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Water quality analysis of the Yalong River in Panzhihua, China

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ABSTRACT

The Yalong River in Panzhihua, China is an important water source for the production and in the lives of people in the region. This river plays an irreplaceable role in economic development and human health. In this study, the cluster (CA) and the discriminant analyses (DA) of multivariate statistical analysis were performed to evaluate the water quality in the Yalong River from 2016 to 2018. Parameters, such as water temperature, flow rate, pH, conductivity, dissolved oxygen, 5-d biochemical oxygen demand (BOD_5), ammoniacal nitrogen, total nitrogen (TN), chlorophyll a (Chl-a), and arsenic (A_S), each of which contains 72 samples, were selected to understand the temporal variations in the water quality of the Yalong River. Through CA, the watershed was divided into three groups based on the similarities of water quality characteristics. The first, second, and third groups comprise the May and June, the August, September, and October, and the January, February, March, April, July, November, and December samples, respectively. These three groups correspond to the dry, flood, and flat seasons. The correctness of the group clustering was verified through DA. The important parameters that sufficiently represent spatiotemporal differences include pH, BOD_5, DO, Chl-a, and TN. The water quality parameters imply that the main problem in the Panzhihua section of the Yalong River is the high water organic pollutant content. However, the pollution level is within the Class III standard, and the overall quality of the water body is acceptable. Therefore, the monitoring frequency of these parameters should be strengthened, and the sampling method should be optimized to provide a scientific basis for the water quality monitoring in the Yalong River.

Keywords: Yalong River; Spatiotemporal changes; Water parameters; Cluster analysis (CA); Discriminant analysis (DA)

1. Introduction

Rivers are important freshwater sources and play a vital role in maintaining the balance of the ecosystem. However, with the gradual acceleration of urbanization, river ecosystems are destroyed by anthropogenic activities, and pollution problems are becoming increasingly severe [1]. The water quality of rivers is mainly affected by natural (e.g., precipitation) and human factors (e.g., industrial wastewater, domestic sewage, and farmland surface runoff) [2]. Therefore, the long-term monitoring and evaluation of rivers are necessary to obtain accurate information to control river pollution [3] and provide support and reference for water quality management. Partial basis can be provided for the management of the water environment by exploring the spatiotemporal changes in river

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water quality characteristics. The effective evaluation of the spatiotemporal changes in river water quality has become an important reference for water quality management decision [4,5].

Multivariate statistical techniques are useful methods for analyzing the spatiotemporal changes in water quality and have been widely used in practical applications [2,6,7]. Solidoro et al. [8] investigated the nutritional development level of the Venetian Lagoon by using multivariate statistical methods based on the characteristics of spatiotemporal changes in water quality. Bu et al. [9] explained the deteriorating process of water quality from upstream to downstream using cluster analysis (CA), factor analysis, and grid method. They also proved the important role of tributaries and ocean exchanges in determining water quality and ecosystem dynamics. Wunderlin et al. [10] used CA, principal component analysis, and discriminant analyses (DA) to evaluate the spatial and temporal changes in the water quality of the Suquia River. Caccia et al. [11] used regression analysis and found that the water quality of Biscayne Bay was influenced by land use. Shrestha et al. [12] used CA and DA to identify the important changes in water quality parameters and studied several methods for optimizing monitoring networks.

