Investigation and Analysis on Rural Domestic Sewage Discharge in Key Watersheds

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Abstract. In order to grasp the latest changes in the quality and quantity of domestic sewage in the Taihu Lake Basin and Chaohu Lake Basin, and to scientifically guide the construction of rural sewage treatment demonstration projects, two typical villages were selected from Taihu Lake Basin and Chaohu Lake Basin respectively for fieldwork continuous monitoring of sewage water quality and quantity. The results show that the typical rural per capita daily drainage in the plain area of the Taihu Lake Basin in summer is 89.4 L·cap⁻¹·d⁻¹, which is significantly higher than that in the typical rural area of the Chaohu Lake Basin (56.5 L·cap⁻¹·d⁻¹). The amount of sewage hourly discharge fluctuated distinctly, and the coefficient of variation of sewage discharge in the two villages ranged from 2.4 to 6.1, showing obvious characteristics of “morning and evening peaks” or “morning, noon and evening peaks”. In addition, the rural sewage water quality in the two places shows the same pattern, and the pollutant concentration of sewage from different sources is significantly different. It was found that the toilet-flush sewage in Wangjiatang village provided 84.42% of TN and 92.94% of NH₄⁺-N in the total domestic sewage, while toilet-flush sewage in Qianying village provided 74.31% of TN and 84.56% of NH₄⁺-N in the total domestic. Therefore, when constructing a sewage treatment demonstration project, the ideological principles of sewage classification and treatment from the source should be considered.

1. Introduction
Taihu Lake and Chaohu Lake are two major freshwater lakes with serious eutrophication problem in China, and the pollution control of them has always been the focus of current research. With the continuous development of urban sewage treatment technology and the continuous improvement of treatment standards, the pollution load caused by the random discharge of rural sewage accounts for a significant proportion of the water body pollution in the river basin [1]. It is urgent to build a new rural sewage treatment demonstration project according to local conditions. However, most of the domestic research on rural domestic sewage pollution is based on the first national census data of rural domestic pollution sources at present [2], and the previous source census data cannot reflect the rural areas in time due to the promotion of new rural construction and changes in farmers’ lifestyles. This might lead to certain limitations for guiding the construction of rural sewage treatment demonstration projects. Therefore, it is very necessary to carry out research work on domestic sewage in rural areas.

This study selected two typical villages respectively from Taihu Lake Basin and Chaohu Lake Basin as research sites, and investigated the situation of rural water use and the characteristics of rural sewage.
The conclusion will provide scientific data for planning and design of rural domestic sewage demonstration projects in key river basins, and it is of great practical significance to improve the ecological the watershed environment and alleviate lake eutrophication.

2. Experimental methods

2.1. Experimental site and time
In this study, five typical farm households in Wangjiatang Village and three typical farm households in Qianying Village were selected based on population structure, economic conditions, and drainage facilities. Wangjiatang Village is located in Xueyan Town, Wujin District, Changzhou City, Jiangsu Province. It is a typical representative of rural villages in the plain areas of Taihu Lake Basin, and the investigation was conducted here for 15 consecutive days in July. However, Qianying Village is located in Zipeng Town, Feixi County, Hefei City, Anhui Province. It is a typical representative of rural villages in the mountainous areas of Chaohu Lake Basin, and the investigation was conducted here for 10 consecutive days in September.

2.2. Investigation method and content
In this study, rural domestic sewage is classified according to its source, which is divided into three categories: kitchen sewage, washing sewage (including bathing sewage, laundry sewage, etc.) and toilet-flush sewage. Each household's kitchen sewage and washing sewage were collected with two 120L plastic buckets, and the water volume was counted every 2 hours. The toilet-flush sewage volume statistics was adopted the counting method. Every time villagers use the flush toilet, they need to tick the corresponding time period and type (stool or urine) on the record book, and then the volume of the toilet-flush sewage can be calculated. Besides, the sampling interval of water quality is 24 hours.

