Challenges and Solutions for On-Site Wastewater Treatment in Rural Areas: Case Study of Chongming, Shanghai, People’s Republic of China

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Introduction

With the support of national projects, Fan Bin, who is affiliated with the Research Center for Eco-Environment Sciences of the Chinese Academy of Sciences, developed a model for integrated rural wastewater governance in the county area (Changshu paradigm), in cooperation with the Changshu Municipal Government over a 6-year period from 2009 to 2015. In 2015, the Ministry of Housing and Urban-Rural Development selected 100 counties across the country to promote the Changshu paradigm, launching the first nationwide rural wastewater governance initiative in the People’s Republic of China (PRC).

The rural sewage treatment plant project on Chongming Island is a typical example of this initiative, which also used Johkasou technology. However, this project faced significant challenges in bringing the quality of the effluent up to local high discharge standards. This challenge stems from the misunderstanding of the goal of rural sewage governance and the blind pursuit of high discharge standards. Now the challenge has been effectively addressed, and the wastewater collection and treatment rate in Chongming Island has reached the set target of 100%. Therefore, it is time to review the process of rural wastewater governance in Chongming Island, summarize the experience, and improve the treatment and management technology.
Experiences and Lessons from Rural Wastewater Treatment Before Johkasou in Chongming

Geographic, Demographic, and Economic Features of Rural Settlements in Chongming

Chongming District, which is part of Shanghai Municipality, is located at the mouth of the Yangtze River. The entire district is flat and consists of Chongming Island, Changxing Island, and Hengsha Island with a total area of 1,413 square kilometers. Chongming Island is the largest alluvial island in the world and the third largest island in the PRC. Chongming District has a subtropical monsoon climate with four distinct seasons, mild and humid climate, abundant sunshine and rainfall, and an average annual temperature of 16.5°C (Chongming Government 2021).

According to the data of the seventh census, the resident population of Chongming District was 637,921 as of 1 November 2020 (Shanghai Qingpu Statistics Bureau 2021). In 2019, the gross domestic product of the region was CNY37.85 billion. The ratio of the output value of the three industries was 6.3/26.0/67.7, and the per capita disposable income of the region was CNY39,953, including CNY27,895 for rural residents (Chongming Government 2020). Compared with Changshu, rural settlements in the Chongming District are more regular, with neatly laid out farmland and well-developed grid-like roads connected to each other, and residential houses arranged in a certain order on both sides of the roads and near traffic junctions that are neatly planned (Figure 1).

Figure 1: Satellite Image of Rural Settlements in Chongming District, Shanghai

The villages in Chongming District are neatly planned, with concentrated farmland and households distributed along the roads (photos adapted by authors from Bai Du. https://map.baidu.com/).
Background of Rural Domestic Wastewater Treatment in Chongming District

The domestic wastewater treatment project in Chongming District covers 232,000 rural households, 42,000 non-farmer households (e.g., rural public welfare institutions, residential households, and the non-local population), totaling 274,000 households. Before the application of Johkasou technology, the process of rural wastewater treatment in Chongming District can be roughly divided into 2 phases.

The first phase took place in 2001–2009. In 2001, Shanghai started rural wastewater treatment. In 2004, the municipal government, under the guidance of the Municipal Water Bureau, issued a comprehensive program to promote rural wastewater treatment projects. In 2004–2009, the District Environmental Protection Bureau and the District Agricultural Committee successively carried out a series of small-scale rural wastewater treatment demonstration projects, which was the first exploration of rural wastewater treatment.

The second phase took place in 2009–2016. During this period, the city invested about CNY590 million to build a series of rural wastewater treatment plants in Chongming District, serving 40,000 households and comprising 12 processes, including self-flow aerated biofilter beds, modular biofilm filter tanks, and integrated membrane bioreactors, with effluent quality meeting the secondary standards of the PRC GB18918-2002 (GB). The plants built during this period have the following problems:

1. The plants occupy a large area, have low construction standards, insufficient investment in maintenance, operate at a normal rate of less than 50%, have leaks in the pipe network, and have substandard water quality.