The Yalong River, the largest tributary in Jinsha River [13], originated from the southern foothills of Bayan Kala Mountain in the Yushu Prefecture, Qinghai Province. This river flows from northwest to southeast and passes through the Ganzi Tibetan Autonomous Prefecture of the Sichuan Province and the Liangshan Yi Autonomous Prefecture. Then, it merges with the Jinsha River at Luoguo County in Panzhihua City, China. It is worth mentioning that Yalong River is an important water source for the daily lives of the residents and for industrial and agricultural production [14]. Large amounts of domestic sewage with simply treated is discharged directly into the middle and upper reaches of Yalong River [15]. However, due to the small pollution load and large runoff-to-fouling ratio, the overall water quality in the upper and middle reaches meet the requirements of the function of the water area. In the lower reaches of the Yalong River, pollution sources are mainly industrial, domestic, and non-point sources of runoff results from the clustered population and the development of industry and agriculture [16]. The water quality of the lower reaches is generally good, as well as the water quality of each monitoring station can reach the surface water category III standard [17]. Our study focused on the Panzhihua reach of Yalong River, which few researchers evaluate the water quality in this area. Based on the analyses of main water quality parameters of Yalong River, the spatial and temporal characteristics of the water quality in the Panzhihua reach of Yalong River were investigated to explore factors of water pollution in the basin and provide a scientific basis for ecosystem management and water environmental protection in the river area.

2. Materials and methods

2.1. Sampling position

The middle and lower reaches of the Yalong River cover 13 counties (cities), including Xinlong and Daofu, with a total area of 10,623 km², and belong to ethnic minority areas (Fig. 1). The population of the basin is unevenly distributed, and the average population densities in the middle and downstream areas are approximately 6.5 and 79 people/km², respectively [18]. The area belongs to the plateau with a semi-humid climate. Precipitation is mainly concentrated in May–October (especially June–September), and the precipitation during winter (November–April) is less than 6% of the total yearly amount, thereby forming distinct dry and flood seasons [19]. The flat season occurs in May, June, and July; the flood season transpires on August, September, and October, and the dry season is observed in January, February, March, April, November, and December. The distribution of precipitation in the Yalong River basin is severely uneven throughout the year. The rainy season from May to September accounts for 87% of the total precipitation in the year. In January, the driest month, about accounts for 0.3% of the annual precipitation [20]. The average annual precipitation in the Yalong River is 250–1,560 mm, which increases from north to south. The high regional value is in the upper reaches and southern part of the Anning River. The average annual temperature is 7.26°C, in which the respective average annual temperatures during spring, summer, autumn, and winter are 8.2°C, 14.1°C, 7.5°C, and −0.8°C. Therefore, the overall temperature in the Yalong River can be described as mild [21].

Panzhihua, which is located at the southernmost tip of Sichuan, which is a denuded mountain hill and plain. The four seasons in this area are unclear because it experiences long summer and rainy seasons from May to October and the slightly rainy season from November to April. This region experiences rainy and dry seasons that last for half a year, and it belongs to the southern subtropical region. The different climatic types in the north temperate zone are referred to as "the three-dimensional climate of the South Asian tropical Panzhihua as the base zone" [22]. Panzhihua is affiliated to the Yangtze River system and belongs to the

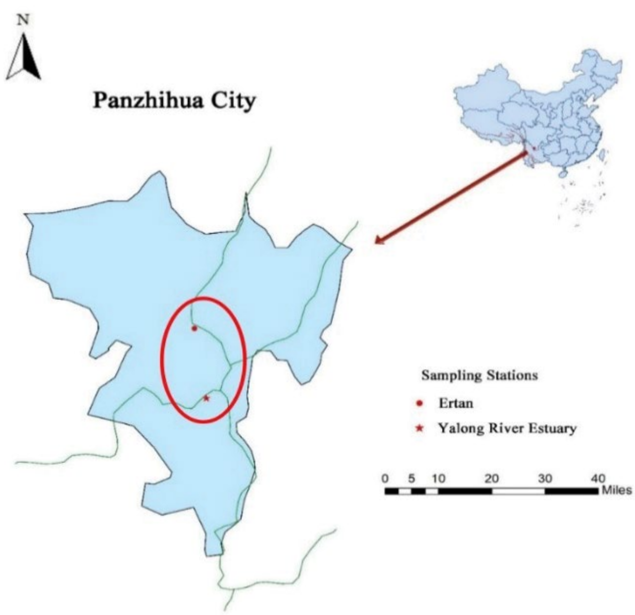

Fig. 1. Panzhihua watershed map of the Yalong River.

