Temporal variation and water quality assessment of Xiaoqing River catchment

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Abstract. Xiaoqing River plays an important role in water supply, flood control and ecological protection in Shandong Province. The deterioration of water quality seriously threatens the safety of drinking water for local residents and water ecological environment. In order to investigate the present situation of Xiaoqing River, the cluster analysis was used to study the temporal variation of water quality, and the composite pollution index was used to assess the river water, lake and reservoir water quality. The temporal variation of COD$_C$, COD$_M$, total nitrogen, total phosphorus and ammonia in the river water was discussed from the year of 2009 to 2016. The results found that the water quality of Xiaoqing River has improved with time on the whole. The results found that total nitrogen was the major pollutant during all the sampling points. And the Mashang sampling station has the worst water quality. The result can help provide the references for the prevention and control of river water pollution and water ecological imbalance in the Xiaoqing River basin.

1. Introduction
Water is one of the important nature resources that enable the survival of living organisms on earth. Although China has been working on water resources protection since the 1970s, the pollution of water resources in China is still spreading gradually. With the rapid development of industry and the continuous improvement of people's living standards, the problem of large quantities of production, domestic sewage and agricultural sewage being discharged without treatment is becoming more and more serious, which leads to the low water efficiency in China's industry and agriculture[1-3]. Xiaoqing River plays an important role in water supply, flood control and ecological protection for Shandong province. With the continuous increase of population, rapid economic development, industrialization and urbanization, water pollution and water ecological destruction problem has attracted much attention in recent years.

The present study of water quality mainly focused on the temporal and spatial variation of water quality and water pollution assessment. Edoreh has found that 12 kinds of water parameters showed obvious seasonal changes in the Delta State[4]. Bettencourt investigated spatial variation of water quality in southeastern coast of Brazil via remote sensing data and discussed the effects of industrialization and rainfall on water quality[5]. Xiang has analysed the temporal and spatial variation of water quality of Erhai Lake[6]. Liu has discussed the water quality of Zhangwei River in Guizhou province[7]. Wu has studied the variation of Daheiting reservoir water quality at different sampling depths (0.5 m, 5 m, 7 m, 10 m, 15 m and 20 m) in different sampling periods in 2018[8]. In recent years, water quality assessment methods have been improved constantly. The evaluation of river water
quality is the basis for the rational development and utilization of river water resources, and can also provide reference basis and data support for the protection of river water resources.

2. Material and methods

The Xiaoqing River was located in the middle (116.80°-118.99°E, 36.27°-37.33°N) of Shandong province, with a total area of 10336 km², the 237 km-long. The river is one of the key rivers in Shandong Province, and it is the only flood discharge channel in Jinan and its coastal areas.

Xiaoqing River basin is located in the semi-arid and semi-humid region of north China, which is a typical temperate continental monsoon climate. The annual rainfall was 617.2 mm and the annual temperature was 12.9 °C.

Water samples were collected from eight typical surface water sampling stations, which included four river water sampling points, two lake water sampling points and two reservoir sampling points (Figure 1) from 2009 to 2016. River water samples were collected about 50 cm below the water surface in the sampling section. Water samples were transported and kept at 4 °C during storage. River water samples were analysed for COD$_{cr}$, COD$_{Mn}$, Total nitrogen (TN), Total phosphorus (TP) and ammonia (NH$_4$-N). Concentrations of TP, TN and NH$_4$-N were measured colorimetrically using a spectrophotometer (JH756 UV/Vis spectrophotometer, Jinghua, Shanghai, China). COD was analyzed using the spectrophotometer method (DR/2400 spectrophotometer, Loveland, Colorado, USA) [9].

![Figure 1. The distribution of eight sampling points in the Xiaoqing River basins](image)

The temporal variation of Xiaoqing River water quality was analyzed via Cluster analysis (CA). CA is a multivariate statistical technique that classifies variables or samples according to multiple variables [10,11]. The above five water quality parameters were used to classify the samples and the Q-type clustering was used. The measured interval is the Euclidean distance matched with the Walder method.

The monitoring data collected from the water body of river water, lake water and reservoir were analyzed with the method of comprehensive pollution index, using the following equation:

$$ P = \frac{1}{n} \sum_{i=1}^{n} P_i $$

Where P is the composite pollution index; n is the number of water quality indicators.

The pollution load rate was calculated using the following equation:
3. Results

3.1. Spatial variation of water quality

The spatial variation of total nitrogen (TN), total phosphorus (TP), ammonia (NH\textsubscript{4}-N), chemical oxygen demand (COD\textsubscript{Cr}) and chemical oxygen demand (COD\textsubscript{Mn}) are shown in Figure 2. As shown in Fig 2, the concentration of COD\textsubscript{Cr} ranged from 30 mg/L to 60 mg/L. And the highest concentration of COD\textsubscript{Cr} was 58.8 mg/L in the year of 2009. The COD\textsubscript{Cr} concentration decreased generally with time. The concentration of COD\textsubscript{Mn} ranged from 8.8 mg/L to 19.3 mg/L. Although the concentration of COD\textsubscript{Cr} was much higher than the COD\textsubscript{Mn}, the variation trend of COD\textsubscript{Cr} with time was similar with COD\textsubscript{Mn}. In addition, the result found that there existed a linear correlation between the concentration of COD\textsubscript{Cr} and COD\textsubscript{Mn} ($R^2=0.65$, $P<0.01$).

