The impact of urban development upon the quality of drinking water sources: Evidence from China

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Abstract. The extent of urban development and human activities may affect the water quality of drinking water sources in different ways. In this study, drinking water sources in different districts and counties of Qingyuan City, China were determined as the study areas, and the correlation between urban development and water quality index was analyzed by Spearman rank correlation analysis and regression analysis. The results showed that: 1) A statistically significant correlation was found between the extent of urban development and part of the water quality index. Specifically, the correlation between the gross annual value of industrial and agricultural production, household registration index and water quality index was the strongest. The fecal coliform index was most affected by the extent of urban development; 2) A function describing the relation between the urban development index and the water quality index was obtained by multiple regression analysis; 3) A certain significant correlation was found among the water quality indexes of drinking water sources in Qingyuan. Most of the water quality parameters were strongly correlated, which could provide a scientific basis for parameter selection in the future water source automatic monitoring.

1. Introduction

In the era of rapid social development, the quality and safety of drinking water has always been one of the most public concerned issues [1, 2]. However, due to the rapid development of the population in cities and inadequate protection measures, the pollution of drinking water resources is still widespread, especially in emerging countries, like China.

With the acceleration of urbanization, the area of urban built-up areas continues to expand and the urbanization rate continues to increase, which may have dramatically affected the water quality of water environment in such urban area, and therefore the drinking water sources undertaking the task of urban water supply will also be needed to cope with the more severe drinking water security difficulties.

Among the existing research studies on the relationship between urban water environment quality and the level of urban development [1], most of them focus on the correlative analysis between river water quality change and the level of urban economic development level [3], while the research on the relationship between water quality of drinking water sources and urban development is still relatively lacking. Meanwhile, in most of the studies, time or time change is considered as one of the main influencing variables, and yet the spatial distribution difference is not specially considered.

To solve this research gap, in this study, six representative urban socio-economic indicators were selected for correlational analysis and regression analysis, including urbanization rate, registered population, industrial and agricultural output value, industrial output value, agricultural output value.
and fixed asset investment. At the same time, the quality monitoring data of all centralized water sources in Qingyuan city, China in 2016 were manually collected to analyze the change trend of the correlation between the degree of social and economic development and the quality of centralized water sources, so as to provide useful technical references for the comprehensive improvement of drinking water sources in Qingyuan city in particular, and in China in general, and for the promotion of sustainable development of the whole social economy. At the same time, the correlation between the various water quality indexes of the centralized water source in Qingyuan city is then analyzed, and this in-depth correlational analysis can be used to test the rationality and usefulness of the index measurement results, which is helpful to predict and find abnormal water bodies in the future.

2. Description of research context
Qingyuan is the largest prefecture-level city in Guangdong province, China and the main settlement of ethnic minorities in Guangdong province. Under the new situation and new challenges in the 21st century, Qingyuan city has gradually promoted the strategic implementation goal of the four development strategies of "aiming to achieve industrialization, urbanization, marketization, and maintaining backyard garden", and its economic and social development has been accelerated.

However, it cannot be ignored that there is a drawback of one-sided pursuit of economic development that leads to the pollution of drinking water sources. Therefore, it is imperative to analyze the change trend of correlation between the degree of social and economic development and water quality of centralized water source.

In 2016, there were 96 centralized drinking water sources in Qingyuan city, including 3 at the municipal level, 11 at the county level, and 82 at the township level, with a total water withdrawal of 346,583,300 tons per year. In fact, the rapid development of social economy\[^5\], the increase of population, the development of industry, the improvement of residents' living standard, the change of urban and rural structure and industrial structure in Qingyuan will definitely increase the discharge of urban sewage and water pollutants. If not properly treated, it will seriously affect the quality of drinking water sources.

In this context, it is necessary to establish the econometrical relationship between economic development and environmental indicators, find out the reason why and the degree of mutual influence between the two indicators, and propose corresponding policy countermeasures accordingly.

3. Data and Method

3.1. Selection of water quality indicators
According to the pollution characteristics of this study area and existing literature\[^8\,9\,10\], seven water quality indexes were selected in this study, including biochemical oxygen demand (BOD, mg/L), ammonia nitrogen (NH3-N, mg/L), total nitrogen (TN, mg/L), total phosphorus (TP, mg/L), chemical oxygen demand (CODcr, mg/L), permanganate index (mg/L), and fecal coliform group (CFU/100mL), to analyze the water quality of 96 centralized drinking water sources in Qingyuan city.