Jinsha River system. The Yalong River system and the main areas of the basin are the major tributaries of the Anning, Sanyuan, and Dahe Rivers [22]. Our study focused on the Panzhihua reach of Yalong River (101.7994°E~101.8087°E, 26.6661°N~27.1058°N), which is the key water source of Panzhihua City. Environmental Monitoring Center of Panzhihua City collected water samples from two locations in the urban of Panzhihua, including Yalong Estuary and Ertan. These monitoring data of tow sampling locations were collected from 2016 to 2018 the beginning of each month. Each monitoring point includes ten water quality parameters, and each parameter has a total of 36 samples.

2.2. Monitoring parameters

A multivariate statistical analysis requires normally distributed water quality parameters (or at least close to a normal distribution) [23–25]. Therefore, the distribution characteristics of the water quality indicators are verified prior to the analysis (Table 1). According to the sampling continuity and distribution characteristics of the water quality parameters of the monitoring points, 10 parameters, namely, water temperature (temp), flow rate (Q), pH, conductivity (Ec), dissolved oxygen (DO), 5 d biochemical oxygen demand (BOD_5), ammoniacal nitrogen, total nitrogen (TN), chlorophyll a (Chl-a), and arsenic (As), are selected. Except for Q (m^3/s), pH, Ec (μs/cm), and temp (°C), the other parameters are expressed in mg/L. The collection, preservation, and analysis of the water samples are in accordance with the relevant requirements of the technical requirements for surface water and wastewater monitoring. These data of the same month in 3 y were averaged so that different water quality periods in a year can be grouped according to time, and the water quality difference between the two sampling points can be compared and analyzed according to space. Temporal and spatial variation can determine the main cause of water pollution. Table 1 presents the normality test of the main water quality parameters, whereas Tables 2 and 3 show the specific analytical methods and surface water environmental quality standards derived from the Regional Water Environmental Quality Standards of the People's Republic of China (GB3838-2002) [26], respectively [14].

2.3. Statistical analysis

This study conducted the investigations through multivariate statistical analysis and independent sample t-test. The different water quality indicators vary in magnitude and units of measurement; thus, the data in the standardized system CA process are used to improve the credibility [10,27]. All data in this study satisfy the normal distribution, and the data of two monitoring points have no correlation. As a consequence, it is suitable to use the independent sample t-test for significance [28]. All mathematical and statistical calculations were performed using IBM SPSS Statistics 23.0.

2.3.1. Cluster analysis

The hierarchical cluster method or CA is a relatively popular exploratory method that is divided into variable (R-type) and sample clustering (Q-type) [29]. The principle behind this analysis is to gather similar objects according to the degree of closeness between the variables or samples and gradually aggregate these variables into one class to form a pedigree. In water quality assessment, CA divides monitoring points or monitoring times into different classes or groups according to the similarity of water quality data to obtain great similarities within a group [30,31]. In this study, Euclidean square distance and Ward's minimum variance methods were used to analyze the temporal similarity within the Panzhihua section of the Yalong River basin systematically.

2.3.2. Discriminant analysis

DA is a multivariate statistical method that can be used to classify research objects under classification and

Table 1
Normality test of main water quality parameters[1]

	Kolmogolov–Sminov[a]			Shapiro–Wilk		
	Statistics	Degree of freedom	p	Statistics	Degree of freedom	p
pH	0.093	12	0.200*	0.990	12	1.000
DO	0.235	12	0.065	0.851	12	0.038
BOD_5	0.141	12	0.200*	0.958	12	0.755
NH_3–N	0.162	12	0.200*	0.947	12	0.587
TN	0.185	12	0.200*	0.953	12	0.676
A_S	0.181	12	0.200*	0.804	12	0.011
Ec	0.201	12	0.194	0.912	12	0.226
Temp	0.164	12	0.200*	0.932	12	0.398
Chl-a	0.145	12	0.200*	0.972	12	0.928
Q	0.154	12	0.200*	0.955	12	0.714

