Surface water quality assessment using hybrid multivariate statistical analysis and geographic information system based on integrated water quality index model for Maozhou River Basin, Guangdong, China

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Abstract The river is a vital component of the water ecosystem in both urban and rural regions. However, its rapidly increasing pollutants are posing a severe threat for water ecosystem security. Using Multivariate statistical technique and Integrated water quality index model (IWQI) to evaluate surface water quality and its spatial distribution based on Geographic information system (GIS). This combinatorial model have been proved to be a feasible tool for evaluating surface water quality at large-scale basin. This study analyzed the spatio-temporal variations of surface water quality, which were determined monthly from samples collected in the Maozhou River Basin Guangdong Province, China from 2018 to 2020. The results demonstrated that the surface water quality status of in the Maozhou River Basin has been steadily improved during the study period. The surface water quality of 82.17% of monitoring site reached the water quality target of function zones (surface water quality of the class V standards), with the IWQI values ranging from 12.118 to 3.650. By the end of 2019, black-odorous water in Maozhou River basin has disappeared from our sight. By 2020, the water quality status of the Maozhou River Basin has been steadily maintained at "Medium and good" level, and the main background pollutants for the water quality target of function zones is NH_3-N. However, the some area in which the surface water quality still need to further improve is estuary and southwest tributary in the basin. This finding calls for further efforts to improve surface water quality and to properly deal with various sources of pollution

in the watershed. It is concluded that this combined surface water quality evaluation model is more efficient and reasonable for surface water quality evaluation at a larger scale. It can provide scientific foundation for the water ecosystem management and planning in efficiently managing and evaluating surface water quality at river or basin scales.

Keywords: Integrated water quality index (IWQI); Multivariate statistical techniques; Geographical Information System (GIS); Black-odorous water; Maozhou River Basin

Introduction

Adequate and high-quality water is one of vital strategic resource for sustainable development of human society and ecosystems (Vorosmarty et al., 2010). Increase in industrialization, the expansion of urbanization, and rapid economic development have created a series of serious pollution problems for surface water (Madan et al., 2020). The river being flowing blood of ecosystems of city is under enormous pressure to fulfill livable environment demands for developing economic society, especially in developing region including the Guangdong–Hong Kong–Macao Greater Bay Area(GBA). With the rapid economic development, the sustainable development of the Guangdong-Hong Kong-Macao Greater Bay Area is constrained by ecosystem environmental problems, and thus affect its goal to build a first-class international bay area (Weng et al., 2020; Cai et al., 2020).Few previous studies addressed the issue of ecosystem environmental development of the Guangdong-Hong Kong-Macao Bay Area, especially in surface water quality (Chen et al. 2020; Fang et al., 2018). Therefore, there is an urgent to formulate effective evaluation and management strategies for sustainable utilization and protection of surface water resources.

The surface water quality safety is one of the most important foundation to ensure economic growth and social development (Gao et al., 2020; Nong et al., 2020). However, Increase in urbanization, industrialization and agricultural activities brought a serious problem of the quality of both surface water and groundwater in many countries and regions (Adimalla et al., 2019; Zhang et al., 2020). Therefore, it is important to take effective management measures to prevent and control the deterioration of water quality (Peyman et al., 2017; Shi et al., 2016). Surface water quality assessment is a process including but not limited to both qualitative study and quantitative evaluation which includes classification of water quality and determination of pollution types (Lin et al., 2017; Wu et al., 2004; Edegbene et al., 2019).Among this, surface water quality evaluation based on field sampling and chemical experiment methods is essential to understand water quality and to control water pollution (Sany et al. 2019; Sun et al. 2016). In past few decades, the WQI and fuzzy comprehensive assessment method are widely used in water quality assessment (Benouara et al., 2016; Ramos et al., 2016; Wu et al. 2019) However, the previous studies addressed the issue that surface water quality are evaluated independently by these methods in the different spatio-temporal condition, but the spatio-temporal variations of surface water quality index are seldom considered. Numerous studies have focused on the applicability of water quality assessment methods and did not make a map for the spatial variation of water quality (e.g., Bolton et al., 1978; Babiker et al., 2007; Naveedullah et al., 2016; Nong et al., 2020). It may lead to unnecessary repeated calculation and evaluation for surface water quality in a large scale.

This paper comprehensively evaluate the surface water quality by Geographical Information System (GIS)-based multivariate statistical techniques (ANOVA, PCA and HCA) and the integrated water quality index model. In addition, the changes of hydrological conditions in space and time also need to be considered. Therefore, all parameters of surface water data has been analyzed by statistical package for social sciences. Meanwhile, the water quality evaluation results corresponding water quality sample points of each group has been obtained by using the IWQI method, and the spatial characteristics of surface water quality has been presented by GIS. This combine model realized the water quality evaluation for a large scale.

Site description

Study Area

Maozhou River Basin is located in the northwest of Shenzhen, Guangdong Province, China, which is 31.29 km length in main stream and covering 388 km^2 drainage area (Fig. 1). The Maozhou River flows gently and affected by high tides. There are 41 rivers in the basin, including 1 main stream, 23 first-grade tributaries, and 17 second-grade or third-grade tributaries. The annual average precipitation of Maozhou River basin is 1938.6 mm, which gradually decreases from west to east. Precipitation is mainly concentrated from April to

September, with about 80% of the annual precipitation. Moreover, this basis has subtropical oceanic monsoon climate with an annual average temperature of 22 °C (Zhou et al., 2010; Shi, et al., 2020). Industrial wastes and sewage from a large number of factories (i.e., papermaking factory) and residential areas distributed along the river are discharged into the river, which caused the deterioration of water ecosystem of Maozhou River (Liu et al., 2019; Zhang et al., 2020). Moreover, the estuary of the river is low-lying and the tidal crest is frequent. As a result, the river ecological is irreversibly destroyed and the water became black and smelly.

