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Research Article

Variation of Water Quality in Ningxia Section of the Yellow River in Recent 5 Years

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The Yellow River is very important for human health and social development in China to require good water quality. This study selected the Ningxia section of the Yellow River as the study area to investigate the water quality variation in 2016–2020. A total of 9 water quality parameters were monitored, and 8 parameters including pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total phosphate, fluoride, ammonia-nitrogen, and permanganate index were in the range of Class II standard requirement. Dissolved oxygen concentrations ranged from 7.5 to 9.4 mg/L. However, total nitrogen concentrations in 2018–2020 ranged from 1.87 to 2.8 mg/L to cause the pollution. Both the Nemerow index method and the contamination degree method showed that total nitrogen with high concentration exerted the water pollution. Principal component analysis also proved this. Stricter environmental management strategies for controlling total nitrogen should be taken in the future. The findings provided some useful information for water pollution of the Ningxia section of the Yellow River.

1. Introduction

Water is considered as the origin of life and it is the critical source for human well-beings and social development [1]. Water quality is very important for water resource usage, agricultural activities, industrial production, aquaculture, and regional safety [2–6]. However, water has been frequently contaminated by diverse pollutants such as heavy metals [7], endocrine disrupting chemicals [8], antibiotic resistance genes [9], microplastics [9], and other emerging chemicals in recent decades. These pollutants have occurred in seawater, groundwater, lakes, and rivers to possibly exert the potential risks to humans [7, 9, 10]. Therefore, water pollution in terms of emerging contaminants has become a study hot-spot in recent years [7–10]. The traditional water quality parameters such as chemical oxygen demand (COD), dissolved oxygen (DO), biological oxygen demand (BOD), ammonia-nitrogen, pH, total nitrogen (TN), total phosphate (TP), permanganate index (IMn), and fluoride are important to evaluate the water quality so that these parameters have been routinely monitored for management of surface water quality. However, the investigations on water quality regarding traditional parameters are not very enough and these parameters have been often used as the influential factors for evaluating emerging pollution [11]. Therefore, water quality evaluation using traditional parameters should be paid attention.

COD is an important index to judge the water quality or effectiveness of wastewater treatment techniques [12, 13]. COD was reported to be lower than 3 mg/L in Spanish river [14]. COD in other rivers in other countries ranged from 2 to 133 mg/L while that in wastewater/sewer was in the range of 9–656 mg/L [15]. Permanganate index (IMn) is COD measured by the permanganate method which is generally used for evaluating water quality of surface water or drinking water. IMn generally shows the inorganic or organic pollution of water. Similarly, BOD which is another index to show organic pollution has also been widely paid attention. DO is another critical index for water quality and water safety. DO is related to the survival of aquatic organisms and water ecological balance. The pH is able to indicate the acid-base degree of the aquatic environment. The animals and plants can live in water with a suitable pH range so that a lower or higher pH can indicate the deterioration of the aquatic environment. Nutrients are important for the growth of aquatic plants. However, excessive nutrients in water could induce extensive growth of plants to consume more DO and make the water quality deteriorate [16]. Ammonia-nitrogen, TN, and TP have been widely accepted as the main parameters for evaluating nutrients in water. Fluoride has widely existed in water to induce many illnesses such as kidney disease and have significant toxicity to aquatic animals [17]. Therefore, fluoride is also a critical index during water quality monitoring. Water quality can be evaluated by comparing these parameters with national water quality standards. Routine monitoring is very important for water protection and environmental management.

The Yellow River is a very important river in China. It originates from Qinghai Province, flows over 9 provinces, and enters into the Bohai Sea in Dongying of Shandong Province. The Ningxia section of the Yellow River has provided water resources for Ningxia so the water quality of this section is very critical for the regional sustainability of Ningxia. This study evaluated the water quality of the Ningxia section of the Yellow River to provide useful information on the variation of the aquatic environment in this area. The findings of this study will provide the basis for the strategy of environmental management for the Ningxia section of the Yellow River and the surrounding area in the future.

2. Materials and Methods

2.1. Chemicals, Reagents, and Analysis Method. NaOH, KI, HgI_2, MgO, HCl, $NaKC_4H_4O_6$ $4H_2O$, $Na_2S_2O_3$, $nSO_4{\cdot}7H_2O$, H_3BO_3, bromothymol blue, soluble starch, Na_2CO, NH_4Cl, H_2SO_4, $K_2Cr_2O_7$, Ag_2SO_4, $HgSO_4$, neutral resin XAD-2, CH_4O, $(NH_4)_2Fe(SO_4)_2$ $6H_2O$, $KHC_8H_4O_4$, $FeSO_4{\bullet}7H_2O$, KNO_3, $ZnSO_4$, $MnSO_4{\bullet}H2O$, $NH_2C_6H_4SO_2NH_2$, $C_{10}H_7NHC_2H_4NH_2{\bullet}2HCl$, C_2H_6O, $KAl(SO_4)_2{\cdot}12H_2O$, $KMnO_4$, $NaNO_2$, sulfamic acid, H_3PO_4, $Na_2C_2O_4$, and phenolphthalein were purchased from Shanghai Aladdin Biochemical Technology Co., Ltd.

