Field investigation on rural domestic sewage discharge in a typical village of the Taihu Lake Basin

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Abstract. Rural sewage is an important non-point pollution that aggravates eutrophication of the Taihu Lake. Practically grasping the characteristics of local villages’ sewage treatment demand, sewage flow and sewage quality has far-reaching significance for constructing suitable and efficient rural sewage treatment systems, and ultimately improving the water environment of the lake basin. To this end, the study conducted a field investigation in a typical village of the Taihu Lake Basin in July and continuously monitored sewage flow and sewage quality in the mode of sewage classification. The sewage quality test included chemical oxygen demand (COD), total nitrogen (TN), ammonia nitrogen (NH3-N), and total phosphorus (TP). This paper reviewed the development status of the typical village and demonstrated the rules of rural domestic water consumption and sewage discharge. It was found that the total sewage discharge flow in summer was around 88.90 L/(cap·d) and the hourly variation coefficient was around 3.92. Kitchen sewage, washing sewage, and toilet sewage had significant differences in sewage quality. Particularly, the nitrogen and phosphorus nutrients in toilet sewage were quite rich, accounting for 84.42% and 61.90% of the corresponding total load, respectively. Thus, the ideas of properties-classified treatment and resource treatment were worth being introduced into the rural sewage treatment process.

1. Introduction
With the continuous improvement of China's national economy, the discharge flow and pollution load of rural sewage are both increasing. According to statistics from the relevant department[1], at the end of 2016, 68.7% of administrative villages across the country had centralized water supply, while only 20% of administrative villages treated domestic sewage. The direct discharge of domestic sewage seriously damages the ecological environment and is not conducive to the healthy development of rural areas. To change this situation, the Chinese government has made improving the rural water environment a key task these years, attracting various urban sewage treatment technologies flushing into the rural sewage market.

The Taihu Lake Basin is one of the earliest areas in China to begin rural sewage treatment. The river network in the Taihu Lake Basin is quite crisscross with a density of 3.2 km / km², making it possible to receive almost all the rural sewage within the basin. Currently, the eutrophication of Taihu Lake is still severe. TP and COD are the main pollution indicators[2]. Although the Taihu Lake Basin has been vigorously promoted the construction of rural sewage treatment facilities since 2008, it is very common that the existing facilities have poor treatment efficiency, high treatment costs, and inability to mobilize...
villagers to maintain and manage consciously[3]. Therefore, the treatment of rural sewage cannot simply learn from the technology of urban sewage treatment plants, and it needs to be tailored according to the actual situation in rural areas.

This study constructed a field investigation in a typical village of the Taihu Lake Basin to understand the humanistic background and villagers’ real needs for sewage treatment, and summarize the discharge rules of sewage quality and flow. The conclusions are beneficial to the optimization of rural sewage treatment in the Taihu Lake Basin, and can also provide some guidance to other similar areas.

2. Experimental design of rural domestic sewage discharge

2.1. Experimental site
In this study, Wangjiatang Natural Village was selected as the experimental site for continuous monitoring. Wangjiatang Village is located in Xinkang Administrative Village, Changzhou City, Jiangsu Province. It is a typical representative of rural villages in the economically developed areas of eastern China. Located in the subtropical monsoon climate zone, Wangjiatang Village has high temperature and rain in summer, and its summer sewage production peaks throughout the year. The rivers surrounding Wangjiatang Village are densely covered, so that the farmland drainage and the treated domestic sewage in the village have direct access to the rivers, contributing to the water pollution of the Taihu Lake.

2.2. Acquisition of the village’s overview
Household-to-household questionnaires and face-to-face interviews were applied to collect statistics of each household on the population, working hours, educational level, economic status and habits of water usage. Information about Wangjiatang Village’s current sewage treatment situation was obtained through manual observation and consulting the manager of the local sewage treatment project.