Figure 1 should be placed here

Sample measurement and data collection

The surface water samples of river channel monitoring sections in the Maozhou River Basin were collected weekly from 2018 to 2020. The monthly average water quality information was obtained from the weekly water quality data in this study area which based on the basic items of the Environmental Quality Standards for Surface Water (China, 2002a) and the standard of the Guidance on Sampling Techniques (China, 2009). Figure 1 shows the locations of surface water sampling points in the study area. There are 8 water quality parameters in total, including flow velocity (m/s), water depth (cm), dissolved oxygen (DO, mg/L), chemical oxygen demand (COD, mg/L), ammonia nitrogen (NH_3-N, mg/L), fluoride (F^-, mg/L), oxidation-reduction potentiometer (ORP, mv) and anionic surfactant (LAS, mg/L).During sampling collection, flow velocity, water depth, and DO were determined by a portable flow velocity meter (LS1206B), portable ultrasonic sounder (ZMSS-100), and YSI multi-parameter probes (556MPS). Other samples for the remaining parameters were collected in polyethylene bottles and stored in refrigerators. All samples were waterproofed on the bottle with detailed information to prevent misdiagnosis. Latitude and longitude coordinates were also noted for each sampling point using the global positioning system (GPS). All water samples were promptly transferred to the laboratory for further testing within 24 hours.

Methodology

Data processing

Detailed surface water quality data were analyzed by conducting analysis of variance ANOVA, principal components analysis (PCA) and hierarchical cluster analysis (HCA) for all parameters by Statistical Package for Social Sciences(SPSS)(Xu et al., 2019; Dassi et al., 2011; Liu et al., 2018; Zhang et al., 2014;Xu et al.2021). For ANOVA test, the controlling factors in this study is time or space, which belongs to one-way ANOVA. The influence of two independent factors towards surface water quality was evaluated by one-way analysis of variance (Varol, et al., 2019). Principal component analysis (PCA) is often used to extract a few potential common factors from numerous observable variables (Xu et al., 2019c; Zhang et al., 2020). These factors explain the information of the original variables to the greatest extent, thus explaining the essence of things (Howladar, et al., 2017). HCA is widely used in cluster grouping, and adopted to obtain comprehensive understanding on the water quality by discretization of sampling into different groups (Lambraski et al., 2004). In essence, the process of cluster analysis is calculating the distance between each hydrochemical characteristics of the surface water samples. The water quality is similar, the more likely it is to be in the same water quality clustering (Shyu et al., 2011; Chin et al., 2012). HCA makes surface water sample to maximize the similarity and minimize the difference between samples within a group (Varol et al. 2012).

Surface water quality index

The IWQI consists of an integer and three or four decimal places (Xu., 2005; Lin et al., 2017). The mechanism is calculated according to the following formula.

$$IWQI = X1.X2X3X4 \tag{1}$$

$$X1.X2 = \frac{1}{n}\sum_{i=1}^{n} Pi \tag{2}$$

Where $X1.X2$ is the integrated water quality index; Pi indicate the parameter value of single water quality index; n is the number of parameters. $X3$ is the number of single index that are inferior to the target of water environment functional area. If $X3$ =1, it means that one of the indexes participating in the comprehensive water quality assessment can’t reach the functional area target. $X4$ is the comparison result between the comprehensive water quality category and the functional area category. If $X4=1$, it indicates that the surface water quality is inferior to the water quality target of function zones.

The single water quality index was computed using the following methods. Only dissolved oxygen is a decreasing index by using the equation 3 (Eq. 3). The remaining incremental water quality indicators are calculated using the equation 4 (Eq. 4).

$$P_{DO} = K_{DO} + \frac{\rho_{DO,k+1} - \rho_{DO,i}}{\rho_{DO,k+1} - \rho_{DO,k}} \quad (3)$$

$$P_i = K_i + \frac{\rho_i - \rho_{i,k}}{\rho_{i,k+1} - \rho_{i,k}} \quad (4)$$

When the surface water quality parameter exceed thresholds of the class V standards (table2), incremental water quality index and dissolved oxygen index are calculated using equation 5 (Eq. 5) and equation 6 (Eq.6).

$$P_{DO} = 6 + \frac{\rho_{DO,k5} - \rho_{DO,i}}{\rho_{DO,k5}} \quad (5)$$

$$P_i = 6 + \frac{\rho_i - \rho_{i,5}}{\rho_{i,5}} \quad (6)$$

Where K_i represents the i th water quality category, according to environmental quality standards for surface water, and the value is 1, 2..., 6. ρ_i is the measured value of the i th water quality index. $\rho_{(i,\ k)}$ is the standard value of the K_i class water quality category.

According to the IWQI value (table2), the surface water quality status in this study is divided into seven grades, i.e., excellent (1-2), better (2-3), good (3-4), medium (4-5), qualified (5-6), inferior class V but not black stink (6-7) and inferior class V and black stink (More than 7). This classification meet China's actual surface water quality management standards.

Table 1 should be inserted here

GIS- IWQI models

The IQWI value of the Maozhou River basis were employed to draw the water quality map following the procedure proposed by Babiker et al (2007). The whole process can be carried out in three main steps viz., the date of surface water sample analysis, surface water quality evaluation and surface water quality mapping based on geographic information system.

Results and discussion

Surface water quality characteristics

It can be seen from Table 2, annual average water depth is greater than 32.49 cm, and the values gradually declined during monitoring period. The annual average flow rate value is more than 0.08 m/s, the maximum value was measured in 2018 and minimum value occurred in 2020. It shows that the hydrodynamic conditions gradually become more disadvantageous during the period of monitoring in the basin.

The annual average concentrations of DO for each year is higher than thresholds of the class V standards (2 mg/L). The lowest concentration of DO (0.39 mg/L) was observed in 2018, while the concentrations of DO at 98.6% sections in 2019 and all sections in 2020 is greater than 2 mg/L. The DO value in the channel had a significant increasing trend. The annual average concentrations of COD decreased from 2018 to 2020, while the highest value is 54.26 in 2018 and annual average concentrations of COD below than 40mg/L from 2019 to 2020. The COD can be used as a parameter for characterizing the pollution levels of water by organic matter, and the degree of organic pollution has been alleviated in the Maozhou River Basin.

The annual average concentration of NH_3-N in 2020 is 1.66 mg/L, which is relatively below than it in 2018 and 2019. The temporal distribution of the NH_3-N showed a decreasing trend with fluctuations from the 2018 to 2020. The maximum value of NH_3-N detected every year is higher than thresholds of the class V standards (2 mg/L), indicating that the parameter of NH_3-N could cause surface water quality turn to inferior class V at some section. The annual average and maximum concentration of TP decreased from 2018 to 2020, but the TP maximum and the average value is higher than thresholds of the class V standards (0.4 mg/L) from 2018 to 2019. The parameter of TP presented a high risk for causing the water quality turn to inferior class V. Both NH_3-N and TP can be used as parameters for characterizing the pollution levels of water by nutrients matter (Mao et al, 2019). It showed that the surface water environment is polluted by nutrients in study area.

