Pol. J. Environ. Stud. Vol. 32, No. 6 (2023), 5403-5410
DOI: *10.15244/pjoes/169395* ONLINE PUBLICATION DATE: 2023-09-13

Original Research

Water Pollution Characteristics and Water Quality Evaluation of Oujiang Estuary (2014-2018)

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Received: 18 May 2023
Accepted: 8 July2023

Abstract

It is necessary to study the characteristics of water pollution in Oujiang Estuary. In this study, the temporal distribution characteristics of 17 water quality indexes in Longwan section in 2014-2018 were tracked, the limiting factors of water quality were explored by principal component analysis (PCA), and the single factor evaluation method was used to find the main pollutants in water quality. Then, water quality evaluation was combined with comprehensive pollution index method. The results showed that the water in Oujiang Estuary was alkalescence, concentration of TN was 0.93~3.68 mg/L, NH_3-N was 0.018~0.53 mg/L, TP was 0.005~0.205 mg/L and COD_{Mn} was 0.4~4.85 mg/L. The limiting factors of water quality in 2014 were pH and arsenic; In 2015, organic pollutants were easy to cause ecological risks; In 2016, the water body faced the risk of being polluted by multiple pollutants; In 2017 and 2018, water temperature, DO and NH_3-N were easy to cause algae growth. Oujiang Estuary water quality in 2014-2016 was class III, 2017-1018 was class II. The comprehensive pollution index was 0.17~0.32. This study is expected to provide reference basis for coastal waters of Wenzhou environmental management and planning, pollution prevention and control.

Keywords: Oujiang Estuary, water pollution characteristics, water quality evaluation

Introduction

The estuarine waters that link the continent to the sea are one of the most active areas of human activity and one of the most important economic zones in the world [1-3]. The ecology of estuarine waters is influenced by both the continent and the sea and is vulnerable to anthropogenic disturbances, making it very sensitive and fragile [4-5]. As pollution from land-based sources intensifies and marine development accelerates, the ecological condition of estuarine waters deteriorates, with algae and aquatic organisms relying on increased nitrogen, phosphorus and organic matter to proliferate in large numbers and eventually eutrophication of the water column [6]. Eutrophication will disrupt the ecological balance of estuarine waters [7], threaten marine ecosystems, alter the structure of existing ecosystems and lead to degradation of ecological functions [8]. The pollution of waters in regional watersheds has become a major constraint to the sustainable development of coastal economic zones [9].

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Located in the southern part of China's Zhejiang Province, the Oujiang as the only river flowing into the sea from the East China Sea, has good conditions for the construction of a port [10]. The Oujiang estuary is backed by the central city of Wenzhou and radiates the urban economic circle of southern Zhejiang and northern Fujian, with a vast hinterland [11]. The port industry and port logistics industry is an important anchor point to drive the synergistic economic development of southern Zhejiang and northern Fujian, and is bound to become an economic engine for the healthy development of coastal areas in southern Zhejiang and northern Fujian. However, the Oujiang estuary is facing an increasing threat of ecological pollution. Taking the Oujiang estuary as the study area, this paper explores the limiting factors of water quality by tracing the water quality distribution characteristics of the area in different months from 2014 to 2018, while using principal component analysis (PCA), and evaluating water quality using the single factor evaluation method and comprehensive pollution index method. In order to provide reference for the local government to reasonably develop and utilize the water resources of the Oujiang, near-coastal ecological and environmental management and planning, and the Oujiang Basin water pollution prevention and control consultation and decision-making.

Material and Methods

Overview of the Study Area

The Oujiang River originates in the mountainous region of western China's Zhejiang Province and is the second largest river in Zhejiang. The main stream of the Oujiang River is 388 km long, with a basin area of 18028 km^2. The river flows from west to east through Wenzhou Bay into the East China Sea [11]. The Oujiang estuary is one of the major estuaries in China after the Yangtze River estuary, the Yellow River estuary, the Pearl River estuary and the Qiantang estuary, and its shipping industry is well developed. The average annual flow of the river in the basin is about 20.27 billion m^3, mainly formed by the confluence of tributaries such as Song Yin Creek, Hao Creek, Xiao Creek and Nanxi River, and has the characteristics of a large tidal estuary. The overlying water bodies at the Longwan monitoring section are influenced and controlled by tides.