2.3. Water sample analysis method
The sewage quality test included chemical oxygen demand (COD), total nitrogen (TN), ammonia nitrogen (NH₄⁺-N), and total phosphorus (TP). The specific measurement methods refer to "Water and Wastewater Monitoring and Analysis Methods (4th Edition)" [3].

2.4. Data processing
The charts are all made with Origin 8.0, and the statistical analysis of data is done with Excel 2019 software.

3. Results and discussions

3.1. Characteristics of water consumption
In recent years, with the continuous promotion of "new rural construction" and "rural drinking water safety project", most towns and villages in China have basically realized the full coverage of tap water, and the structure of water supply for villagers in rural areas has changed. According to the investigation results, there are two main sources of daily water for farmers in Wangjiatang Village and Qianying Village, respectively: tap water and well water. Occasionally, rain water and pond water are used when villagers’ washing mops or watering vegetable plots. Due to the uncertainty and low frequency of the occurrence of the event (cleaning mops or watering vegetable plots), the amount of water used in these two parts is small, and it can be ignored during the survey.

The well water is used for cleaning activities in Wangjiatang Village, such as washing vegetables, bathing, and washing clothes. However, villagers of Qianying Village tend to use the well water only for flushing toilet. Similarly, villagers in both two places use tap water for drinking water.

Table 1 reflects the water consumption structure and average daily water consumption of farmers in Wangjiatang Village and Qianying Village. According to the data in the Table 1, the total water consumption of farmers is closely related to the economic level. The average water consumption of rural
residents in plain area can reach 94.1 L·cap⁻¹·d⁻¹. Compared with the hygienic standard for rural drinking water consumption (GB 11730-89) [4], this water quota falls within the standard range of 60~100 L·cap⁻¹·d⁻¹ and is close to the upper limit. In rural areas with backward economy, the average household water consumption is relatively low (only 60.4 L·cap⁻¹·d⁻¹). The proportion of well water is higher than that of tap water in the structure of residents' water use in both places, and the non-priced water supply method of well water and the living habits of local residents are the main reasons for this result.

Table 1. Statistics on water consumption

| Village          | Terrain        | Income level | Well water (L·cap⁻¹·d⁻¹) | Tap water (L·cap⁻¹·d⁻¹) | Total (L·cap⁻¹·d⁻¹) | Kd |
|------------------|----------------|--------------|--------------------------|------------------------|---------------------|----|
| Wangjiatang Village | plain areas   | high         | 59.9                     | 34.2                   | 94.1                | 1.3 |
| Qianying Village   | mountainous areas | low          | 33.8                     | 26.6                   | 60.4                | 1.4 |

3.2. Characteristics of sewage discharge

Figure 1 and Table 3 show the average daily drainage statistics of Wangjiatang Village and Qianying Village. Similar to the statistical results of water consumption, the displacement of farmers in the Wangjiatang Village reached 89.4 L·cap⁻¹·d⁻¹, which was about 1.6 times that of farmers in Qianying Village. The rural domestic sewage volume of the two places both fluctuated greatly, and in Wangjiatang Village the large displacement was mainly concentrated in 6:00 ~ 8:00 and 18:00 ~ 20:00, presenting an obvious "morning and evening peaks" feature. However, it shows that the sewage hourly discharge in Qianying Village is characterized by "morning, noon and evening peaks". The large displacement was mainly concentrated in 6:00 ~ 8:00, 10:00~12:00, and 18:00 ~ 20:00. In addition, the water displacement of residents in Wangjiatang Village was much higher than that in Qianying Village, which was as high as 20.9L. Besides, the hourly variation coefficient of sewage discharge was large. The hourly variation coefficient of sewage discharge in Wangjiatang Village was 2.4 ~ 6.1, while that in Qianying Village was 2.5 ~ 3.6. Therefore, when constructing rural sewage treatment facilities, it is necessary to
take into full account the hourly variation coefficient of domestic sewage flow, and to add a flow regulating pool at the front end of the main process to alleviate the impact of the peak drainage period.

