Changes in the footprint of grey water from 2005 to 2017 in Fuzhou City

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Abstract. Based on the concept of grey water footprint, this study quantified the pollutants generated by agricultural, industrial and tertiary industries in Fuzhou City from 2005 to 2017 using the diluted water demands. The results showed: 1) the mean agricultural grey water footprint of Fuzhou City was $15.88 \times 10^8$ m$^3$/a at the study period, which is about 16.69% of the water consumption; 2) among three sectors, grey water footprint in the living sectors is the largest, and agricultural grey water footprint is the smallest; 3) the grey water footprint of Fuzhou City shows a declining trend from 2005 to 2017, with the agricultural, industrial and living sectors decreasing by 24.92%, 60.78% and 17.11%, respectively; 4) the footprint of Fuzhou City's grey water showed a downward trend, while the water quality in urban areas also showed a downward trend. The footprint of grey water is greater than the amount of water resources, implying the limited water resources in Fuzhou City can not fully dilute the pollutants for the environmental water quality standards.

Keywords: water resource, water footprint, grey water, Water pollution, Fuzhou City

1. Introduction
Water plays significant role in human survival and production, and water resources is one of the key factors of economic and social sustainable development. Nearly one-third of the world’s population is facing the threat of water shortages [1-2]. It has been pointed out that the water crisis is the most important risk affecting global economic development [2], which is particularly important to carry out an accurate water resource assessment at a regional scale. Among the evaluation of water resources, the grey water footprint is becoming one of the essential part in assessing the quality of regional water resources. Grey water footprint is a pollution-related indicator, defined as the natural background concentration and existing environmental water quality standards. In a detailed definition, the grey water footprint will eventually calculate the amount of water needed to dilute the pollutants.

It is well known that grey water footprint is the latest concept proposed in all water footprint evaluations, and it is still in a beginning period of rapid development. Thus, grey water footprint has received great attention [2]. Although the global grey water footprint assessment can realize the pollution degree of the global river basins and the sustainable development of the river basins, due to the limitation of data coverage and data resolution, the research results are often not accurate. Therefore, the global grey water footprint assessment needs more accurate data support.

In China, current studies have calculated the agricultural, industrial and tertiary industries in 31
provinces under a comprehensive assessment of the grey water footprint in different regions [6-8], providing scientific data for understanding water pollution in different regions. At the river scale, the grey water footprint was evaluated in the Heihe River basin, Qiantang River basin, Huangqi basin, and Haihe River basin. At a more detailed scale, the footprint of grey water has been evaluated in Beijing [7], where the grey water footprint has dropped significantly from 1995 to 2005.

The grey water footprint in Fuzhou City is still at an unknown stage. Therefore, this study analyzes the temporal changes in grey water footprint in Fuzhou City, and estimates the sustainable utilities of water resources in Fuzhou City. This study can support scientific data for the water environment management according to the assessment and analysis of grey water footprint.

2. Materials and methods

2.1 Studying area
Fuzhou City is located in the eastern part of Fujian Province. It occupied five districts, six counties and two county-level cities under its jurisdiction, with a total area of 11,968 square kilometers, of which the urban area is 1,786 square kilometers. The permanent population in Fuzhou City is 7.28 million in 2017. It belongs to the subtropical maritime monsoon climate. Originating from the Wuyi Mountains, the largest river in Fujian Province. The Minjiang River flows through Fuzhou City into the East China Sea, with a river section of 150km in length. There are dense waterways in downtown of Fuzhou City. Forty two large and small rivers are connected to the Minjiang River. Therefore, Fuzhou City has many water systems, wide water areas and abundant water resources. With the rapid development of the national economy and the improvement of people's living standards, Fuzhou City's water resources are also facing increasingly serious pollution problems. In 2017, the total length of rivers in the water quality evaluation was 1120.6 kilometers. The rivers better than grade III water were 948.5 kilometers, accounting for about 84.6% of the rivers evaluated; the length of rivers exceeding the standard (Category IV, Category V, inferior to Category V) was 172.1 kilometers, accounting for 15.4% (Table 1). According to the data obtained from the governmental observation, the main pollutant indicators of the river water body exceeding the standard are total phosphorus and ammonia nitrogen (Fig. 1).