DO was measured by a dissolved oxygen meter while pH was determined by the pH meter. $NH_4{}^+$-N was analyzed by Nessler's reagent spectrophotometric determination while TN was determined by using digestion coupling with ultraviolet spectrophotometry. IMn was determined by the permanganimetric method while COD was analyzed by the potassium dichromate method. TP was determined by the ammonium molybdate spectrophotometric method while BOD was analyzed by using the standard dilution method. Fluoride was determined by the ion selective electrode method. All detailed analysis methods referred to reference [18].

Total 6 sites of the Ningxia section of the Yellow River (Figure 1) were selected for monitoring in 2016–2020. The 6 sites were named as W1, W2, W3, W4, W5, and W6. Total 9 water quality parameters were measured.

2.2. Water Quality Evaluation Method. Water pollution of the Ningxia section of the Yellow River was evaluated by using the Nemerow index and contamination degree. The Nemerow Index was calculated according to the following equation [19]:

$$\text{Nemerrow Index} = \sqrt{\frac{(C_i/S_i)_{\text{mean}}^2 + (C_i/S_i)_{\text{max}}^2}{2}}, \quad (1)$$

where S_i refers the standard concentration of water quality parameter; C_i means the measured concentration of water quality parameter; $(C_i/S_i)_{\text{mean}}$ represents the average value of all (C_i/S_i); and $(C_i/S_i)_{\text{max}}$ is the maximal value among all (C_i/S_i). S_i for each water quality parameter used in this study was the Class II or Class III levels of the "Surface water quality standard of China (GB 3838–2002)". Pollution evaluated by the Nemerow index could be categorized into Class I (insignificant pollution with a Nemerow index less than 1), Class II (slight pollution with a Nemerow index less than 2.5 but equal or higher than 1), Class III (moderate pollution with a Nemerow index less than 7 but equal or higher than 2.5), and Class IV (heavy pollution with a Nemerow index equal or higher than 7).

The following equation showed the calculation of *contamination degree* [20]:

$$\text{contamination degree} = \sum_{i=1}^{n} \frac{C_i}{S_i}. \quad (2)$$

The evaluation criterion included: Class I (low pollution with contamination degree less than 6), Class II (moderate pollution with contamination degree less than 12 but equal or higher than 6), Class III (considerable pollution with contamination degree less than 24 but equal or higher than 12), and Class IV (very heavy pollution with contamination degree equal or greater than 24).

2.3. Data Processing. Data were processed by using Origin 2018. Correlation analysis was performed by SPSS 19. The correlation matrix was shown as a heatmap with *<0.05 and **<0.01. Principal component analysis was performed by Origin 2018.

3. Results and Discussion

3.1. Water Quality Variation of Ningxia Section of the Yellow River during 2016–2020. The pH of 6 sites was nearly higher

