Water Supply

Water Supply Vol 22 No 1, 674 doi: 10.2166/ws.2021.240

Water quality assessment and pollution source analysis of Yaojiang River Basin: a case study of inland rivers in Yuyao City, China

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ABSTRACT

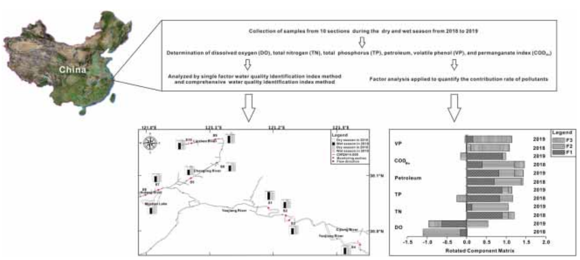
To fully understand the water quality status of the Yuyao section in the Yaojiang River Basin, we utilized the single factor and comprehensive water quality identification index methods, as well as factor analysis in this study. The single factor water quality assessment results showed that the common parameters exceeding the standard in both the wet and dry seasons included dissolved oxygen and total nitrogen, which were inferior to the target water quality grade III by 1–6 grades. The comprehensive water quality order reaching the target grade III was Hutang River (87.5%), Changling River (50.0%), Yaojiang River (43.8%), and Linzhou River (37.5%). The comprehensive water quality in the dry season (90.0% standard-achieving rate) was better than that in the wet season (25.0% standard-achieving rate). These results suggested that the surface runoff might considerably impact water quality. The factor analysis results showed that the basin surveyed in 2018 was mainly polluted by urban sewage and agricultural sources, while the primary pollution source in 2019 was agricultural pollution. Integrated with comprehensive water quality assessment results, in this study, we demonstrated that the series of water treatment projects carried out in Yuyao City positively impacted municipal sewage treatment.

Key words: factor analysis, pollution source, water quality identification index, Yaojiang River Basin

HIGHLIGHTS

- A method was applied to intuitively identify whether the water quality grade conforms to the functional area standard and the number of water quality parameters that fail to meet the standard.
- Surface runoff might significantly impact the water quality.
- Series of water treatment projects carried out in Yuyao City played a positive role in reducing the deterioration effect of urban sewage on the water quality.

GRAPHICAL ABSTRACT



INTRODUCTION

As an essential part of the ecological environment, the water environment plays a critical role in human life and economic development. Therefore, water environmental assessment techniques have been continuously improved to understand the quality of the water environment more systematically and comprehensively. At present, the most extensively used water quality assessment techniques include the single factor index (SFI) method (Lu *et al.* 2019), Nemerow pollution index (NPI) method (Chen *et al.* 2016; Chen *et al.* 2021), the single factor water quality identification index (SFWQII) method (Xu 2005a), the comprehensive water quality identification index (CWQII) method (Xu 2005b; Miao *et al.* 2009; Ban *et al.* 2014a, 2014b), component analysis method (Ouyang 2005), and fuzzy comprehensive evaluation method (Jiang *et al.* 2020; Li *et al.* 2020a, 2020b). Among them, the NPI method is often used in the assessment of heavy metals in water bodies, highlighting the impact of the heavy metals with the highest pollution index on the quality of the water environment. By using the SFI method, a direct understanding of the relationship between assessed water quality status and the standard can be achieved. Even better, the SFWQII method and the CWQII method proposed by Xu (2005a, 2005b) can quantitatively and accurately analyze the water quality, and the evaluation results obtained can intuitively reflect whether the water quality grade conforms to the functional area standard and the number of water quality parameters that fail to meet the standard. At present, these two methods have been widely used in water environment assessment in China (Miao *et al.* 2009; Liu *et al.* 2010; Ban *et al.* 2014a, 2014b; Pan *et al.* 2020). Moreover, factor analysis has become one of the most applicable multivariate statistical methods and has been widely used in the study of water quality pollutant sources (Ouyang 2005; Ikem *et al.* 2013; Shirnezhad *et al.* 2020; Zhang *et al.* 2021). The basic principle of this protocol includes reduction of variable dimensions, extraction of fewer uncorrelated comprehensive parameters from multiple original variables, objective determination of the weights of these factors, and identification of the primary sources of pollutants.

Yuyao City is located in the middle of the Ningshao Plain in the south wing of the Yangtze River Delta. The entire water area in Yuyao City covers 289.26 km^2 (including sea area), where the inland water surface is basically covered by the Yaojiang River system. Yaojiang River, originating from Xiajialing, Dalan Town, Yuyao City, is one of the largest tributaries in the Yongjiang River system. It exits through Yuyao City in the southeast and runs into the East China Sea through the Yongjiang River downstream. The crucial tributaries along the Yaojiang River include Hutang River, Changling River, Linzhou River, Gaoqiao River, Linsi River, Xijiang River, Zhongjiang River, Dongjiang River, and Cijiang River. The mainstream of the Yaojiang River is a straight and vast water body with an optimal self-purification capacity. However, a large number of upstream wastewater pollutants are discharged into the river due to the economic activities and incomplete sewage treatment facilities, leading to an increase in the exceeding-standard water quality factors, expansion of the eutrophic area, and significant deterioration of the overall water quality environment. In the water quality surveys of the 1990s, the dissolved oxygen (DO) in Yaojiang River ranged from 0.42 to 7.46 mg/L, reflecting a generally low level of DO (Shen 2000). In contrast, the permanganate index (COD_{Mn}) values were at high levels (up to 59.6 mg/L) (Shen 2000; Wang 2001). In 1999, the average content of total nitrogen (TN) and total phosphorus (TP) was 2.45 mg/L and 0.2 mg/L, respectively, indicating eutrophication existed in Yaojiang River (Wang 2001). Besides, petroleum was another exceeding index, and the content in upstream of Yaojiang was higher than that in the downstream (Wang 2001). Although annual regular monitoring and studies of the water quality of Yaojiang River have been carried out, analyses mainly focused on the evaluation of the single monitoring index. Since water quality is affected by various factors, it is therefore necessary to conduct a comprehensive assessment of the degree of pollution of the Yaojiang River Basin. In this work, the SFWQII method and CWQII method were employed to assess the water quality of the Yaojiang River, as well as its upstream tributaries Changling River, Hutang River, and Linzhou River, in the wet and dry seasons from 2018 to 2019. Moreover, the factor analysis method was applied to analyze the pollution sources. To a certain extent, the conclusions of this study provide a reference to the assessment of water quality monitoring data and have a guiding significance for the proposal of watershed water pollution prevention and management policy.