Monitoring data of drinking water quality were selected from the first and second quarters of 2016. In accordance with the relevant provisions of water and wastewater monitoring and analysis method (4th edition), the national standard water quality monitoring and analysis method was adopted to monitor and record these water quality indexes.

3.2. Selection of indicators of urban development degree
Since agriculture and industry account for the largest proportion in most areas of Qingyuan city, and investment in fixed assets is an important part of GDP, these indicators can clearly represent the degree of local economic development in Qingyuan city. Therefore, the indicators of industrial and agricultural output value and fixed asset investment are selected to reflect the economic development level of Qingyuan city.
The index that selected to measure the urban development degree of Qingyuan city includes: the total output value of industry and agriculture (100 million Yuan), the urbanization rate (%), the registered population (people), the total output value of industry (100 million Yuan), the total output value of agriculture (100 million Yuan), and the fixed asset investment (100 million Yuan).

3.3. Statistical analysis
The quality of drinking water source was selected from the monitoring data of each region in the first and second quarters of 2016, and the average value of each monitoring point was taken for analysis. The data of urban development index are from Qingyuan statistical yearbook. The correlation analysis of seven water quality indexes was carried out respectively.

Correlation analysis [7, 12] among all data sequences was completed in SPSS17.0, and Spearman rank correlation analysis was used for some indexes that did not meet normal distribution.

In addition, we also establish the multivariate linear regression analysis, with urban development indicators as independent variables, selection of water quality index as the dependent variable to examine the possible relationship between urban development index and the water quality indexes. By doing so, we aim to use the statistical method to reveal the inner link of urban development index and the water quality index.

4. Research results

4.1. Correlation and regression analysis between urban development degree and water quality
1) Findings of rank correlation analysis
As you can see from the result of correlation analysis (see Table 1), fecal coliform group indexes showed a positive correlation with indexes of urban development, including population number, industrial and agricultural output value, industrial output, and investment in fixed assets. The level of the correlation is moderate, shows that with the improvement of city development level, the content of fecal coliforms in the drinking water sources also increases.

There was a significant positive correlation between the total nitrogen TN of drinking water quality index and the total output value of industry and agriculture and the total output value of agriculture in the urban development index, and the correlation was moderate, indicating that the total nitrogen of drinking water quality index was related to the regional agricultural development level in Qingyuan city.

Ammonia nitrogen (NH3-N) has a significant positive correlation with the registered population and urbanization rate, indicating that ammonia nitrogen has a certain positive correlation with the level of urbanization. There was no significant correlation between other water quality indexes and the selected urban development indexes.
Table 1. Correlation matrix between indicators of water pollution and urban development

|                          | CODcr | TN     | TP     | BOD    | NH3-N  | Permanganate index | Fecal coliform group |
|--------------------------|-------|--------|--------|--------|--------|--------------------|----------------------|
| Registered population    | -0.131| 0.085  | 0.102  | -0.214 | 0.299* | 0.162              | 0.304*               |
| Urbanization rate        | 0.022 | -0.031 | 0.257  | 0.125  | 0.349* | 0.169              | 0.162               |
| Total output value of industry and agriculture | -0.016 | 0.356* | 0.067  | 0.008  | 0.031  | 0.171              | 0.439*               |
| Total output value of industry | -0.050 | 0.147  | 0.271  | -0.094 | 0.205  | 0.233              | 0.436*               |
| Total output value of agriculture | -0.227 | 0.358* | 0.022  | -0.221 | 0.088  | 0.037              | 0.275                |
| Fixed asset investment   | 0.115 | 0.194  | 0.178  | -0.028 | 0.095  | 0.204              | 0.337*               |

Notes: * P<0.05

2) Findings of regression analysis

According to the regression analysis (See Table 2), the coefficient R corresponding to the multiple linear functions of the urban development index and the water quality index of fecal coliform group is 0.874, with a good degree of fitting. The coefficient R of multiple linear functions of water quality indexes NH3-N and TN and urban development indexes is 0.686 and 0.518, respectively.

