river meet the National Level III standard, and the water quality of the Jinsha River is generally good. Spatial results show that the Luoguo station is seriously polluted compared with the other two stations. Significant negative correlation is found between forest land and COD ($P < 0.05$). Therefore, the management of land use and pollutant discharge should still be strengthened in the Luoguo section to improve the overall water quality of the Jinsha River.

Key words | Jinsha River Basin, multivariate technology statistics, Panzhihua Section, spatiotemporal characteristics, water quality parameter

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HIGHLIGHTS

- Spatiotemporal changes in the water quality index are important measures to with which analyze the water quality.
- The water quality of the Panzhihua Section of the basin greatly affects the Panzhihua region and the middle and lower reaches of the Yangtze River.
- Multivariate statistical analysis can provide a powerful theoretical support in the study of the interaction of multiple indicator variables.

INTRODUCTION

Rapid modernization has resulted in the discharge of large amounts of pollutants into the rivers, and worsening of river pollution. Rivers are important natural resources for the development of urban society and play a substantial role in farmland irrigation, industrial water use, and water supply (Vega *et al.* 1998; Ngoye & Machiwa 2004). Water pollution and shortage threaten the stable development of society and economy (Bo *et al.* 2009). The water quality of rivers is affected by natural factors, such as precipitation and atmospheric deposition, and by human factors, such as industrial production, urban domestic wastewater, and surface runoff of farmland (Singh *et al.* 2005a, 2005b). Rivers have seasonal and regional

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characteristics because of the different hydrological conditions and human activities (Sundaray *et al.* 2006; Gurjar & Tare 2019). Zeinalzadeh & Rezaei (2017) analyzed the water quality of the Shahr Chai River in the Lake Urmia basin, Iran and found that the NO_3^- values decreased at most stations during winter, while the biochemical oxygen demand (BOD), chemical oxygen demand (COD), Sodium (Na), and NH_4^+ showed an increasing trend in the downstream area. Lu & Yu (2018) used multivariate statistics analysis to analyze the hydrological data of the Songhua River basin to examine the relation between human activities and the spatiotemporal change in the heavy metals (Pb and Cu) in water.

The dynamic information for the effective management of the water environment can be obtained by studying the variation in the spatiotemporal characteristics of the quality of river water. Therefore, monitoring the water quality and effective evaluation of the spatiotemporal variations are important for formulating decisions in water environment management (Ouyang *et al.* 2006; Zhou *et al.* 2007). Some scholars assessed the water quality and health of rivers based on the water quality index (WQI) (Hossain *et al.* 2013; Hameed *et al.* 2016). Plummer & Long (2007) used a weight-of-evidence approach (land use analysis by using GIS, sanitary surveys, traditional water quality monitoring, and MST (microbial source tracking) targets) to identify the sources of pollution. Multivariate statistical analysis can provide a powerful theoretical support in the study of the interaction of multiple indicator variables (Kitagaki *et al.* 2019). This process has been widely applied in the fields of environment, economy, and industry, especially in water quality assessment (Cai *et al.* 2019; Raoni *et al.* 2019). Multivariate statistical methods were used to examine the nutritional development level of the Venetian lagoon based on the characteristics of water quality changes in time and space (Solidoro *et al.* 2004). Tang *et al.* (2018b) used multivariate statistical analysis to analyze the water quality and spatiotemporal characteristics of the Hunhe River Basin. Sundaray *et al.* (2006) applied linear regression, factor, and cluster analyses to study the spatiotemporal variations in the water quality of the Mahanadi estuary system of India, and identified natural and man-made pollution sources. These aforementioned methods are important for the multivariate and multisampling analyses of the quality of river water.

The Jinsha River stems from the winter snow mountain in Gladan, in the Tanggula Mountains in Qinghai and is named for its yellow sandy soil. This river flows approximately 130 km into Panzhihua City and is the main source of water for industrial and domestic use in this city. The Jinsha River also receives municipal domestic sewage and industrial wastewater (Yang & Dai 2016). Water consumption has increased dramatically with the economic development and increase in population. Considerable volumes of domestic sewage and industrial wastewater have also been produced, leading to the deterioration of the environment and serious pollution of water resources (Luo 2008; Jiang 2010; Xu *et al.* 2018). The water quality of the Panzhihua Section of the basin greatly affects the Panzhihua region and the middle and lower reaches of the Yangtze River (Wang 2018; Liu *et al.* 2019). Scholars at home and abroad have mainly explored the hydrological condition of the Jinsha River (Li *et al.* 2014; Zhang *et al.* 2018b). However, the characteristics of the spatiotemporal distribution of the water quality of the river is poorly examined. In this study, cluster analysis (CA) and discriminant analysis (DA) with multivariate statistical methods, independent sample t-test, and correlation analysis were performed to analyze the water quality in the Panzhihua Section of the Jinsha River Basin. In addition, a practical basis was provided to determine the pollution sources, optimize monitoring programs, and protect and improve the water quality of the Jinsha River Basin.