MATERIALS AND METHODS

Sampling section layout and sampling time

A total of 10 sampling sections was laid out in Yuyao City, including S1 Xiachendu Village, S2 Pukou Village, S3 Wantou Village, S4 Xinzheng Village in Yaojiang River, S5 Nanwei Village and S6 Dongjia Village in Changling River, S7 Fangjia Village and S8 Wufu Village in Hutang River, S9 Xinxin Village and S10 Xinqiao Village in Linzhou River (Figure 1).

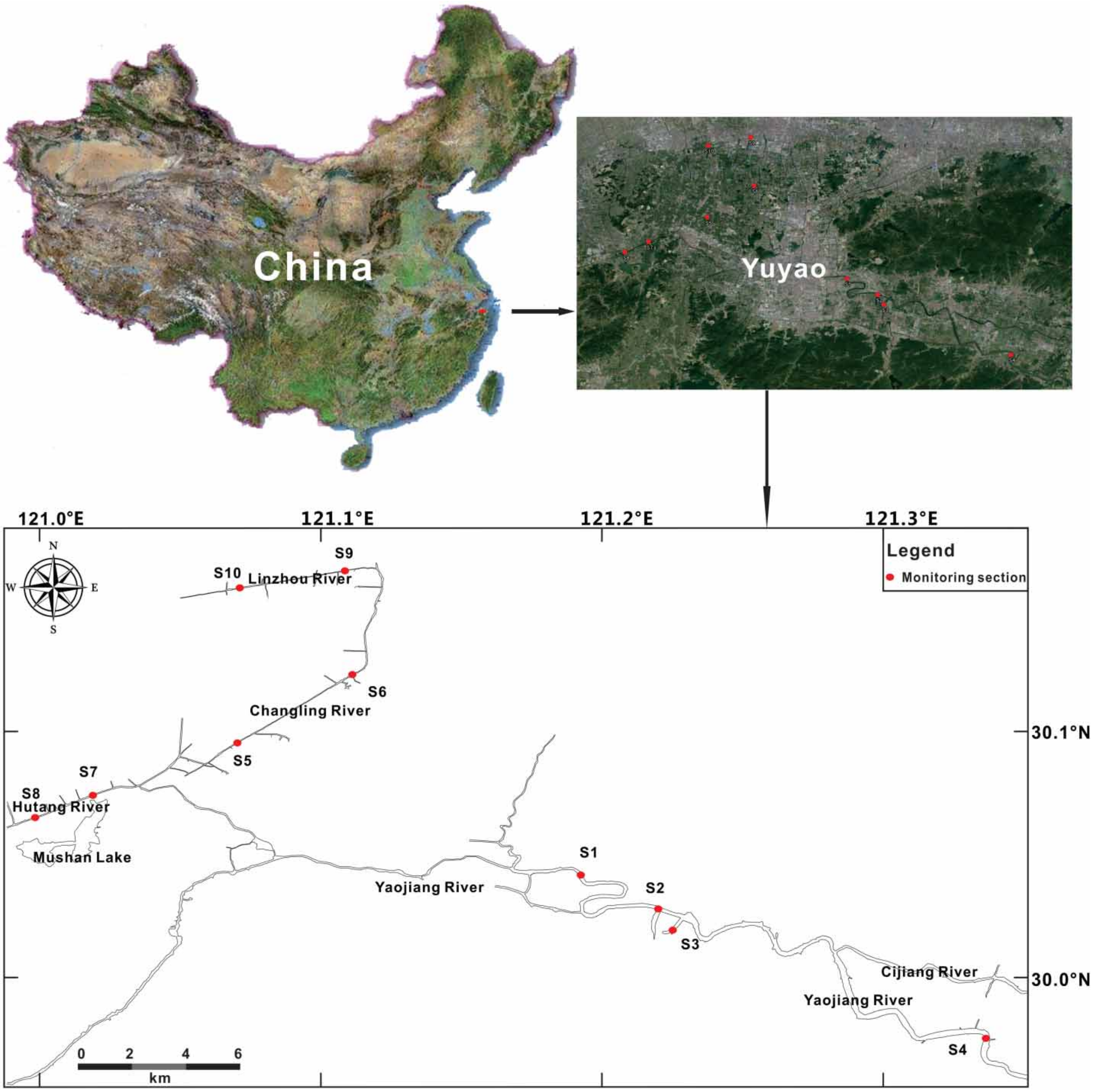


Figure 1 | Schematic diagram of the monitoring sections in the main inland rivers of Yuyao City.