Figure 2: Artesian Oxygenated Ecological Bed Technology: Modular Biological Filter Technology

In 2009–2016, a number of domestic wastewater treatment facilities involving 12 processes were constructed in Chongming District. Bio-ecological coupling technology is an important component of them. Left photo shows a self-flow oxygenated biofilter bed process; right photo shows a modular biofilter bed process (photos by Zixiao Wang and Jean Joël Roland Kinhoun).

Main indicators: COD$_c$≤100 mg/L, BOD$_5$≤30 mg/L, SS≤30 mg/L, NH$_3$-N≤25(30) mg/L, TP≤3 mg/L.
2. Some processes require the use of construction land indicators to build new houses in order to protect the above-ground part of the sewage treatment plants, resulting in high costs.

3. Many types of processes differ greatly, resulting in different ways of maintenance. Due to the independence of construction companies, it is difficult to coordinate O&M teams and standardize the O&M process.

In 2016, Chongming proposed an overall plan to build a world-class ecological island by 2030. The city and district governments attach great importance to the plan and aims to achieve comprehensive wastewater collection and treatment in Chongming District by 2020 to meet the 2030 target. According to the Shanghai water environment zoning, Chongming District is mainly used for ecological and landscape recreation, and the water function zoning is surface class 3. After several rounds of discussion and demonstration, Chongming District proposed in 2017 that wastewater from the district’s rural wastewater treatment plants should meet the local Shanghai standard of 1A. However, the effluent quality of the treatment plants built in 2009–2016 could hardly meet the discharge requirements, leaving rural water management in the region in a difficult situation. The Changshu decentralized wastewater treatment PPP project implemented by CRRC, in which the Johkasou household wastewater treatment plant played the main role, achieved good results and was praised by relevant government sector and industry. This laid the foundation for entering Chongming District to implement the project.

Design and Implementation of the Johkasou Application Project

Project design

Against the background that the rural wastewater treatment project in Changshu has achieved phased results and received the affirmation of national authorities, Chongming District signed a strategic agreement with CRRC in 2017 to take rural wastewater as a starting point and rely on CRRC’s technical advantages, brand resources, and investment and financing capabilities to realize comprehensive cooperation. Following the Johkasou demonstration project in Sanxing Town, CRRC was awarded the wastewater treatment project for 120,000 households in seven townships in Chongming District. The project was implemented in engineering procurement construction (EPC) + operation (O) mode, with household Johkasou as the main technology.

In June 2017, Chongming District released the “Implementation Plan for Accelerating the District’s Rural Living Sewage Treatment” and the “Shanghai Chongming District Rural Living Sewage Treatment Construction and Raising Integration” Management Measures (Chongming Government 2017a). The document clarifies the four working mechanisms for construction and maintenance: (i) changing the discharge standard that rural wastewater treatment plants must implement from the GB secondary standard to the local 1A standard; (ii) integrating the bidding of project design, construction, maintenance, and implementation; (iii) the township as

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2 Main indicators: COD≤50 mg/L, SS≤10 mg/L, NH3-N≤8 mg/L, TN≤15 mg/L, TP≤1 mg/L.
a unit combining rural domestic wastewater treatment plant projects, unified bidding, unified construction, and unified maintenance and servicing; and (iv) in promoting the project, the use of information technology, the synchronized construction of an intelligent monitoring platform covering the entire region, and real-time monitoring of plant operation.

The document also specifies how project funds will be paid (Chongming Government 2017b). The city will fully fund the construction cost of CNY20,000 per household (generally two–three households share one household Johkasou). Of the total cost, 50% will be paid initially when the construction is completed and the remaining 50% will be paid in 3 years after completion and acceptance, 10%, 10%, 30%, which is linked to the results of the current year’s water quality assessment. The standard for the maintenance fund is CNY280 ($48) per household per year (including sludge disposal), with the district and city governments each contributing 50%.