The concentration of TN ranged from 7.25 mg/L to 19.6 mg/L, which exceeded surface water Class V water standard. The concentration of TN generally decreased from the year of 2009 to 2016. The result showed that the pollution of total nitrogen was serious in the surface water. The concentration of NH\textsubscript{4}-N decreased generally with time, and the highest concentration (5.08 mg/L) found in 2009, the lowest concentration (0.62 mg/L) found in 2016.

The concentration of TP ranged from 0.4 mg/L to 1.54 mg/L, which exceeded surface water Class V water standard. The results investigated that the all of the water quality of Xiaoqing River showed an improvement overall from 2009 to 2016. The government has given high priority to the protection of Xiaoqing River in recent years. Thus, the pollution control and harness in the river basin has been be strengthened.

![Figure 2. The temporal variation of TN, TP, COD\textsubscript{Cr}, COD\textsubscript{Mn}, and NH\textsubscript{4}-N concentration from 2009 to 2016](image)

3.2 Cluster analysis of annual change

The result of cluster analysis of water quality annual change was presented in Figure 3. Based on the cluster analysis of annual change, annual variation of water quality can be classified to three categories. For different years, the year of 2009 and 2010 belongs to the first class, the year of 2013 and 2014
belongs to the second class, the year of 2011, 2012, 2015 and 2016 belongs to the forth class. The results showed that the water quality of Xiaoqing River shows a trend of improvement as a whole accompanied by occasional fluctuations. According to the survey, the river started to implement comprehensive treatment in 2009, water quality improved significantly in subsequent years. However, water quality declined and pollution was serious in 2013 and 2014, which is due to a significant emissions increase of any pollutant from agriculture and industry. Till 2015, because of expansion of a large sewage treatment plant, laying of large-scale sewer networks, the sewage treatment capacity of the Xiaoqing River has enhanced obviously. Therefore, the results showed that the river water quality improved in the year of 2015 and 2016.

![Figure 3. Cluster analysis of water quality annual change](image)

### 3.3 Water quality assessment

The results of water quality assessment via composite pollution index were presented in Table 1. The results indicated that the water quality of lake and reservoir was moderately and lightly polluted, the water quality of river water was between heavy and severe pollution. The water quality of lake and reservoir was obviously better than the river water. Among the water samplings, the water quality in Mengshan reservoir was the best, and the water quality in Mashang was the worst. Except Daming lake, Linli lake and Taihu reservoir, water quality of the other five sampling points, the worst water quality occurred in the year of 2009 during the sampling periods.
Table 1. The water quality evaluation results of composite pollution index method in Xiaoqinghe River Basin

| Sampling points | Year | P    | Water quality | KCODMn | CODCr | NH4-N | TP  | TN  |
|-----------------|------|------|---------------|--------|-------|-------|-----|-----|
| Binzi Qiao      | 2009 | 2.99 | severe        | 0.09   | 0.1   | 0.1   | 0.26| 0.46|
|                 | 2010 | 2.65 | severe        | 0.07   | 0.09  | 0.16  | 0.23| 0.44|
|                 | 2011 | 2.66 | severe        | 0.06   | 0.06  | 0.18  | 0.2 | 0.5 |
|                 | 2012 | 1.75 | heavy         | 0.09   | 0.11  | 0.13  | 0.11| 0.54|
|                 | 2013 | 2.13 | severe        | 0.06   | 0.08  | 0.17  | 0.19| 0.5 |
|                 | 2014 | 2.53 | severe        | 0.06   | 0.09  | 0.18  | 0.3 | 0.37|
|                 | 2015 | 1.45 | heavy         | 0.08   | 0.12  | 0.09  | 0.18| 0.52|
|                 | 2016 | 1.34 | heavy         | 0.09   | 0.11  | 0.05  | 0.21| 0.54|
| Chahe           | 2009 | 2.87 | severe        | 0.04   | 0.1   | 0.33  | 0.04| 0.48|
|                 | 2010 | 2.78 | severe        | 0.05   | 0.1   | 0.31  | 0.05| 0.48|
|                 | 2011 | 2.34 | severe        | 0.05   | 0.06  | 0.2   | 0.07| 0.62|
|                 | 2012 | 1.94 | heavy         | 0.06   | 0.08  | 0.2   | 0.06| 0.5 |
|                 | 2013 | 2.42 | severe        | 0.04   | 0.07  | 0.19  | 0.11| 0.59|
|                 | 2014 | 2.63 | severe        | 0.04   | 0.08  | 0.17  | 0.11| 0.59|
|                 | 2015 | 2.54 | severe        | 0.04   | 0.09  | 0.15  | 0.09| 0.63|
|                 | 2016 | 2.38 | severe        | 0.04   | 0.08  | 0.11  | 0.11| 0.66|
| Daminghu        | 2009 | 0.79 | medium        | 0.06   | 0.09  | 0.04  | 0.08| 0.73|
|                 | 2010 | 0.86 | medium        | 0.04   | 0.06  | 0.04  | 0.07| 0.79|
|                 | 2011 | 0.77 | medium        | 0.05   | 0.08  | 0.02  | 0.1 | 0.75|
|                 | 2012 | 1.03 | heavy         | 0.05   | 0.06  | 0.03  | 0.1 | 0.77|
|                 | 2013 | 0.9  | medium        | 0.05   | 0.09  | 0.05  | 0.12| 0.69|
|                 | 2014 | 0.81 | medium        | 0.05   | 0.1   | 0.04  | 0.09| 0.73|
|                 | 2015 | 0.8  | medium        | 0.05   | 0.09  | 0.03  | 0.06| 0.76|
|                 | 2016 | 0.9  | medium        | 0.04   | 0.04  | 0.03  | 0.08| 0.81|

