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Research/Technical Note

Temporal Changes in Water Quality Parameters of Two Sections of the Ancient Canal: A Case of a Reach for Yangnong Chemical Plant

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Abstract: The water quality of the Ancient Canal has changed significantly due to the continuous urbanization of Yangzhou City. The main objective of this study was to reveal the temporal changes of conventional water quality parameters in a specific section of the Ancient Canal that flows through the Yangnong Chemical Plant. Two sections (Sec. 1 and Sec. 2) located upstream and downstream of this chemical plant, respectively, were chosen for observation of water quality parameters, including temperature (WT), pH, dissolved oxygen concentration (DO), electrical conductivity (EC) and total dissolved solids (TDS) content. The correlation coefficient method (CC), single factor index method (SFI) and variation coefficient method (VC) were used to analyze the data obtained from October 2015 to September 2016. The results indicated that (1) WT of Sec. 2 was higher than Sec.1 by an average of 0.8°C. In addition, the pH increased and decreased occasionally and with no obvious trend. The mean DO of Sec. 2 was 1.80 mg/L lower than that of Sec. 1. The EC and TDS of Sec. 2 were higher than those of Sec. 1; a relatively high correlation existed between the observed results of each corresponding parameter between Sec. 1 and Sec. 2. Overall, the water quality of Sec. 2 was worse than that of Sec. 1 over the study period; VC of the DO was the maximum, while the VC of the pH was the minimum. The results provide a partial basis for further studies on water quality of the Ancient Canal and urban river of Yangzhou City.

Keywords: Ancient Canal, Water Quality Parameter, Correlation Coefficient Method (CC), Single Factor Index Method (SFI), Variation Coefficient Method (VC)

1. Introduction

More than 60% of the world's rivers have undergone profound changes due to urbanization. Urbanization has become a main factor affecting the change of regional river networks [1, 2]. In China, the problem of urban water pollution is becoming very serious [3, 4]. In recent years, the discharge of urban domestic sewage has increased at a rate of 5% per year. More than 1/3 of industrial waste water and more than 90% of domestic sewage are discharged into rivers without treatment, which results in the loss of drinking water sources for 70% of urban rivers [5]. The deterioration of water quality caused by urban river pollution not only affects the normal development of urban functions but also poses a serious threat to the health and ecological safety of urban residents. The improvement of water quality of urban river networks is a pressing problem for many cities in China [6].

The China Grande Canal was added to the world cultural heritage list in June 2014. The Ancient Canal was the incipiency of the Grande Canal. It connects the Grande Canal and flows through Yangzhou City from north to south, into the Yangtze River. The total length is 28.1 km, and the urban stretch of the Yangzhou City is 14.3 km. Due to the control of sluices and dams at both ends, the flow discharge is small, with very little self-purification ability. The water quality of the Ancient Canal has changed significantly with the continuous urbanization of Yangzhou City. As the Ancient Canal was once an important sewage channel of Yangzhou City, dozens of sewage outlets existed along the river, and the river was seriously polluted. Although water quality has been greatly improved in recent years through river regulation and sewage interception, the amount of wastewater discharge is increasing year by year, and the water pollution has not been fully mitigated [7]. As the central axis of the urban river network, the Ancient Canal joins many rivers in the urban area, plays an important role in tourism, decontamination and water transport of Yangzhou City. Therefore, the investigation and monitoring of the water quality of the Ancient Canal can provide fundamental data not only for the continuous study of the water quality of the Ancient Canal but also for the improving regulations and policies regarding the quality of urban river networks.