MATERIALS AND METHODS

Study area and parameters of water quality

The Jinsha River (Figure 1) is upstream of the Yangtze River in China. The rainfall in the Jinsha River occurs mainly from June to October during the flood season. Panzhihua (26°05′-27°21′N, 101°08′-102°15′E), a prefecture-level city in Sichuan Province, is situated at the junction of Sichuan and Yunnan in southwest China. This point is where the Jinsha and Yalong Rivers meet. Panzhihua is a south subtropical city with long summers, but the durations of the four seasons are ambiguous. However, the dry and flood seasons are clear. This city is characterized by a dry

Figure 1 | Location map of monitoring points in the Jinsha River Basin (Panzhihua Section).

climate, concentrated rainfall, long sunshine, strong solar radiation, high evaporation, and a complex and diverse microclimate. Panzhihua City has the highest annual average temperature in Sichuan Province and a frost-free period of more than 300 days. Many studies have shown the significant relationship between land use and the parameters for water quality (Kibena *et al.* 2014; Teixeira *et al.* 2014). The change in land use directly reflects the important influence of human activity on the water quality and ecology of a river (Gu *et al.* 2019; Mello *et al.* 2020). Guo *et al.* (2010) found a positive relation of urban land with NO_2-N, dissolved oxygen (DO), and NO_3-N. Xu *et al.* (2019) showed that forest land and grassland have positive effects on water quality, and these land types could be used as pollution buffers along rivers to protect the water environment. Panzhihua is mainly forest land, followed by construction land. The Panzhihua Section of the Jinsha River Basin has three monitoring stations, namely, Longdong, Luoguo, and Jinjiang, which are located in the west, east, and Renhe districts, respectively. Land use at these three points in the Jinsha River Basin is shown in Table 1. The Panzhihua Environmental Monitoring Center collected water samples from these stations every month from January 2016 to December 2018.

Fifteen parameters were chosen based on the sampling continuity of all selected monitoring points

Table 1 | Land use at three points in the Jinsha River Basin

	West district (Longdong)		East district (Luoguo)		Renhe district (Jinjiang)	
	Area/hm^2	Percentage/%	Area/hm^2	Percentage/%	Area/hm^2	Percentage/%
Forest land	5,827.66	47.43	7,848.97	47.57	110,627.78	63.98
Cultivated land	1,063.28	8.65	487.84	2.96	19,158.33	11.08
Construction land	2,907.61	23.66	5,642.12	34.19	10,457.42	6.05
Water area	410.17	3.34	529.42	3.21	4,481.14	2.59
Other type	2,078.42	16.92	1,991.73	12.07	28,173.67	16.30
The total area	12,287.14	100	16,500.08	100	172,898.34	100

Data resource: Natural Resources and Planning Bureau of Panzhihua City.

(Table 2). The collection, preservation, and analysis of water samples were according to the requirements of *Water and Wastewater Monitoring and Analysis Methods* (4th Edition), which is a summary of the national environmental monitoring scientific research, monitoring method research, and monitoring method standardization results (GB3838-2002 2002; Panzhihua 2018). Table 3 lists the surface water environmental quality standards for 15 water quality parameters to evaluate the water quality of the Jinsha River.

Analytical methods

The parameters for determining the water quality should be of normal distribution or close to a normal distribution when multivariate statistical analysis, independent sample t-test and correlation analysis are applied (Johnson & Wichern 2005; Papatheodorou *et al.* 2006). Therefore, the distribution characteristics of the water quality indicators should be checked before CA and DA (Table 4). Given that the water quality indicators differ in quantity and unit of measurement, the reliability of CA by standardizing the data during the analysis should be improved (Alberto *et al.* 2001; Singh *et al.* 2005a). The software IBM SPSS 23.0 was used for all mathematical and statistical calculations in this study. The specific research flow chart is shown in Figure 2.

As a general method for exploratory analysis, systematic clustering (CA) can be divided into two categories, namely, variable clustering (R-type clustering) and sample clustering (Q-type clustering) (Brown 1998). CA aggregates the closest attributes in accordance with the degree of proximity

Table 2 | Fifteen parameters and monitoring methods[a]

Parameters	Monitoring Method	Method Sources
pH	Portable pH meter method	*Water and Wastewater Monitoring and Analysis Methods* (4th Edition) (GB3838-2002 2002)
DO	Electrochemical probe method	HJ506-2009
COD_{Mn}	Acid method	GB11892-1989
NH_3-N	Nessler Reagent Spectrophotometry	HJ535-2009
COD	Dichromate method	GB11914-1989
TN	Flow Injection Spectrophotometry of Naphthalene Ethylenediamine Hydrochloride	HJ668-2013
TP	Flow injection spectrophotometry of ammonium molybdate	HJ671-2013
Cu	Inductively coupled plasma optical emission spectrometry	HJ 776-2015
F	Ion Selective Electrode method	GB7484-87
As	Atomic fluorescence spectrometry	*Water and Wastewater Monitoring and Analysis Methods* (4th Edition) (GB3838-2002 2002)
Fecal coliforms	Multi-tube fermentation	HJ/T347-2007
EC	Portable conductivity meter method	*Water and Wastewater Monitoring and Analysis Methods* (4th Edition) (GB3838-2002 2002)
Temperature	Thermometer method	GB13195-1991
Transparency	Secchi disk method	*Water and Wastewater Monitoring and Analysis* (4th Edition) (GB3838-2002 2002)
Chl-a	Determination of chlorophyll a	*Water and Wastewater Monitoring and Analysis Methods* (4th Edition) (GB3838-2002 2002)
Q	Acoustic Doppler flow test specification	SL 337-2006