**Table 1 Summary of Water Quality in Fuzhou City**

| River     | Trunk stream | Length | Period      | I, II | III | IV | V, Bleow V |
|-----------|--------------|--------|-------------|-------|-----|----|------------|
|           |              | Length |             | Length | Ratio | Length | Ratio | Length | Ratio |
| Minjiang River | Main steam | 197.6  | Flood       | 80.5  | 40.7 | 116.2 | 58.8 | 0.9  | 0.5   |
|            |              |        | Non-flood   | 51.6  | 26.1 | 73.1  | 37.9 | 72.9 | 36.9  |
|            |              |        | Entire      | 76.3  | 38.6 | 120.4 | 60.9 | 0.9  | 0.5   |
|            | Mei River    | 125.3  | Flood       | 78.7  | 62.8 | 9.4   | 7.5  | 37.2 | 29.7  |
|            |              |        | Non-flood   | 49.4  | 39.4 | 38.7  | 30.9 | 37.2 | 29.7  |
|            |              |        | Entire      | 88.1  | 70.3 | 37.2  | 29.7 |      |       |
| Dazhang River | 399        |        | Flood       | 335   | 84   | 64    | 16   | 84.7 | 21.2  |
|            | Non-flood    |        | 230.9      | 57.9  | 59.8 | 15    | 23.6 | 5.9  | 84.7  |
|            | Entire       |        | 269.1      | 67.5  | 55.6 | 13.9  | 74.3 | 18.6 |       |
| Xiaozhi River | 103.3      |        | Flood       | 21.2  | 20.5 | 50.2  | 48.6 | 31.9 | 30.9  |
|            | Non-flood    |        | 43.6       | 42.2  |      | 31.9  | 30.9 | 27.8 | 26.9  |
|            | Entire       |        | 43.6       | 42.2  |      | 31.9  | 30.9 | 27.8 | 26.9  |
| Ao River   | Ao River     | 234.2  | Flood       | 159.9 | 68.3 | 18.5  | 7.9  | 6    | 2.6   |
|            | Non-flood    |        | 96.7       | 41.3  | 106.2| 45.3  | 31.3 | 13.4 |       |
|            | Entire       |        | 183.4      | 78.3  | 50.8 | 21.7  |      |      |       |
| Long River | Long River   | 61.2   | Flood       | 2.3   | 3.8  | 28.4  | 46.4 | 30.5 | 49.8  |
|            | Non-flood    |        | 61.2       | 100   |     |      |      |      |       |
|            | Entire       |        | 61.2       | 100   |     |      |      |      |       |
| Total      |              | 1120.6 | Flood       | 677.6 | 60.5 | 286.7 | 25.5 | 38.8 | 3.5  |
|            | Non-flood    |        | 533.4      | 47.6  | 277.8| 24.8 | 159.7| 14.2 | 149.7 |
|            | Entire       |        | 721.7      | 64.4  | 226.8| 20.2 | 107.1| 9.6  | 65    | 5.8  |
2.2 Methods

Based on the methods of water footprint evaluation manual, published by the International Water Footprint Network as the guiding standard [9], this study performed the water quality weekly report data provided by the Fuzhou City Environmental Protection Department, the Fujian Provincial Water Resources Regulations (July 21, 2017 Adopted at the 30th meeting of the Standing Committee of the Congress) as the guiding ideology. The guidelines [Guidelines for the Construction of a Safe Ecological Water System in Fujian Province] planned to restore the ecological environment of the river, reshape the healthy and naturally curved river bank, and build an ecological water system with sufficient water volume, natural flow and good water quality. The goal is 1) to clear the accumulation process of pollutants in the waters of Fuzhou City in different periods; 2) assess the volume of fresh water needed to dilute the pollutants; 3) assess the temporal and spatial changes of the grey water footprint and the evolution mechanism; 4) predict the future grey water footprint and water resources of Fuzhou City; 5) discuss a comprehensive evaluation and management of water quantity and quality in Fujian Province.

The grey water footprints of the industrial, domestic and agricultural sectors are calculated separately. To ensure the accuracy of the calculation, this study estimates the grey water footprint of Fuzhou City and assess the grey water footprint of Fuzhou City. The common calculation method for grey water was shown as follows,

\[
\text{Grey water footprint} = \frac{L}{(C_{\text{max}} - C_{\text{nat}})} \quad (1)
\]

where L represents the emission of the pollutant (kg/a), \(C_{\text{max}}\) represent the maximum pollutant concentration under a certain water target quality; \(C_{\text{nat}}\) represents the original pollutant concentration. The Grey water footprint is the calculated water demand as grey water.

The ratio of total grey water footprint to the total water resource can mirror the water recover power. If the ratio is greater than one, this means the study region needs more water for dealing with the polluted water; if the ratio is less than one, this implies the study region can recover the polluted water without more clean water input.