Water Sample Collection and Analysis

From 2014 to 2018, Longwan section of the Oujiang estuary was sampled and preserved in accordance with the Technical Guidance on Water Quality Sampling (HJ 494-2009), and the sampling section diagram is shown in Fig. 1. 17 water quality indicators were measured in accordance with the Surface Water Environmental Quality Standard (GB3838-2002), part of the table, and the water quality indicators were measured in accordance with the current valid national standard methods [12]. The water pH, DO and water temperature were read directly on site using a portable water quality meter (HQ40d, Hash, USA). Permanganate index (COD_{Mn}) by acidic method; total nitrogen (TN) by potassium persulphate UV spectrophotometric method; ammonia nitrogen (NH_3 -N) by nano reagent photometric method; total phosphorus (TP) by molybdenum antimony anti-spectrophotometric method.

Water Quality Assessment Methods

Single Factor Evaluation Method

Single factor index method is by the ratio of the measured concentration of a water quality indicator to its standard concentration, to determine whether the indicator is identified as a pollution factor. Among all water quality indicators, the indicator with the highest degree of pollution is selected to determine the water quality, as in Equation (1).

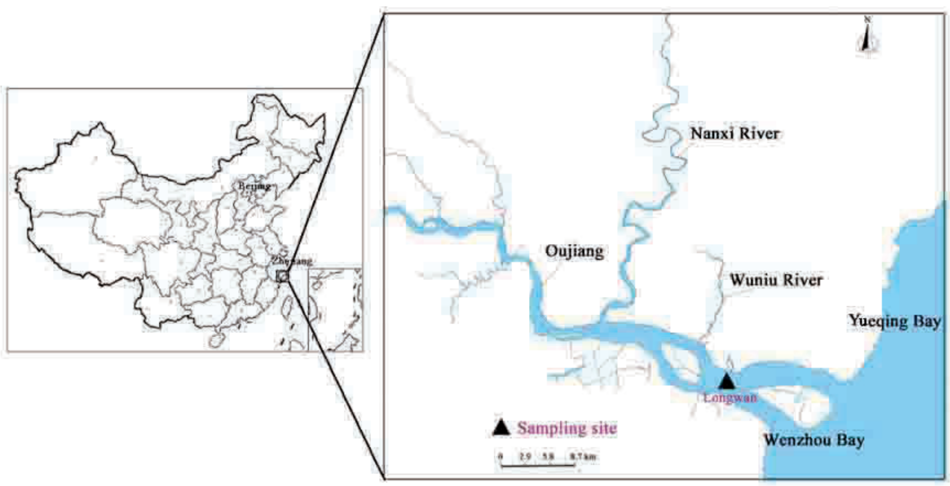

Fig. 1. Sampling section of Oujiang Estuary.

$$P_i = \frac{C_i}{S_i} \tag{1}$$

In Equation (1), the P_i indicates the degree of exceedance of the pollution factor, when $P_i \leq 1$ means that the water body is not polluted by the factor; when $P_i > 1$ when, that the water body by the factor pollution, the specific degree of pollution by the value of the decision. C_i presents the measured concentration of the i^{th} water quality indicator (mg/L). S_i presents the standard concentration of the i^{th} water quality indicator (mg/L). The water management category of the Longwan monitoring section is surface water class III, so the evaluation standard used in this study refers to the Class III standard in the Surface Water Environmental Quality Standard (GB3838-2002).