The annual average concentration of F^- and LAS showed little variations, which range from 0.57 to1.2 mg/L and 0.13 to 0.65 mg/L. Due to the maximum concentration of LAS is higher than in the water thresholds of the class V standards (0.3 mg/L), the surface water quality and the survival of aquatic organisms may be at risk from organic pollutant. The annual average value of ORP increased year by year. It shows that the tendency of pollutants oxidized in water is increasing. The nitrogen, phosphorus and other nutrients in water are more likely to be oxidized into inorganic substances, reducing the risk of water eutrophication.

Table 2 should be inserted here

Correlation analysis of water quality index

The relationship between different water parameter is represented by Pearson's correlation (r). If the r values is greater than 0.7, the correlation is considered strong. While the weak correlation is represented by r value and it less than 0.3.When r values are between 0.3 and 0.7, the relationship is considered moderate. (Xu et al., 2019b; Zhang et al., 2020; Emenike et al., 2018). In the study area, the DO has a strong positive relationship with NH_3-N, TP and ORP. Similarly, COD also has a strong positive relationship with NH3-N, while NH3-N has a strong positive relationship with TP. It can be seen from (Fig. 2) that there is a moderate correlation between LAS and flow, DO, COD, NH_3-N, TP and ORP. Additionally, this is a moderate correlation of ORP between depth, COD, NH_3-N, TP and LAS. It shows that the concentrations of organic pollutants and nutrients in water and ORP present a moderate correlation. The hydrodynamic parameters showed moderate or weak correlation with the water quality chemical parameter, indicating that the hydrodynamic had influence on the surface water quality, but it was not the main reason.

Figure 2 should be placed here

Principal components analysis (PCA)

Principal component analysis (PCA) is a multivariate statistical method, which can identify the correlation between variables (Xiao et al., 2019). The interpretation of principal components (PC) was performed on the hydrochemical characteristics of the surface water samples using a scree plot (Fig. 3) and principal component loadings (Table 3). (Zhang et al., 2019). The factor with eigenvalue greater than 1 was selected as the PC (Xu et al., 2019c). PCA generates three components PC1, PC2 and PC3, each PC load can be used to explain the surface water quality characteristics (Xu et al., 2019b). The PC1 with the maximum variance (48.8%) dominated the hydrochemical characteristics of the surface water samples ,which affected by positive loadings of COD (0.915), NH_3-N (0.943), LAS (0.9), TP(0.843) and negative loading of DO (-0.792).The loading on PC1 can be regarded as organic and nutrient pollutant. The domestic sewage and rainfall runoff are the main pollution sources in study area (O'Sullivan AD., 2016). In particular, residents in the river basin discharge a large amount of domestic sewage to the river through municipal pipelines, and factories on both sides of the river dump industrial garbage and sewage into the river. PC2 accounted for 20.9% of the total variance and was dominated by F^- (0.746), indicating that water pollution in the basin was affected by Industrial wastewater (Liu et al., 2019). The contribution rate of PC3 variance was 13.4%. The absolute value of factor load greater than 0.7 in the rotational component matrix table were respectively COD, NH_3-N, TP, F^-, LAS and DO. Namely, these 6 variables are selected as the important indexes of surface water quality evaluation.

Figure 3 should be placed here

Table 3 should be inserted here

Analysis of variance (ANOVA)

The date of surface water Samples collected from Maozhou River trunk stream and branch stream were determined by one-way ANOVA (Table 4, 5). During the monitoring period, the surface water quality parameter of COD and F^- are no significant difference, but the parameter of DO, NH_3-N, TP and LAS are significant differences. Between different section, there are significant difference in DO, COD, NH_3-N, TP and F^-, only LAS is no significant difference. The surface water parameter are variations in the spatio-temporal scales, surface water samples can be grouped according to the differentiation between hydrochemical characteristics in this study.

Table 4 should be placed here

Table 5 should be placed here

Hierarchical cluster analysis (HCA)

The HCA is a method that can distinguish the various parameter data has been used in the hydrochemical research of the surface water. HCA clustered the water sample data with similar hydrochemical characteristics into the same group. A visual overview of the clustering process is presented as a dendrogram. Based on the, boreholes with similarities are mainly categorized into three distinguishable groups. According to the dendrogram, the similar water samples are mainly categorized into 8 groups by SPSS20.0 in this study (Table 6). The data features are represented by the average value of parameter in each group .On this basis, the average value of surface water quality after grouping is obtained (Table 7). The average value of parameter in each group evaluated by IWQI. The evaluation results of each group are assigned to their corresponding sample points according to Table 6.

Table 6 should be inserted here

Table 7 should be inserted here

The first group are constituted by the surface water sampling S9, S17 and S20 which situated in the upper and middle reaches from Maozhou River tributaries at the nonflood season in 2018. This group clusters the maximum concentrations of COD, NH_3-N, TP, F^- and LAS, and the minimum concentrations of DO, which reflects the most serious water pollution in the study area. Group 2 was located the water samples of S9, S11, S16, S17 and S18 which situated in middle reaches from Maozhou River tributaries in 2018. The average concentrations of COD, NH_3-N, TP and LAS in this group are relatively high, but the average concentrations of DO and LAS up to the thresholds of the class V Standards. The degree of water pollution rank only second to the first group. Third group clustering the maximum concentrations of F^- from Maozhou River tributary is most serious. The fourth group mainly clustered the water quality sampling from trunk S1, S7 and tributary S8, S14, S17, S23, S24 in 2018. The fifth group includes water samples from parts of trunk and tributaries in 2018-2020. Among them, the average concentrations of DO, COD and F^- are below the thresholds of the class V Standards, while the concentrations of NH_3-N, TP and LAS are above than the thresholds of the class V Standards. The sixth group clustered the minimum concentrations of NH_3-N, TP, F^- and LAS at different season in 2020, which are below than the thresholds of the class V Standards. The seventh group had the largest number of clustering samples, which involved water samples of different sections and periods. The eighth group clustered the water samples with the highest concentration of DO and the lowest concentration of COD from the study area.

