Study on the Spatio-temporal Differences of Water Pollution in Shandong Province from 2010 to 2017

Xiaowei Wang1,*
1School of tourism, Shandong Women’s University, Jinan, China

*Corresponding author e-mail: wxw_sd1@163.com

Abstract. Water is the source of life. Water is not only the main component of the body, but also many physiological functions. Water resources are the basic resources and basic conditions on which humans depend. This paper uses the data of Shandong Statistical Yearbook (2011-2019) and ArcGIS spatial analysis technology to study the spatial and temporal distribution pattern of water pollution in Shandong Province from the perspective of wastewater. The results show that the wastewater discharge from 2010 to 2017 shows an overall upward and downward trend. In 2015, compared with 2010, the wastewater discharge increased by a net increase of 113.158 million tons, with an average annual increase rate of 5.22%. In 2015, the amount of wastewater discharged was reduced by 50.346 million tons, with an average annual decline rate of 4.58%. From the time distribution characteristics of water pollution in Shandong Province, the wastewater discharge in Weifang, Qingdao, and Jining accounts for 29.20% of the province's wastewater discharge. The water pollution in the central region is more serious, showing a heavy-light pollution distribution. At present, lightly polluted flower arrangement enclaves appear. From the perspective of the spatial distribution characteristics of water pollution in Shandong Province, the gaps between severe water pollution conditions in different cities have gone from increasing to decreasing. The water pollution situation in the province is obvious, the distribution of cold and hot spots is obvious, and Qingdao is a wastewater discharge hot spot (Z = 2.24> 2.0), Weihai is a cold spot area for wastewater discharge (z = -1.11 <-1.0).

1. Introduction
Water resources are the basic resources and basic conditions necessary for human survival. According to the definition of water resources in the International GLOSSARY OF HYDROLOGY published by the World Meteorological Organization (WMO) and UNESCO, water resources refer to water sources that can be used or are likely to be used. This water source should be of sufficient quantity and suitable quality, and meet the needs of a specific use of a place over a period of time. With the increasing population in the 21st century, the increasing living standards of the people, and the increasing demand for water resources, environmental stress has become a major bottleneck restricting the sustainable development of China's economy and society. Ensuring the recycling and clean use of water resources is the primary task of human survival and development. The promotion of urbanization, the development of the secondary industry, and population growth are the main driving factors of China's industrial wastewater discharge[1]. Relevant research at home and abroad has mainly focused on the ecological safety research of wastewater treatment[2], the factors affecting wastewater discharge[3,4], and the relationship between industrial land and water body pollutant concentrations[5]. Wastewater discharge contains a variety of toxic and harmful substances, which
have large discharge amounts and are difficult to handle. The pollution of water bodies has become increasingly widespread and aggravated, which directly threatens the safety of the ecological environment and human life and health. Population density has an impact on environmental pollution, and places higher requirements on controlling population density and the speed of urbanization in various regions. With the acceleration of urbanization, many cities have suffered from large-scale urban diseases such as traffic congestion and air pollution. The extremely high population flow and excessive population density have stimulated demand, brought excessive waste water, waste gas and solid waste in production and life, and affected the ecological environment quality of the city. This paper uses the data of Shandong Statistical Yearbook for 9 consecutive years from 2011 to 2019, and uses ArcGIS spatial analysis technology to study the spatial and temporal distribution pattern of water pollution environment in Shandong Province. Water safety and capacity for sustainable development, in order to clarify the key areas for joint prevention and control of wastewater discharge at the provincial level, provide practical countermeasures for further optimization and improvement of prevention and control strategies, provide decision-making reference for water pollution treatment in Shandong Province, and provide reference for sustainable development of water resources.