Combined Pollution Index (K) Method

Comprehensive pollution index (*K*) method [13] is a comprehensive representation of water quality pollution and comprehensive evaluation of water pollution method, its evaluation items are DO, permanganate index, biochemical oxygen demand, ammonia nitrogen, volatile phenols, lead, mercury and petroleum, the calculation method as Equation (2).

$$K = \sum_{i=1}^{n} C_i \cdot C_k / C_s \tag{2}$$

in Equation (2), *K* that the water body by the degree of pollution, $K \leq 0.1$ indicates that the water body in general or not polluted; $0.1 < K \leq 0.2$ for slight pollution; $0.2 < K \leq 0.5$ for light pollution; $0.5 < K \leq 1.0$ for moderate pollution; $1.0 < K \leq 5.0$ for heavy pollution. C_i represents the measured concentration of the i^{th} water quality indicator (mg/L). C_k For the surface water quality indicators of the unified standard value (weighting), set value to 0.1. C_s represents the standard limit value of the i^{th} water quality indicator (mg/L).

Data Analysis and Mapping

All data were measured twice in parallel and finally expressed as mean values. The differences in nitrogen and phosphorus concentrations in the water samples at different times were obtained by one-way ANOVA test using SPSS 24.0 software, with significant differences at $P<0.05$. A principal component analysis was carried out using the R language "Vegan" package to find the limiting factors of water quality in the Oujiang estuary at different years.

Results and Discussion

Water Quality Factor Characteristics

Physico-Chemical Indicators

As can be seen from Fig. 2a), the water temperature trend in the Oujiang estuary is consistent for 5 consecutive years, with the lowest water temperature of the year occurring in January and February in winter and the highest temperature in August in summer, and the highest water temperature of the year in September 2017. The overall water temperature is consistent with the change in temperature in Wenzhou, showing a trend of higher water temperatures in summer and lower water temperatures in spring and winter. The pH of the estuarine lake water in Fig. 2b) is relatively stable, with its value exceeding 7 except for a few months. From 2014 onwards, the annual pH averages of the water body are 7.85, 7.66, 7.45, 7.43 and 7.69 respectively, which are generally weakly alkaline. The pH of the water bodies in February and December 2016 were 6.65 and 6.81, respectively, and the pH of the water bodies in August and September 2017 was 6.38, showing weak acidity, probably related to the high precipitation in Wenzhou in that month. As shown in Fig. 2c), the dissolved oxygen content in the lake water was highly variable with significant period variability (P<0.05), with the dissolved oxygen content in the water column in winter being higher than that in the water column in summer

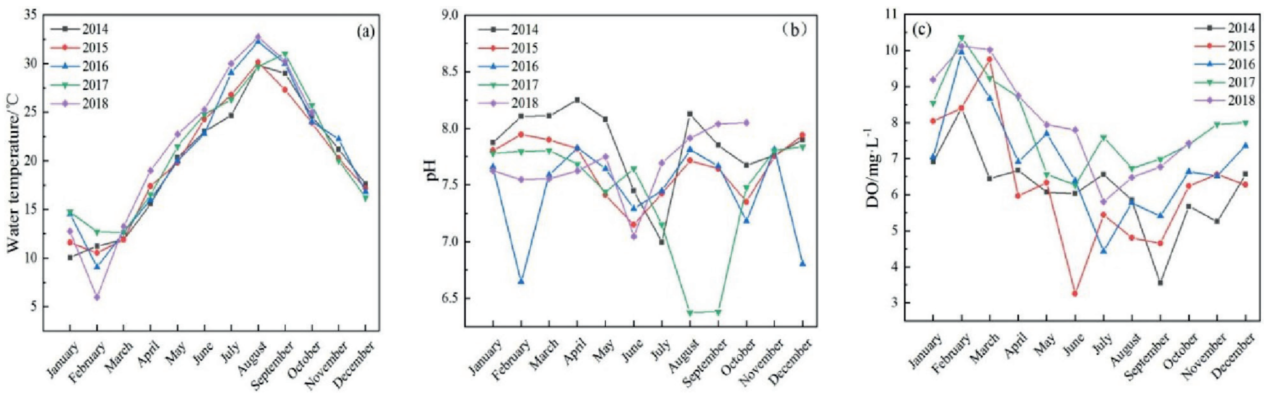

Fig. 2. Variation characteristics of physical and chemical indexes of water quality in Oujiang Estuary.

of the same year. This is due to the high precipitation entering the rainy season in May and June, causing the dissolved oxygen levels to begin to decrease. Some studies have shown that excessive dissolved oxygen levels in water tend to induce algae growth [14]. This can lead to water pollution.