[1]Significant difference $p \geq 0.05$.
*This is a lower bound of the true significance
[a]Lilliefors significance correction

Table 2
Water quality parameter monitoring methods

Parameters	Monitoring method	Method source
Temperature	Thermometer method	GB13195-1991
Q	Acoustic Doppler flow test specification	SL 337-2006
pH	Portable pH meter method	Water and Wastewater Monitoring and Analysis Methods (Fourth Edition)
Ec	Portable conductivity meter method	Water and Wastewater Monitoring and Analysis Methods (Fourth Edition)
DO	Electrochemical probe method	HJ 506-2009
BOD_5	Dilution and inoculation method Dilution and inoculation	HJ 505-2009
NH_3–N	Nessler's reagent spectrophotometry	HJ 535-2009
TN	Water quality determination of total nitrogen alkaline-potassium persulfate digestion	HJ 636-2012
Chl-a	Water quality determination of chlorophyll a spectrophotometry	HJ 897-2017
A_S	Water quality determination of arsenic atomic fluorescence method	HJ 694-2014

Table 3
Environmental Quality Standards for surface water (GB3838-2002)

Standard	pH	DO	BOD_5	NH_3–N	TN	A_S
I	6—9	≥7.5	≤3	≤0.15	≤0.2	≤0.05
II	6—9	≥6	≤3	≤0.5	≤0.5	≤0.05
III	6—9	≥5	≤4	≤1.0	≤1.0	≤0.05

recognition conditions and establish a suitable discriminant function (DF) for the research objects in the Panzhihua section of the Yalong River Basin. The function is based on certain criteria and discovers the undetermined coefficients in the DF using substantial raw data [5]. Unlike CA, DA first distinguishes the classification of samples. The function can also be used to determine the significance of the different variables in each group.

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

where i is the number of group type G, n is the pollution parameter of the number of group type, 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 inherent constant of each group [32]. The criterion can be divided into distance discrimination and Fisher discriminant. The verification methods for the direction-finding effects include self- and external-verifications, sample dichotomy, and cross-validation. DA is typically performed on the test data using standard, forward, and backward methods. The results were applied to the spatial analysis of water quality, and the optimal DF and matrix were obtained to verify the results of CA and identify the key pollutants at each monitoring station [33]. In this study, a stepwise model was used to process the raw data to determine the clusters in the CA and estimate the spatiotemporal variations in the basin based on the discriminant variables. The monitoring period (time) corresponds to a grouping variable, whereas the measurement parameters are independent ones.

3. Results and discussion

3.1. Temporal similarity and period grouping

The pedigree map was obtained through systematic CA (Fig. 2). The watershed was divided into three groups, namely, flat (May and June), flood (August, September, and October), dry seasons (January, February, March, April, July, November, and December), according to the similarities in their physical and chemical water quality characteristics. In addition to hydrological conditions (e.g., flood and dry seasons), the water quality of Yalong River is also affected by seasonal changes. The second group is consistent with the flood season, whereas the third group slightly deviated from the dry season, which can be ascribed to climate change [34]. Thus, the sampling frequency of the dry season can be increased appropriately to improve monitoring quality, avoid climate change, and interfere with the monitoring results. Table 4 shows that Wilks' lambda value of DF is 0.245, and the chi-square value is 90.648. In addition, the significance of DF is less than 0.05, thereby indicating the significance of temporal DA. The classification function coefficient of the temporal DA indicates that pH, DO, BOD_5, and TN are important water quality parameters used for distinguishing the three groups; moreover, this coefficient can explain most of the temporal similarities and period groupings [35]. The stepwise model processing requires only four major water quality indicators to construct DFs (Table 5). Hence, the discriminating ability of this model will not be significantly reduced. Moreover, the correct distribution ratio can be maintained above 72% (Table 6).