2. Research scope and research data

2.1. Area of research
Shandong Province, a coastal province in East China, is simply referred to as Lu, the capital of Jinan. It is located on the eastern latitude of 34°22.9′-38°24.01′ on the eastern coast of China, and is between 114°47.5′-122°42.3′ on the longitude east. Shandong Province belongs to the three major river basins of Yellow, Huai, and Hai. Except for the Yellow River running through the east and west, and the Grand Canal running north-south, the other small and medium-sized rivers are densely packed in Shandong Province. Lake, Ma Dahu, etc. The main characteristics of water resources in Shandong Province are: insufficient total water resources; low per capita and acres; uneven distribution of water resources in regions; violent changes from year to year; and close connection between surface water and groundwater. The total amount of water resources in Shandong Province accounts for only 1.09% of the country's total water resources, and the per capita water resources are 334 cubic meters, which is only 14.9% (less than 1/6) of the national average, and 4.0% of the world's (1/25), ranking third in the provinces (municipalities, autonomous regions) of the country, far less than the internationally recognized threshold of 1,000 cubic meters necessary to maintain economic and social development in a region, per capita occupation is less than 500 cubic meters Areas of severe water shortage[6]. The centralized discharge of pollutants is an inevitable result of the agglomeration of polluting industries. To prevent the agglomeration of polluting industries from damaging the water environment, it is necessary to strengthen the control of pollution discharge, make use of the characteristics of centralized discharge in the agglomeration area, and make the level of environmental governance and the pollution discharge in the agglomeration area. The quantity is matched to form a "economy of scale" for water pollution control. According to the regional differences in the effects of driving factors, we should formulate industrial wastewater prevention and control measures according to local conditions, pay attention to the control of population density and urbanization speed, handle the relationship between economic development and environmental protection, and practice ecological priority and green development[7]. The extent of water resources development, the deterioration of water quality, the intrusion of seawater, the depletion of spring water resources, and the contradiction between industrial and agricultural water use are the existing problems of water resources in Shandong Province. The delineation of water function zones and the enhancement of real-time monitoring of water quality will be beneficial to the control of wastewater discharge, the clean conversion of wastewater and the adjustment and adjustment of industrial structure, and to promote the conversion of new and old kinetic energy and the construction of a resource-saving and environment-friendly society in Shandong Province.
2.2. Data sources

The water pollution data are derived from the water environment information in the "Shandong Province Statistical Yearbook (2011-2019)" published by the Statistics Bureau of Shandong Province. The water environment information from 2010 to 2017 is compiled. Water pollution information in 16 cities including Jinan, Qingdao, Zibo, Zaozhuang, Dongying, Yantai, Weifang, Jining, Tai’an, Weihai, Rizhao, Linyi, Dezhou, Liaocheng, Binzhou, and Heze. Since 2010, water pollution in Shandong Province has undergone a process of change from heavy to light. In 2015, compared with 2010, wastewater discharge increased by a net increase of 113.895 million tons to 26.09 percentage points, with an average annual increase rate of 5.22%. Wastewater discharge reached its maximum in 2015. In 2017, it was a net reduction of 503.46 million tons from 2015, reaching 9.15 percentage points, with an average annual decrease rate of 4.58%. From the perspective of linear fitting, the overall sewage discharge is increasing, $R^2 = 0.605$, and the linear slope is $+11894$. In 2015, the State Council issued and implemented the "Water Pollution Prevention and Control Action Plan" (referred to as the "Water Ten"), which brought historic and turning changes to water pollution control. That is, the "three waters" integrated water environment management system has made bright and breakthrough explorations to improve the new mechanism for pollution prevention[8,9]. At the end of 2015, the provincial government formally issued the "Implementation Plan for the Implementation of the" Water Pollution Prevention Action Plan "in Shandong Province", Provincial river basin pollution control work has made comprehensive arrangements and deployment, and the implementation of the water pollution prevention and control action plan should be an important reason for the reduction of wastewater discharge starting in 2016. Taking 2015 as the boundary, before 2015, the waste water discharge in Zaozhuang City showed a decreasing trend, a reduction of 18.57 million tons, and the average annual decline rate reached 1.50%; the overall trend of waste water discharge in other cities is the same as that of the province, with the most waste water discharge Qingdao City increased by 15.79 million tons with a growth rate of 39.52%. The least increase was in LiaoCheng with an increase of 34.44 million tons with a growth rate of 11.13%. After 2015, with the exception of Qingdao and Jining cities, where wastewater discharge increased, other cities are in line with the province's trend. Qingdao City increased 1.86 million tons, a growth rate of 0.35%; Jining City increased 3.29 million tons, a growth rate of 0.72%. Liaocheng City has the fastest decline in wastewater discharge, which fell 125.29 million tons in two years, a decrease rate of 36.44%; Linyi City, which has the least decline in wastewater discharge, decreased 702 tons, a decrease rate of 1.51%.