2.3. Statistics on sewage discharge flow and water consumption
According to the overview of the typical village, five representative households were selected as samples for the 15-day continuous monitoring. During the period, the willingness of each family member to participate in the experiment was fully considered, and necessary security work was done, so as not to disturb the normal life of the villagers as far as possible.

The idea of sewage classification was adopted to design the experiment. In this study, domestic sewage was classified into three parts depending on their usage: kitchen sewage, washing sewage (including washing clothes, bathing, and other personal care sewage) and toilet sewage. During the research, two 120L plastic buckets with graduations were placed in each sample household to collect kitchen sewage and washing sewage respectively. Recording readings, sampling, and cleaning plastic buckets were all performed every two hours. Besides, toilet registration forms were set up in the sample households to calculate the toilet sewage discharge. Participants needed to tick the corresponding time interval and type (urination or defecation) when using the toilet. The toilet sewage samples were obtained daily from the first compartment of the septic tank. The tap water meter values of the sample households were recorded every 24 hours. All relevant calculation formulas are as follows:

\[ Q_s = Q_k + Q_w + Q_t \]  
\[ Q_t = q_1 n_1 + q_2 n_2 \]  
\[ Q_0 = \alpha Q_s = Q_{well} + Q_{tap} \]
Where $Q_0$ is the flow of total water consumption, $Q_{well}$ is the flow of well water consumption, $Q_{tap}$ is the flow of tap water consumption and $\alpha$ is the coefficient of sewage discharge, whose value is 0.8 here (considering the dissipation and evaporation of water)\textsuperscript{[4]}.

$$K_h = \frac{Q_{h-max}}{Q_{h-avg}}$$

Where $K_h$ is the hourly variation coefficient, $Q_{h-max}$ is the maximum hourly flow of sewage and $Q_{h-avg}$ is the average hourly flow of sewage.

$$K_d = \frac{Q_{d-max}}{Q_{d-avg}}$$

Where $K_d$ is the diurnal variation coefficient, $Q_{d-max}$ is the maximum diurnal flow of sewage and $Q_{d-avg}$ is the average diurnal flow of sewage.

### 2.4. Analysis of sewage water quality.

Daily samples (kitchen sewage, washing sewage, and toilet sewage) of each household were obtained by mixing all corresponding two-hour samples in proportion to the quantity of sewage produced in each period. After the water samples were collected, the pH was measured at once, and then 1 + 1 sulfuric acid was added to avoid sample deterioration. The samples were stored at -4 °C and sent to the Wuxi Taihu Water Environment Engineering Research Center of Southeast University for testing every other day. The water quality analysis items and methods are shown in Table 1:

| Test items | Test methods                                      |
|------------|---------------------------------------------------|
| COD$_{cr}$ | Potassium dichromate method                       |
| NH$_4^+$-N | Nessler's reagent colorimetric method              |
| TN         | Alkaline potassium persulfate oxidation - ultraviolet spectrophotometry |
| TP         | Molybdenum-antimony resistance spectrophotometry  |

### 3. Results and discussion

#### 3.1. Development trends of the typical village and its sewage treatment

#### 3.1.1. Changes in population and industry. According to the field investigation, the phenomenon of rural population loss is widespread in the Taihu Lake Basin, and rural industries are becoming increasingly industrialized and modernized. There are 58 registered households in Wangjiatang Village, but only 28 of them are long-term living households, and most of the left-behind population is elderly and children. Most young and middle-aged people registered in this village have purchased new houses in cities or market towns with better infrastructure and medical education, but they will still maintain rural self-built houses as fixed assets. This kind of short-distance migration is mainly made up of young and middle-aged people, which has a close causal relationship with changes of local non-agricultural industry\textsuperscript{[5]}. Due to the low output value of traditional agriculture, it is difficult for the economic benefits of individual farming to sustain family living expenses. Instead, village and township enterprises around the countryside have flourished, providing villagers with a lot of nearby employment opportunities. It is worth mentioning that although local villagers now rarely farm, their fields are not deserted. Through land circulation, the scattered cultivated lands of villagers are uniformly contracted by various professional growers and breeders, who can achieve high efficiency and high yield through large-scale and scientific management.