Table 2. Statistics on rural domestic sewage discharge

| Sample | Washing sewage (L·cap⁻¹·d⁻¹) | Kitchen sewage (L·cap⁻¹·d⁻¹) | Toilet-flush sewage (L·cap⁻¹·d⁻¹) | Total Sewage (L·cap⁻¹·d⁻¹) | Kd | Kh |
|--------|-------------------------------|-------------------------------|-----------------------------------|----------------------------|----|----|
| plain  | 1 66.3                        | 45.5                          | 31.2                              | 143.0                      | 1.5| 2.7|
| rural areas | 2 31.3                        | 19.1                          | 50.4                              | 100.8                      | 1.3| 3.9|
|        | 3 39.2                        | 16.0                          | 27.1                              | 82.3                       | 1.1| 6.1|
|        | 4 26.3                        | 9.5                           | 13.2                              | 49.0                       | 1.6| 4.5|
|        | 5 31.6                        | 25.0                          | 15.2                              | 71.8                       | 1.2| 2.4|
| Average| 38.9                         | 23.0                          | 27.4                              | 89.4                       | 1.3| 3.9|
| mountainous | A 18.4                        | 6.4                           | 12.9                              | 37.7                       | 1.5| 2.5|
| rural areas | B 22.3                        | 17.9                          | 20.2                              | 60.3                       | 1.1| 3.6|
|        | C 31.4                        | 15.0                          | 25.0                              | 71.4                       | 1.7| 3.5|
| Average| 24.0                         | 13.1                          | 19.4                              | 56.5                       | 1.4| 3.2|

3.3. Characteristics of sewage quality

3.3.1 Characteristics of overall sewage quality. The daily sewage quality and quantity of the sample farmers in Wangjiatang Village and Qianying natural Village were monitored continuously for 15 days and 10 days respectively, and the weighted average concentration and average concentration of COD, NH₄⁺-N, TN and TP in rural domestic sewage were calculated according to Eq.(1) and Eq.(2).

\[ \bar{C} = \frac{\sum_{i=1}^{n} (V_i C_i)}{\sum_{i=1}^{n} V_i} \]

\[ C_i = \frac{\sum_{j=1}^{m} (\bar{C}_j)}{m} \]

Where \( \bar{C} \) is the weighted average concentration of pollutants, \( C_i \) is the daily pollutant concentration, \( V_i \) is the daily discharge volume of sewage, and \( n \) is the number of days.

Where \( C_A \) is the average concentration of pollutants, \( \bar{C}_j \) is the weighted average concentration of pollutants, and \( m \) is the number of households.

The calculated results showed that the average concentrations of COD, TN, NH₄⁺-N, and TP of domestic sewage in Wangjiatang Village were 881.04 mg/L, 46.28 mg/L, 36.50 mg/L and 10.95 mg/L, respectively. Among them, the concentration of TN was similar to the TN concentration (38 mg/L) of rural domestic sewage obtained by Xu [5] in the Taihu Lake Basin (Yixing). The concentrations of COD and TP were higher than that obtained by Xu [5] (600 mg/L of COD and 2.75 mg/L of TP), and the concentration of NH₄⁺-N was lower than that obtained by Zhou [6] (14.1 ~ 52.638 mg/L of NH₄⁺-N).

The average concentrations of COD, TN, NH₄⁺-N and TP of domestic sewage in Qianying Village were 647.67 mg/L, 84.64 mg/L, 30.31 mg/L and 3.99 mg/L, respectively. In comparison to the conclusion of the investigation of rural domestic sewage in Chaohu Lake Basin drawn by Sun [7], the average concentration of TN and NH₄⁺-N were relatively high in this study, which may be related to the high nitrogen load in the toilet-flush sewage.

3.3.2 Characteristics of pollution load distribution. The per capita discharge load of COD, TN, TP and NH₄⁺-N of each type of sewage and its proportion are shown in Table 3 and Figure 2. The loads of pollutants from different sources of rural residents' domestic sewage were obviously different. However, no matter in Wangjiatang Village or Qianying Village, TN and NH₄⁺-N pollution loads of toilet-flush sewage accounted for a high proportion of the total pollution load as shown in Figure 2. The toilet-flush
sewage in Wangjiatang Village provided 84.42% of TN and 92.94% of NH₄⁺-N in the total domestic sewage, while that in Qianying Village provided 74.31% of TN and 84.56% of NH₄⁺-N in the total domestic sewage. It was similar to the conclusion drawn by Wang [8] that rural toilet - flush sewage contributed the most to nitrogen compounds in rural domestic sewage.