3. Results and analysis

3.1. Time distribution change

3.1.1. Early distribution characteristics. During this period, Weifang City, Qingdao City, and Zibo City ranked among the top three provinces with severe pollution, Tai'an City, Rizhao City, and Weihai City ranked among the last three provinces with severe pollution. The top left of Figure 1 is the waste water discharge distribution map of the province. The waste water discharges of Weifang, Qingdao, and Zibo are 45.733 million tons, 38.156 million tons, and 34.735 million tons. The waste water discharge in the three cities accounts for 27.18% of the province's waste water discharge. Tai'an City, Rizhao City, and Weihai City's wastewater discharge were 152.72 million tons, 148.98 million tons, and 11.403 million tons, respectively. The wastewater discharge of the three cities accounted for 9.52% of the province's wastewater discharge. It can be seen from the figure that the water pollution situation in the central region is relatively serious, showing a continuum of severe pollution, and two lightly polluted flower enclaves appear.

3.1.2. Medium-term distribution characteristics. During this period, Weifang City, Qingdao City, and Jinan City ranked among the top three provinces with severe pollution, and Zaozhuang City, Rizhao City, and Weihai City ranked among the latter three provinces with severe pollution. Water pollution in the central region is more serious than in the surrounding regions. The worst pollution was found in
Weifang, Qingdao, Jinan, Jining, and Linyi. The top right of Figure 1 is the waste water discharge distribution map of the whole province. The waste water discharges of Weifang, Qingdao, and Jinan are 54106.85 million tons, 551.536 million tons and 436.3319 million tons respectively. The waste water discharge of the three cities accounts for 30.19% of the province's waste water discharge. Wastewater discharge from Zaozhuang, Rizhao and Weihai was 20,517,900 tons, 155,557,900 tons, and 11,473,660 tons respectively. Wastewater discharge from the three cities accounted for 9.61% of the province's wastewater discharge. It can be seen from the figure that water pollution in the central region is relatively serious, and a lightly polluted flower arrangement enclave appears.

![Wastewater discharge distribution map of Shandong Province](image)

**Figure 1 Spatial pattern of wastewater discharge in Shandong Province from 2010 to 2017**

### 3.1.3. Late distribution characteristics.

During this period, Qingdao, Weifang and Jining ranked among the top three provinces in terms of severe pollution. Zaozhuang City, Weihai City, and Rizhao City rank among the last three in the province with severe pollution. The water pollution in Ludong and Lunan areas is more serious than in the surrounding areas. The most serious pollution situation was in Qingdao, Weifang, Jining and Linyi. The bottom left of Figure 1 is the distribution of wastewater discharge in the province. Qingdao, Weifang, and Jining have wastewater discharges of 53.421 million tons, 52.293 million tons, and 459 million tons. The waste water discharge in the three cities accounts for 30.33 %. Wastewater discharge from Zaozhuang City, Weihai City, and Rizhao City were 194.66 million tons, 188.64 million tons, and 147.57 million tons, respectively. Wastewater discharge from the three cities accounted for 9.44% of the province's wastewater discharge. It can be seen from the figure that the water pollution situation in Ludong and Lunan areas is relatively serious, showing a continuum of severe pollution and two lightly polluted flower enclaves.