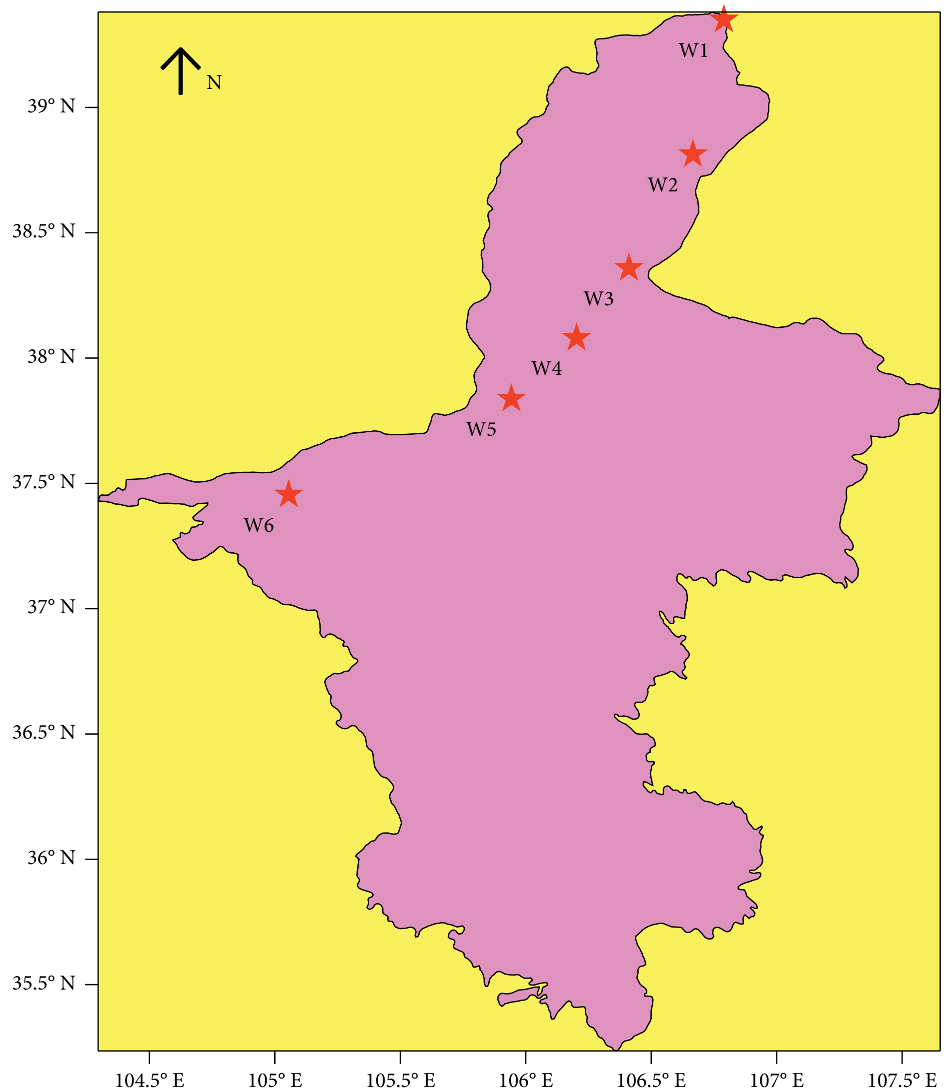

Figure 1: Sampling sites of this study.

than 8 except W6 in 2020 with a pH of 7.8 (Figure 2(a)). The pH of W1 ranged from 8 to 8.2. It was interesting that the pH of W1 showed a slightly increasing trend during 2016–2020. The pH of W2 ranged from 8 to 8.3. The pH of W2 did not show the significant variation trend during recent 5 years. The pH of W3 ranged from 8 to 8.3 and it showed a slightly decreasing trend. The pH of W4 ranged from 8 to 8.4 with the highest pH occurring in 2019. The pH of W5 ranged from 8 to 8.3 and it showed slightly increasing trend. The pH of W6 ranged from 7.8 to 8.3 with a significantly lower pH in 2020.

The DO concentration of 6 sites was nearly higher than 8.2 mg/L except W5 in 2020 with a DO concentration of 7.5 mg/L (Figure 2(b)). The DO concentration of W1 ranged from 8.2 to 9.1 mg/L while the DO concentration of W2 ranged from 8.3 to 8.9 mg/L. The DO concentration of W3 ranged from 8.4 to 9.1 mg/L and it showed a slightly increasing trend. The DO of W4 ranged from 8.4 to 9.4 mg/L with the highest DO concentration occurring in 2020. The DO concentration of W5 ranged from 7.5 to 9 mg/L and it showed significant variation in 2019 and 2020. The DO concentration of W6 ranged from 8.6 to 9.4 mg/L. The DO concentrations in 2019 and 2020 generally showed higher than before, illustrating that environmental management might take action for improving the water quality.

The IMn of 6 sites was higher than 1.8 mg/L (Figure 2(c)). The IMn of W1 ranged from 2.1 to 3 mg/L while IMn of W2 ranged from 2.1 to 2.8 mg/L. The highest IMn of W1 and W2 occurred in 2016, and IMn showed slightly decreasing trend to prove the effectiveness of environmental management strategy. The IMn of W3 ranged from 2 to 2.6 mg/L and it showed a slightly decreasing trend. The IMn of W4 ranged from 1.9 to 2.6 mg/L. The IMn of W5 ranged from 2 to 2.6 mg/L and it was stable in 2017–2020. The IMn of W6 ranged from 1.8 to 2.3 mg/L to show a slightly increasing trend. In summary, IMn values were all relatively low to illustrate the good water quality of the study area.

The BOD of 6 sites was higher than 0.8 mg/L (Figure 2(d)). The BOD of W1 ranged from 1.2 to 1.9 mg/L