Evaluation results of surface water quality Identification index

The water quality categories of 8 group samples distributed in the class III to Inferior V, including 1 group belongs to class III Standards (G6), 2 groups belong to the class IV Standards (G7 G8),1 group belongs to V class Standards (G5), 4 groups belong to the Inferior V class standards (G1, G2 and G3 and G4) (Table 8). The surface water quality of 82.17% of monitoring site reached the water quality target of function zones. The surface water quality of G6 is best, and the status of water quality is “good”, which collect from upstream of basis at the flood season in 2020. The surface water quality of G1 is worst, and the status of water quality is “Inferior class V and black stink”, which taken from the upper tributaries at nonflood season in 2018.For water quality samples of the same water quality grade, the IWQI method can compare their advantages and disadvantages (e.g. water quality of G7 and G8 are both class IV standard, but water quality G8 (IWQI=4.060) is better than G7 (IWQI=4.540)). In addition, IWQI method can determine water pollution levels within inferior V class standard.

Table 8 should be placed here

Analysis of spatial distribution of water quality

It is apparently that from (Fig. 4 (A)), the surface water quality of the upper and middle stream IS better than the estuary, the mainstream is better than the tributaries, and the southwest tributaries is the worst in 2018. The IWQI results of the all streams is inferior to the water quality target of function zones objectives, and the water quality reaches Inferior class V but not black stink. The estuary water pollution is more serious and water quality is inferior V and black stink. Due to the mainstream is fed by tributaries and groundwater and river have a recharge-discharge relation. The upper and middle reaches of main stream less polluted than the tributaries. In non-flood season, as the flow of the river decreases, the dilution and diffusion capacity of pollutants decrease, which leads to the decrease of water quality status. By comparing the surface water quality of flood season, non-flood season and annual average in 2018, the water quality in flood season is better than annual average and non-flood season. The key background pollutants for the water quality target of function zones are COD, NH_3-N, TP, DO and LAS. The external and internal pollution sources were major reasons to cause the deterioration of water quality, and the main pollution sources includes industrial sewage, domestic garbage, rainfall runoff and internal source. In addition, at the early stage of rainfall, a lot of non-point source pollution is brought into the river and leading to the increase of pollutant concentration, which indicated that non-point source pollution has become the main reason affecting river water quality (O'Sullivan AD., 2016).

As can be seen from (Fig. 4 (B)), the spatial distribution characteristics of water quality in 2019 are similar to those in 2018, water quality is still poor during non-flood season. However, the water quality has been significantly improved, and black-odorous water have been completely improved. With the water environment management project is nearing completion on the Maozhou River Basin (e.g. thorough-going reform, silt removal and water supply, etc.), the municipal sewage pipes on both sides of the river have been obsoleted, and the industrial and domestic sewage is collected and transported to the sewage treatment station through the newly-built municipal pipeline network. After being treated by the sewage treatment station, the tail water comply with discharge standard then supply for river flow. The key background pollutants for the water quality target of function zones are NH_3-N and TP. The main reason affecting river water quality is rainfall, which brought a lot of non-point source pollution into the river.

By 2020, the water environment quality of the river basin continued to improve from

(Fig. 4 (C)), and the water quality status has been steadily maintained at “Medium and good” level. The water quality status upstream of main stream and its tributaries has “good” at all year round. The water quality of northeast and southwest tributaries and estuary still need to further improve, indicating that the pollution phenomenon occurs in the main stream and the root is in the tributaries. The concentration of NH_3-N at nonflood season has a risk to approach the water quality target of function zones.

Figure 4 should be placed here

Conclusions

The spatio-temporal variation of surface water quality in Maozhou River Basin from 2018 to 2020 is analyzed in this paper. The surface water quality was evaluated by the multivariate statistical and the integrated water quality index according to the monthly average surface water quality data. The main conclusions are as follows:

The results demonstrated that the water quality status of in the Maozhou River Basin has been steadily improved during the monitor period. The surface water quality of 82.17% of monitoring site reached the water quality target of function zones (surface water quality of the Class V Standards), with the IWQI values ranging from 12.118 to 3.650. The key pollutants source of surface water ecosystem in study area are organic and nutrient pollution from industrial sewage, domestic garbage, rainfall runoff and internal source. By 2020, the main background pollutants for the water quality target of function zones is NH_3-N.

From the perspective of time, the water quality of the river improves year by year. By 2019, black-odorous water has disappeared from our sight. By 2020, the water quality of the river had basically reached the water quality target of function zones objectives and the water quality status has been steadily maintained at “Medium and good” level.

From the perspective of space, the water quality of tributaries is more serious than main streams, while the surface water quality in the southeast tributaries is the worst. The surface water quality in upstream of main stream is better than the estuary. Therefore, it is necessary to strengthen the water quality control of the tributaries, especially the southeast tributaries.

In the process of water quality evaluation, geographic information system (GIS) based on multivariate statistical technique and integrated water quality index model (IWQI) to evaluate surface water quality and draw spatial distribution map. This water quality model can judge surface water quality status and pollution level at same water quality rank. In addition, it can achieve the objective of quantitative evaluation of water quality inferior to Class V. This method is suitable for assessing surface water quality at a larger scale. It can provide scientific foundation for the water ecosystem management and planning in efficiently managing and evaluating surface water quality at river or basin scales. Meanwhile, this study presented useful water quality models and provided a reference for ecosystem projects of Guangdong-Hong Kong-Macao Greater Bay Area to more accurately evaluate water quality and to determine distribution of water pollution.