Nevertheless, the loss of the rural population is not irreversible. With the implementation of China's rural revitalization strategy, the phenomenon of people returning to the village for retirement will become more and more popular, forming a reverse flow of population. Therefore, it is still necessary to build infrastructure such as long-term rural sewage treatment facilities adapted to local conditions.
3.1.2. Overview of sanitation facilities. With the development of the rural economy, the infrastructure of rural households in the Taihu Lake Basin is also modernizing. Wangjiatang Village realized tap water supply as early as the beginning of the 21st century, and flush toilets and shower facilities also widely entered villagers' houses. However, due to local customs and living habits, some villagers still choose traditional dry toilets and bath pots (a kind of traditional bathing facilities common in the rural areas of Jiangsu and Zhejiang), or a mix of new and old facilities for three reasons: 1) the older generation is difficult to change their traditional bathing and toileting habits; 2) flush toilets are not convenient for the collection and utilization of feces; 3) The older generation thinks that new sanitary facilities cost too much water. At present, the domestic sewage of each household is discharged in an organized manner, but no source classification and differential treatment of sewage has been performed according to the differences in sewage water quality and water flow.

3.1.3. Demand for resources in sewage. It is found that despite the widespread land circulation in rural areas, villagers still have the habit of planting some vegetables and fruits in front of and behind their houses. Most villagers prefer manuring the vegetable fields with separately collected urine or septic sludge, which reflects that villagers have a significant demand for the utilization of rural domestic sewage resources. Thus, if the rural sewage treatment system is to be truly popular with the villagers, it is necessary to select and design technologies that can combine sewage treatment with recycling nutrients, improving purification capacity as well as economic value.

3.2. Characteristics of water consumption

Local families generally have two water sources: well water excavated in their patios and tap water provided by the municipal pipe network. Most households in Wangjiatang Village choose to use free well water for flushing, bathing, and laundry while using tap water for cooking and drinking. Very few households have abandoned their wells and use tap water only. Table 2 provides the average water consumption rate and sewage discharge flow of the sample households. During 15-day monitoring, the ratio of Q_well to Q_tap was about 13: 7, revealing that well water has played an important role in local family life. The total water consumption rate was 111.13 L/(cap·d), which exceeded the corresponding standard range of 60 ~ 100 L/(cap·d) in GB 11730-89[6]. Also, Q_s was higher than the accounting value of 63.2 L/(cap·d) in China's Second National Pollution Source Survey (CSNPSS)[7]. Understandably, the sewage flow was relatively high because the values measured only represented the summer levels. However, it cannot be ignored that villagers’ excessive water consumption does exist, for a large proportion of households have poor consciousness of saving water when facing free well water.

| Table 2. The average water consumption rate and sewage discharge flow. Unit: L/(cap·d). |
|-----------------|-----------------|-----------------|-----------------|
| Q_well          | Q_tap           | Q_ass           | Average         |
| 71.78           | 39.34           | 111.13          | 88.90           |

3.3. Characteristics of discharged sewage

3.3.1. Sewage discharge flow. As shown in Table 3, this study obtained the distribution of the summer domestic sewage discharge flow in Wangjiatang Village through 15-day continuous monitoring. The per capita drainage of village residents was 88.90 L/(cap·d), of which 34.15 L/(cap·d) was kitchen sewage, accounting for 38.41%, 27.31 L/(cap·d) was washing sewage, accounting for 30.72%, and 27.44 L/(cap·d) was toilet sewage, accounting for 30.87%. The mean K_d of the sample households was 1.34, indicating that the daily variation of sewage flow was small. However, the hourly flow of sewage fluctuated greatly, and the mean K_h was as high as 3.92, exceeding the variation coefficient of urban domestic sewage flow. It is mainly because rural households have a very consistent and regular lifestyle, which makes the village domestic sewage flow have obvious peak and valley periods. The specific manifestation is that the drainage is concentrated in the three meals and bathing stages of the day, especially reaching a peak at 18-22 o'clock, and there is little water consumption at mid-night and in the
afternoon. Therefore, the construction of rural sewage treatment facilities in this area must fully consider the big hourly variation coefficient of the domestic sewage flow, and design or introduce a technology with good resistance to shock flow load, such as the sewage volume adjustment pool.