[a]Notes: GB indicates that it is part of the national standards of China.
HJ indicates that it is part of the national environmental protection standards of China.
SL indicates that it is part of the water conservancy industry standards of China.

Table 3 | Standards of surface water environment quality (GB3838-2002, China)

	I	II	III
pH		6–9	
DO	≥7.5	6	5
COD_{Mn}	≤2	4	6
NH_3-N	≤0.15	0.5	1
COD	≤15	15	20
TN	≤0.2	0.5	1
TP	≤0.02	0.1	0.2
Cu	≤0.01	1.0	1.0
F	≤1.0	1.0	1.0
As	≤0.05	0.05	0.05
Fecal coliforms	≤200	2,000	10,000
Temperature	Maximum mean temperature rise weekly ≤1,Maximum mean temperature drop weekly ≤2		

between variables or samples and forms the closest objects until they are aggregated into one class. During the evaluation of the water quality, CA is usually based on the sampling points and sampling time to analyze the spatiotemporal characteristics of the water quality, or on the clustering results in accordance with the evaluation indices to analyze the similarity among indicators (Singh *et al.* 2005b; Zou *et al.* 2007). In this study, the Euclidean square distance method and Ward minimum variance method were performed to cluster the temporal similarities in the Panzhihua Section in the Jinsha River Basin. DA is a multivariate statistical analysis to determine the type of attribution of the study object in accordance with its various eigenvalues under a defined classification (Tang 2019). In this study, through classification and recognition, the research objects were classified, and a discriminant function (DF) was established for the research objects in the Panzhihua Section of the Jinsha River Basin. The DF discovers the undetermined coefficients from numerous raw data based on specific criteria (Zhou *et al.* 2007). Compared with DA, CA first classifies the samples, uses DF to distinguish the attributes of the samples, and identifies the important pollution parameters of the research objects, as follows:

$$f(G_i) = k_j + \sum_{j=1}^{n} w_{ij} p_{ij}$$

where i is the number of group types (G); n is the number of pollution parameters used to classify a set of data into a given group; w_{ij} is the weight coefficient; p_{ij} is the concentration of the main pollution indicator; f is the DF; and k_j is the constant

Table 4 | Normality tests of main water quality parameters

	Kolmogorov-Smirnov			Shapiro-Wilk		
Parameters	**Statistics**	**Freedom**	**Significance**	**Statistics**	**Freedom**	**Significance**
pH	0.174	12	0.200*	0.943	12	0.532
DO	0.193	12	0.200*	0.894	12	0.132
COD_{Mn}	0.204	12	0.179	0.907	12	0.197
NH_3-N	0.215	12	0.131	0.897	12	0.143
COD	0.102	12	0.200*	0.982	12	0.989
TN	0.180	12	0.200*	0.923	12	0.308
TP	0.237	12	0.062	0.926	12	0.340
Cu	0.307	12	0.003	0.664	12	0.000
F	0.154	12	0.200*	0.958	12	0.756
As	0.206	12	0.171	0.868	12	0.061
Fecal coliforms	0.203	12	0.186	0.887	12	0.106
Temperature	0.207	12	0.167	0.919	12	0.278
Transparency	0.123	12	0.200*	0.960	12	0.791

Note: * indicates that this is a lower bound of the true significance.