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Table 1 The IWQI range and status of surface water quality

IWQI	Rank	water quality status
$1 < X1.X2 \leq 2$	Class I	Excellent
$2 < X1.X2 \leq 3$	Class II	Better
$3 < X1.X2 \leq 4$	Class III	Good
$4 < X1.X2 \leq 5$	Class IV	Medium
$5 < X1.X2 \leq 6$	Class V	Qualified
$6 < X1.X2 \leq 7$	Inferior class V	Inferior class V but not black stink
$X1.X2 > 7$	Inferior class V	Inferior class V and black stink

Table 2 Comparison of the variations of the water quality parameters from 2018 to 2020

Parameters	Thresholds of the Class V Standards [a]	2018			2019			2020		
		Avg. ± S.D.	Min	Max	Avg. ± S.D.	Min	Max	Avg. ± S.D.	Min	Max
flow(m/s)	N/A	0.15±0.09	0.02	0.51	0.09±0.06	0	0.28	0.08±0.06	0	0.23
depth(cm)	N/A	65.62±63.11	8.42	300	35.51±13.09	6.71	57.67	32.49±14.7	6.36	84.45
DO(mg/l)	≥2 mg/L	2.74±1.75	0.39	7.12	4.21±0.99	1.74	5.92	5.08±0.73	3.23	9.27
COD(mg/l)	≤40 mg/L	54.26±39.61	17.99	205.4	31.25±10.46	18.81	73.12	25.18±2.18	21.56	37.11
NH_3-N(mg/l)	≤2 mg/L	13.78±10.88	0.99	45.8	5.63±4.07	0.57	18.94	1.66±0.84	0.57	4.79
TP(mg/l)	≤0.4 mg/L	2.11±3.48	0.16	29.04	0.76±0.57	0.12	3.15	0.27±0.26	0.07	2.13
F^-(mg/l)	≤1.5 mg/L	1.20±3.55	0.24	32.32	0.59±0.38	0.30	2.94	0.57±0.18	0.3	1.19
LAS(mg/l)	≤0.3 mg/L	0.65±0.53	0.08	2.31	0.26±0.17	0.10	1.04	0.13±0.05	0.09	0.37
ORP(mv)	N/A	245.10±47.92	117.93	335.42	286.40±18.54	218.92	328.92	300.89±14.27	252.34	326.59

a Standards from the Environmental Quality Standards for Surface Water (China, 2002a);Avg.: Average; S.D.: Standard deviation.

Table 3 The water quality rotation factor load matrix

Evaluation index	Principal components		
	1	2	3
flow	-0.369	0.07	-0.083
depth	0.087	-0.461	0.410
DO	-0.792	0.323	-0.176
COD	0.915	0.022	-0.151
NH_3-N	0.943	-0.05	0.215
TP	0.843	0.356	-0.075
F^-	0.123	0.746	0.452
LAS	0.9	-0.115	-0.134
ORP	-0.109	0.498	0.148

Table 4 ANOVA of spatial variation among section

Time	Significance					
	DO	COD	NH_3-N	TP	F^-	LAS
2018	0.002	0.574	0.002	0.081	0.153	0
2019	0.460	0.980	0.444	0.014	0.101	0.001
2020	0.396	0.476	0.002	0.212	0.002	0.021

Note: The significance level was 5%

Table 5 Anova of spatial variation among 2018-2020

Section	Significance					
	DO	COD	NH_3-N	TP	F^-	LAS
S1	0.988	0.160	0.182	0.517	0	0.623
S2	0.140	0.085	0.180	0	0.324	0.012
S3	0.055	0.462	0.257	0.128	0.132	0.032
S4	0.288	0.009	0.094	0.029	0	0.003
S5	0.206	0.005	0.140	0.005	0	0.012
S6	0.813	0.091	0.721	0.330	0.070	0.001
S7	0.468	0.325	0.077	0.039	0.008	0.001
S8	0.216	0	0.121	0.024	0.027	0.134
S9	0.934	0.568	0.735	0.718	0	0.349
S10	0.085	0.051	0.131	0.048	0.246	0.004
S11	0.115	0.008	0.171	0.153	0	0.005
S12	0.022	0.074	0.003	0.007	0.223	0
S13	0.125	0.022	0.001	0.003	0.013	0.023
S14	0.143	0.021	0.001	0.023	0.293	0.325
S15	0.275	0.003	0.004	0.003	0	0.124
S16	0.480	0.025	0.629	0.148	0	0.909
S17	0.174	0.002	0.007	0.002	0.552	0.014
S18	0.373	0.026	0.234	0.027	0.017	0.355
S19	0.523	0	0	0	0.017	0
S20	0.975	0.469	0.723	0.695	0.437	0.317
S21	0.298	0	0.013	0.025	0.736	0.001
S22	0.465	0.016	0.259	0.431	0.029	0.012
S23	0.984	0.278	0.452	0.001	0.015	0.012
S24	0.950	0.030	0.185	0.513	0.098	0.001