| Sample number | Kitchen sewage [L/(cap·d)] | Toilet sewage [L/(cap·d)] | Washing sewage [L/(cap·d)] | Total [(L/cap·d)] | K_h | K_d |
|---------------|-----------------------------|---------------------------|---------------------------|------------------|-----|-----|
| Average       | 34.15                       | 27.31                     | 27.44                     | 88.90            | 3.92| 1.34|

3.3.2. Characteristics of pollutants in sewage. The box diagram in Figure 1 shows the concentration distribution of COD_{cr}, NH3-N, TN, and TP in all collected samples of kitchen sewage, toilet sewage, and washing sewage. The main body of the box represents 25% - 75% parts arranged in concentration. The thick black line in the middle of the box indicates the median concentration. The upper T and lower T represent the upper and lower limits, and the parts outside the T shape are abnormal values.

Figure 1. The boxplot of pollutants’ concentration in kitchen sewage, toilet sewage, and washing sewage. (a), (b), (c), and (d) present the concentration of COD_{cr}, TN, NH3-N, and TP respectively.

Figure 1 (a) shows that the COD_{cr} of most sewage samples are over 500 mg/L, and some of them even exceeds 1500 mg/L. It means that domestic sewage is rich in the organic pollutants, which is, to be honest, conducive to anaerobic or aerobic technologies to make the most of their treatment efficiency. From the perspective of their median COD_{cr} value, toilet sewage has the highest COD_{cr} level, the level
of kitchen sewage is slightly inferior, and washing sewage has the lowest COD cr level. According to Figure 1 (b) and Figure 1 (c), the NH3-N and TN of toilet sewage are much higher than those of the other two types of sewage. The NH3-N concentration of kitchen sewage is very close to that of washing sewage, and they are both significantly lower than their TN values. It can be speculated that the proportion of nitrate-nitrogen in these two types of sewage is relatively large. Figure 1 (d) shows that in terms of TP, toilet sewage is still far ahead, kitchen sewage is second, and washing sewage is the least. The nitrogen and phosphorus nutrients in toilet sewage are very rich and worthy of recycling. In addition, the CODcr and TP of kitchen sewage are relatively high. Extra test found that, the CODcr, NH3-N, TN, and TP of the rice-washing sewage were in the range of 1656~2906 mg/L, 5~14 mg/L, 13~20 mg/L, and 55~134 mg/L, respectively. Rice-washing sewage is especially rich in CODcr and TP, maybe because washing rice can leave organic matters such as rice bran protein and starch in the water[8]. Taking into account the concentration level of the pollutants, rice-washing sewage is more suitable to be classified into the category of toilet sewage for discharge and treatment.

By integrating the information of sewage flow and pollutant concentration, the per capita discharge loads of CODcr, NH3-N, TN, and TP in sewage and the contribution rate of three types of sewage were obtained, as shown in Table 4. During monitoring, despite the low CODcr concentration of washing sewage, the CODcr load of washing sewage was the highest due to its huge flow. Toilet sewage provided 84.42% of TN, 92.94% of NH3-N, and 61.90% of TP in the total domestic sewage. Thus, toilet sewage is the main source of nitrogen and phosphorus in rural domestic sewage. In order to achieve efficient resource utilization of sewage, it is necessary to separate toilet sewage from other sewage for targeted collection and treatment.