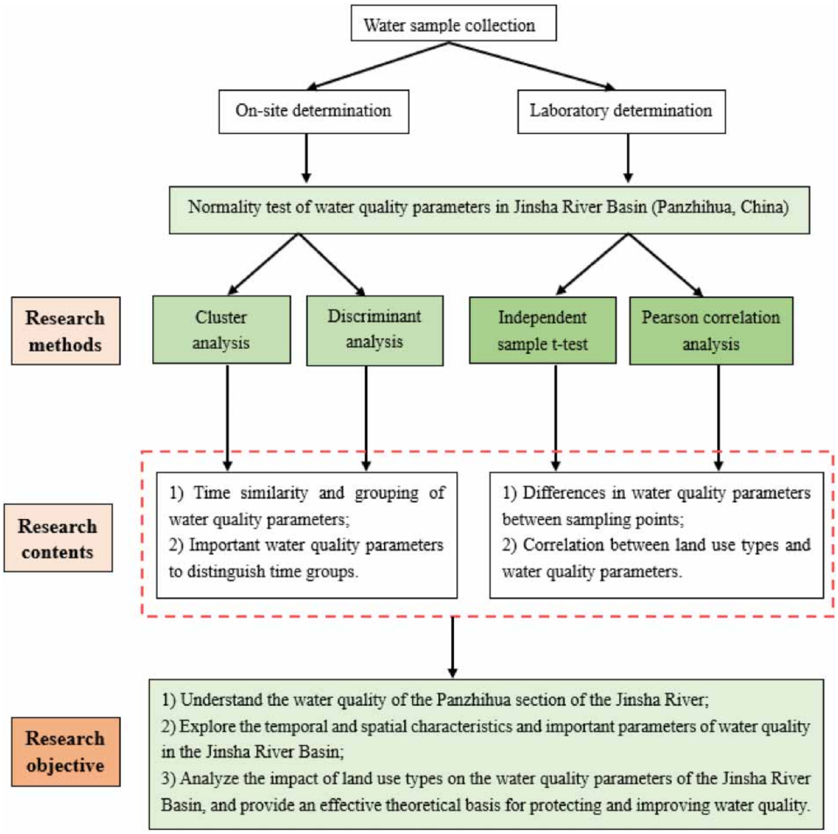

Figure 2 | Specific flow chart of our study.

inherent to each group (Yao 2015). The discriminant criterion can divide the process into distance and Fisher discriminants. The verification methods for direction finding include self-verification and external verification, sample dichotomy, and cross-validation. DA usually uses standard, forward, and backward methods to execute the test data. The results are applied to the spatial analysis of water quality, and the optimal DF and matrix are obtained to test the CA results and identify the key pollutants at each monitoring point (Meng 2012). In this study a step-by-step model was used for DA in manipulating the raw data to confirm the clusters found in CA and evaluate the spatiotemporal variations on the basis of the discriminant variables. The monitoring group was categorized using variables, and the measurement parameters were independent variables.

The t-test method is usually used to compare the differences between two sets of data under various conditions (Bo & Xia 2006). Therefore, in this study, the independent sample t-test method was used to compare and analyze the differences in the water quality between the two monitoring points.

RESULTS

Temporal similarity and period grouping

The pedigree map of the systematic CA was obtained in accordance with the water quality characteristics of the Jinsha River Basin (Figure 3). Through clustering, when the squared Euclidean distance is ≥ 5 and < 9, the pedigree map divided the basin into the following three time groups with the same physical and chemical water quality characteristics: group 1 (dry season), January-April and December; group 2 (wet season), August-September; and group 3 (flat season), May-July, and October-November. Figures 4–8 show the results of the temporal DA.

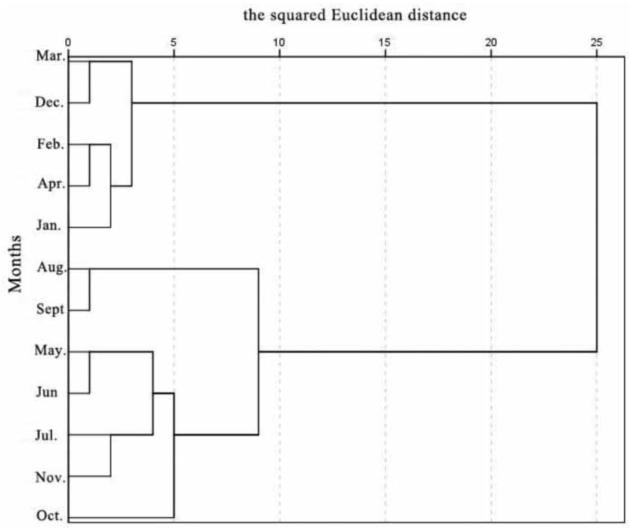

Figure 3 | Cluster analysis pedigree of monitoring group in Jinsha River Basin, Panzhihua.

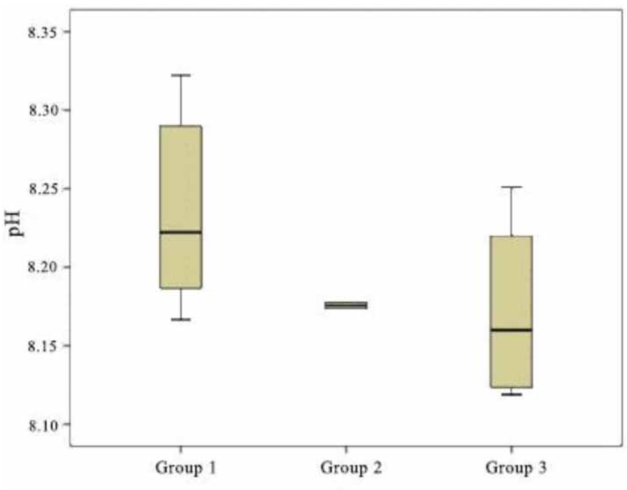

Figure 4 | Temporal variations: pH.

