A Comparative Analysis of Rural Domestic Wastewater Discharge Standards in the Yangtze River Delta Region, China

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Abstract. With the deepening of comprehensive improvement of rural living environments in China, various regions have issued rural domestic wastewater discharge standards based on their economic foundations, management levels, and characteristics of rural wastewater discharge. The Yangtze River Delta region, in particular, has been at the forefront of exploring these standards nationwide. By analyzing the local standards for rural domestic wastewater discharge in Shanghai, Jiangsu, Zhejiang, and Anhui provinces within the Yangtze River Delta region, along with the "Discharge standard of pollutants for municipal wastewater treatment plant" and the "Standard for irrigation water quality", it was found that the standards in each region primarily consider the classification based on the water environmental grade of the receiving water body. The pollutant concentration control requirements are generally consistent with the pollutant concentration limits for urban wastewater treatment plant discharge, but the total nitrogen and total phosphorus limits are more lenient than those for urban wastewater treatment plants. This paper can guide the transformation of rural domestic wastewater discharge from high standards to resource utilization, and provide references for the selection of wastewater treatment technologies, models, and governance strategies in the Yangtze River Delta region.

Keywords: Rural domestic wastewater, discharge standards, control indicators, resource utilization, Yangtze River Delta.

1. Introduction

As one of the significant sources of water pollution, rural domestic wastewater directly affects the rural ecological environment and is closely related to the quality of residents' lives. According to the results of the second national pollution source census, the annual discharge of rural domestic wastewater is 7.591 billion tons, with chemical oxygen demand (COD) emissions of 4.9962 million tons and ammonia nitrogen emissions of 0.245 million tons, accounting for 23.3% and 25.4% of the total emissions of water pollutants, respectively, and 50.8% and 35.0% of the emissions from domestic sources [1]. However, due to the imbalance between urban and rural development, there is a significant disparity in the level of domestic wastewater treatment between urban and rural areas. By 2022, the urban sewage treatment rate has exceeded 95%, while the rural domestic wastewater treatment rate is only about 31%, still falling short of the target of 40% by 2025 [2, 3]. Furthermore, challenges in rural domestic wastewater treatment arise from issues such as inadequate and irrational system planning, difficulties in sewage collection and treatment, insufficient investment in infrastructure construction, and suboptimal operation and management quality [4].

The Yangtze River Delta region has a high level of economic development, and rural residents have a strong willingness to participate in wastewater treatment. They also possess sufficient economic support and long-term operational capacity, which provides favorable conditions for rural domestic wastewater treatment. In this region, rural settlements are scattered, and the volume of wastewater discharge fluctuates significantly, increasing year by year [5]. Additionally, the influent carbon-to-nitrogen (C/N) ratio is relatively low, with COD levels generally ranging from 100-200mg/L, and even lower than 100mg/L in some areas, which is much lower than in other parts of China [6]. Therefore, measures such as the addition of external carbon sources need to be considered. Moreover, being located in a subtropical monsoon climate zone with hot summers and mild winters and a relatively high average annual temperature, the region provides favorable conditions for microbial growth, making above-ground, underground, and semi-underground rural wastewater

treatment facilities feasible. The Yangtze River Delta region has a well-developed water system with numerous rivers and lakes, offering sufficient conditions for resource utilization of wastewater. However, strict pollution control measures and discharge standards need to be implemented as well.

Numerous domestic and foreign scholars have conducted extensive research and practical work on rural wastewater treatment characteristics in the Yangtze River Delta region. Kong Lingwei et al. [7] summarized the water quality characteristics and application of treatment technologies for rural domestic wastewater based on the research findings of over 530 rural wastewater treatment terminals in Zhejiang Province. He Leilei et al. [8] analyzed the standard system for rural domestic wastewater treatment in Zhejiang Province from five aspects: special planning, design and construction, operation and maintenance, supervision and management, and water quality requirements, and proposed corresponding suggestions. Lan Hong et al. [9] conducted research on the current status of rural domestic wastewater discharge and on-site treatment technologies in the suburbs of Shanghai. They proposed a rural domestic wastewater treatment model tailored to local conditions and comprehensive considerations. Liu Xiaohui [10] selected three typical administrative villages in Anhui Province to conduct field investigations and water quality monitoring of rural domestic wastewater, and provided suggestions on wastewater treatment methods based on factors such as terrain, village layout, population density, and economic level.