Samples were collected during the wet season of 2018, the dry season of 2018, the dry season of 2019, and the dry season of 2019 according to the water storage capacity of the basin.

Sample collection

Water samples were collected in 1,000 mL glass bottles. Before sampling, the bottles were rinsed with raw water repeatedly. Sulfuric acid was added to the TN and TP samples to acidify the solution to $pH < 2$, and then the samples were sealed and stored at 0–4 °C.

According to the primary indexes of 'Environmental Quality Standards for Surface Water (GB 3838–2002)' and the existing monitoring results (Shen 2000; Wang 2001; unpublished data), six indexes including DO, COD_{Mn}, TN, TP, petroleum and volatile phenol (VP), were measured. Among them, DO was measured *in situ* by a portable dissolved oxygen analyzer (9010, JENCO, USA), while TN, TP, petroleum, COD_{Mn}, and VP were analyzed by using the methods proposed in

'Environmental Quality Standards for Surface Water (GB 3838–2002)'. Briefly, TN and TP were measured by alkaline potassium persulfate digestion UV spectrophotometric method and ammonium molybdate spectrophotometric method, respectively. COD_{Mn} determination was achieved by the titration method. Infrared spectrophotometry was applied for petroleum measurement, while flow injection analysis and 4-aminoantipyrine spectrophotometric method were utilized for VP measurement.

Data analysis and assessment methods

Single-factor water quality identification index

The *SFWQII* is composed of 1 integer and 2 or 3 significant digits after the decimal point (Xu 2005a), which is expressed as:

$$SFWQII = X_1.X_2X_3 \quad (1)$$

wherein, $X1$ represents the water quality grade of each water quality index (Table 1); $X2$ represents the location of the monitoring data in the $X1$ water quality change interval, which is calculated and determined according to the formula based on the principle of rounding; $X3$ represents the comparison result of water quality grade with the functional zone setting category, which has one or two significant figures depending on the pollution degree of the evaluation index. According to the 'Ningbo City Water Function and Water Environmental Function Oriented Zoning (Main Rivers and Reservoirs)', the Grade III standard in 'Environmental Quality Standards for Surface Water (Table 1)' is implemented to assess the studied water area.

Comprehensive water quality identification index

The *CWQII* is composed of a *SFWQII* (Xu 2005b), expressed as:

$$CWQII = X_1.X_2X_3X_4 \quad (2)$$

wherein, $X1.X2$ is the average value of all the measured *SFWQII*, which is expressed by formula (3). $X3$ is the number of evaluated single factor indexes that is inferior to the standard of the water environment function zone. $X4$ is the comparison result between the comprehensive water quality grade and the water functional zone category, which has one or two significant digits depending on the pollution degree of comprehensive water quality.

$$X_1.X_2 = \frac{1}{m}\sum_{i=1}^{m} Pi \quad (3)$$

wherein, m and Pi represent the number of participating water quality assessment indexes and the *SFWQII* of each water quality assessment index, respectively. The criteria for the determination of comprehensive water quality grade are presented in Table 2 (Xu 2005b; Ban *et al.* 2014a).

Factor analysis

Factor analysis of water quality data of 2018 and 2019 was performed by using SPSS software (v16.0) (Jung *et al.* 2016; Kale *et al.* 2020). Briefly, descriptive statistics were produced to note the missing/abnormal values. The correlation matrix test was

Table 1 | Standard value of water quality parameters for surface water in China according to environmental quality standards for surface water (GB 3838–2002) (mg/L)

Parameter	Grade I	Grade II	Grade III	Grade IV	Grade V
DO	7.5	6	5	3	2
COD_{Mn}	2	4	6	10	15
TN	0.2	0.5	1.0	1.5	2.0
TP	0.02	0.1	0.2	0.3	0.4
petroleum	0.05	0.05	0.05	0.5	1.0
VP	0.002	0.002	0.005	0.01	0.1

Table 2 | Determination of comprehensive water quality grade based on the average value of all the measured *SFWQII*

Criteria	Comprehensive water quality grade
$1 < X_1.X_2 \leq 2$	Grade I
$2 < X_1.X_2 \leq 3$	Grade II
$3 < X_1.X_2 \leq 4$	Grade III
$4 < X_1.X_2 \leq 5$	Grade IV
$5 < X_1.X_2 \leq 6$	Grade V
$6 < X_1.X_2 \leq 7$	Inferior Grade V, no malodorous black
$X_1.X_2 > 7$	Inferior Grade V, malodorous black

adopted for the applicability test using Kaiser-Meye-Olkin (KMO) and Bartlett sphere methods. KMO detection of greater than 0.5 and Bartlett sphericity test probability of $p < 0.05$ indicate that the data are appropriate for factor analysis (Kaiser 1974). Varimax rotation (maximum variance orthogonal rotation method) was used to rotate the factor loading, select representative factors, and clarify the pollution source information of each primary component. Selection of the component number was referred to Cattel Scree criteria (1966). As cumulative variance contribution rate is more than 80%, the original data set can be replaced approximately (Chen *et al.* 2013; Li *et al.* 2020a, 2020b). Comrey and Lee (1992) elaborated that loadings in excess of 0.71 (50% overlapping variance) were considered excellent.