### 3.1.4. Overall distribution characteristics.

Based on the average of 2010-2017 wastewater discharge, the overall distribution of water pollution in the province was counted. Weifang, Qingdao, and Jining ranked among the top three provinces in terms of severe pollution. Dongying City, Rizhao City, and Weihai City rank among the last three provinces with severe pollution. Water pollution in the central region is more serious than in the surrounding regions. The lower right of Figure 1 is the distribution
map of the whole province's wastewater discharge. The wastewater discharges of Weifang, Qingdao, and Jining are 525.3 million tons, 492.22 million tons, and 41.518 million tons, respectively. 29.20% of Dongying City, Rizhao City, and Weihai City have wastewater discharges of 19.91 million tons, 15.02 million tons, and 13.349 million tons, respectively. Wastewater discharge from the three cities accounts for 9.84% of the province's wastewater discharge. It can be seen from the figure that the water pollution situation in the central region is relatively serious, showing a distribution pattern of heavy-light pollution, and the phenomenon of flower pollen enclaves with light pollution.

Figure 2 Distribution of cold and hot spots in wastewater discharge in Shandong Province, 2010-2017

3.2. Spatial distribution change
3.2.1. Inter-city difference. In general, Weifang is the city with the most severe water pollution in the province, and Weihai is the city with the most severe water pollution in the province. There is a large difference in severe water pollution between cities, and the difference in wastewater discharge is 39.181 million tons. The former is 3.94 times the latter. In the early period, Weifang City had the largest wastewater discharge and Weihai City had the smallest wastewater discharge, with a difference of 343.3 million tons, the former being 4.01 times the latter. In the medium term, Weifang has the largest wastewater discharge and Weihai has the smallest wastewater discharge, with a difference of 426.3319 million tons, the former being 4.72 times the latter. In the later period, Qingdao had the largest wastewater discharge and Rizhao had the smallest wastewater discharge. The difference between the two was 38.64 million tons, the former was 3.62 times the latter. The disparity in the serious situation of water pollution across cities has experienced a change from increasing to decreasing. Clarify and implement the responsibilities of governments, businesses and the public. Strengthen the local government's responsibility for environmental protection, implement the main responsibility of corporate pollution control in accordance with the law, and guide the public to change their lifestyles[7]. Wastewater refers to the collective name of water and runoff rainwater discharged during the activities of residents. It includes domestic sewage, industrial wastewater, and other rainwater that flows into drainage pipes, such as the initial rain trail. According to the regional
differences in the effects of driving factors, we should formulate industrial wastewater prevention and control measures according to local conditions, pay attention to the control of population density and urbanization speed, handle the relationship between economic development and environmental protection, and practice ecological priority and green development. While strengthening the prevention and control of industrial wastewater, we should increase the intensity of urban domestic wastewater treatment, and comprehensively improve the level of water environment supervision and pollution prevention.

3.2.2. Cold and hot distribution. Cold-hot spot analysis of water pollution in Shandong Province is performed using the hot spot analysis tool with rendering in ArcGIS. The hot spot analysis tool can calculate Getis-Ord Gi * statistics (called G-i-asterisk) for each element in the data set. From the obtained z-score and p-value, you can know where the high-value or low-value features cluster in space. This tool works by looking at each feature in the context of nearby features. High-value elements are often easy to notice, but may not be hot spots with significant statistical significance. To be a hotspot with significant statistical needs, the elements should have high values and be surrounded by other elements that also have high values. The local sum of a feature and its neighboring features will be compared with the sum of all features; when the local sum is so different from the expected local sum that it cannot be a randomly generated result, a significant statistic will be produced Significant z-score. If FDR correction is applied, statistical significance is adjusted based on multiple tests and spatial dependence. Figure 2 shows the distribution of cold and hot spots in the water pollution situation in Shandong Province. The distribution of cold and hot spots is obvious. Qingdao is a hot spot for wastewater discharge (z =2.24>2.0) and Weihai is a cold spot for wastewater discharge (z =-1.11<-1.0 ).

4. Conclusion

This paper uses ArcGIS spatial analysis and mapping technology to study the spatial-temporal distribution pattern of water resources pollution in Shandong Province. The main conclusions are as follows:

Firstly, since 2010, water pollution in Shandong Province has undergone a process of change from heavier to lighter. In 2015, compared with 2010, wastewater discharge increased by a net increase of 113.859 million tons, reaching 26.09 percentage points, with an average annual increase rate of 5.22%. Wastewater discharge reached its maximum in 2015. In 2017, it was a net reduction of 503.46 million tons from 2015, reaching 9.15 percentage points, with an average annual decrease rate of 4.58%.