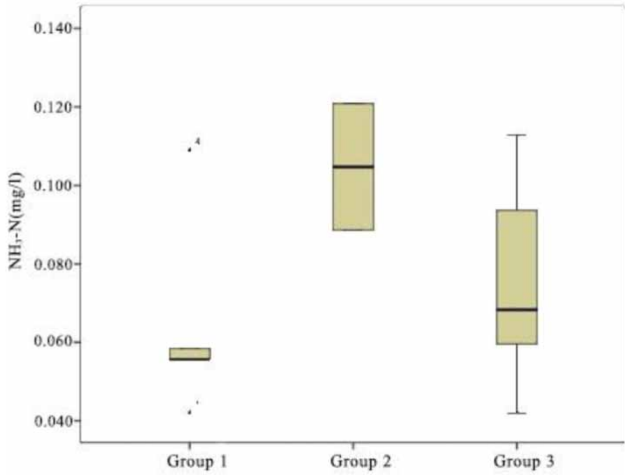

Figure 5 | Temporal variations: NH_3-N.

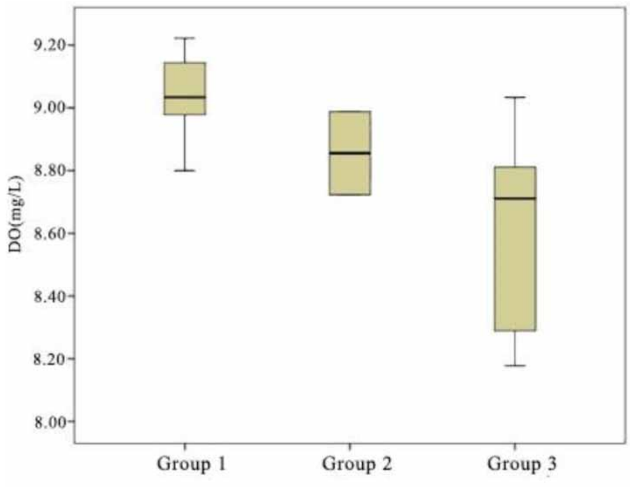

Figure 6 | Temporal variations: DO.

Table 5 shows that the value of Wilk's lambda for the DF was small (0.131), the χ^2 value was high (196.922), and the significance (0.000) was less than 0.05, indicating that time DA was significant. Tables 6 and 7 present the DFs and classification matrices (CMs), respectively, as obtained by using the temporal DA. These tables show that stepwise DA requires only four main water quality indicators to construct the DFs. The discriminating capability of the DA would not be significantly reduced, and correct assignments could still be maintained at above 66.7%. Temporal DA shows that pH level, DO, COD_{Mn}, and NH_3-N were the most important water quality parameters to distinguish the three groups and could explain most of the time distribution characteristics of water quality.

Spatial characteristics

Comparative analysis was conducted through the independent sample t-test in accordance with the water quality characteristics of the Longdong, Luoguo and Jinjiang monitoring points (Table 8). Given that only two sets of data can be compared at a time, the three monitoring points should be compared three

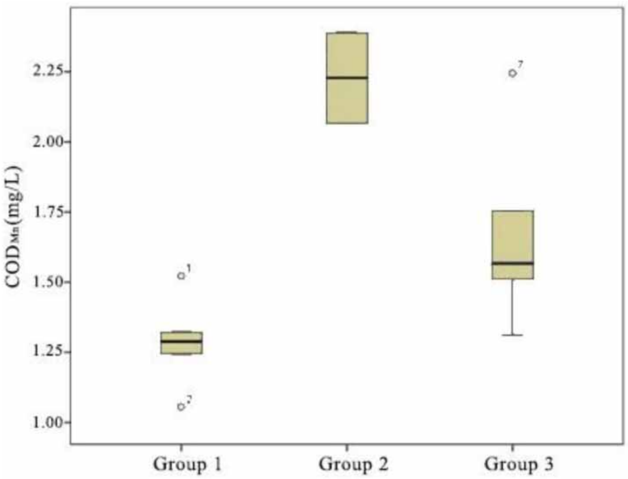

Figure 7 | Temporal variations: COD_{Mn}.

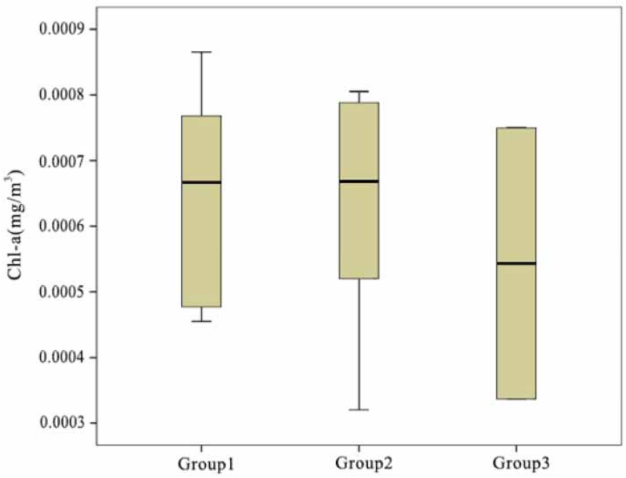

Figure 8 | Temporal variations: Chl-a.