RESULTS AND DISCUSSION

Assessment of *SFWQII*

The assessment results of the *SFWQII* value reflected the level of each assessment factor in Yaojiang River, Changling River, Hutang River, and Linzhou River during the wet and dry seasons in 2018–2019 (Figure 2, Table 3). In Yaojiang River, the overall levels of TP and VP were optimal, with a slightly exceeded level of COD_{Mn} and petroleum, and significantly exceeded levels of DO and TN (Figure 2). In Changling River, the overall level of TP was also optimal, with slightly exceeded levels of COD_{Mn} and VP, and significantly exceeded levels of DO, petroleum, and TN (Figure 2). The overall levels of TP, petroleum, and VP in Hutang River were optimal, whereas the levels of DO and TN were significantly exceeded the standards (Figure 2). The assessment result of VP in Linzhou River was optimal while the levels of COD_{Mn}, DO, TP, TN, and petroleum severely exceeded the standards (Figure 2). All these results indicated that eutrophication pollution existed in Yuyao main inland rivers. In Yaojiang River, Changling River and Hutang River, nitrogen was the primary contributor to eutrophication pollution, while in Linzhou River both nitrogen and phosphorus were the main contributors.

During the monitoring period, the mean *SFWQII* value of TN of each inland river was the highest, indicating that the TN pollution was the most severe. The *SFWQII* values of TN of Yaojiang River, Changling River, Hutang River, and Linzhou River were in the ranges of 4.02–7.84, 4.02–6.83, 4.21–7.14 and 4.71–7.84, respectively, showing significant variation at each section (Table 3). The TN assessments of the upstream (section S1) were mostly significantly worse than that of the downstream (section S2-S4) in Yaojiang River. The TN assessments of the upstream (section S5) were slightly inferior to that of the downstream of Changling River (section S6), while the situation in Linzhou River was opposite. In Hutang River, the TN assessments of upstream (section S8) and downstream (section S7) were very close. Overall, the assessment results of TN index of each inland river in both the wet and dry seasons of 2018 were significantly better than those in 2019. As one of the important nutrient elements, the TP assessment results of each inland river were much better than those of TN. Except for Linzhou River, other rivers could meet the target water quality (Grade III). The *SFWQII* values of TP of Linzhou River, ranging from 3.20 to 6.23, were significantly higher than those of other rivers. When comparing the TP assessment between upstream and downstream of Yaojiang River and Linzhou River, the results were the same as that of the TN assessments. However, the opposite results were observed in Changling River. The average value of the TP index in the dry season was better than that in the wet season. The *SFWQII* value of another over-standard index, DO, varied considerably at different monitoring periods. The DO index of the inland rivers in 2019 exhibited the highest value in the wet season, and each river section was inferior to the target water quality level by two grades or more. In contrast,

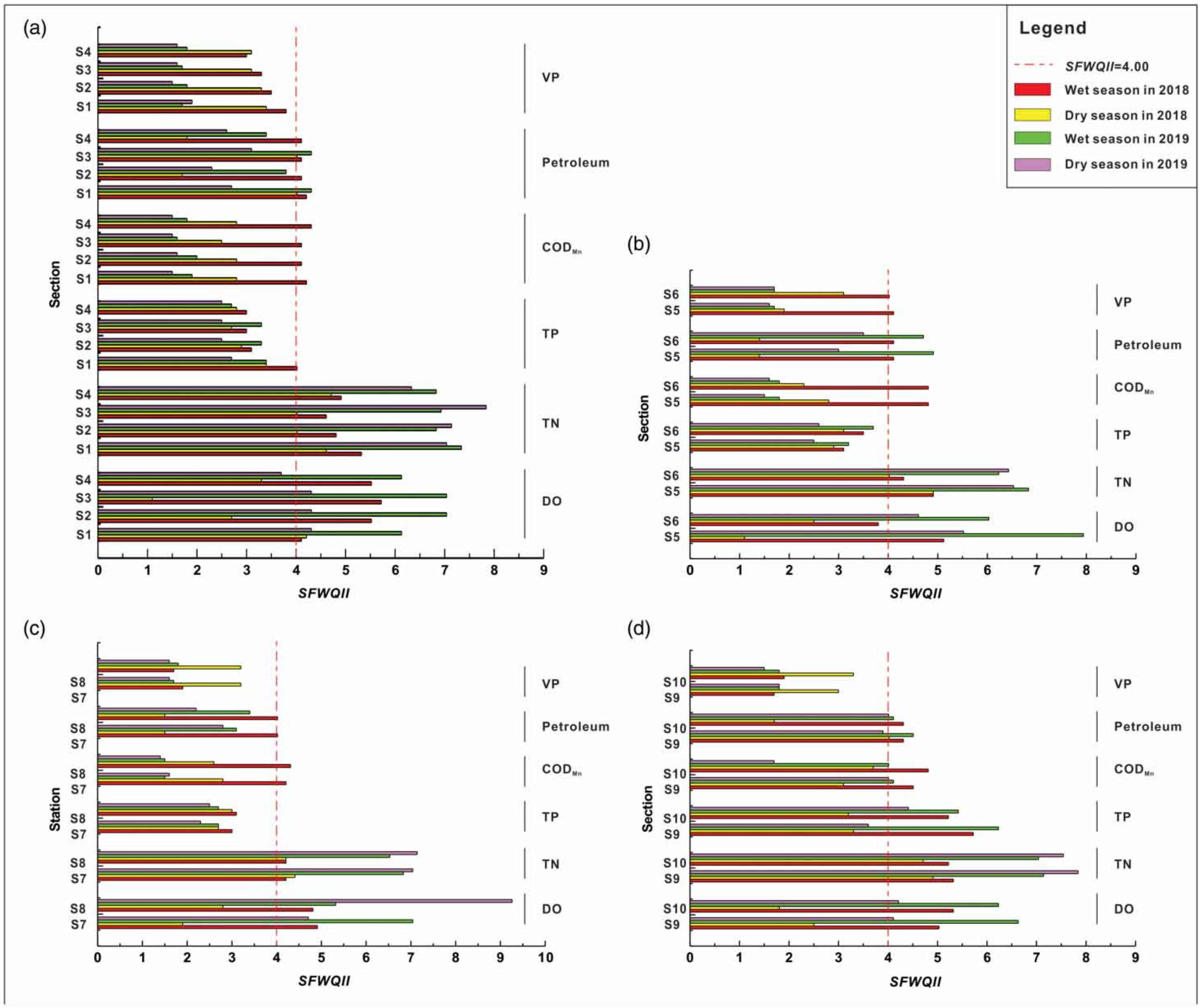


Figure 2 | Changes of *SFWQII* value of Yaojiang River (a), Changling River (b), Hutang River (c), and Linzhou River (d) from 2018 to 2019.