2. Materials and Methods

2.1. Study Location and Local Observation

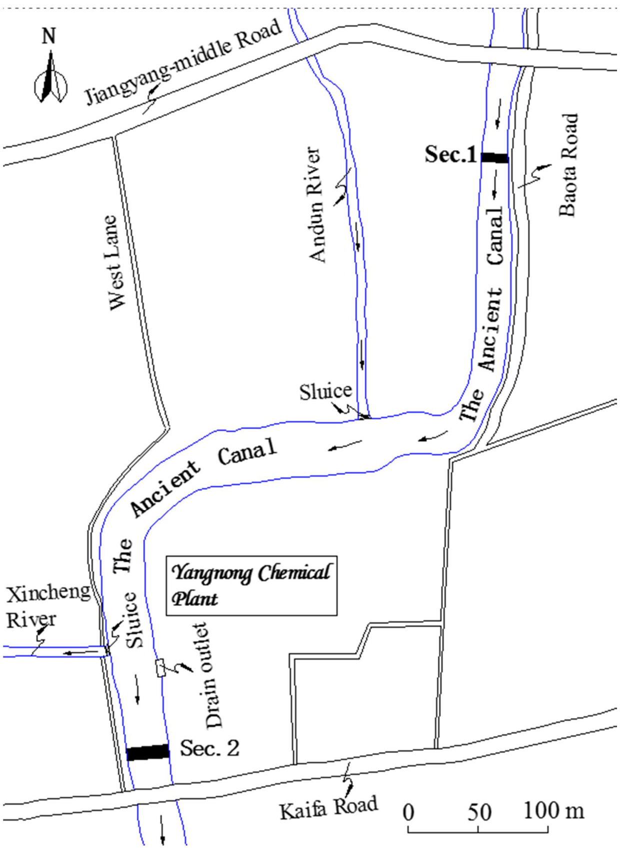

Figure 1. *Sketch of the study location.*

A section of the Ancient Canal that flows through the Yangnong Chemical Plant was selected as the study location (Figure 1). The Yangnong Chemical Plant has continuously discharged industrial wastewater for many years, which greatly impacts the water quality of the downstream sewage outlet. Two sections (Sec. 1: upstream section, 32°22′58.69″ N, 119°25′32.3″ E; Sec. 2: downstream section, 32°22′20.37″ N, 119°25′0.42″ E) were chosen for water quality monitoring. Observation of conventional parameters, including WT, pH, DO, EC and TDS, (Instrument: Multi parameter water quality analyzer, mode: 615, *Australia*) was performed on water samples collected at Sec. 1 and Sec. 2. The time interval of observation was 3 days, and the period for observation was one year (October 2015 to September 2016)

2.2. Methods

2.2.1. Correlation Coefficient Method (CC)

CC was adopted to evaluate the degree of correlation of each corresponding parameter between Sec.1 and Sec.2 in the temporal process from October 2015 to September 2016. The formula is as follows [8]:

$$r=\frac{\sum_{i=1}^{n}(X_i-\overline{X})(Y_i-\overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i-\overline{X})^2\cdot\sum_{i=1}^{n}(Y_i-\overline{Y})^2}} \tag{2}$$

where Y_i is the observed result of a parameter at Sec. 1; X_i is the observed results of the corresponding parameter at Sec 2; $\bar{Y}$is the mean of the observed results of a parameter at Sec.1; $\bar{X}$is the mean of the observed results of the corresponding parameter at Sec. 2.

2.2.2. Single Factor Index Method (SFI)

SFI is a method for determining the degree of water quality by comparing the measured concentration of certain pollutants with the evaluation criteria of the pollutants. In other words, the classification of water quality is determined by comparing the measured results of a parameter with the national environmental quality standard for surface water (GB3838 — 2002). SFI assesses the influence of a parameter with the most serious pollution situation. Therefore, it is important to highlight the most critical evaluation factor for the entire evaluation result, and the role of other factors is less significant [9, 10]. SFI is composed of one integer and two or three significant figures after the decimal point. It is expressed as follows:

$$P_i = X_1.X_2X_3 \tag{2}$$

where, X_1 is water quality classification evaluated by the SFI of a parameter; X_2 is the location of measured data in the water quality classification of X_1. Its value is determined by rounding based on the calculated results. X_3 compares the water quality classification and the standard classification of functional zoning. It is one significant digit or two significant digits, according to the degree of pollution.

2.2.3. Variation Coefficient Method (VC)

VC is a statistical index, often used to measure the difference between data. It is expressed as the ratio of the standard deviation and the average value of the data series. It is a relative value that is simultaneously affected by standard deviation and average value. When comparing two or more than two samples, VC is not limited by standard deviation and average value. As VC increases, the degree of volatility increases [11, 12], and it is calculated by equation (3).

$$V_j = \frac{S_j}{Q_j} \tag{3}$$

where, V_j is the VC of a water quality parameter; S_j is the standard deviation of this water quality parameter; Q_j is the mean value of this water quality parameter; S_j and Q_j are calculated by equation (4) and equation (5), respectively.

$$S_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{ij} - Q_j)^2} \tag{4}$$

$$Q_j = \frac{1}{n}\sum_{i=1}^{n} X_{ij} \tag{5}$$

3. Results and Discussion

3.1. Correlation Analysis

CC of the corresponding water quality parameters in temporal process, including WT, pH, DO, EC, and TDS, between Sec. 1 and Sec. 2 from October 2015 to September 2016 are represented in Table 1.