The result of the temporal DA is displayed in Fig. 3. The average pH of the third group is higher than those of

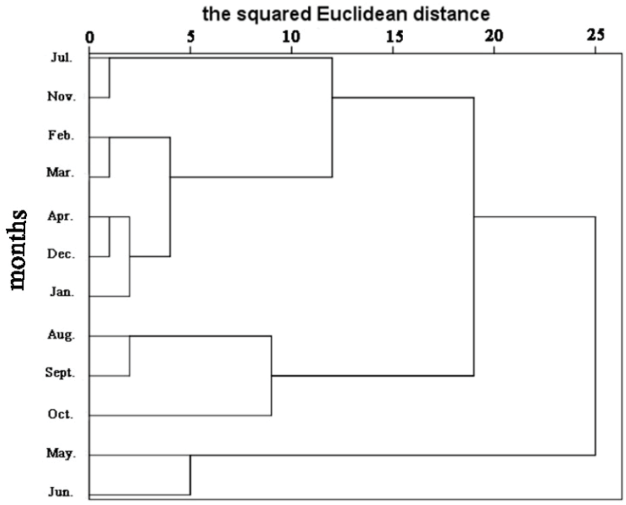

Fig. 2. CA of the monitoring cycle in the Yalong River Basin in Panzhihua.

the first and second groups and demonstrates significant time effects. It can be attributed to a decrease dilution capacity of the river in the dry season, as well as the increase of alkaline wastewater from industrial and agricultural made the increase of pH value [36]. Compared with the first group, the second group has larger precipitation, thereby increasing the water volume of the river and catchment area. In addition, agricultural activities have accelerated the dissolution of rainwater on the soil, thereby causing a large amount of Ca^{2+}, Mg^{2+}, and HCO^{3-} to be precipitated and brought into the river and increasing the pH accordingly [37]. The second group, which demonstrated a significant temporal effect, also has the highest DO among the three groups. The reason for this phenomenon is that the second group is under the summer season, in which the temperature and water are more favorable for the growth of aquatic plants. These aquatic plants release oxygen through photosynthesis [38]. The average concentration of BOD_5 in the third group is the highest among the three, which might be because the discharge of domestic and industrial sewages increases the organic matter in the river, thereby promoting the consumption of DO [39]. The average concentration is lower than that of the third group, which may be due to the high temperature in the second group in summer, and the increase of DO consumption in the water due to intense activity of microbial. The average concentration of BOD_5 in the first group is the lowest due to less pollutant discharge in the flat water [40]. The average concentration of TN in the second group is the highest. Agricultural activities (e.g., activities that involve nitrogen-containing organic chemical fertilizers and livestock) are the main source of TN in the water, followed by sewage and industrial waste water [41]. All indicators of the three groups are in line with the Surface Water Environmental Quality Standard for Class III Water.

Table 5
Classification function coefficients of temporal discriminant analysis

Parameter	Group		
	First group	Second group	Third group
pH	158.352	158.075	161.124
DO	24.291	28.025	26.626
BOD_5	5.767	6.554	6.186
E	21.846	29.085	27.330
Constant	–783.653	–825.464	–821.610

Excessively high TN content leads to the eutrophication of water bodies [41]. The water quality assessment standard for surface water in Panzhihua City is the national standard limit for Class III water in the Environmental Quality Standard for Surface Water (GB3838-2002, China) [26]. The findings indicate that the water quality in the region is in good condition.

3.2. Spatial distribution characteristics of water quality

Table 7 shows the changes in the parameters of the water quality indicators during the 3 y period (2016–2018) for the two monitoring points in the Yalong Estuary and Ertan. Although the pH range of the two monitoring stations is relatively small, usually between 7.7~8.6 and 7.6~8.7, it is relatively stable. Other water quality parameters are in line with the Class III water quality standard with a good condition. However, the BOD_5, TN, and Chl-a were significantly different ($P \leq 0.05$). Moreover, TN is the main pollutant. The average monthly BOD_5 and TN in the Yalong Estuary, both of which are comprehensive indicators of water quality organic pollution, were 30% and 27% higher than that of Ertan, respectively.