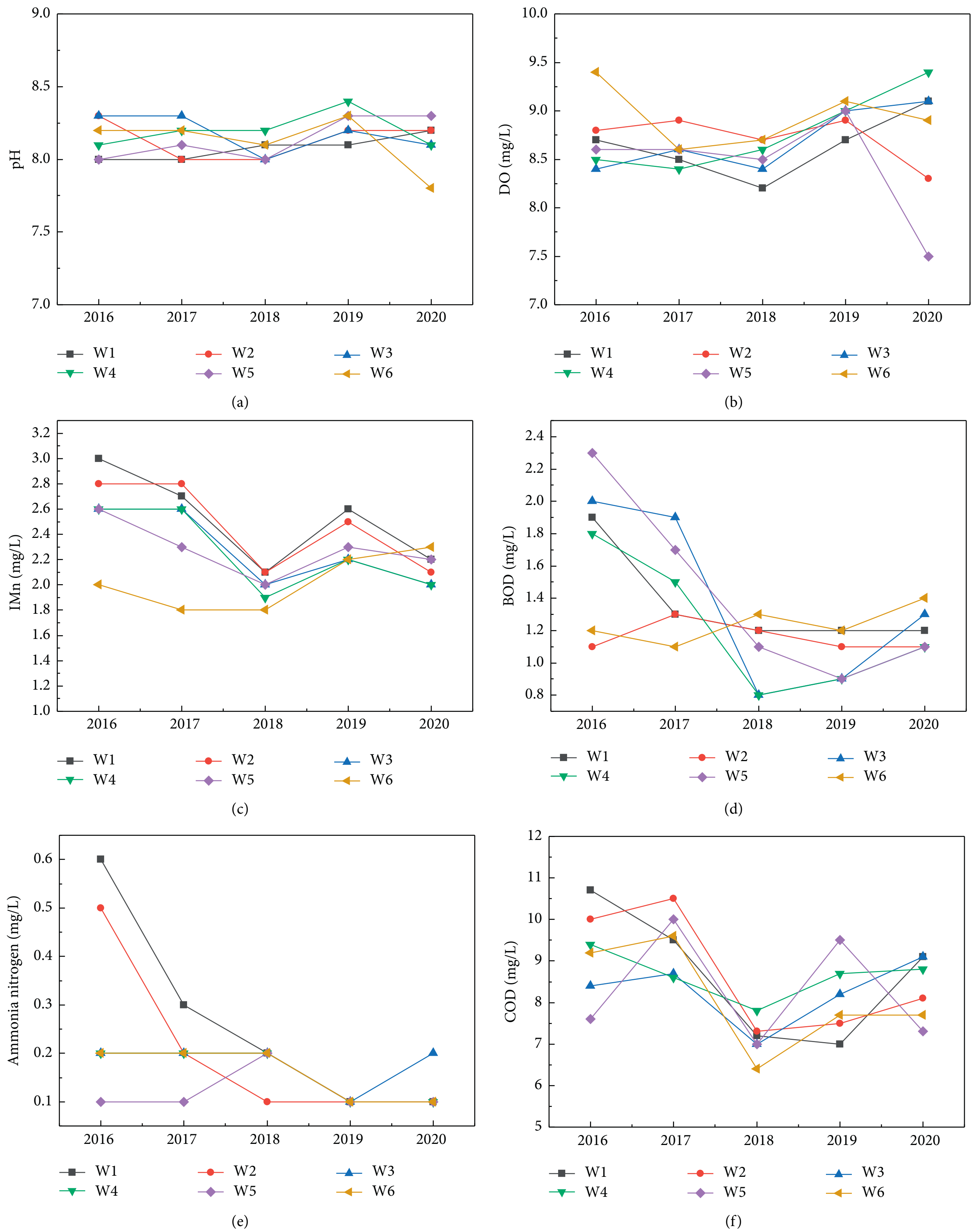

Figure 2: Continued.