3. Data Sources

The data used in this study were mainly from the Fuzhou City Statistical Yearbook and China Statistical Yearbook. The data on the amount of nitrogen fertilizer and the number of livestock and poultry are from the Fuzhou City Statistical Yearbook. The nitrogen fertilizer leaching rate is selected from the national average nitrogen leaching rate with a data of 7%. The data on livestock and poultry excretion coefficient, unit manure COD and total nitrogen emissions, and water loss rate was from
National Survey of Pollution in Large-scale Livestock and Poultry Farming and Countermeasures for Prevention and Control. The emissions data from the industrial sector are derived from the China Statistical Yearbook, China Environment Statistical Yearbook and Fuzhou City Statistical Yearbook. Selected total water resources data was taken from the China Water Resources Bulletin and the annual Fujian Water Resources Bulletin. Regarding the pollutant concentration threshold, the standard limits for basic items of surface water environmental quality standards (GB 3838-2002) was used as a guide to define Class III water as the minimum environmental water quality standard for biological survival with the COD concentration of 20mg/L. In this study, the standard concentration of Class III water COD was selected as the basis for calculating the grey water footprint of industrial and domestic sectors, namely the Cmax concentration was settled as 0.002 kg/m³. The leaching loss of nitrogen fertilizer in agriculture is mainly nitrate nitrogen, and thus the standard concentration limit of nitrate (calculated as N) in the above standards is 10 mg/L, and this concentration is used as the calculation of the grey water footprint of the agricultural sector basis. Cnat is the original concentration of pollutants in the water body, which is often assumed to be 0 [9]. In addition, the weekly pollution data announcement of each river comes from the Public Environmental Research Center (http://sthjt.fujian.gov.cn/gzcy/bmfwcx/szcx/).

4. Results

4.1 Grey water footprint in Fuzhou City

The mean grey water footprint of the agricultural sector in Fuzhou City from 2005 to 2017 was $15.88 \times 10^8 \text{ m}^3/\text{a}$, which is about 16.69% of the total water resources of Fuzhou City; the grey water footprint of the industrial sector was $142.4 \times 10^8 \text{ m}^3/\text{a}$, which is about 1.49 times of the total water resources of Fuzhou City; the grey water footprint of the living sector is $191.86 \times 10^8 \text{ m}^3/\text{a}$, which is about 2.01 times of the total water resources of Fuzhou City. It can be seen that the living sector contributes the most to the grey water footprint of Fuzhou City, followed by the industrial sector, while the agricultural sector contributes the least roles in the footprint. The mean total grey water footprint of Fuzhou City from 2005 to 2017 was $350.22 \times 10^8 \text{ m}^3/\text{a}$ (Fig. 2).

![Fig. 2](image-url) Changes in the grey water footprint in Fuzhou City from 2005 to 2017. The lines present agriculture grey water for red line; domestic grey water for blue line, industry grey water for green line.

From 2000 to 2017, the grey water footprint of life sector kept stable, while the grey water footprint
of the agriculture and industrial sectors showed a downward trend. The grey water footprint of the life sector increased from $174.94 \times 10^8$ m$^3$ to $221.79 \times 10^8$ m$^3$ from 2005 to 2011 with an increase of $46.85 \times 10^8$ m$^3$/a; while from 2011 to 2017, the grey water footprint of the living sector decreased from $221.79 \times 10^8$ m$^3$ to $191.86 \times 10^8$ m$^3$ with a decrease of $29.93 \times 10^8$ m$^3$/a. The grey water footprint of the agricultural sector decreased from $21.15 \times 10^8$ m$^3$ to $15.88 \times 10^8$ m$^3$ with a decrease of $5.27 \times 10^8$ m$^3$/a from 2005 to 2017. The grey water footprint of the industrial sector decreased from $363.28 \times 10^8$ m$^3$ to $142.48 \times 10^8$ m$^3$ with a decrease of $220.81 \times 10^8$ m$^3$/a from 2005 to 2017 (Fig. 3). Further, the ratio of total grey water footprint reached the peak in 2008 and 2011, representing the most needs for water to deal with the polluted water (Fig. 4).

![Fig. 3](image1.png)

**Fig. 3** Changes in the grey water footprint and water resource in Fuzhou City from 2005 to 2017. The red line represents the total grey water footprint in Fuzhou City; the green line represents the water resource in Fuzhou City.

![Fig. 4](image2.png)

**Fig. 4** Changes in the ration of total grey water footprint to the total water resource in Fuzhou City from 2005 to 2017.
4.2 Grey water footprint and water consumption in Fuzhou City