the DO index of inland rivers possessed the lowest value in the dry season of 2018, which met the target water quality. Compared with the surveys in 1990s, the levels of TN and DO were stable, but the average content of TP was reduced by one fold (Shen 2000; Wang 2001).

Although the *SFWQII* value of COD_{Mn} and petroleum varied significantly with monitoring periods, their assessment results were generally optimal. Both the COD_{Mn} and petroleum index of each river in the wet season of 2018 were worse than the target water quality level by one grade (Table 3). The assessment result of COD_{Mn} in the dry season of 2018 was the best, all of which met the target water quality. The assessment of petroleum in the dry season of 2019 was best, among which 90% of monitored sections met the target water quality. During the survey in 2019, all rivers were in line with the target water quality except the COD_{Mn} of Linzhou River, which was one grade lower than the target water quality. In the dry season of 2018, all others met the target water quality, except the ratio of petroleum index in Yaojiang River and Linzhou River are inferior to the target water quality was 50.0%. During the wet season of 2019, except for the Hutang River, of which all the sections met the target water quality, the ratios of petroleum indexes of Yaojiang River, Changling River and Linzhou River inferior to the target water quality were 50.0%, 100.0%, and 100.0%, respectively. The VP assessment of the *SFWQII* value was the best among all the determined indexes. Except that the Changling River was inferior to the target water quality by one grade during the wet season of 2018, all others met the target water quality. Comparison of DO, COD, petroleum and VP assessments of upstream with downstream of inland rivers showed inconsistent results among different monitoring periods.

Table 3 | *SFWQII* values of DO, TN, TP, COD_{Mn}, petroleum, and VP, and *CWQII* values of ten monitoring sections located in the main inland rivers of Yuyao City in different seasons of 2018 and 2019

		SFWQII						
Time	**Monitoring section**	**DO**	**TN**	**TP**	**COD_{Mn}**	**Petroleum**	**VP**	***CWQII***
2018 wet season	S1	4.11	5.32	4.02	4.21	4.21	3.80	4.351
	S2	5.52	4.81	3.10	4.11	4.11	3.50	4.241
	S3	5.72	4.61	3.00	4.11	4.11	3.30	4.141
	S4	5.52	4.91	3.00	4.31	4.11	3.00	4.141
	S5	5.12	4.91	3.10	4.81	4.11	4.11	4.451
	S6	3.80	4.31	3.50	4.81	4.11	4.02	4.141
	S7	4.91	4.21	3.00	4.21	4.02	1.90	3.740
	S8	4.81	4.21	3.10	4.31	4.02	1.70	3.740
	S9	5.03	5.32	5.72	4.51	4.31	1.70	4.451
	S10	5.32	5.22	5.22	4.81	4.31	1.90	4.531
2018 Dry season	S1	4.21	4.61	3.40	2.80	4.02	3.40	3.730
	S2	2.70	4.02	2.90	2.80	1.70	3.30	2.910
	S3	1.10	4.02	2.70	2.50	4.02	3.10	2.920
	S4	3.30	4.71	2.80	2.80	1.80	3.10	3.110
	S5	1.10	4.91	2.90	2.80	1.40	1.90	2.510
	S6	2.50	4.02	3.10	2.30	1.40	3.10	2.710
	S7	1.90	4.41	2.70	2.80	1.50	3.20	2.810
	S8	2.80	4.21	3.00	2.60	1.50	3.20	2.910
	S9	2.50	4.91	3.30	3.10	4.02	3.00	3.520
	S10	1.80	4.71	3.20	3.70	1.70	3.30	3.110
2019 Wet season	S1	6.13	7.34	3.40	1.90	4.31	1.70	4.131
	S2	7.04	6.83	3.30	2.00	3.80	1.80	4.121
	S3	7.04	6.93	3.30	1.60	4.31	1.70	4.131
	S4	6.13	6.83	2.70	1.80	3.40	1.80	3.820
	S5	7.94	6.83	3.20	1.80	4.91	1.70	4.431
	S6	6.03	6.23	3.70	1.80	4.71	1.70	4.031
	S7	7.04	6.83	2.70	1.50	3.10	1.70	3.820
	S8	5.32	6.53	2.70	1.50	3.40	1.80	3.520
	S9	6.63	7.14	6.23	4.11	4.51	1.80	5.152
	S10	6.23	7.04	5.42	4.01	4.11	1.80	4.851
2019 Dry season	S1	4.31	7.04	2.70	1.50	2.70	1.90	3.420
	S2	4.31	7.14	2.50	1.60	2.30	1.50	3.220
	S3	4.31	7.84	2.50	1.50	3.10	1.60	3.520
	S4	3.70	6.33	2.50	1.50	2.60	1.60	3.010
	S5	5.52	6.53	2.50	1.50	3.00	1.60	3.420
	S6	4.61	6.43	2.60	1.60	3.50	1.70	3.420
	S7	4.71	7.04	2.30	1.60	2.80	1.60	3.320
	S8	9.26	7.14	2.50	1.40	2.20	1.60	4.021
	S9	4.11	7.84	3.60	4.01	3.90	1.80	4.231
	S10	4.21	7.54	4.41	1.70	4.01	1.50	3.940