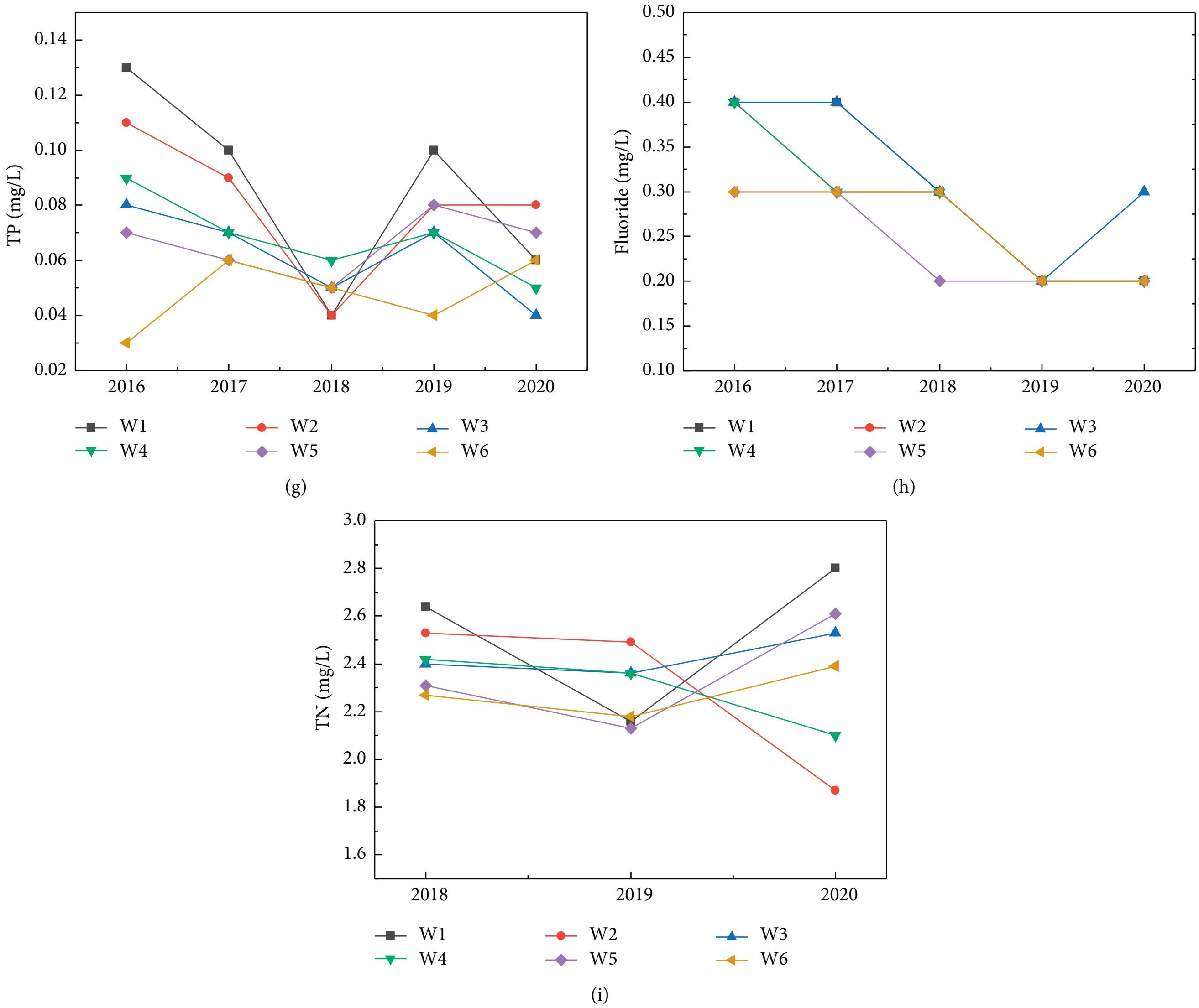

Figure 2: Variation of water quality parameters of the Ningxia section of the yellow river during 2016–2020.

with decreasing trend while the BOD of W2 ranged from 1.1 to 1.3 mg/L. The BOD of W3 ranged from 0.8 to 2 mg/L while the BOD of W4 ranged from 0.8 to 1.8 mg/L with a slightly decreasing trend. The BOD of W5 ranged from 0.9 to 2.3 mg/L while the BOD of W6 ranged from 1.2 to 1.4 mg/L. In summary, BOD values were all relatively low to illustrate the good water quality of the study area.

The ammonia-nitrogen concentrations of 6 sites were in the range of 0.1–0.6 mg/L (Figure 2(e)). The ammonia-nitrogen concentration of W1 and W2 in 2016 was 0.6 and 0.5 mg/L, respectively. The ammonia-nitrogen concentrations of the remaining sites and periods were all below 0.2 mg/L, except W1 in 2017 with 0.3 mg/L, showing good water quality.

The COD concentrations of 6 sites were in the range of 6.4–10.7 mg/L (Figure 2(f)). The COD concentrations of W1 ranged from 7 to 10.7 mg/L while the COD of W2 ranged from 7.3 to 10.5 mg/L. The COD concentrations of W3 ranged from 7 to 9.1 mg/L while the COD of W4 ranged from 7.8 to 9.4 mg/L. The COD concentrations of W5 ranged from 7.3 to 10 mg/L while COD of W6 ranged from 6.4 to 9.6 mg/L. W6 showed better water quality in terms of COD in 2018–2020. In contrast, the water quality of W1 and W2 was worse than that of other sites.

The TP concentrations of 6 sites were in the range of 0.03–0.13 mg/L (Figure 2(g)). The TP concentration of W1 and W2 in 2016 was 0.13 and 0.11 mg/L, respectively. The TP concentrations of different sites generally showed a decreasing trend especially with low concentrations in 2018–2020, showing good water quality and an effective environmental management strategy.

The fluoride concentrations of 6 sites were in the range of 0.2–0.4 mg/L (Figure 2(h)). The fluoride concentrations of all sites exhibited the decreasing trend, showing good water quality and effective environmental management strategy.

The TN concentrations of 6 sites were in the range of 1.87–2.8 mg/L (Figure 2(g)). The TN concentration of all sites in 2016 and 2017 was not measured. The TN