Table 5 | Wilk's lambda and chi square values of DA of temporal variations in water quality

Function testing	Wilk's Lambda	chi square	Freedom	Significance
	0.131	196.922	34	0.000
	0.6664	39.764	16	0.001

times to observe the differences among parameters. Variations in WQIs at the Longdong, Luoguo, and Jinjiang points were recorded from 2016 to 2018. The pH levels of the three monitoring sites were relatively stable but varied slightly and ranged from 7.59 to 8.70, 7.81 to 8.70, and 7.77 to 8.50, respectively.

Table 6 | Classification function coefficients for DA of temporal variations

	Group 1	Group 2	Group 3
pH	401.329	395.955	394.829
NH_3-N	80.185	89.317	79.383
DO	45.020	44.667	43.644
COD_{Mn}	21.470	24.989	22.900
Constant	−1,861.495	−1,847.795	−1,821.083

Table 7 | CM for DA of temporal variations

		Period assigned by DA[a]		
	Percent correct	Group 1	Group 2	Group 3
Group 1	86.7%	39	1	7
Group 2	66.7%	0	12	8
Group 3	66.7%	6	5	30
Total	100%	45	18	45

Note: [a] checked by cross-validation method.

The corresponding NH_3-N contents ranged from 0.025 mg/L to 0.154 mg/L, 0.034 mg/L to 0.142 mg/L, and 0.025 mg/L to 0.154 mg/L. These values met the Class I water quality standards. The DO values at the Longdong, Luoguo and Jinjiang stations ranged from 7.60 mg/L to 10.10 mg/L, 7.90 mg/L to 10.40 mg/L, and 7.60 mg/L to 10.70 mg/L. The corresponding COD_{Mn} values ranged from 0.8 mg/L to 3.3 mg/L, 0.9 mg/L to 2.8 mg/L, and 0.9 mg/L to 4.3 mg/L. All these values met the Class III water quality standards. A significant difference in Chl-a was found between Longdong and Luoguo, as well as between Luoguo and Jinjiang ($P < 0.05$).

Correlation between land use and water quality parameters

Correlation analysis of the area proportion of forest land, cultivated land, construction land, water area and the water quality data of the corresponding river section sampling points was performed (Kibena *et al.* 2014; Zhang *et al.* 2020a, 2020b). The correlations between land use and the water quality data is shown in Table 9. The results show a significant negative correlation between forest land and COD ($P < 0.05$).

Table 8 | Comparison of spatial monitoring*

Parameter	Monitoring section	Mean ± SD	Max	Min
pH	Longdong	8.21 ± 0.19a	8.70	7.59
	Luoguo	8.36 ± 0.18a	8.70	7.81
	Jinjiang	8.16 ± 0.19b	8.50	7.77
DO	Longdong	8.83 ± 0.70a	10.10	7.60
(mg/L)	Luoguo	8.76 ± 0.59a	10.40	7.90
	Jinjiang	8.89 ± 0.58a	10.70	7.60
COD_{Mn}	Longdong	1.40 ± 0.56a	3.30	0.80
(mg/L)	Luoguo	1.60 ± 0.59a	3.30	0.70
	Jinjiang	1.80 ± 0.69a	4.30	0.90
NH_3-N	Longdong	0.07 ± 0.10a	0.15	0.03
(mg/L)	Luoguo	0.08 ± 0.08a	0.14	0.03
	Jinjiang	0.07 ± 0.04a	0.15	0.03
COD	Longdong	11.04 ± 2.75ab	19.00	6.00
(mg/L)	Luoguo	11.06 ± 3.39a	18.00	6.00
	Jinjiang	10.01 ± 2.41b	15.00	5.00
TN	Longdong	0.57 ± 0.13a	0.83	0.45
(mg/L)	Luoguo	0.66 ± 0.14a	1.03	0.42
	Jinjiang	0.66 ± 0.13a	0.96	0.52
TP	Longdong	0.02 ± 0.01a	0.06	0.01
(mg/L)	Luoguo	0.03 ± 0.01a	0.07	0.01
	Jinjiang	0.03 ± 0.01a	0.07	0.01
Cu	Longdong	0.00 ± 0.00a	0.01	0.00
(mg/L)	Luoguo	0.00 ± 0.02a	0.13	0.00
	Jinjiang	0.00 ± 0.00a	0.01	0.00
F	Longdong	0.17 ± 0.02a	0.22	0.15
(mg/L)	Luoguo	0.18 ± 0.03a	0.23	0.15
	Jinjiang	0.17 ± 0.03a	0.20	0.15
As	Longdong	0.00 ± 0.00a	0.00	0.00
(mg/L)	Luoguo	0.00 ± 0.00a	0.00	0.00
	Jinjiang	0.00 ± 0.00a	0.00	0.00
Fecal coliforms	Longdong	2,943.06 ± 4,707.92c	5,400.00	80.00
(N/L)	Luoguo	29,692.50 ± 30,478.45a	160,000.00	430.00
	Jinjiang	23,044.44 ± 23,273.39b	54,000.00	1,100.00
EC	Longdong	48.83 ± 15.21a	87.80	34.60
(ms/m)	Luoguo	50.22 ± 13.67a	88.80	33.70
	Jinjiang	38.66 ± 9.55b	68.30	26.40
Temperature	Longdong	17.85 ± 3.92a	27.10	13.00
(°C)	Luoguo	17.18 ± 3.17a	22.80	11.50
	Jinjiang	17.30 ± 3.21a	20.90	12.40
Transparency	Longdong	108.03 ± 69.84a	300.00	0.00