Nutrient Salt Indicators

The period variation characteristics of TN and NH_3-N concentrations in the Oujiang River estuary are shown in Fig. 3a) and Fig. 3b). The TN concentrations ranged from 0.93 to 3.68 mg/L over the 5 years. The TN concentrations varied widely throughout the year, with the lowest TN concentration of 0.93 mg/L occurring in October 2016 and the highest value of 3.68 mg/L occurring in January 2018. Overall, the peak TN concentrations in the same year mostly occur in December, January or February, while the increase in TN concentrations in winter, when conditions are not available to cause water pollution, may be due to the large release of endogenous pollutants leading to water pollution [15] NH_3-N concentrations ranged from 0.018 to 0.53 mg/L, with mean concentrations from 2014-2018 of 0.118, 0.073, 0.145, 0.159 and 0.211 mg/L. NH_3-N concentrations in 2015 were the lowest of 5 years, and the lowest NH_3-N concentrations were found during the three winter months of each year, when nitrate-nitrogen levels in the water column were high. Among the various inorganic forms of nitrogen, ammonia nitrogen is considered to have a high ecological risk, and its toxicity is easily influenced by water temperature and pH [16]. As the temperature in Wenzhou gradually increased in February, ammonia concentrations in the water column remained high until September when the temperature began to drop and ammonia concentrations declined. The source of ammonia nitrogen in the water is mainly the decomposition products of nitrogenous organic matter, which is transformed from organic to inorganic state under the action of microorganisms, and the recovery of the port transportation and tourism industries in the spring and summer months leads to the diffusion of exogenous pollutants.

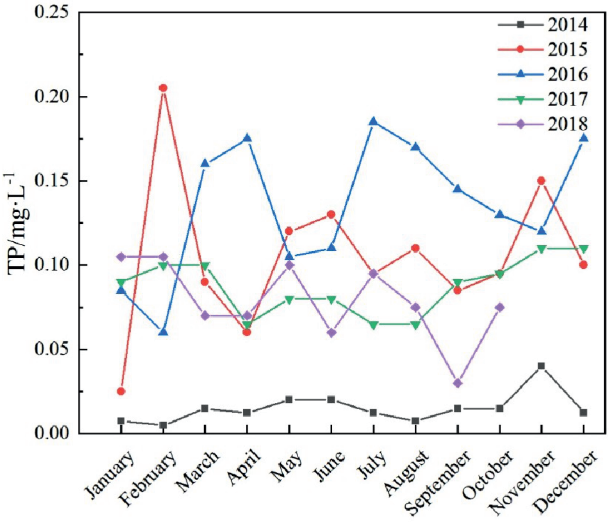

Fig. 4. Variation characteristics of total phosphorus concentration in Oujiang Estuary.

As shown in Fig. 4, the range of TP concentrations in the Oujiang estuary is highly variable, ranging from 0.005-0.205 mg/L. In general, TP concentrations in the water body were low in 2014, increased in 2015 and 2016, and then decreased in 2017 and 2018. In 2014, TP concentrations were relatively stable, with a peak of 0.04 mg/L in November. From 2015 onwards, TP concentrations fluctuated, in line with the trend of TN concentrations, and in the season of high precipitation, the lowest values of TP concentrations were observed in April, July and August. Through field research and analysis of nutrient indicators, it can be seen that the concentrations of nitrogen and phosphorus in the