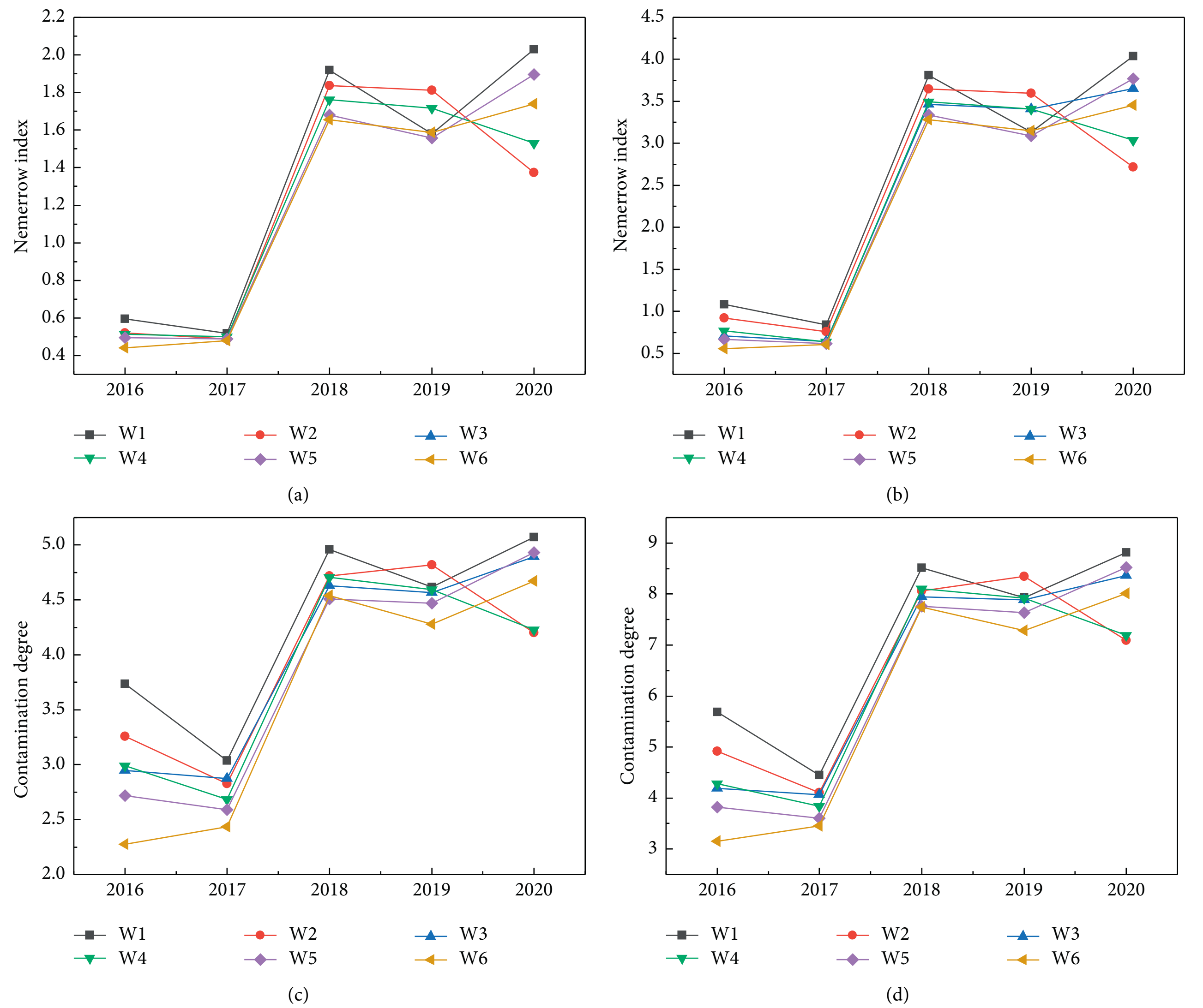

Figure 3: Nemerow index and contamination degree of water in the Ningxia section of the Yellow River during 2016–2020. (a) Nemerow index by using Class III; (b) Nemerow index by using Class II; (c) contamination degree by using Class III; (d) contamination degree by using Class II.

concentrations of different sites were higher than 1 mg/L in 2018–2020, which exceeded the standard of Class II and Class III, showing the possible pollution risks. Agriculture is well developed along the Ningxia section of the Yellow River, which might introduce some nitrogen pollutants into the water to cause a higher concentration of TN.

3.2. Water Pollution Variation of Ningxia Section of the Yellow River during 2016–2020. The pH, DO, IMn, BOD, ammonia-nitrogen, COD, and fluoride of all sites in 2016–2020 were below the Class II standard, showing good water quality of the study area. TP in W1 and W2 in 2016 exceeded the Class II standard but was lower than the Class III standard. The TP concentrations of all sites in 2017–2020 were below the Class II standard, showing that the water quality was greatly improved in 2017–2020 under the effective environmental management strategy. It was a little regretful to find that TN concentrations of all sites in 2018–2020 exceeded the Class III standard. TN concentrations of all sites in 2018–2020 exceeded the Class IV standard and 17 out 18 samples exceeded the Class V standard in terms of TN.

Both Nemerow index and contamination degree were used to comprehensively evaluate the water pollution of Ningxia section of the Yellow River during 2016–2020 (Figure 3). Class III (Figure 3(a) and 3(c)) and Class II (Figure 3(b) and 3(d)) standards were used as the criterion. Nemerow index values of all sites in 2016–2017 were all below 1.0 using Class III standards (Figure 3(a)), illustrating that water quality of all sites in Ningxia section of the Yellow River is good. However, Nemerow index values of all sites in 2018–2020 were higher than 1, illustrating the slight contamination occurred in the study area (Figure 3(a)). More strict criterion Class II was adopted, only W1 in 2016 showed slight contamination while W1 and W2 in 2016–2017