(*continued*)

Table 8 | continued

Parameter	Monitoring section	Mean ± SD	Max	Min
(cm)	Luoguo	66.00 ± 43.86a	181.00	20.00
	Jinjiang	58.89 ± 48.02a	193.00	5.00
Chl-a	Longdong	0.00 ± 0.00b	2.00	0.00
(mg/m^3)	Luoguo	0.28 ± 0.00a	2.00	0.00
	Jinjiang	0.00 ± 0.00b	2.00	0.00

Note: * In the same water quality parameter results, the same letters indicate that there is no significant difference in the mean value of the parameters of the monitoring points, and different letters indicate that there is a significant difference. If there is a significant difference in the water quality parameters of the monitoring points, "a" is added after the result with the maximum mean value, and the order from large to small is b, c.

Table 9 | The correlation analysis of land use and water parameters[a]

	Forest land	Cultivated land	Construction land	Water area
NH_3-N	−0.494	−0.964	0.785	0.353
COD	−1.000*	−0.724	0.935	0.984
TN	0.506	−0.252	−0.144	−0.634
TP	0.506	−0.252	−0.144	−0.634
Fecal coliforms	0.286	−0.476	0.097	−0.431
Chl-a	−0.494	−0.964	0.785	0.353

[a]*Note:* *represents significant correlation ($P < 0.05$).

DISCUSSION

Time distribution of water quality

The first group (January-April and December) is consistent with the dry season. The second group (August-September) is consistent with the flood season, and the third group (May-July and October-November) includes the flat season. Hence, the water quality of the Jinsha River Basin is affected by seasonal changes and hydrological conditions, such as flood and dry seasons (Zhai 2015; Zhang *et al.* 2017). The sampling frequency during the wet season can be appropriately increased to improve the monitoring of water quality and reduce the impact of seasonal climate change (Lü & Mu 2017; Jing *et al.* 2019). The average pH of the first group (8.24) is higher than those of the second (8.18) and third groups (8.17). This result is due to the fact that the first group covers the dry season, during which there is less precipitation. The area of cultivated land accounts for 10.27% of the Jinsha River Basin. The residue from burning straw is commonly used as a traditional agricultural fertilizer (Gao 2018), and its main component is K_2CO_3 (Zhang *et al.* 2016). Large amounts of agricultural wastewater contaminated by the residual straw ash increase alkalinity in the basin. The proportion of alkaline wastewater discharged from industries and agriculture compared to the total amount of wastewater discharged is high. These characteristics increase the pH level of the surface water in the environment. Compared with the first group, the precipitation of the second group is higher, which enlarges the catchment area of rivers and increases the water volume. The proportion of alkaline wastewater discharged from the industries and agriculture compared to the total amount of wastewater discharged naturally decreases. Hence, the pH level of the surface water consequently decreases. The precipitation in the third group is between those of the first and second groups. However, the pH level of the alkaline wastewater discharged in the third group may be slightly lower because of the reduced actual production of factories (Teng *et al.* 2016; Lü & Mu 2017; Ji & Wang 2019). The average DO (9.04) of the first group is higher than those of the second (8.86) and third (8.60) groups and showed a significant time effect. Compared with the third group, the first and second groups have a highly suitable temperature and sufficient light, which are conducive to the photosynthesis of aquatic plants to release additional O_2. (Yu *et al.* 2017). DO is an important indicator to reflect the degree of water pollution and a key factor to ensure the survival of aquatic organisms (He *et al.* 2014; Du *et al.* 2019).

Likewise, Chl-a is the main pigment of photosynthesis for phytoplankton (Wang *et al.* 2014b). Our results (Figures 2 and 8) suggest that Chl-a concentration is high when DO is high, which is similar to the results of Yang *et al.* (2020). Phytoplankton release O_2 during the photosynthesis process, which increases the DO content in the water body (Li *et al.* 2010; Yu *et al.* 2017). In addition, the saturated oxygen concentration varies depending on the water temperature. High temperatures can hinder the exchange of oxygen between the atmosphere and water (Akkoyunlu *et al.* 2011), resulting in the phenomenon in which a high temperature leads to low DO (Zhou 2016; Cong *et al.* 2019; Hu *et al.* 2019; Ji & Wang 2019). The water temperature in the Jinsha River Basin ranges from 11.5 to 27.1 °C, and the DO concentration ranges from 7.60 to 10.70 mg/L, which is close to saturation in this temperature range.