The main pollution sources include domestic sewage, agricultural production (animal and poultry breeding), and industrial wastewater [41]. The area around the Yalong Estuary is more affected by human activities than the Ertan area, wherein domestic sewage, industrial production, sewage outlets, and agricultural production activities are abundant [21]. Thus, the emission management of pollution sources, such as urban sewers, factory sewage, and agricultural irrigation water in areas around the Yalong Estuary, should therefore be strengthened. Chl-a is an important

Table 4
Wilks' lambda values

Fun. (s)	Wilk–Lambda	Chi-square	Degree of freedom	Significance
1–2	0.245	90.648	20	0.000
2	0.648	28.015	9	0.001

Fun. (s): function test

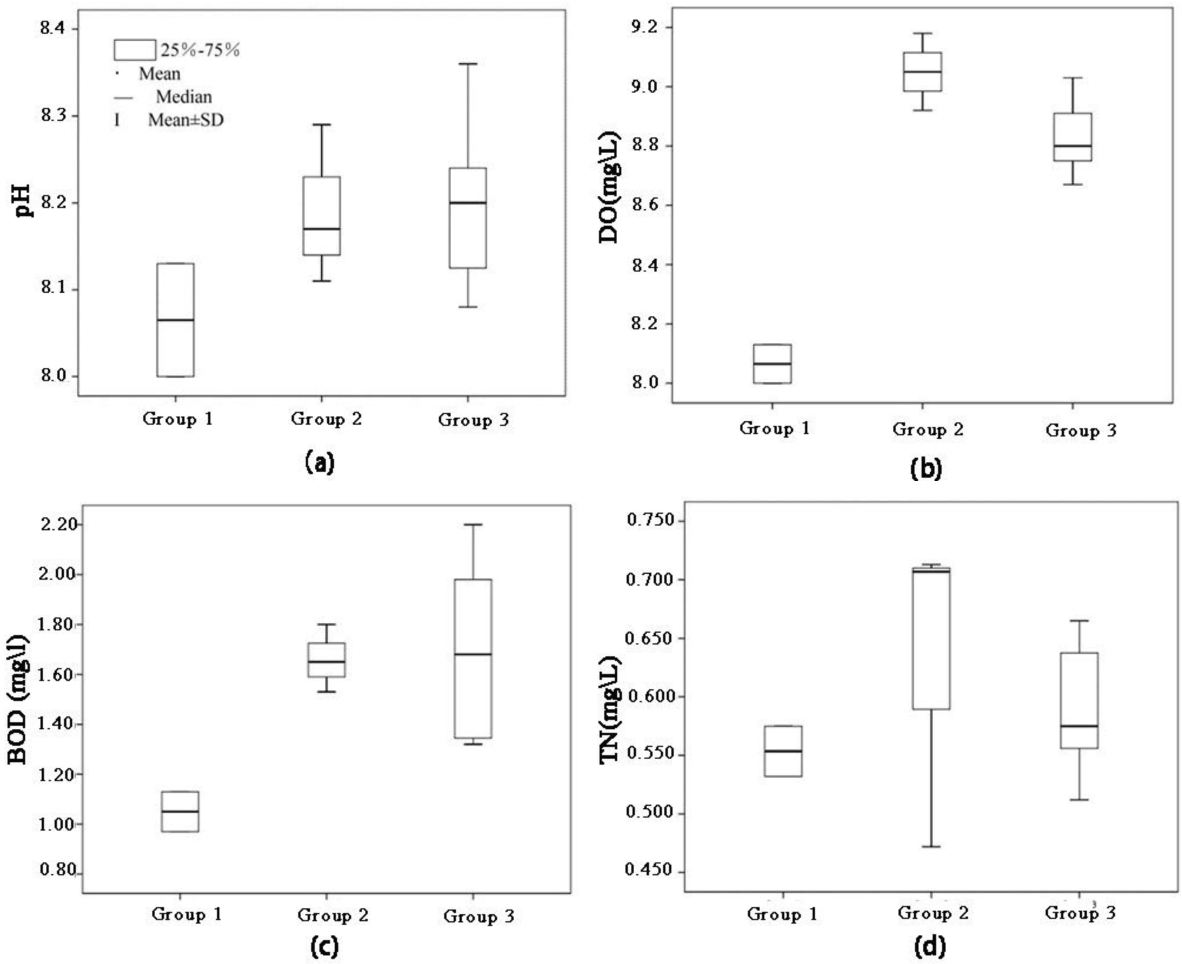

Fig. 3. Temporal variations in pH, DO, BOD_5, and TN.