Table 1. *CC of the corresponding water quality parameters between Sec. 1 and Sec. 2 (October 2015 to September 2016).*

CC	WT	pH	DO	EC	TDS
r	0.99	0.95	0.87	0.91	0.91

A significant positive correlation exists between the WT measurements of Sec. 1 and Sec. 2 (CC=0.99), according to the results in Table 1. Figure 2 depicts a similar change in WT for Sec. 1 and Sec. 2 during the observation period. The mean WT values of the observed period for Sec. 1 and Sec. 2 were 17.9°C and 18.7°C, respectively, with a difference of 0.8°C. The WT of Sec. 2 was higher than that of Sec. 1 from late January to late June 2016. An obvious temperature difference was also found from February 29 to March 7, 2016. The maximum difference measured was 4.5°C (March 7). The WT of Sec. 2 was almost always higher than that of Sec. 1 (Figure 2), which indicated the drainage of the chemical plant increased the WT in that section.

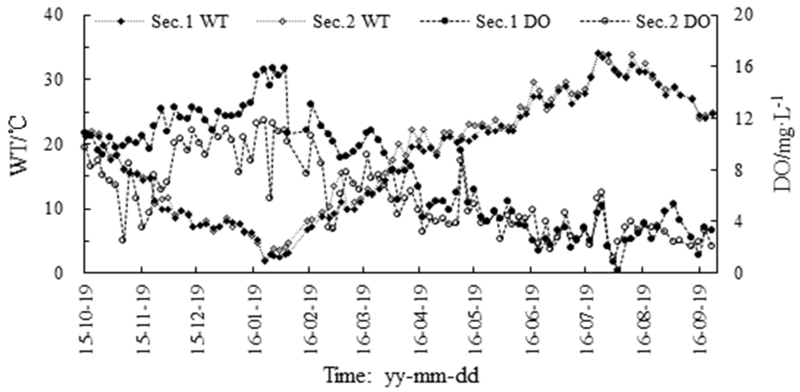

Figure 2. *Temporal change in WT and DO for Sec.1 and Sec.2 from October 19, 2015 to September 27, 2016.*

The CC of DO measurements for Sec. 1 and Sec. 2 was 0.87, which proved the variation in DO in the two sections followed a similar trend (Figure 2). The mean DO values for Sec. 1 and Sec. 2 were 7.73 mg/L and 5.93 mg/L, respectively. The difference was 1.80 mg/L. The DO of Sec. 2 was obviously lower than that of Sec. 1 in some periods, such as from October 19, 2015 to June 9, 2016. In this period, the mean DO values for Sec. 1 and Sec. 2 were 9.82 mg/L and 7.14 mg/L, respectively. The difference attained 2.68 mg/L. Sec. 2 is located downstream and close to the drain outlet. The chemical plant drainage caused to temporal decrease in DO in this section of the Ancient Canal.

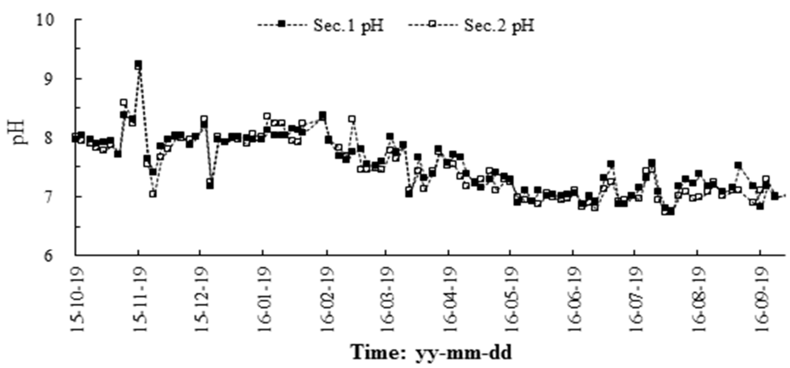

Figure 3. *Temporal change in pH for Sec. 1 and Sec. 2 from October 19, 2015 to September 27, 2016.*

A significant positive correlation exists between the pH of Sec. 1 and Sec. 2, as the CC value was 0.95. The mean pH values of Sec. 1 and Sec. 2 were 7.54 mg/L and 7.49 mg/L, respectively, with a difference of 0.05 mg/L. Although the pH measurements of the two sections exhibit a similar temporal variation trend, the pH of Sec. 2 was occasionally higher or lower than Sec. 1. From February 20 to March 3, 2016, the mean pH values of Sec. 1 and Sec.2 were 7.74 and 7.94, respectively, while from August 31 to September 15, 2016, the means were 7.22 and 7.02, respectively (Figure 3). Therefore, the chemical plant drainage caused occasional increases or decreases in pH near the outlet.