Assessment of *CWQII*

The *CWQII* assessment of the main inland rivers in Yuyao City was conducted (Table 3). According to the classification standard of *CWQII* value, the water quality of the Yaojiang River was in grade III to IV. The water quality of Changling River and Hutang River was in Class II to IV, and the water quality of Linzhou River was in Class III to V (Table 4). According to the ratio of the water quality level that reached the target grade III, the water quality of Hutang River was the best while that of the Linzhou River was the worst.

From the perspective of the sampling section, the overall comprehensive water quality of the upstream of Yaojiang River (section S1) was inferior to that of the downstream (sections S2-S4). The comprehensive water quality of Xiachendu Village in Yaojiang River section S1 in 2018 was significantly inferior to its downstream (sections S2-S4). In contrast, there was no

Table 4 | Classification of comprehensive water quality of the main inland rivers of Yuyao City in different seasons of 2018 and 2019 based on the *CWQII* values

River	Monitoring section	2018		2019	
		Wet season	Dry season	Wet season	Dry season
Yaojiang River	S1	IV	III	IV	III
	S2	IV	II	IV	III
	S3	IV	II	IV	III
	S4	IV	III	III	III
Changling River	S5	IV	II	IV	III
	S6	IV	II	IV	III
Hutang River	S7	III	II	III	III
	S8	III	II	III	IV
Linzhou River	S9	IV	III	V	IV
	S10	IV	III	IV	III

significant difference among different sampling sections of Yaojiang River in 2019 (Figure 3). Yaojiang River section S1 and section S4 are mainly urban residential areas surrounded by farmland. Their pollutants are majorly attributed to urban domestic sewage, followed by agricultural wastewater. In 2018, the second batch of 'Zero Sewage Direct Drainage Area' was launched in Yuyao City, including Lizhou Street located in S1 section and Hemudu Town located in S4 section, to achieve the full collection of sewage and complete coverage of the pipe network in the jurisdiction area. The comprehensive water quality assessment of these two sections during the wet and dry seasons of 2019 was significantly better than those of 2018, showing 'Zero Sewage Direct Drainage Area' infrastructure implemented by Yuyao government significantly improved the surface water quality (Ma *et al.* 2020). Section S2 around Pukou Village was mainly farmland, indicating that the pollution of this river section is primarily attributed to farming wastewater. In contrast, section S3 of Wantou Village is surrounded by aquaculture ponds, indicating that the pollution source of the section is primarily aquaculture wastewater. The comprehensive water quality of the Changling River downstream (section S6) during the wet season was better than that of the upstream (section S5), but the upstream water quality during the dry season was better or similar to the downstream water quality. In

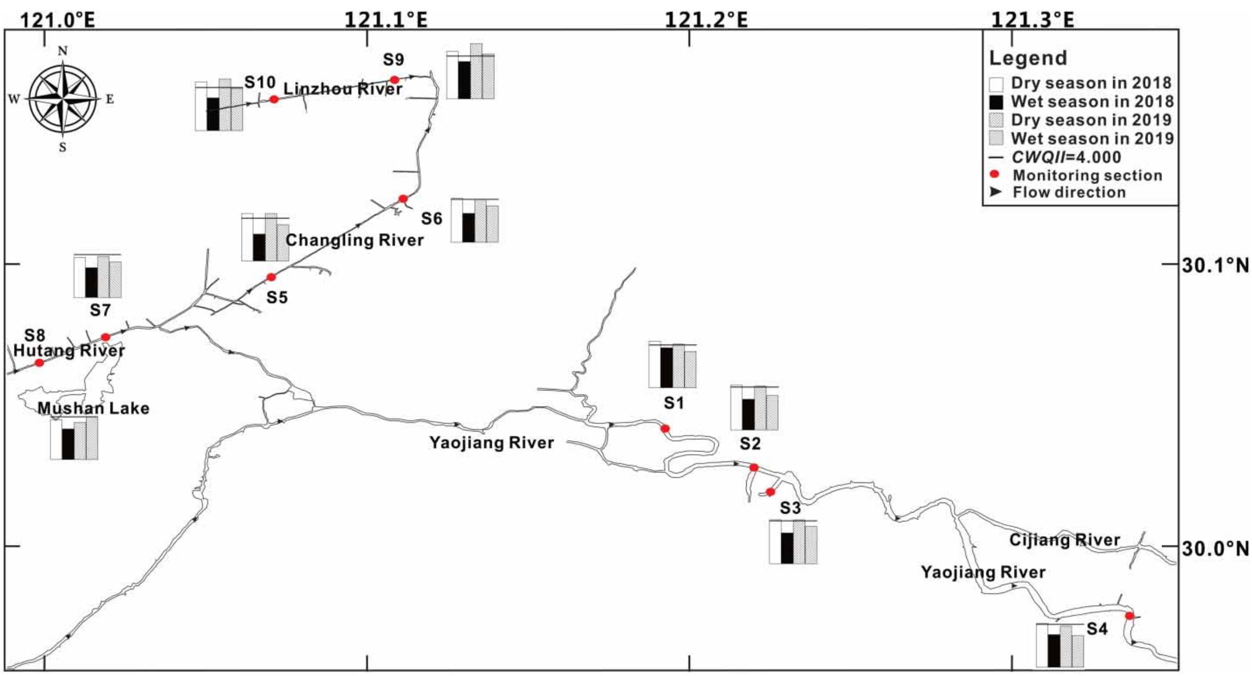


Figure 3 | Changes in *CWQII* value of the main inland rivers of Yuyao City from 2018 to 2019.