**Design implementation**

During the project, Chongming District developed a comprehensive technical model for plant operation and maintenance (O&M) and monitoring.

1. **O&M technology**: CRRC established an O&M station in the town where the project is located, which is coordinated and managed by CRRC and employs a three-tier management framework (station manager–team leader–staff). The O&M tasks include four areas, such as data collection, equipment maintenance, mechanical maintenance, and equipment cleaning. The O&M staff consists mainly of local villagers and workers. Equipment maintenance will be done once a month. CRRC will randomly check and evaluate the O&M team. The evaluation results will be linked to the payment of O&M expenses.

2. **Supervision technology**: The evaluation team, led by Chongming Water Bureau and composed of the District Finance Bureau and the District Ecological Environment Bureau, conducts irregular supervision and evaluation of the operation, maintenance, and management of the municipality’s commissioned wastewater treatment plants. The content of the evaluation includes two aspects: management measures and management effects.

The management measures accounted for 30 points, scoring from the implementation of daily supervision, establishing mechanisms and institutions, and ensuring safety. On the construction side, it is necessary to ensure the effective collection of the sewage network and the normal operation of the facilities; inspection patrols should be carried out on time to respond to the masses in a timely manner; water quality standards and sludge disposal safety must be consistently maintained; and establishment of a sound regulatory mechanism and system, the implementation of long-term financing of O&M costs, and reliance on grassroots common supervision.

Management impacts account for 70 points, scored by environmental impacts and social impacts of facilities. The environmental impact of the facilities is scored by the evaluation team, which examines the water quality and intact condition of the treatment plants during the conservation period based on the relevant monitoring and sampling results of the Municipal Water Bureau, District Ecological Environment Bureau, District Water Resources Bureau, and other departments.
The social impact of the treatment plants will be studied through field visits and inspection of working documents to determine how satisfied the people are with the rural wastewater treatment project.

**Remote control platform:** The use of information technology to support rural wastewater management is one of the characteristics of Chongming District. The remote monitoring and control information system used by CRRC is an internet platform for the operation, maintenance, monitoring and management of wastewater treatment plants. The system collects and sends the operation status and data of the plants to the server via the company-developed wireless GPRS module. The server analyzes, processes, and saves the uploaded data. Through the preset functions, demand functions, and the division of multilevel authority, it carries out the independent work of maintenance management and supervision.

**Project Challenges and Solutions**

The Johkasou project in Chongming District encountered two major challenges in addition to some successes. Based on staff interviews and field research, we have summarized the following challenges in and corresponding solutions for the application of household Johkasou in Chongming District (Figure 3):

**Challenge 1: The household Johkasou’s difficulty of meeting the Shanghai Rural Domestic Wastewater Treatment Facility’s wastewater quality requirements of Water Pollutant Discharge Standard 1A**

In order to achieve Chongming District’s goal of building a world-class ecological island, after many rounds of discussions and demonstrations, Shanghai proposed that Chongming District’s wastewater treatment plants must meet the local standard 1A. However, due to the wide fluctuation of water quality and quantity and the lack of phosphorus removal, the household Johkasou wastewater treatment plant has difficulty in achieving a stable treatment effect, let alone meeting local standard 1A. As a result, the acceptance of the project with household Johkasou as the main technology has been delayed.