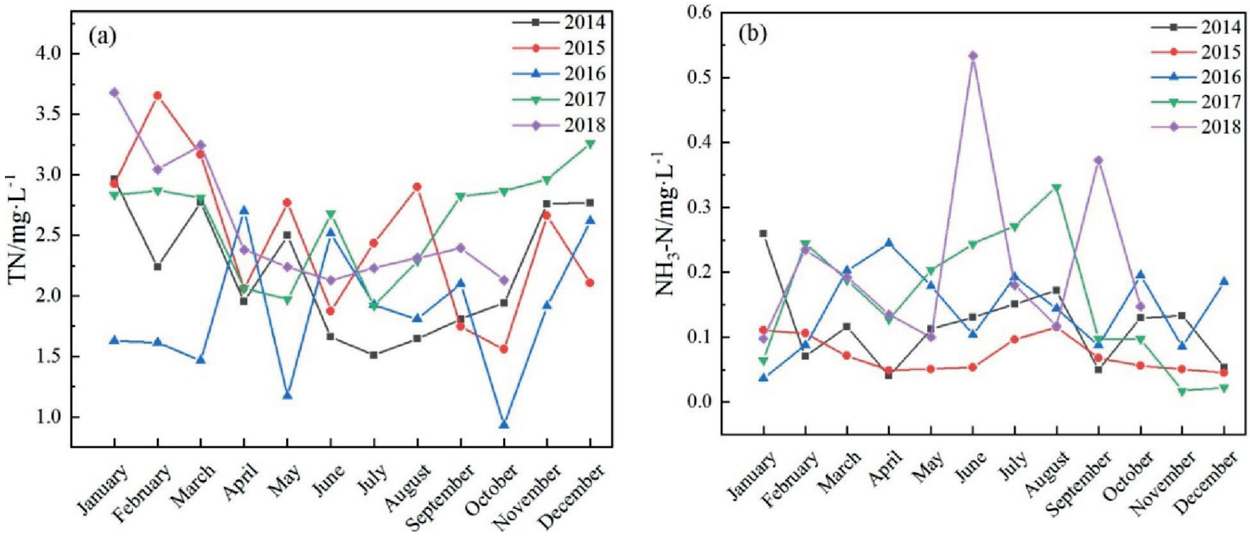

Fig. 3. Variation characteristics of nitrogen concentration in Oujiang Estuary.

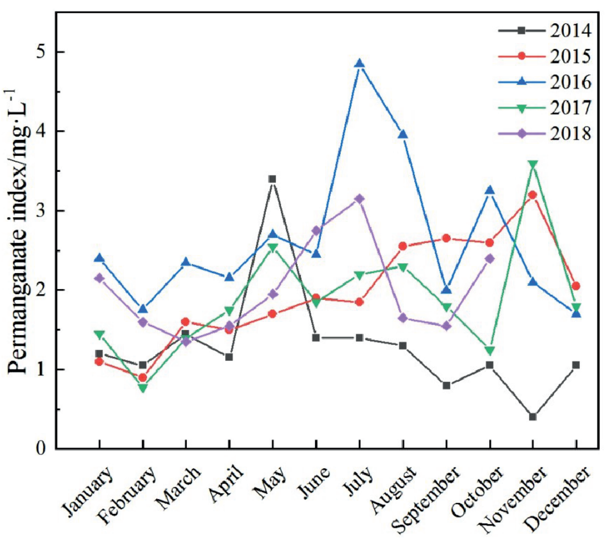

Fig. 5. Variation characteristics of permanganate index in Oujiang Estuary.

water bodies of the Oujiang River estuary are higher in November and December in winter, and lower in April, July and August due to heavy rainfall and faster water flow.

Organic Pollution Indicators

The permanganate index is often used to indicate the extent to which surface water is contaminated with organic pollutants and reduced inorganic substances [17]. Fig. 5 shows that the permanganate index varied between 0.4 and 4.85 mg/L during the five-year follow-up survey, with an overall mean of 1.96 mg/L. The Oujiang estuary was highly contaminated with organic matter in 2016. The peak of the permanganate index occurred in May 2016 at 4.85 mg/L, probably due to a decrease in DO concentration in the water column as the water temperature decreased, resulting in a portion of pollutants in the sediment being released into the overlying water in an anaerobic environment under the action of microorganisms, caused a higher level of chemical oxygen demand in the water column.