contrast to the Changling River, the comprehensive water quality of the Hutang River upstream (section S8) was better than that of the downstream (section S7) during the wet season, but the upstream water quality was worse than the downstream during the dry season. From 2018 to 2019, the comprehensive water quality of the Linzhou River upstream (section S10) was significantly better than that of the downstream (section S9) (Figure 3). According to the results of the field investigation, the Linzhou River upstream was mainly polluted by agricultural wastewater while the downstream was contaminated by urban domestic sewage and industrial wastewater.

In the two-year survey, the comprehensive water quality of each section in the dry season of 2018 was the best, all of which met the target of the water environment function zone. The *CWQII* value of each section in the dry season of 2019 was in the range of 3.0 to 4.2, and the ratio reaching grade III water quality standards accounted for 80% of the total, showing the second-best assessment result. The wet season of 2018 has the worst assessment result, ranging from 3.7 to 4.5, and the ratio meeting grade III water quality standard only accounts for 20%. Overall, the *CWQII* value in the dry season is better than that in the wet season. According to the Climate Bulletin of Yuyao City, the average annual precipitation in 2018 was about 16.9% more than the typical year. In particular, the precipitation in August was 313.0 mm, which was more than that of a normal year, whereas the precipitation in October was 51.6 mm, which was less than normal. The average annual precipitation in 2019 was the second most abundant compared with the same period in history, which is 367.5 mm more than that in 2018. Specifically, the precipitation in August is similar to the same period in 2018, while the precipitation in October is 120.5 mm more than the same period in 2018. Combined with the comprehensive water quality conditions in 2018 and 2019, it could be presumed that the surface runoff significantly impacts the pollution level. This presumption needs to be consolidated by the analyses of flow rate; however, flow rate data of each inland river are unavailable at present.

Analysis of pollution sources

Factor analysis can quantitatively reflect the contribution of each pollution source to the overall pollution of river water bodies. Through the test, the KMO values in 2018 and 2019 were 0.652 and 0.714, respectively. The Bartlett spherical test probability *p*-value in both years were all less than 0.01, indicating that the data were appropriate for factor analysis.

According to the Cattel Scree criteria (1966), the first three principal components were selected for factor analysis in 2018 and 2019 (Figure 4). It was shown that cumulative variance contribution rates of 2018 and 2019 were 90.701% and 86.597%, respectively (Table 5). The result indicated that the selected three principal components contain most of the information in the original data set, which could fully reflect the characteristics of water quality.

According to the rotation load distribution of the first three principal components (Table 6), TN and TP in the first principal component (F1) in 2018 had a significant factor load, which was highly positively correlated with F1, reflecting the eutrophication of the water body. It has been reported that the TN and TP pollution could result from industrial and municipal wastewater, agricultural activities, and household wastes (Liu & Diamond 2005). In our investigation, it was found that

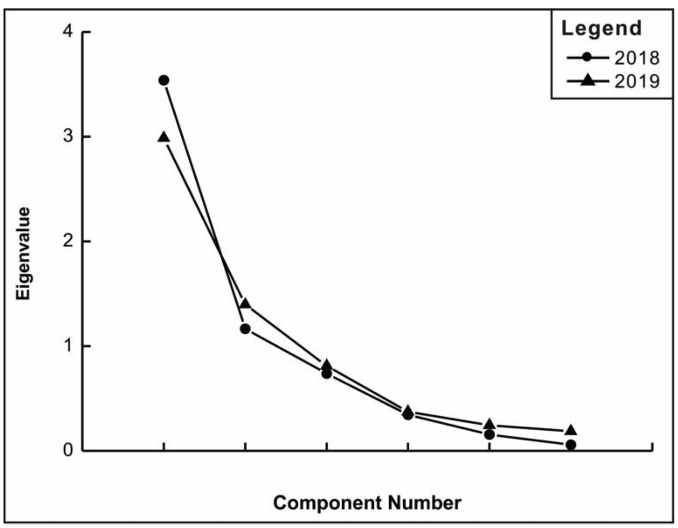


Figure 4 | Scree plot of factor analysis of water quality parameters in 2018 and 2019.

Table 5 | Eigenvalue and variance contribution from factor analysis of water quality parameters

	2018			2019		
Principal component	**Eigen value**	**Contribution %**	**Cumulative Contribution %**	**Eigen value**	**Contribution %**	**Cumulative Contribution %**
F1	3.539	58.982	58.982	2.987	49.788	49.788
F2	1.165	19.420	78.402	1.396	23.270	73.057
F3	0.738	12.299	90.701	0.812	13.540	86.597
F4	0.344	5.729	96.430	0.373	6.221	92.818
F5	0.157	2.620	99.050	0.244	4.701	96.889
F6	0.057	0.950	100.000	0.187	3.111	100.000

Table 6 | Rotated factor correlation coefficients for the water quality parameters