In order for the Johkasou’s effluent quality to meet standard discharge and pass project acceptance, CRRC designed and implemented several improvement measures based on the Johkasou, such as the installation of a septic tank before the household Johkasou to strengthen stabilization treatment and regulate water quality and quantity; the installation of an aeration unit through renovation to increase the removal rate of organic matter and ammonia nitrogen; the coupling of autotrophic sulfur denitrification technology to strengthen the removal of nitrogen; the coupling of artificial wetlands and ecological filters for deep treatment of Johkasou wastewater. However, with these measures, it is still difficult to achieve the goal of meeting the discharge standards, and thus, the acceptance of the Johkasou application project has reached an impasse.
Solution: To achieve the discharge standard, after several different renovation solutions based on the existing Johkasou were ineffective, CRRC proposed the solution of again collecting and centralizing the Johkasou wastewater. Specifically, the household Johkasou tailwater flows into the newly installed storage tank nearby, and a wastewater lift pump is installed in the tank, which is regularly pumped to the central treatment plant in the region for deep treatment. The central wastewater treatment plant uses an integrated moving bed reactor to which carbon sources and phosphorus removal chemicals are added, so that the wastewater can meet Shanghai’s local standard 1A. According to the results of the field research, the cost of collecting and recycling wastewater from the Johkasou is at least CNY10,000 per household (the investment includes one Johkasou wastewater collection tank of 1 cubic meter (\(m^3\)) fiber reinforced plastic/polymer (FRP), one wastewater transfer pump, a 60 cm deep wastewater transfer pipe over a length of 50 meters – DN75 PE, a protective cover for the transfer pipe over the river, and one central treatment plant). Although this solution achieved the discharge standard and the smooth acceptance of the project, the construction cost of wastewater treatment increased to over CNY30,000 per household. In addition, the maintenance costs for the treatment plant also increased significantly due to the additional chemicals and centralized treatment plant equipment. The introduction of this addition for the implementation of this wastewater treatment supplement naturally prompted the researcher and experts to ask the questions: How can the discharge standards for rural wastewater treatment plants be developed scientifically? Is the higher the standard, the better?

Figure 3: Challenges and Solutions in the Application of Johkasou in Chongming District

Source: Authors.
Challenge 2: Emphasis on construction but not operation, lack of mechanisms for long-term operation of Johkasou, and difficulties in ensuring the quality of water discharged from the facilities.

Regarding the financing of rural water governance projects in Chongming District, the construction cost of the plants (CNY20,000 per household, average value) is fully subsidized by the Shanghai Municipal Finance Bureau, while the operating cost of the plants (CNY280 per household) is shared by the district and township governments, with each side contributing 50%. However, with the operating cost of CNY280 per household, it is difficult to maintain the wastewater quality of the plant to meet the requirements of local standard 1A. The main reason that the investment is not increased to ensure the supply of O&M funds is that the district and township can hardly afford the higher cost. The proportional characteristics of Chongming District’s industrial structure show that agriculture and service industries are the main industries in Chongming District. In order to create a world-class ecological island, almost no production and manufacturing industry is kept in the district, so the financial income is not high and the maintenance funds are hardly guaranteed, which directly leads to poor operation of the facilities.

On the other hand, there is a clear difference between the O&M technology of decentralized treatment plants and that of centralized treatment plants. The O&M team of the centralized treatment plant consists of a group of professionals with a clear division of labor and a relatively single repetitive process. At the same time, the O&M cost of the plant per ton is not high due to the economies of scale of centralized treatment. The complexity of maintenance and repair of decentralized plants is determined by the scattered and numerous locations and the various operating conditions. Extensive O&M experience and efficient management technology for rural wastewater treatment plants are required to develop good O&M technology and achieve stable operation effect. However, Chongming District and even the PRC currently lack experienced and highly qualified rural wastewater treatment plant O&M teams. Most of them are local teams that grow under the standardized support of the local government and are less professional. The result is a long-term dislocation of O&M work, leading the district government to pin its hopes for environmental governance on new plant projects with sufficient financial support. Thus, the phenomenon of tearing down old facilities to build new ones and building instead of maintaining results in a great waste of public funds and government property.