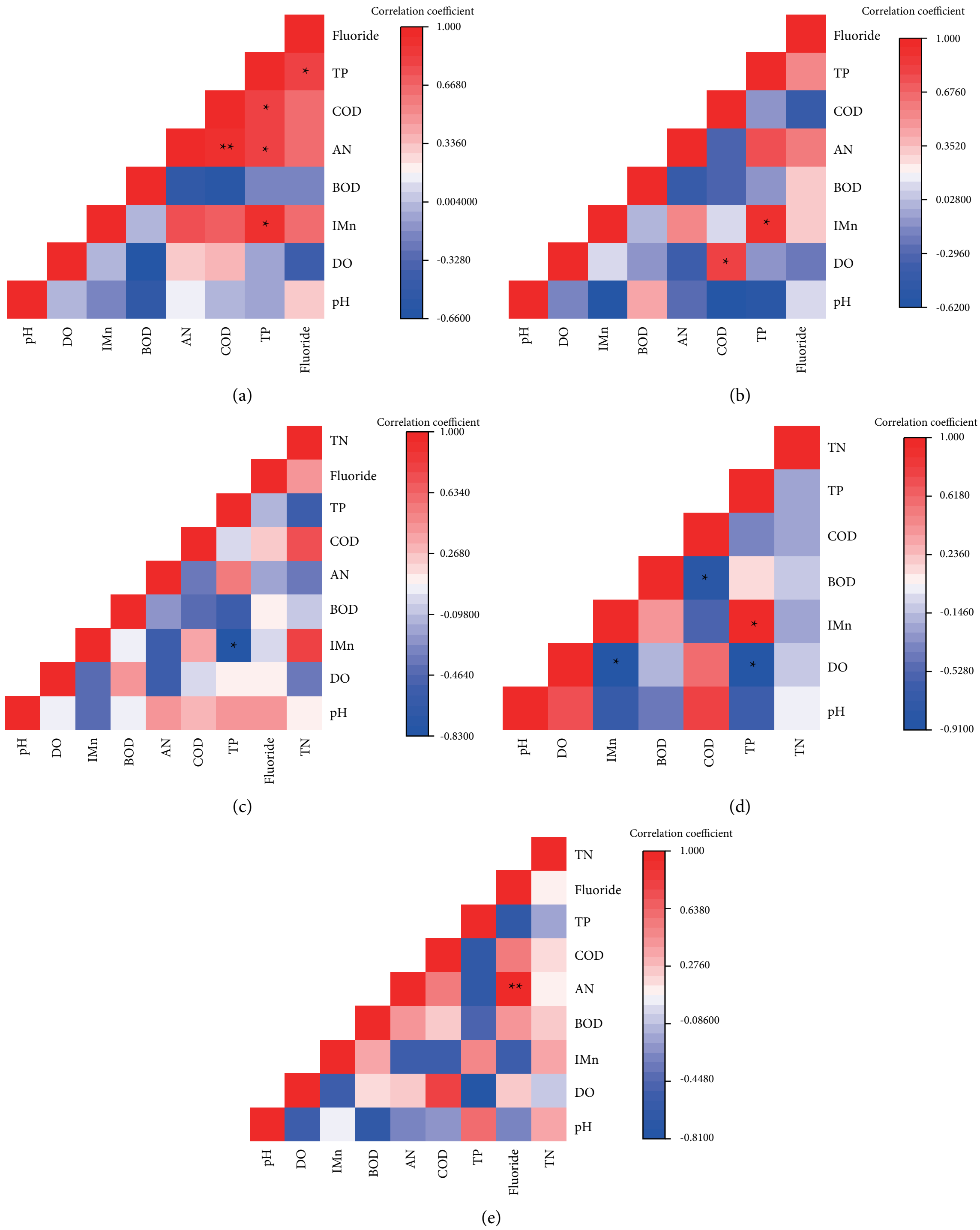

Figure 4: Correlation heatmap among the water quality parameters of the Ningxia section of the Yellow River during 2016–2020. (a) 2016; (b) 2017; (c) 2018; (d) 2019; (e) 2020. AN means ammonia-nitrogen.

showed uncontaminated state (Figure 3(b)). The remaining sites in the remaining periods all showed moderate contamination (Figure 3(b)). TN with higher concentrations in all sites in 2018–2020 served as the predominant contamination contributor.

Different from Nemerow index evaluation, contamination degree showed that all sited in 2016–2020 possessed low contamination with contamination degree less than 6 by using Class III standards (Figure 3(c)). However, all sites in 2018–2020 showed moderate water pollution by using Class II standards although these sites showed low contamination in 2016–2017 (Figure 3(d)). TN was also the major pollution contributor for the contamination degree.

Stricter criterion will obtain worse evaluation results. Taking Class II standards as the evaluation criterion, the results were worse. The worse scenario was generally used