Principal Component Analysis (PCA) of Variance

To further explore the pollutants in the Oujiang estuary, a principal component analysis was conducted. By dimensionality reduction of 13 environmental factors, three principal components with large contribution were extracted, and their cumulative contribution was 93.05%, of which the total explained degree of principal component 1 and principal component 2 was 81.18%, indicating that the first two extracted principal components already contained most of the information of the data. In which, the variance contribution of PC1 was 51.40%. From Fig. 6, BOD, COD and Cr(VI) have a very strong contribution to PC1. BOD and COD are comprehensive indicators reflecting the content of organic pollutants in water bodies, and Cr(VI), as a heavy metal and a hazardous metal [18, 19] As a heavy metal and hazardous to human health, PC1 represents the pollution characteristics of water bodies by organic matter and the heavy metal chromium. Permanganate index and total phosphorus contribute strongly to PC2, with permanganate index reflecting the degree of pollution of the water body by oxidisable substances and total phosphorus being easily absorbed by algae for their own growth, so PC2 shows the impact

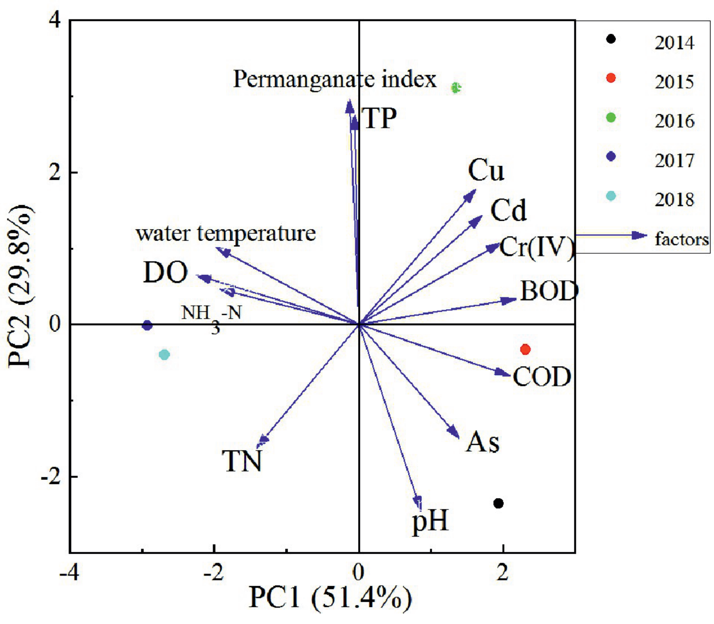

Fig. 6. Principal component analysis of environmental factors in Oujiang Estuary.

of phosphorus and oxidisable substance pollution on the water quality of the Oujiang estuary. There is variability between environmental factors in different years, and they are grouped into four categories according to their contribution to environmental factors, including one category in 2014, one category in 2015, one category in 2016, and one category in 2017 and 2018, with significant variability between categories. in 2014, the water body was more affected by pH and arsenic concentrations; in 2015, the focus should be on the water body's biochemical oxygen demand and chemical oxygen demand to avoid ecological risks to water quality from organic pollutants in the water body; in 2016, attention should be paid to the permanganate index, total phosphorus and the content of each heavy metal in the water body, when the water body is at risk of being polluted by multiple pollutants; in 2017 and 2018, water temperature, DO and ammonia nitrogen will have an impact on water quality, and all three are algal growth factors [20, 21], with ammonia nitrogen being susceptible to molecular ammonia in the form of aquatic organisms, which can be toxic [22]. The water temperature, DO and ammonia nitrogen can affect water quality. Therefore, based on the variance of each environmental factor in different years, it is concluded that the water quality situation is improving year by year.

Water Quality Assessment

Single Factor Evaluation

According to the "Environmental Quality Standards for Surface Water" (GB3838-2002), the basic project standard limits for surface water classification evaluation (Table 1) were used to conduct a single factor evaluation of the 24 water quality indicators of this section. According to the assessment requirements of the national surface water monitoring network, the water environment function of the Longwan section of the Oujiang estuary is classified as Class III surface water body. The evaluation results are shown in Table 1. At the same time, in accordance with the requirements of the original Ministry of Environmental Protection document in the "Surface Water Environmental Quality Assessment Measures (Trial)", water temperature, TN,

Table 1. Water quality results of Oujiang Estuary by single factor evaluation method.