Solution: To solve the phenomenon of “emphasizing construction over maintenance and repair,” it is critical to ensure the quality of maintenance and repair on the most essential factors. Municipal wastewater management departments can leverage social capital to ensure the provision of funds for maintenance and repair, while sharing project risks with contractors, and mobilizing social capital enthusiasm to participate in the public facility construction and maintenance projects. In addition, the contractor should seek changes to improve the professionalism of its own O&M team while creating a well-structured team and management model for long-term operations. The ideal O&M team structure should be a pyramid-shaped team consisting of a small number of specialized rural wastewater managers and a large number of local staff familiar with public opinion. This structure not only ensures professionalism and long-term effectiveness of plant maintenance, but also reduces labor costs and management difficulties.
On the other hand, Chongming District emphasizes in the 14th Five-Year Plan that it will carry out the upgrading of old plants in the district and that some of the old processes can be maintained up to the standard (GB 2 level) with low operating costs and treatment effects. Old plants that incur high operation and maintenance costs and whose effluent quality does not meet standards will be removed after evaluation and replaced with new plants or upgraded to meet standards.

**Summary**

Chongming Island’s achievements in rural domestic wastewater governance are remarkable. From 2017 to 2020, in just 3 years, the complete collection and treatment of rural wastewater in the region was achieved, and the quality of the residential environment was significantly improved, with the application of household Johkasou technology playing a key role. On the other hand, the rapid push of the project has also revealed some problems. For example, the high local discharge standard for rural wastewater treatment plants was set, for which both Chongming District and the project company had to pay a heavy price. Then again, in the case of difficulty to secure O&M funds, the EPC+O model was used to carry out the project, which pushed all the engineering responsibilities and risks to the enterprise while ignoring the brand resources and financing ability of CRRC, an excellent condition to solve the O&M funds.

After reviewing the entire process of rural sanitation in Chongming Island, we make the following recommendations.

1. Wastewater governance in rural areas should be guided by improving the quality of the living environment rather than achieving performance goals. Environmental resilience should be considered as one of the most important factors in setting emission standards for facilities, to strive for adaptation to local conditions and not to go too high (Fan et al. 2021).

   Indeed, as rural economies improve and modernization gradually arrives, it makes sense to improve in all areas and aim for higher emission standards accordingly. But in the case of rural wastewater treatment, we should also resist the excessive pursuit of high-quality wastewater without considering the economic and environmental balance. Wastewater is discharged in a decentralized manner, and the various pollutants in wastewater can also be further dispersed through ecosystems such as ditches, so that drainage standards can be lowered, which is a common practice worldwide.

   In addition, although the effluent quality of decentralized wastewater treatment facilities like the household Johkasou fluctuates, the overall effluent situation of a group of facilities in the region, or the overall situation of a single facility over a relatively long period (for example, within a month) should be examined because the treatment capacity of a single facility is very low.

2. Standardization of the rural wastewater treatment industry is very important, including standardization of design, procedures, construction, operation and supervision, and the relevant industry standards should be implemented by management departments as soon as possible.
The management of rural wastewater treatment is carried out under three aspects: government management, industry management, and technical management (Fan 2016). These three levels of management are successively interrelated (Figure 4). Among these three aspects, industry management is an important link between the parties involved, but also the one most likely to cause problems. Industry managers should be able to properly understand the country’s needs and have the organizational skills to set and refine goals, and then work with relevant parties to provide appropriate direction.

Figure 4: Responsibilities and Relationships at All Levels of Management

Source: Authors.
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Study Questions

1. Which of the solutions presented in this case study can be applied to your country or city?
2. After reading the case study, list 1–2 problems that you think still need to be solved in order to introduce Johkasou in developing countries?
3. Reflecting on the key messages from the case study, what challenges do developing countries face in fulfilling the roles and responsibilities of local government and the private sector to successfully plan, operate, and maintain the wastewater management system in a local community?

Note: In this publication, “$” refers to United States dollars.

The Asian Development Bank refers to “China” as the People’s Republic of China.

Cover photo: A household Johkasou in Chongming (photo by Ao Li).