COD_{Mn} is usually used as a comprehensive indicator of the degree of water pollution by reducing organic matter (Fang *et al.* 2019). The amount of COD_{Mn} is closely related to the development status of industry, sewage discharge, and large-scale livestock and poultry breeding (Hua 2012; Cheng *et al.* 2015). The average permanganate index of the second group (2.23) is higher than those of the first (1.29) and third (1.68) groups. The result is probably due to the increase in municipal sewage and industrial wastewater discharge, an increase in reducing organic pollutants, and the significant organic pollution during this stage. In addition, the second group is in the high-water period, during which the rainfall is abundant, the river flow rate is fast, and the water turbidity and permanganate index are large (Ji & Wang 2019).

The TN in water mainly comes from agricultural production (livestock and poultry farming), followed by domestic sewage and industrial wastewater (Wang *et al.* 2015). The average NH_3-N (0.105) in the second group is higher than those in the first (0.064) and third (0.075) groups. The nitrogen residues in soil and other organic pollutants in the agroecological process enter the river through surface runoff as a result of heavy rainfall in the flood season (Zhang 2001; Wang *et al.* 2014a). The average values of the pH level, DO, COD_{Mn}, and NH_3-N of the three groups reach the National Level I standard for surface water environmental quality.

Spatial distribution of water quality

The results of the water quality monitoring show differences in the water quality at the three monitoring sites. The five water quality parameters: pH level, COD, fecal coliforms, Chl-a, and EC exhibit significant differences ($P < 0.05$).

The pH level of water is a comprehensive reflection of the hydrochemical characteristics and one of the important indicators of water quality. This parameter can directly reflect the content of CO_2, existence of organic acids, and water pollution (Feng *et al.* 2017). The average pH level of Luoguo is higher than that of Longdong, indicating that the drainage basin of the former is more polluted by human and animal feces than that of the latter. In addition, considerable differences in pH exist between Longdong and Jinjiang, as well as between Luoguo and Jinjiang. The average pH level (8.36) of Luoguo is higher than those of Jinjiang (8.16) and Longdong (8.20). This phenomenon is due to the fact that Luoguo is located in the concentrated industrial and agricultural region where higher alkaline wastewater is discharged. These characteristics cause substantial harm to the body of water (Kirschner *et al.* 2017) and lead to an increase in the pH level of the river water. The forested lands in Longdong and Luoguo account for a low proportion, and their abilities to intercept and absorb organic pollutants are weak, resulting in the high COD content. (Sliva & Williams 2001; Chen *et al.* 2019). COD has a considerable effect on the turbidity of factory wastewater. Industrial wastewater contains a large amount of suspended matter, colloidal matter and pathogenic microorganism components. Substantial metal ions exist in suspended and colloidal matter (La *et al.* 2017). The complex metal ions form macromolecules that increase the turbidity of the wastewater (Gao & Yan 2017; Zou & Yang 2019). The transparency is low in the Luoguo and Jinjiang sections, which is related to the high industrial wastewater discharge. As an important photosynthetic pigment in plant photosynthesis, Chl-a is one of the critical indicators of water eutrophication (Reynolds 1984; Fu *et al.* 2009). Luoguo has a higher Chl-a value than Jinjiang and Longdong, and serious eutrophication. This phenomenon is due to the fact that the Luoguo section accounts for a large proportion of the construction land, urbanization has increased population density, human activities discharge a large amount of organic pollutants, and impervious construction land has a role in promoting surface runoff (Rajput *et al.* 2017). Thus, the unabsorbed N and P enter the rivers and lakes through runoff erosion and rain splash erosion. These events accelerate the eutrophication of the water body (Sliva & Williams 2001; Zhang *et al.* 2020a). There are considerable differences in EC between Longdong and Jinjiang, as well as between Luoguo and Jinjiang. Luoguo has the highest EC, because it is located in a concentrated industrial area (Kirschner *et al.* 2017), the construction land area in Luoguo is greater than those of the other two sections. EC is greatly affected by the concentrations of cations and anions. However, the concentrations of anions and cations in the Jinsha River are low, suggesting a slight impact on EC (Tang *et al.* 2018a; Feng *et al.* 2020). The concentration of EC is affected by pH, temperature and DO (Li *et al.* 2017; Zhang *et al.* 2018a), thus, the mechanism of action should be further strengthened.

CONCLUSION

The time similarity analysis of the Jinsha River Basin shows that the monitoring months can be divided into the following groups: group 1 (dry season), January-April and December; group 2 (flood season), August-September; and group 3 (flat season) May-July and October-November. The pH level, DO, NH_3-N and COD_{Mn} are the most important discriminant variables to distinguish the three groups. The spatial comparison shows that the parameters with significant differences are pH, COD, fecal coliforms, Chl-a, and EC. Water quality parameters reflect that the main problem in the water quality in the Panzhihua Section of the Jinsha River Basin is due to the high content of organic pollutants. All sections meet the National Level III standard. Thus, the water quality of the Jinsha River is generally good. Land use has several effects on water quality. The management of land use and human pollutant emissions should still be strengthened in the Luoguo section to improve the overall water quality of the Jinsha River.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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