### Table 4. The discharge loads of CODcr, NH3-N, TN, and TP in sewage and the contribution rate of each kind of sewage to the total load.

|                 | CODcr [gCOD/(cap·d)] | Rate a | TN [g/(cap·d)] | Rate b | NH3-N [g/(cap·d)] | Rate c | TP [g/(cap·d)] | Rate d |
|-----------------|-----------------------|--------|----------------|--------|------------------|--------|---------------|--------|
| Kitchen         | 20.78                 | 29.31% | 0.22           | 6.85%  | 0.08             | 3.14%  | 0.15          | 23.81% |
| Toilet          | 23.34                 | 32.92% | 2.71           | 84.42% | 2.37             | 92.94% | 0.39          | 61.90% |
| Washing         | 26.77                 | 37.76% | 0.28           | 8.72%  | 0.10             | 3.92%  | 0.09          | 14.29% |
| Total           | 70.89                 | 100%   | 3.21           | 100%   | 2.55             | 100%   | 0.63          | 100%   |

a, b, c, d the contribution rate of each kind of sewage to the total discharge load of CODcr, TN, NH3-N and TP, respectively.

### 3.3.3. Current sewage discharge model.

At present, Wangjiatang Village adopts a rural sewage treatment model that simply combines three types of domestic sewage and collects them for unified treatment, ignoring the differences between different types of domestic sewage. As can be obtained from Table 4 and Figure 1, the flow of washing sewage and kitchen sewage accounts for 69.28% of the total sewage, but their concentrations of NH3-N, TN, and TP are less than a fraction of those in toilet sewage. The combined sewage pipe will greatly cause the dilution of nitrogen and phosphorus nutrients in toilet sewage, increasing the difficulty of resource utilization.

Therefore, we suggest introduce the ideas of properties-classified treatment and resource treatment into the rural sewage treatment process. For example, kitchen sewage and washing sewage with low pollution concentrations do not require advanced treatment. The villagers can be consciously guided to use water-saving toilets to further reduce the dilution of toilet sewage, and to separate the toilet sewage for efficient anaerobic treatment. Resource treatment should be closely integrated with local agriculture, for example, economic crop-type constructed wetlands or vegetable filter beds can be added to the sewage treatment system to cater to villagers’ demand for resources in sewage.
4. Conclusions and suggestions
Through the field investigation, this study has grasped the development trend of rural sewage treatment and characteristics of domestic sewage discharge in the Taihu Lake Basin. The main conclusions and suggestions are summarized as follows:

(1) There is the possibility of reverse population flow in the rural areas of the Taihu Lake Basin. Rural sewage treatment in the Taihu Lake Basin is very necessary and should be developed as a long-term project to optimize the long-term stability of the sewage treatment system.

(2) Rural water consumption and sewage discharge flow in the Taihu Lake Basin are all at a high level. Wells are still important water sources of local life. During 15-day monitoring, the per capita total discharge flow of Wangjiatang Village was as high as 88.90 L/(cap·d). The mean hourly coefficient of variation of sewage discharge was 3.92. It is very necessary to add a sewage volume adjustment pool before sewage treatment.

(3) Kitchen sewage, toilet sewage and washing sewage have significant differences in quality. During 15-day monitoring, toilet sewage contributed 84.42% of TN and 61.90% of TP to the total discharge load of household sewage. Rice-washing sewage was found to be similar with toilet sewage in quality. The concentrations of NH3-N, TN, and TP in other kitchen sewage and washing sewage were far less than those of toilet sewage. CODcr of toilet sewage was only slightly higher than that of kitchen sewage and washing sewage.

(4) The existing combined sewage discharge model in the Taihu Lake Basin cannot provide targeted treatment for different household sewage. The ideas of properties-classified treatment and resource treatment should be introduced into the rural sewage treatment process. Local sewage treatment systems can employ agricultural constructed wetlands to recycle nitrogen and phosphorus.

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