The CC of EC measurements for Sec. 1 and Sec. 2 was 0.91, which indicates that a significant positive correlation exists between EC of the two sections. Figure 4 shows the EC measurements of Sec. 2 were mostly higher than that on Sec. 1 from September 2015 to October 2016. The mean EC values of Sec. 1 and Sec. 2 were 97.8 μS/cm and 108.6 μS/cm, respectively, with a difference of 10.8 μS/cm. In April of 2016, a significant difference in the EC of the two sections was observed. The mean EC values of Sec. 1 and Sec. 2 were 113.2 μS/cm and 135.3 μS/cm, respectively. Throughout the observed period, the EC of Sec. 2 was higher than Sec. 1, which indicates that chemical plant drainage increased the amount of impurities in this section of the Ancient Canal, and the water quality, therefore, decreased.

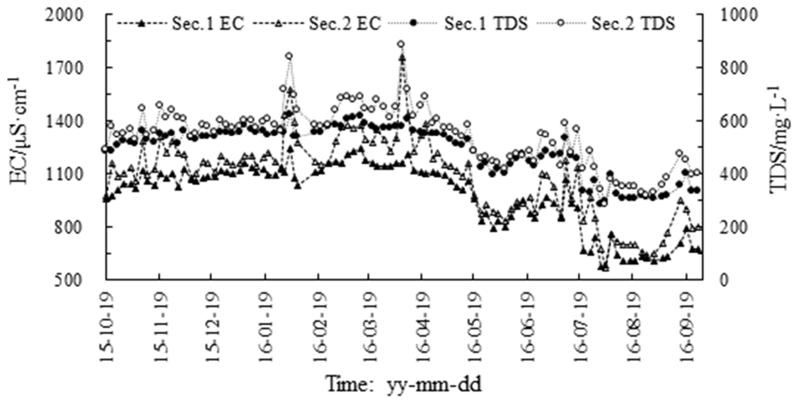

Figure 4. *Temporal change in EC and TDS for Sec. 1 and Sec. 2 from October 19, 2015 to September 27, 2016.*

The CC of the TDS measurements for Sec. 1 and Sec. 2 was 0.91, which indicates a similar trend in TDS for the two sections (Figure 4). TDS of Sec. 1 was lower than that of Sec. 2 from October 2015 to September 2016. The mean TDS values in this period for Sec. 1 and Sec. 2 were 49.0 mg/L and 54.4 mg/L, respectively, with a difference of 5.4 mg/L. In April 2016, a significant difference in TDS between Sec. 1 and Sec. 2 was observed, and the means were 56.6 mg/L and 67.6 mg/L, respectively (a difference of 11.0 mg/L). The temporal change in TDS was similar to the change in EC for the two sections. Figure 4 shows the TDS measurements for Sec. 1 were lower than that of Sec. 2, for the most part. This indicates the chemical plant drainage increased the amount of impurities in the river water, causing the TDS to increase.

3.2. SFI Analysis

DO is one of the most important indexes for evaluating water quality of rivers, reservoirs and other water bodies [13-15]. Equation (2) was adopted to calculate monthly SFI of DO (P_i) from October 2015 to September 2016, and the results are shown in Figure 5.