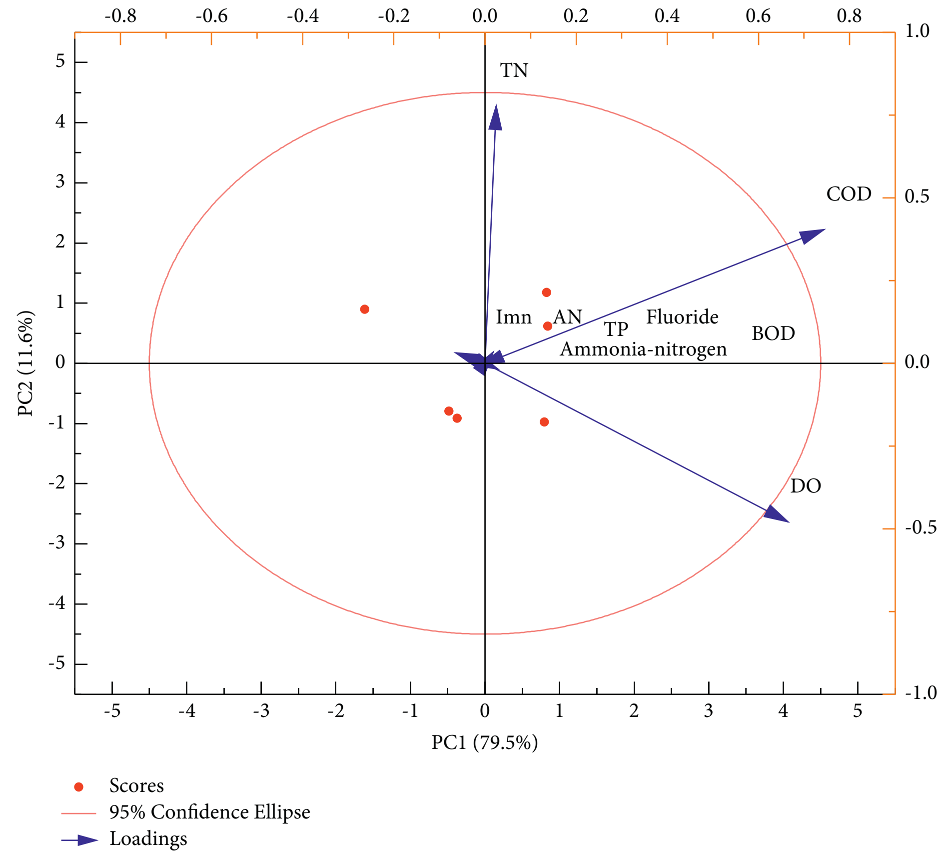

Figure 5: Principal component analysis on water quality of the Ningxia section of the Yellow River in 2020.

for the evaluation result. Therefore, the contamination degree method obtained a better evaluation result in comparison to the Nemerow index method, which might be ascribed to the fact that Nemerow index method enlarged the contribution of maximal C/S value. It should be noted that TN concentrations should be greatly decreased to be less than 1.0 even 0.5 mg/L to make the water quality become good. Therefore, more new strategies should be taken in the future. Another important point was that TN was not monitored in 2016 and 2017 so that the Nemerow index and contamination degree did not comprise TN in 2016 and 2017. More data including 2021, 2022, or longer should be used to obtain more reasonable evaluation results.

3.3. Correlation Analysis of Water Quality Parameters of Ningxia Section of the Yellow River during 2016–2020. Correlation among different water quality parameters of the Ningxia section of the Yellow River during 2016–2020 was assessed (Figure 4). Significant differences in correlation among water quality parameters occurred in different periods. Significantly positive relationship existed between COD-ammonia-nitrogen, TP-IMn, TP-ammonia-nitrogen, TP-COD, and TP-fluoride in 2016 (Figure 4(a)). Significantly positive relationship existed between COD-DO and TP-IMn in 2017 (Figure 4(b)). Tp was only significantly negatively related with IMn in 2018 (Figure 4(c)), which changed a lot with the previous 2 years. Significantly negative relationship existed between IMn-DO, COD-BOD, and TP-DO while significantly positive relationship existed between IMn and TP in 2019 (Figure 4(d)). Only fluoride was significantly positively related with ammonia-nitrogen in 2020 (Figure 4(e)).

Multiple factors might influence the correlation among different water quality parameters [21, 22]. The water quality parameters in 2016 showed the most complex relationship while those in 2018 and 2020 showed the simplest relationship. A simple relationship between water quality parameters meant more complicated factors might have an effect on the water quality.

3.4. Principal Component Analysis on Water Quality of Ningxia Section of the Yellow River. Principal component analysis was employed to determine the possible pollution source of the Ningxia section of the Yellow River (Figure 5). Data of 2020 were used considering that all parameters were monitored and the period was recent for illustrate the real situation. Two principal components were obtained after analysis with PC1 accounting for 79.5% of variation and PC2 describing 11.6% of variation (Figure 5). The first component might be agricultural activities while the second component was regarded as the domestic activities. Input of excessive nitrogen might induce the pollution of TN in the Ningxia section of the Yellow River, which might serve as the principal component. Therefore, stricter control strategies of nutrients especially nitrogen chemicals should be taken.

4. Conclusions

The variation of water quality parameters in the Ningxia section of the Yellow River during 2016–2020 was investigated. Most of the water quality parameters were good enough to be lower than Class II or Class III standards while TN exceeded Class III in 2018–2020 to show the pollution. The Nemerow index and contamination degree showed that water pollution occurred in the Ningxia section of the Yellow River during 2018–2020 due to high-concentration TN. Stricter environmental management strategies should be taken to decrease the TN concentrations for making water quality better in the study area.

Data Availability

The data used in the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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