Table 2. The regression of water quality and indicators of urban development

| Water quality index | Multiple regression model | R   |
|---------------------|---------------------------|-----|
| TN                  | $y_1 = 1.034 - 1.746 \times 10^{-5} x_1 - 1.399 \times 10^{-5} x_2 + 0.064 x_3 + 0.215 x_4 - 0.028 x_5 + 0.029 x_6$ | 0.518 |
| NH3-N               | $y_2 = 0.111 - 5.515 \times 10^{-7} x_1 + 9.739 \times 10^{-7} x_2 - 0.011 x_3 - 0.012 x_4 - 0.003 x_5 + 0.004 x_6$ | 0.686 |
| Fecal coliform group | $y_3 = -22759.896 + 1.281 x_1 + 0.431 x_2 - 2827.373 x_3 - 2960.828 x_4 - 582.429 x_5 + 739.429 x_6$ | 0.874 |

Notes: $x_1$ is registered population, $x_2$ is urbanization rate, $x_3$ is fixed asset investment, $x_4$ is total output value of agriculture, $x_5$ is total output value of industry, $x_6$ is total output value of industry and agriculture.

4.2. Correlation analysis of water quality parameters

There is a certain correlation between the various water quality indexes of drinking water sources in Qingyuan city (See Table 3). In particular, BOD was positively correlated with CODcr and total nitrogen. There was a significant negative correlation between CODcr and total nitrogen. There was a significant positive correlation between ammonia nitrogen and total phosphorus. The permanganate index was positively correlated with CODcr, and positively correlated with total phosphorus, and ammonia nitrogen. Fecal coliform group was positively correlated with ammonia nitrogen and permanganate index, and positively correlated with total phosphorus.

Table 3. Correlation matrix between indicators of water pollution

|           | COD   | TN    | TP    | BOD   | NH3-N  | Permanganate index | Fecal coliform group |
|-----------|-------|-------|-------|-------|--------|--------------------|----------------------|
| COD       | 1.000 | 0.507**| 0.008 | 0.773**| -0.172 | 0.367*             | -0.079               |
| TN        | 1.000 | 0.089 | 0.408**| 0.182 | 0.024  | 0.209              |                      |
Discussion and conclusion

Different from previous studies that observe changes from the perspective of time [4, 6, 13], this study focuses on the fact of space difference by analysing the relationship between water quality and urbanization level in different regions in the same time with different spaces, which can reduce the influence of national conditions, policies and other factors. In further research, the spatial position and change of pollution can be described on the map and analyzed in combination with the relevant socio-economic indicators, so as to more easily find the innate connection between water quality and urbanization level.

Main conclusions of the study include:

(1) The total output value of industry and agriculture and the registered population have a great impact on the water quality index, and these factors are significantly positively correlated with the total nitrogen, ammonia nitrogen and fecal coliform group of the drinking water quality index.

(2) The functional relationship between urban development index and water quality index of fecal coliform group was obtained through multiple regression analysis, and the coefficient R was 0.874, with a good degree of fitting, which reveals the importance of identifying the internal relationship between urban development index and water quality index.

(3) It can be seen from the correlation analysis results that there is a certain correlation among some of the water quality indexes of drinking water sources in Qingyuan city, and most of the water quality parameters are strongly correlated, which can provide a scientific basis for parameter selection for automatic monitoring of water sources.

Our findings also provide key policy implications. We find that a series of social changes caused by the improvement of residents' living standards, and the incomplete supporting sewage treatment facilities may lead to the increase of the accumulation of domestic sewage, domestic garbage and other non-point source pollutants. Meanwhile, with the rapid development of industry, untreated industrial waste water has a great impact on the quality of drinking water. Non-point source pollution caused by the development of agriculture also affects the safety of drinking water sources in the downstream areas, causing water bodies to exceed the standard. Therefore, it is necessary to increase investment in environmental treatment and make comprehensive efforts to improve the environment, continuously optimize and adjust the industrial structure, eliminate outdated technologies and equipment that consume a lot of water and cause heavy pollution, and deepen water pollution control in key industries.

In the treatment of agricultural non-point source pollution, it is mainly through the source control, farmland non-point source, livestock and poultry scene source classification control, improve the level of agricultural modernization, and reduce the use of pesticides and fertilizers. At the same time, the concept of water conservation should be actively publicized to the residents, and the domestic sewage treatment facilities should be improved to improve the level of domestic sewage treatment. Under the combination of these measures, we hope that we will finally achieve a long-term victory in the battle of environmental protection.

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