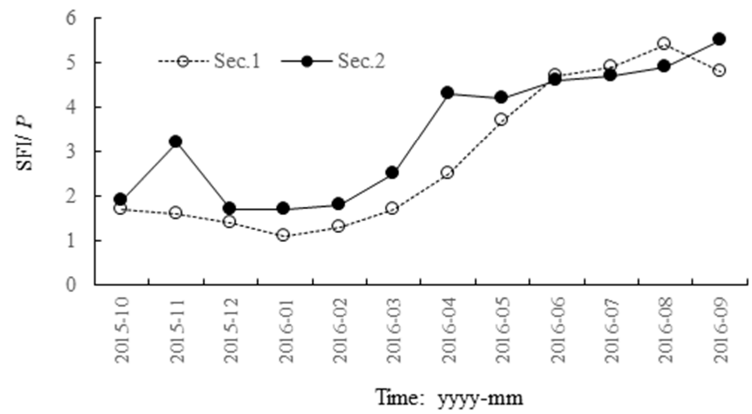

Figure 5. *Temporal change in SFI of DO for Sec. 1 and Sec. 2.*

The water quality standard for water functional area of the Ancient Canal is classification Ⅲ. The SFI (P_i) of DO for Sec. 1 from October 2015 to May 2016 was between 1.30 and 3.70. Therefore, X_1 (Eq. 2) was 1 or 2 or 3, meaning the DO index during this period met the national water quality standards of China (classification I, II or III "GB3838: surface water environmental quality standard"). The DO of this section of the river met the water quality standard of water functional area from October 2015 to May 2016. However, from June to September in 2006, P_i was between 4.72 and 5.42, X_1 was 4 or 5, and the DO index was classified as IV or V, meaning this section of the river did not meet the national water quality standards. For Sec.2, P_i was 1.10-3.50 in October 2015, and from December 2015 to March 2016, the DO values met the national water quality standards of classification I, II or III. In November 2015, and from April to September 2016, P_i was between 4.11 and 5.52 (X_1 was 4 or 5), which indicates the DO index was classified as IV or V, thus, the DO of this section of the river did not meet the water quality target of water functional area.

Figure 5 shows P_i of Sec. 2 was greater than that of Sec. 1 from December 2015 to May 2016, which indicates water quality of Sec. 2 was worse than Sec. 1, despite the classifications in this period. Moreover, in summer of 2016 from June to September, the water quality of the two sections was worse than in winter and spring (from November 2015 to May 2016).

3.3. VC Analysis

The calculated VC results of the corresponding series of water quality parameters (WT, pH, DO, EC and TDS) of Sec. 1 and Sec. 2 from October 2015 to September 2016 are shown in Table 2.

Table 2. *Calculated VC results.*

Parameter	*WT*	*DO*	pH	*EC*	*TDS*
Sec.1	0.50	0.55	0.06	0.19	0.19
Sec.2	0.48	0.50	0.07	0.21	0.21

The VC values of DO measurements for Sec. 1 and Sec. 2 were 0.55 and 0.50, respectively, which was the highest among the five parameters of WT, DO, pH, EC, and TDS for both Sec.1 and Sec. 2, and indicates the dispersion degree of the DO was the maximum (Table 2). The VC values of pH for Sec. 1 and Sec. 2 were 0.06 and 0.07, respectively, which indicates the dispersion degree of pH was the lowest of the five parameters. Whereas, the dispersion degree of pH of Sec. 2 was slightly higher than that of Sec. 1. The VC values of WT were 0.50 and 0.48, respectively. The dispersion degree of WT for Sec. 1 and Sec. 2 was not significant different; however, a significant difference exists between the WT of Sec. 1 and Sec. 2 for some corresponding time points (Figure 1). The VC of the WT measurements followed a similar trend to that of the DO measurements for the two sections. WT gradually decreased from October 2015 to January 2016, while DO increased. The WT and DO exhibit the opposite changing trend. The VC values of EC and TDS for Sec. 1 and Sec. 2 were 0.19 and 0.21, respectively, which indicates similar temporal processes and dispersion degree of EC and TDS for Sec. 1 and Sec. 2 (Figure 4). The dispersion degree of both EC and TDS for Sec 2 was slightly greater than those of Sec. 1.

Two tributaries flow into the Ancient Canal between Sec. 1 and Sec. 2; one is the Andun River and the other is the Xincheng River (Figure 1). Water exchange occurs between these two tributaries and the Ancient Canal. A sluice is installed at the intersection between the Andun River and the Ancient Canal. This sluice is opened once a month of a period of 24h. A sampling survey was conducted at the intersection, and the measured values of WT, DO, pH, EC and TDS approximately correspond to that of Sec. 1. A sampling survey was also conducted at the intersection between the Xincheng River and the Ancient Canal, because this intersection is close to the drain outlet of the chemical plant. The result of each parameter was approximate to that of Sec. 2.

4. Conclusion and Remarks

In this study, water quality parameters were measured and evaluated for two sections of the Ancient Canal near the Yangnong Chemical Plant. The main conclusions for temporal changes in water quality parameters are based on the analysis of data obtained from October 2015 to September 2016, as follows.

(1) WT, EC and TDS increased, DO decreased, and pH changed occasionally in the section of the river near the drain outlet of the Yangnong Chemical Plant.

(2) A relatively high correlation exists between the corresponding series of each water quality parameter of the upstream section and the downstream section, relative to the Yangnong Chemical Plant.

(3) The DO index indicates water quality downstream of the Yangnong Chemical Plant was worse than upstream of the plant.

The results provide a foundation for future studies on the water quality of the Ancient Canal and a method reference for evaluating water quality of other urban rivers.

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