From 2005 to 2017, grey water footprint in Fuzhou City was greater than Fuzhou City's total water resources in each year. There are dense waterways in downtown Fuzhou City, and 42 large and small rivers are connected to the Minjiang River. Therefore, Fuzhou City has many water systems, wide water areas and abundant water resources. However, with the rapid development of the national economy and the improvement of people's living standards, the water resources of Fuzhou City are also facing more and more serious pollution problems. Taking the year of 2013 as an example, surface water resources in Fuzhou City was 8.575 billion cubic meters; the groundwater resources was 2.777 billion cubic meters; the total water resources was 8.604 billion cubic meters. Thus, the water resource per capita was 1240 cubic meters. However, the water supply in Fuzhou City is 3.104 billion cubic meters. From the perspective of water quality, The grey water footprint of Fuzhou City is 39.232 billion cubic meters, indicating that 39.232 billion cubic meters of fresh water resources are needed to dilute the pollution generated by the agricultural, industrial and living sectors of Fuzhou City in order to maintain the water quality. However, the total water resources of Fuzhou City are 8.575 billion cubic meters, which is smaller than the grey water footprint of Fuzhou City. Coupled with the large amount of direct water supply, the existing water resources in Fuzhou City can not be effectively carried out water pollutants as the water demands of dilution. Therefore, although Fuzhou City has abundant water resources compared with other regions, it is characterized by a typical water shortage due to maintain the water quality. The grey water footprint exceeds the total amount of water resources, which is a direct indicator of the water shortage.

5. Discussion

Although the grey water footprint of Fuzhou City has been declining from 2005 to 2017, the water quality of surface water systems in Fuzhou City has shown a trend of deterioration at the same study period. The proportion of rivers that meet the water quality standards of Class III and above (including Class III) showed an overall downward trend, indicating a relative water shortage in Fuzhou City.

Due to the special geographical location of the inland river and the influence of various practical factors, the ecological water supply of the inland rivers is unevenly distributed. The water environment is improved unbalanced. In detail, there are many dead rivers, which have been siltated and blocked for many years in Fuzhou City. Domestic sewage is continuously discharged, and the sewage can not be discharged in the appropriate time, causing black and odor for long terms. According to the observation in situ, although the waters is updated with intensive input, the black and odor of the inland river is still serious. In detail, the dissolved oxygen content is still low, and the organic matter is difficult to be decomposed. According to the investigation of the pollution sources of inland rivers in the urban area by the Fuzhou City Inland River Management Office, there are many sources of inland river pollution, especially the industrial waste water and domestic sewage along the banks. After the municipal government’s compulsory demolition of illegal industries and strict control of industrial waste water discharge, the pollution level of inland rivers has declined, but the corresponding domestic sewage discharge has been increasing year by year, which has become the main source of inland river pollution in Fuzhou City.

This study provides the most conservative estimate of the grey water footprint in Fuzhou City. There are two main reasons: 1), The amount of nitrogen fertilizer used in agriculture and the sewage discharge data of the industrial sector mainly come from official statistics, and data from other sources are not considered. 2) This study assumes that COD and nitrogen are the main pollutants and does not consider other pollutants. When the polluted water contains heavy metals, even a small amount of heavy metals also will cause great harm to human health. Therefore, the actual grey water footprint may be higher than the results obtained in this study.

However, there still other limitations in this study. This study is only a preliminary study and simple evaluation of the grey water footprint in Fuzhou City, without considering the impact of time and different pollutants on water bodies. Various pollutants in the water body continue to undergo physical and chemical reactions in different seasons. The water quality will continue to change, and then the
concentration of pollutants in the water body will change. In addition, the grey water footprint does not consider the changing process of water quality during the water flow, so the self-purification ability of the water body can reduce the grey water footprint. Therefore, more comprehensive data and models are needed to calculate the grey water footprint in the future.

According to the grey water footprint of different human activities in Fuzhou City, this study suggests that Fuzhou City establish grey water footprint indicators for various human activities. In order to achieve further optimization of the water environment, taking into account the total amount of water resources in Fuzhou City, strictly control the amount of grey water footprint could be one way for keep the water quality. Since the grey water footprint of each human activity department is different, the grey water footprint of each department is quantified in this study. Establishing effective pollutant discharge indicators for different pollutants in each industry should be carried out for effective water quality control, and ultimately to achieve the overall improvement of the water environment.

6. Conclusion
This study mainly quantitatively analyzes the trends in the grey water footprint of the agricultural, industrial and living sectors in Fuzhou City from 2005 to 2017. The results of the study showed that: (1) The mean grey water footprint of Fuzhou City in the study period was 350.22×10^8/a, which was about 3.68 times the water consumption of Fuzhou City at the same study period. Among the three sectors of agriculture, industry, and life, life has the largest grey water footprint, while agriculture has the smallest grey water footprint. (2) The grey water footprint of Fuzhou City has shown a downward trend from 2005 to 2017. The agricultural, industrial, and living parts have decreased by 24.92%, 60.78%, and 17.11% respectively from 2005 to 2017. The grey water footprint of Fuzhou City is showing a downward trend. Because the grey water footprint is greater than the amount of water resources, the limited water resources are difficult to completely dilute the pollutants for the general environmental water quality standard.

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