Table 6
Temporal-varying DA

Group	Proper composition	Group		
		First group	Second group	Third group
First group	75.0%	9	1	4
Second group	72.2%	1	13	6
Third group	76.2%	2	4	32
Total	100%	12	18	42

photosynthetic pigment in plant photosynthesis and can be used as an indicator of eutrophication. The excessive organic matter in water will consume a large amount of oxygen and will also ferment and breed bacteria, thereby causing serious damage to the water quality [42]. This finding suggests that human activities negatively impact water quality.

4. Conclusion

- The key water quality parameters of Panzhihua section of the Yalong River include pH, BOD_5, DO, Chl-a, and TN, and imply that the main problem is the high water organic pollutant content. However, the pollution level is within the Class III standard, and the overall quality of the water body is acceptable.
- The temporal similarity analysis divided the monitoring months into three groups: May and June (the dry season); August, September, and October (the rainy season); and January, February, March, April, July, November, and December (the flat season). The rainy season is more polluted than the dry season, which signifies a significant time effect. Therefore, the discharge management of pollution sources during the rainy season should be improved and strengthened.

Table 7
Comparison of space monitoring using independent sample *t*-test

	Monitoring section	Average value	Range	Standard deviation	Standard error mean	*P*
pH	Yalong River Estuary	8.1	7.7—8.6	0.187	0.031	≥0.05
	Ertan	8.2	7.6—8.7	0.233	0.039	
DO	Yalong River Estuary	8.8758	7.7—9.8	0.47	0.08	≥0.05
	Ertan	8.6953	7.2—10.4	0.61	0.10	
BOD_5	Yalong River Estuary	1.8667	0.7—3.3	0.71	0.12	≤0.05
	Ertan	1.4319	0.05—2.8	0.642	0.107	
NH_3–N	Yalong River Estuary	0.05678	0.025—0.121	0.024	0.004	≥0.05
	Ertan	0.07614	0.025—0.256	0.053	0.009	
TN	Yalong River Estuary	0.6852	0.49—0.99	0.12	0.02	≤0.05
	Ertan	0.5394	0.02—0.89	0.20	0.03	
As	Yalong River Estuary	0.001525	0.0003—0.012	0.0021	0.0003	≥0.05
	Ertan	0.001231	0.0003—0.0049	0.0008	0.0001	
Ec	Yalong River Estuary	25.861	19.6—40.8	5.22	0.87	≥0.05
	Ertan	26.430	20.1—48.3	5.12	0.85	
Temperature	Yalong River Estuary	16.804	12.1—20.6	2.54	0.42	≥0.05
	Ertan	17.565	12.5—24.9	2.84	0.47	
Chl-a	Yalong River Estuary	0.0008513	0.00005—0.0018	0.0005	0.0001	≤0.05
	Ertan	0.0014136	0.0001—0.0047	0.0010	0.0002	
Q	Yalong River Estuary	1,383.153	518—2,620	574.35	95.73	≥0.05
	Ertan	1,451.903	410—4,293	760.57	126.76	

- The parameters with a significant difference include BOD_5, TN, and Chl-a using spatial comparison The comparative analysis shows that the Yalong Estuary are more affected by human activities than those of the Ertan. The discharge management for agricultural wastewater, domestic sewage, and industrial wastewater around the Yalong Estuary should be strengthened, and improve the collection and treatment technologies for livestock and agricultural sewages.

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