	Component					
	F1		F2		F3	
Index	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
DO	−0.157	−0.64	−0.943	0.539	0.014	−0.314
TN	0.898	0.135	0.159	0.923	0.149	−0.011
TP	0.834	0.892	0.329	0.168	−0.245	0.087
Petroleum	0.700	0.809	0.678	0.395	0.051	0.232
COD_{Mn}	0.389	0.900	0.815	−0.152	0.256	0.094
VP	−0.012	0.162	0.101	−0.041	0.983	0.980

domestic sewage in many rural areas was still discharged without regulation, except that domestic sewage in urban areas and several large towns could be effectively treated through sewage network management. In agricultural cultivation, a large amount of chemical fertilizer is used to increase soil fertility. The unabsorbed nitrogen and phosphorus in the fertilizer enter the groundwater body through surface runoff, which pollutes the river by TN and TP. In addition, since the leading agricultural industries in the surveyed area are poultry, pigs, and aquatic products, the impact of nitrogen and phosphorus contained in the farming wastewater on the eutrophication of water quality cannot be underestimated. In conclusion, the sources of F1 pollution were agricultural wastewater followed by urban domestic sewage. DO and COD_{Mn} had a more substantial factor load in the second principal component (F2), where COD_{Mn} was positively correlated with F2 but negatively correlated with DO (Figure 5). COD_{Mn} was an indicator of organic and reducing inorganic pollutants. The primary sources of COD_{Mn} were industrial sewage discharge and uncontrolled domestic sewage discharge caused by rapid urbanization. Yuyao City has a large number of dye houses and electroplating plants. Therefore, the direct discharge of industrial wastewater without treatment was one of the reasons for the higher COD_{Mn} factor load value in the water body. Thus, the source of F2 pollution could be defined as industrial pollution. The factor loading of the VP in the third principal component (F3) was the highest (Table 6), which further reflected industrial pollution might be caused by dye houses, paper mills, and so on.

In 2019, COD_{Mn}, petroleum, and TP had a significant factor loading in F1, and all exhibited a positive correlation with F1 (Figure 5), reflecting the status of organic pollution and eutrophication of water bodies. Therefore, F1 pollution was mainly attributed to industrial sewage discharge and agricultural sources. The factor loading of TN was the largest in F2 (Table 6). TN pollution generally originated from agricultural runoff, municipal sewage, and fertilizer plant wastewater. Because the survey sections S2, S3, S4, S5, S7, S8, and S10 are agricultural production areas while S1 and S9 are urban residential areas, F2 pollution is mainly caused by agricultural sources, followed by urban domestic sewage. The factor loading of VP in F3 was the highest with an industrial pollution source of dye houses and paper mills. In 2019, Ningbo Environmental Protection Bureau Yuyao Branch Bureau implemented 'Blue Water Project', which focused on the industries of metal surface treatment, non-ferrous metals and agricultural and sideline food processing. About 123 plants have completed the rectification. Hence,

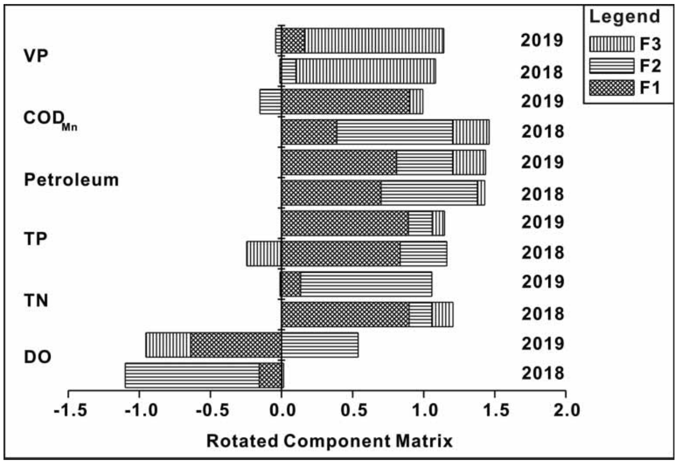


Figure 5 | Rotated component matrixes of the first three principal components in factor analysis.

SFWQII values of VP in 2019 were significantly lower than that in 2018, reflecting a reduction of industrial wastewater pollution. Compared with the pollution sources in 2018, it was found that the discharge of urban domestic sewage and industrial wastewater significantly reduced, while that of agriculture wastewater increased due to the higher average annual precipitation in 2019.

CONCLUSIONS

The study on Yaojiang River Basin employing the SFWQII method showed that DO and TN of all rivers severely exceeded the standards, which was consistent with the previous studies. However, TP was remarkably improved in the two-year survey compared to the 1990s. The comprehensive water quality of each river during the wet season was inferior to the dry season, which was probably caused by the surface runoff carrying various pollutants. The surveyed watershed in 2018 was mainly polluted by agricultural wastewater followed by urban domestic sewage, while the watershed in 2019 was polluted by industrial sewage discharge and agricultural wastewater. Thus, with the combination of *CWQII* result of each section, this result could reflect the positive effect of the 'Zero Sewage Direct Drainage Area' infrastructure and the 'Blue Water Project' implemented by Yuyao city government.

ACKNOWLEDGEMENTS

This study was supported by the Special Scientific Research Funds for Central Non-profit Institutes, Chinese Academy of Fishery Sciences (2020TD14) and the Project of Environmental Monitoring and Fishery Resources Investigation of Main Inland Rivers in Yuyao City (1988-H-2017). We appreciate Hai Liu and Jian-Ping Wang from Ningbo Ocean and Fisheries Research Institute for providing advice on the project, as well as Yuan-Ge Chen, Wei Tian from East China Sea Fisheries Research Institute for assisting sample collection.

DATA AVAILABILITY STATEMENT

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

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First received 20 February 2021; accepted in revised form 16 July 2021. Available online 30 July 2021