Note: The significance level was 5%

Table 6 The corresponding samples of 8 groups

No	Number	Water samples
G1	17	S9-18-1~9、S16-18-1、S17-18-2~5、S18-18-1、S20-18-1、S20-18-2
G2	40	S9-18-8、S9-18-10~12、S10-18-1、S11-18-1~4、S16-18-2~7、S17-18-7、S17-18-10、S18-18-1、S18-18-2、S18-18-8、S S22-18-1、S22-18-2、S22-18-4、S22-18-6、S22-18-8、S9-18-3、S9-19-1~3、S20-19-6、S20-19-7
G3	48	S8-19-4、S11-19-2、S11-19-3、S16-19-4、S20-19-1、S20-19-2、S20-19-9、S22-19-5、S22-19-6、S1-18-1、S1-18-7、S8- S16-18-8、S16-18-10、S16-18-11、S17-18-8、S17-18-9、S18-18-3~9、S18-19-1、S20-18-6、S20-18-8、S21-18-6、S21 S11-19-1、S14-19-2、S16-19-1、S16-19-2、S16-19-3、S16-19-5、S18-19-3、S20-19-3、S21-19-9、S24-19-1
G4	39	S1-18-2~4、S1-18-8、S1-18-9、S6-18-12、S7-18-1、S7-18-12、S8-18-1、S8-18-3~5、S14-18-1~4、S17-18-6、S17-18- S21-18-4、S21-18-8、S22-18-7、S23-18-1、S23-18-3、S23-18-4、S23-18-6、S23-18-11、S23-18-12、S24-18-1、S24-1
G5	97	S1-19-1、S1-19-3、S1-19-4、S1-19-6、S1-19-7、S4-19-3、S5-19-2、S6-19-1、S6-19-2、S7-19-2、S8-19-2、S8-19-3、 S18-19-2、S18-19-5、S18-19-6、S19-19-10、S20-19-4、S20-19-5、S20-19-8、S20-19-11、S20-19-12、S21-19-5、S21-19 S23-19-1、S22-19-8、S22-19-12、S23-19-2~8、S24-19-2
G6	107	S1-20-1、S1-20-7、S1-20-6、S1-20-10、S2-20-5、S2-20-2、S2-20-6、S2-20-10、S3-20-2、S3-20-4、S3-20-6、S3-20-1 S4-20-10、S5-20-1、S5-20-3~5、S5-20-10、S7-20-1、S7-20-3、S7-20-7、S7-20-11、S7-20-8、S8-20-1、S8-20-5~7、S8-20- S11-20-10、S12-20-1、S12-20-3、S12-20-5~7、S12-20-10、S13-20-1~3、S13-20-9、S14-20-7、S14-20-10、S14-20-8、S1 S17-20-1~3、S18-20-1、S18-20-2、S18-20-4、S19-20-1、S19-20-6、S19-20-7、S19-20-8、S19-20-9、S19-20-4、S20-2 S21-20-9、S21-20-10、S22-20-1、S22-20-6、S22-20-9、S22-20-3、S22-20-8、S23-20-7、S23-20-3、S23-20-9、S23-20 S1-20-8、S6-20-4、S7-20-9、S8-20-9
G7	81	S2-18-1~3、S2-18-5~11、S3-18-1~12、S4-18-2、S5-18-2、S8-18-10、S8-18-11、S10-18-9~11、S12-18-2、S12-18-4、S12-18- S14-18-5、S14-18-6、S14-18-10、S15-18-9、S19-18-2、S19-18-12、S21-18-9、S22-18-12、S1-19-2、S2-19-2、S2-19-8、 S12-19-3、S12-19-4、S13-19-3、S17-19-6~10、S18-19-9、S18-19-12、S19-19-2、S1-20-2、S2-20-11、S4-20-11、S8-2 S13-20-11、S14-20-1、S15-20-11、S16-20-11、S18-20-11、S19-20-1
G8	437	S1-18-10、S1-18-11、S1-18-12、S2-18-4、S2-18-8、S2-18-12、S3-18-10、S4-18-1、S4-18-3~12、S5-18-4~7、S5-18-9 S10-18-2~8、S10-18-12、S11-18-9、S12-18-1、S12-18-3、S12-18-5、S12-18-6、S12-18-8、S12-18-11、S12-18-12、S1 S14-18-8、S14-18-9、S14-18-11、S14-18-12、S15-18-1、S15-18-2、S15-18-6、S15-18-11、S15-18-12、S16-18-9、S1 S22-18-10、S23-18-10、S24-18-2、S24-18-3、S1-19-8~12、S2-19-1~6、S2-19-7、S2-19-9~12、S3-19-1、S3-19-4~12、S4-1 S7-19-1、S7-19-3~11、S8-19-5~11、S9-19-4、S9-19-7~12、S10-19-3~2、S11-19-4~12、S12-19-1、S12-19-2、S12-19- S16-19-8、S17-19-5、S17-19-9、S17-19-11、S17-19-12、S18-19-4、S18-19-7~11、S19-19-1、S19-19-3、S19-19-5~12、S20- S22-19-10、S22-19-11、S23-19-10、S23-19-11、S23-19-9、S23-19-12、S24-19-3~12、S1-20-3~5、S1-20-9、S1-20-11、S S4-20-3、S4-20-6、S4-20-8、S4-20-9、S5-20-2、S5-20-6、S5-20-7、S5-20-8、S5-20-9、S5-20-11、S6-20-3、S6-20-5、 S7-20-4、S7-20-5、S7-20-6、S8-20-2、S8-20-4、S8-20-8、S7-20-12、S8-20-12、S9-20-1、S9-20-3、S9-20-4、S9-20-5、S S11-20-1~4、S11-20-8、S11-20-9、S11-20-12、S12-20-12、S12-20-2、S12-20-4、S12-20-8、S12-20-9、S13-20-4、S13-20 S14-20-11、S15-20-1、S15-20-2、S15-20-6~10、S15-20-12、S16-20-12、S16-20-1、S16-20-2、S16-20-4、S16-20-7、S16-20- S18-20-3~5、S18-20-7、S18-20-8、S18-20-10、S19-20-2、S19-20-3、S19-20-5、S19-20-10、S19-20-12、S20-20-12、S20 S21-20-7、S21-20-11、S21-20-12、S22-20-2、S22-20-4、S22-20-7、S22-20-10~12、S23-20-12、S23-20-1、S23-20-2、S23 S24-20-11、S24-20-12

Table 7 The mean value of each water quality indicator of 8 groups Unit: mg/l

No	DO	COD	NH_3-N	TP	F^-	LAS
G1	1.02	169.95	38.69	5.63	0.83	1.76
G2	2.10	99.98	26.24	3.20	0.80	1.41
G3	2.42	64.85	16.08	2.00	0.97	0.84
G4	2.74	43.86	13.23	1.59	0.79	0.59
G5	3.01	36.47	8.24	1.32	0.84	0.36
G6	5.08	27.05	1.59	0.26	0.58	0.13
G7	4.51	24.08	2.87	0.49	0.63	0.17
G8	5.64	17.14	1.86	0.35	0.64	0.16

Table 8 The surface water quality assessment results of 8 groups Unit: mg/l

No	Individual water quality identification index						Integrated water quality index	Rank
	DO	COD	NH_3-N	TP	F^-	LAS		
G1	6.49	9.25	24.35	19.09	2.83	10.86	12.118	Inferior class V
G2	5.10	7.50	18.12	12.99	2.80	9.69	9.414	Inferior class V
G3	5.42	6.62	13.04	9.99	2.97	7.80	7.612	Inferior class V
G4	5.74	6.10	11.61	8.97	2.79	6.97	7.012	Inferior class V
G5	4.00	5.65	9.12	8.30	2.84	6.21	5.921	V
G6	3.08	4.70	5.17	3.62	2.58	2.63	3.650	III
G7	4.76	4.41	6.44	6.22	2.63	2.83	4.540	IV
G8	3.64	3.43	5.72	5.49	2.64	2.82	4.060	IV