Secondly, from the time distribution characteristics of water pollution in Shandong Province, the waste water discharge of Weifang City, Qingdao City, and Zibo City accounted for 27.18% of the province's waste water discharge in the early stage, and Weifang City, Qingdao City, and Jinan City 3 The city's wastewater discharge accounted for 30.19% of the province's wastewater discharge. In the later period, Qingdao, Weifang, and Jinan cities accounted for 30.33% of the province's wastewater discharge. Overall, Weifang City, Qingdao City, and Jining City 3 Municipal wastewater discharge accounts for 29.20% of the province's wastewater discharge. The water pollution situation in the central region is relatively serious, showing a distribution pattern of heavy-light pollution, and the phenomenon of light-polluted flower enclaves.

Thirdly, from the perspective of the spatial distribution characteristics of water pollution in Shandong Province, the gap between severe water pollution conditions in different cities has gone from increasing to decreasing. On the whole, Weifang City is the most severely polluted city in the province. Weihai is the city with the lightest water pollution in the province, and the former is 3.94 times the latter. In the early stage, Weifang City had the largest wastewater discharge, and Weihai City had the smallest wastewater discharge. The former was 4.01 times the latter. In the medium term, Weifang City has the largest wastewater discharge, and Weihai has the smallest wastewater discharge, the former being 4.72 times the latter. In the later period, Qingdao had the largest wastewater
discharge and Rizhao had the smallest wastewater discharge, the former being 3.62 times the latter. The province's water pollution situation is obvious, and the distribution of cold and hot spots is obvious. Qingdao is a wastewater discharge hotspot area \((z = 2.24 > 2.0)\), and Weihai is a wastewater discharge cold spot area \((z = -1.11 < -1.0)\).

**Acknowledgments**

This work was financially supported by Ministry of Education Humanities and Social Sciences Youth Fund(No.15YJCZH175), Shandong Provincial Social Science Planning Research Fund(No.18CLYJ34), Shandong Provincial Higher Education Research Fund(No.J18RB200) and Research Project of Cultural Tourism Development in Shandong Province(No.19WL38).

**References**

[1] Zhuang R L, Mi K N, Liang L W. China’s industrial wastewater discharge pattern and its driving factors. Resources and Environment in the Yangtze Basin, 27(2018)1765-1775.

[2] Cocranb, Loguec. A watershed approach to improve water quality: case study of clean water services tualatin river program. Journal of the American Water Resources Association, 47(2011) 29-38.

[3] Liu G A, Jiang M Y, Yang K Z, et al. Study on the validity and regional differences of environmental policy and envi ron-mental technology innovation-a case study of industrial wastewater discharge in China. Journal of Capital University of Economics and Business,13(2011) 25-33.

[4] Geng Y, Wang M, Sarkis J, et al. Spatial-temporal patterns and driving factors for industrial wastewater emission in China. Journal of Cleaner Production, 76(2014) 116-124.

[5] Shandong. http://www.gov.cn/guoqing/2013-04/17/content_2583746.htm

[6] Wu S, Wang D, Ma L K, et al. An Action Plan for Declaring War on Water Pollution-Interpretation of the Action Plan for Water Pollution Prevention. Environmental Protection, 43 (2015)15-18.

[7] Lu Y. Effects of Industrial Agglomeration on River Basin Pollution: A Case of Haihe River Basin. Journal of Beijing Jiaotong University(Social Sciences Edition), 18(2019)61-68.

[8] State Council. Notice on Printing and Distributing Action Plans for Water Pollution Control Action Plan for Water Pollution Control: Guofa [2015] No.17. Beijing: State Council, 2015.

[9] Xu M, Zhang T, Wang D, et al. 40 years review and prospect of water pollution prevention and control in China. China Environmental Management, 3(2019)65-71.