The results also found that TN in all sampling sites had the highest pollution load rate. The pollution load rate of TN in the lake and reservoir was higher than that in the river water. The value of TN pollution load rate in lake and reservoir sampling points, except the Mengshan reservoir, was around 70%. While pollution load rate of other water quality parameters in river water sampling was relatively low.

4. Conclusion
The temporal variation of Xiaoqing River water quality including the concentration of CODCr, CODMn, TN, TP and NH4-N was discussed. And the method of cluster analysis was used to investigate the annual change of Xiaoqing River quality. The result found that the Xiaoqing River gradually improved from 2009 to 2016, which was owing to the implement of comprehensive reclamation of river basin since 2009. But the water quality deteriorated in 2013 due to a surge in domestic sewage, livestock and industrial pollution. The composite pollution index was used to assess the river water, lake and reservoir water quality in the Xiaoqing River basin. The results showed that TN was the major pollutant in the Xiaoqing River basin. Based on the above conclusion, much more attention should be paid to prevent and control water environmental pollution, such as expanding or building new sewage treatment plants, strengthening the construction of urban drainage networks, regulating sewage outlets into rivers, and implement the system of river chiefs.

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References

[1] Yu, Y.L.; Song, X.F.; Zhang, Y.H.; Zheng, F.D.; Liu, L.C. Impact of reclaimed water in the watercourse of Huai River on groundwater from Chaobai River basin, Northern China. Front. Earth Sci. 2017, 11, 643–659.

[2] Ernst, M.; Sperlich, A.; Zheng, X.; Gan, Y.; Hu, J.; Zhao, X.; Wang, J.; Jekel, M. An integrated wastewater treatment and reuse concept for the Olympic Park 2008, Beijing. Desalination. 2007, 202, 293–301.

[3] Zheng, F.D.; Liu, L.C.; Li, B.H.; Yang, Y.; Guo, M.L. Effects of reclaimed water use for scenic water on groundwater environment in a multilayered aquifer system beneath the Chaobai River, Beijing, China: Case Study. J. Environ. Eng. 2015, 20.

[4] Edoreh, J.A., Inegbenosun, C.U., Elimhingbovo, I.O., et al. Spatial and temporal variation in physico-chemical parameters at Ugbevwe Pond, Oghara, Delta State. Tropical Freshwater Biology. 2019, 28(2): 141-157.

[5] Bettencourt, P., Wasserman, J.C., Dias, F.F., et al. Remote Sensing Applied to the Evaluation of Spatial and Temporal Variation of Water Quality in a Coastal Environment, Southeast Brazil. Journal of Geographic Information System. 2019, 11(05): 500-521.

[6] Xiang, S., Wan, L., Pang, Y., Spatial-temporal variation of inflow river water quality under land use effect [J]. Journal of Agro-Environment Science, 2020, 39(01): 160-170.

[7] Liu, X.M., Zhou, Z.F., Zhang, H.T., et al., Assessment Of Water Quality And Its Spatial And Temporal Characteristics Of Rivers In Karst Mountain Area Based On Principal Component Analysis: A Case Study On Zhangwei River In Guizhou Province. Environmental Engineering. 2019, 37(10): 49-54+132.

[8] Wu, t., Wang, J.B., Hao, Z.X., Spatio-temporal characteristics of water quality in Daheiting Reservoir and downstream water transfer strategy[J]. Water Resources Protection, 2020, 36(2): 65-72.

[9] Wei, F.S.; Qi, W.Q.; Sun, Z.G.; Huang, Y.R.; Shen, Y.W. Water and Wastewater Monitoring and Analysis Method; China Environmental Science Press: Beijing, China, 2002; ISBN 978-7-8016-3400-9.

[10] Zhao, J.G. Spatio-temporal distribution and migration of nitrogen and phosphorus in the Huailai section of the Yongding River. Heibei University. 2018

[11] Tang, Y., Lu, Y.M., Wu, S., Spatio-temporal Distribution and Source Identification of Water Pollutants in Minjiang River Basin. Journal of Yangtze River Scientific Research Institute, 2019, 36(08): 30-35+48.