Figures

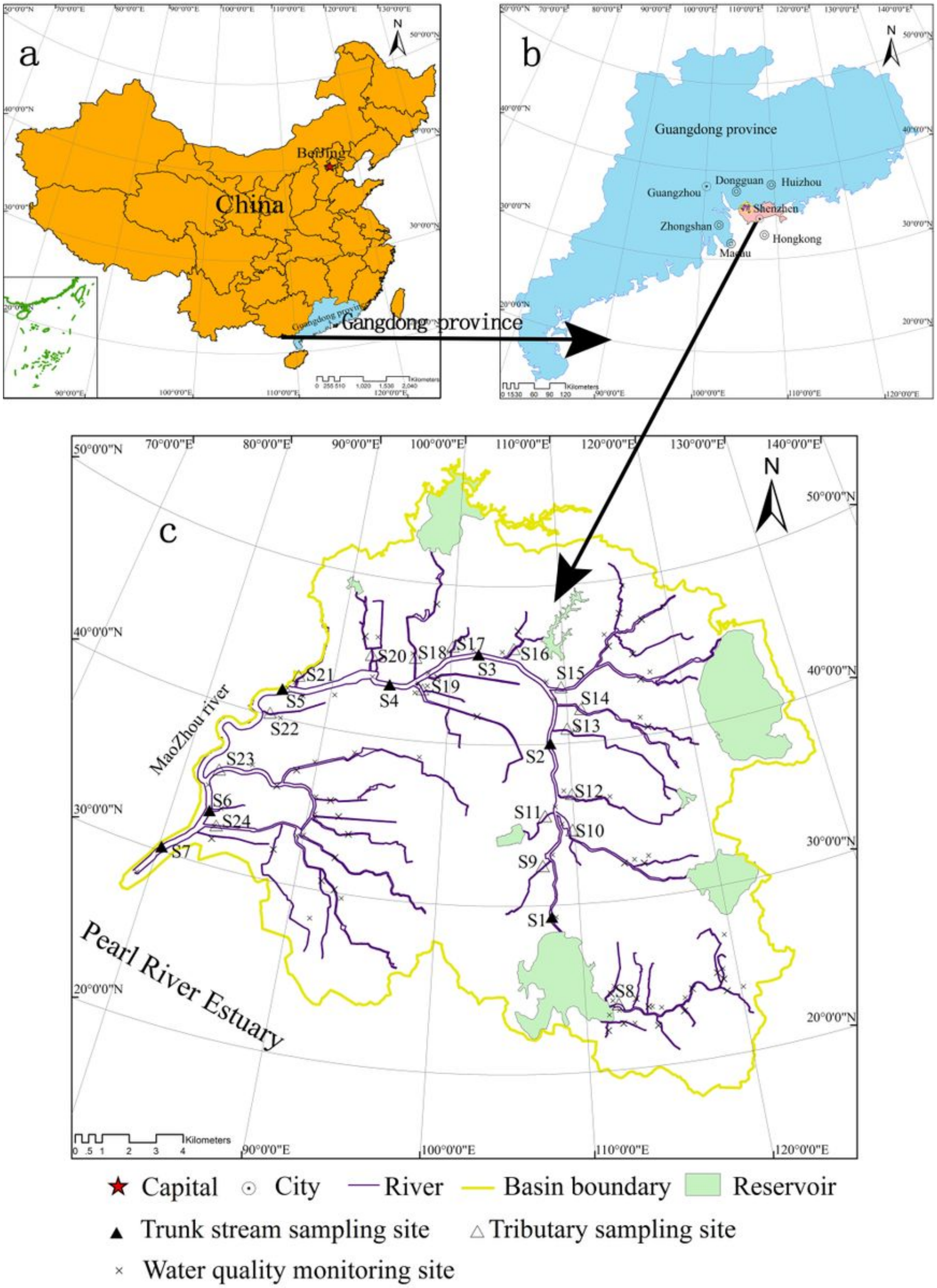

Figure 1

Location map of water samples in part of Maozhou River Basin, China. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

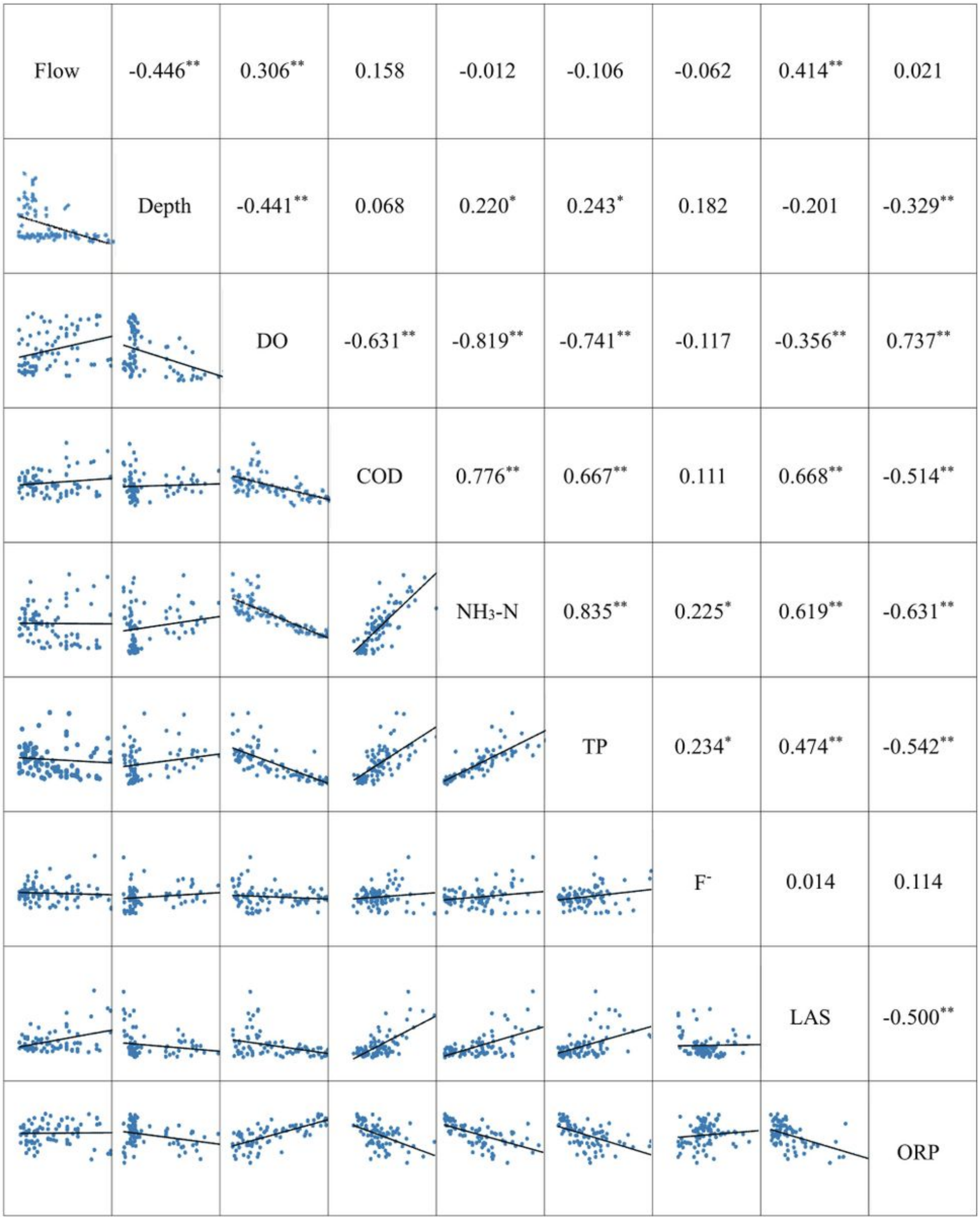

Figure 2

Relationships between different indices in this study region.