![Figure 2](image.png)

Figure 2. The contribution ratio of each kind of sewage to the total discharge load of CODcr, TN, TP, and NH₄⁺-N. (a) and (b) present Wangjiatang Village and Qianying Village, respectively.

| Areas          | Index | Washing sewage (g·cap⁻¹·d⁻¹) | Kitchen sewage (g·cap⁻¹·d⁻¹) | Toilet-flush sewage (g·cap⁻¹·d⁻¹) | Total Sewage (g·cap⁻¹·d⁻¹) |
|----------------|-------|--------------------------------|-------------------------------|-----------------------------------|----------------------------|
| plain rural areas | CODCr | 26.77                          | 20.78                         | 23.34                             | 70.89                      |
|                | TN    | 0.28                           | 0.22                          | 2.71                              | 3.21                       |
|                | TP    | 0.09                           | 0.15                          | 0.39                              | 0.63                       |
|                | NH₄⁺-N | 0.10                          | 0.08                          | 2.37                              | 2.55                       |
| Mountainous rural areas | CODCr | 13.26                          | 12.29                         | 9.75                              | 35.29                      |
|                | TN    | 1.08                           | 0.51                          | 4.60                              | 6.19                       |
|                | TP    | 0.02                           | 0.10                          | 0.10                              | 0.22                       |
|                | NH₄⁺-N | 0.15                          | 0.08                          | 1.26                              | 1.49                       |

Based on the data in Table 2 and Table 3, the amount of toilet - flush sewage was less than that of kitchen sewage and washing sewage, but its pollution load was far away higher than that of kitchen sewage and washing sewage. Just mixing the three types of sewage will increase the difficulty of treatment, and it is a typical type of "dilution is pollution". Therefore, the treatment and disposal of rural domestic sewage should follow the idea of source classification and treatment, so as to effectively and cheaply treat rural domestic sewage according to local conditions, and then solve the problem of rural water environmental pollution control and treatment.
4. Conclusion and suggestion

Through the sampling survey and analysis of rural domestic sewage in two villages of Taihu Lake Basin and Chaohu Lake Basin, the following conclusions can be drawn:

(1) Water consumption and sewage displacement of rural villages are closely related to the economic level and living habits of local farmers. The per capita daily water consumption volume (94.1 L·cap⁻¹·d⁻¹) and daily sewage discharge volume (89.4 L·cap⁻¹·d⁻¹) of Wangjiatang Village are both higher than that of Qianying Village (60.4 L·cap⁻¹·d⁻¹ and 56.5 L·cap⁻¹·d⁻¹). The daily variation coefficient of water consumption for rural residents in the two villages is not high and the water consumption is relatively stable.

(2) The amount of rural sewage hourly discharge fluctuates greatly (the hourly variation coefficient of sewage discharge is about 2.4~6.1), showing obvious characteristics of “morning and evening peaks” or “morning, noon and evening peaks”, and the discharge peak in Wangjiatang Village is about 2.2 times that in Qianying Village. Therefore, when constructing rural sewage treatment demonstration project, it is necessary to design a regulating pool before the main process so as to alleviate the impact of the peak water flow.

(3) Toilet-flush sewage in Wangjiatang Village provided 84.42% of TN and 92.94% of NH₄⁺-N in the total domestic sewage, while that in Qianying Village provided 74.31% of TN and 84.56% of NH₄⁺-N in the total domestic sewage. As a result of its high pollution load of nitrogen pollutants, toilet-flush sewage has a great potential for resource utilization. Besides, when constructing demonstrative project of sewage treatment, the idea of source classification and treatment should be followed.

Acknowledgments

This work was financially supported by National Major Project on Water Pollution Control and Treatment(2017zx07202004-002).

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