Year	Class	Classification index of Environmental Protection Bureau [2011] No. 22
2014	III	Volatile phenol
2015	III	TP, volatile phenol
2016	III	TP
2017	II	NH_3-N, TP
2018	II	DO, TP

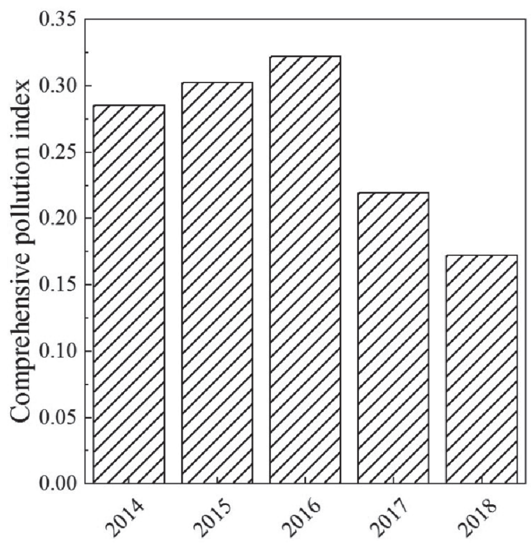

Fig. 7. Comprehensive pollution index of Oujiang Estuary.

and fecal coliform group are used as reference indicators for separate evaluation and assessment. Therefore, the single factor water quality evaluation was classified as Class III from 2014 to 2016, and Class II from 2017 to 2018. However, although TN is not currently included in the water environment quality assessment requirements, the reason for the high concentration of TN may be caused by the combination of endogenous pollutants in the Oujiang River and external pollutants [23,24].

Comprehensive Pollution Index Evaluation

The comprehensive pollution index of the Oujiang estuary ranges from 0.17 to 0.32, and the results in Fig. 7 show a mild pollution level from 2014 to 2017, with comprehensive pollution index values of 0.29, 0.30, 0.32, and 0.22. The water quality in 2018 showed a slight pollution level, with a comprehensive pollution index value of 0.17. The current water quality situation of the Oujiang estuary from 2014 to 2017 indicates that its water body is slightly polluted, and the original function of the water body faces the risk of not being able to safely and fully exert its water body effect, which will have a certain degree of harm and impact on the aquatic environment. However, the water quality situation improved in 2018, and it is recommended to continue monitoring in the future.

Conclusions

(1) From 2014 to 2018, the water bodies in the Oujiang estuary were generally weakly alkaline. the TN concentrations varied widely, with TN concentrations ranging from 0.93-3.68 mg/L, ammonia nitrogen concentrations ranging from 0.018-0.53 mg/L, TP concentrations ranging from 0.005-0.205 mg/L, and permanganate index ranging from 0.4-4.85 mg/L.

TN and TP concentrations in the water bodies in the same years were higher in November and December in winter due to heavy rainfall and higher water flow. TP concentrations follow the same trend, with higher concentrations of nitrogen and phosphorus in the water column in the winter months of November and December in the same year, and lower pollutant concentrations in April, July and August due to high rainfall and faster water flow.

(2) There is temporal variability between water environmental factors, with water bodies being more affected by pH and arsenic concentrations in 2014; organic pollutants in water bodies being susceptible to ecological risks to water bodies in 2015; water bodies being at risk of contamination by multiple pollutants in 2016; and water temperature, DO and ammonia nitrogen being susceptible to algal growth in water bodies in 2017 and 2018.

(3) The single factor water quality evaluation of the Longwan monitoring section at the Oujiang estuary was classified as Class III from 2014 to 2016, and Class II from 2017 to 2018. The comprehensive pollution index ranges from 0.17 to 0.32, with slight pollution in 2018 and mild pollution in other years.

Acknowledgments

This paper is supported by Wenzhou Basic Social Development Science and Technology Project (S20200014). We thank the timely help given by staff from the analysis office of Zhejiang Province Wenzhou Ecological Environment Monitoring Center in analyzing a large number of samples.

Conflict of Interest

The authors declare no conflict of interest.

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