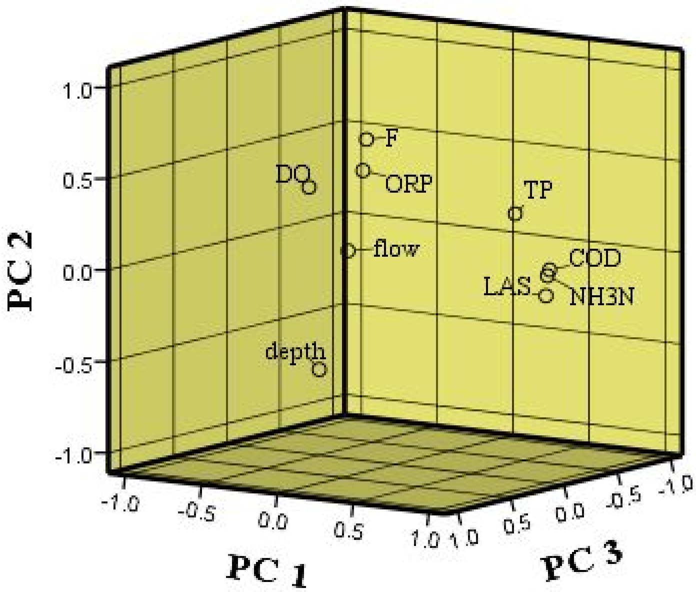

Figure 3

Scree plot from PCA loadings scores for dataset of water samples.

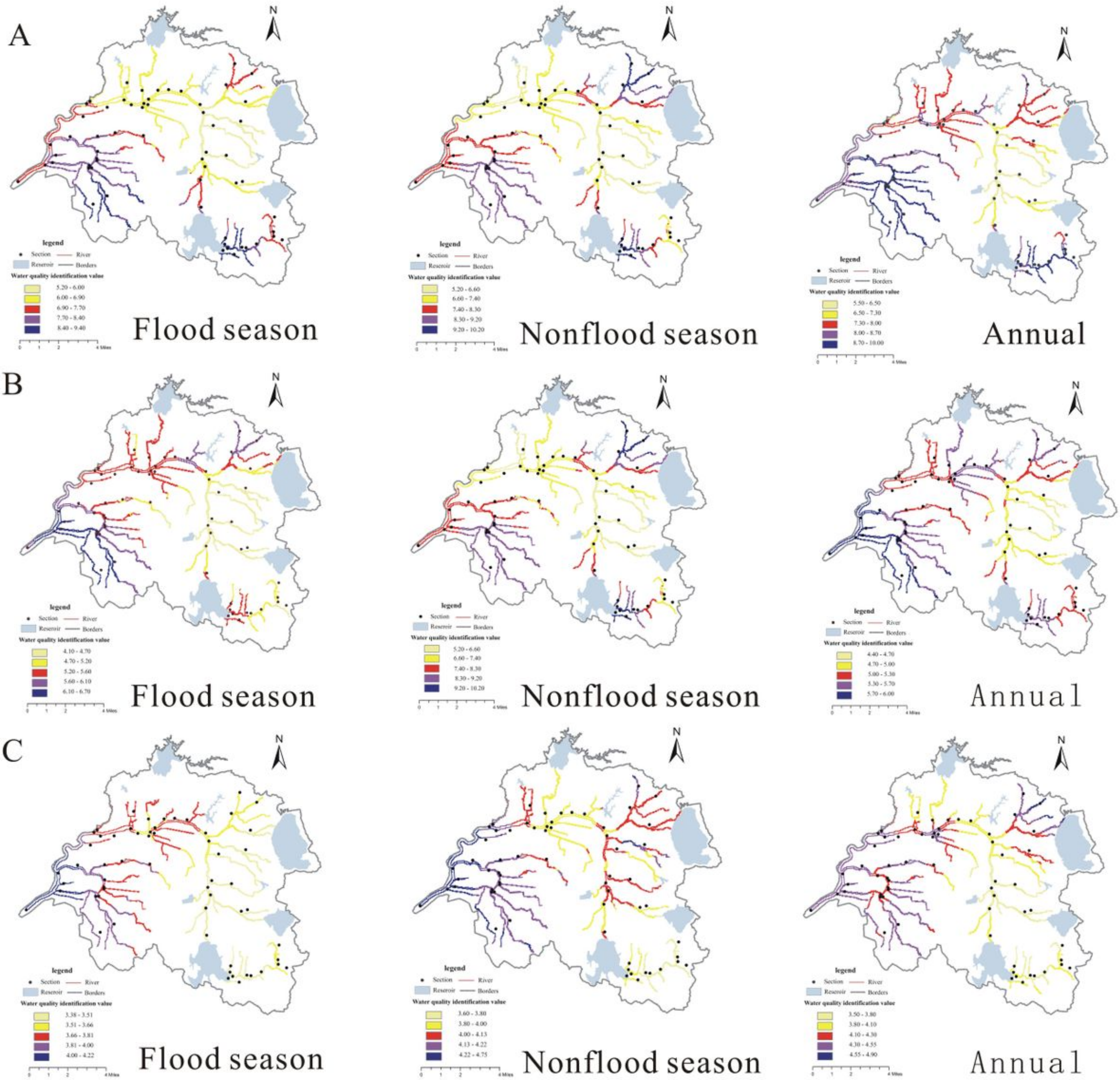

Figure 4

Surface water quality distribution map of Maozhou River Basin from 2018 to 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.