In recent years, various provinces and cities have successively promulgated and implemented rural domestic wastewater treatment standards, gradually adopting an adaptive approach to better suit local conditions and promote rural domestic wastewater treatment. As one of the most economically active and open regions in China, the Yangtze River Delta region has been one of the early explorers of location-specific rural wastewater treatment models and has established corresponding emission standards. This article aims to provide guidance for the transition from high-standard discharge of rural wastewater to its resource utilization by comprehensively comparing and analyzing the rural domestic wastewater discharge standards issued in Zhejiang Province, Jiangsu Province, Anhui Province, and Shanghai. It also seeks to provide references for wastewater treatment technologies, models, and management approaches in the Yangtze River Delta region.

2. Grading of Rural Domestic Wastewater Treatment Standards in the Yangtze River Delta Region

The four provinces (municipalities) in the Yangtze River Delta region have implemented different levels of grading for rural domestic wastewater treatment discharge standards, aligning with the target requirements stated in the "Three-Year Action Plan for Rural Human Settlement Environment Improvement" issued in 2018, which emphasizes the need for differentiated standards based on drainage methods and discharge destinations [11]. There are variations in the definition of rural domestic wastewater among the four provinces (municipalities) in the Yangtze River Delta region. Shanghai Municipality and Anhui Province have narrower definitions, which only include wastewater generated from rural residential activities such as washing, showering, and toilet use. On the other hand, Zhejiang Province and Jiangsu Province have broader definitions that encompass wastewater generated from rural public service facilities, including public toilets, rural medical institutions, rural schools, and other public buildings. Additionally, there are differences in the scope of application for local standards in the four provinces (municipalities). The rural domestic wastewater treatment discharge standards in Zhejiang Province, Jiangsu Province, and Anhui Province are applicable to centralized treatment facilities with a capacity smaller than $500m^3/d$, while the standard in Shanghai Municipality applies to facilities with a capacity smaller than $300m^3/d$.

The grading of standards in the four provinces (municipalities) of the Yangtze River Delta region is mainly based on the functional classification of receiving water bodies, discharge methods, and the scale of treatment facilities. In Zhejiang Province and Shanghai Municipality, the standards are graded based on the water environmental functions of the receiving water bodies according to the "Environmental quality standards for surface water" (GB 3838 - 2002) [12]. Jiangsu Province

classifies the standards based on the environmental sensitivity of areas such as drinking water source protection zones, Taihu Lake basin protection zones, ecological protection red lines, and Tongyu River protection zones. In Anhui Province, the standards are classified based on the water environmental functions of the receiving water bodies according to GB 3838 and the scale of treatment facilities, where stricter discharge requirements apply to larger treatment facilities. The specific grading structure of the standards is summarized in Table 1 [12-16]. Regarding resource utilization, except for Shanghai Municipality, the other three provinces have stipulated that treated rural domestic wastewater should not be discharged into water bodies and should meet the corresponding national or local standards for recycled water quality.

Table 1. Summary of Grading Results of Rural Domestic Wastewater Discharge Standards in the Four Provinces (Municipalities) of the Yangtze River Delta Region

<table>
<tr><th>Province</th><th>Class I A standard</th><th>Class I B standard</th><th>Class II standard</th></tr>
<tr><td rowspan="2">Zhejiang</td><td colspan="2" rowspan="2">When discharging, the water is directly discharged into Class II and Class III surface water functional areas according to GB3838 (excluding designated drinking water sources protection zones and swimming areas), Class II seawater functional areas according to GB3097, as well as enclosed or semi-enclosed water bodies such as lakes and reservoirs.</td><td>When discharging indirectly, the water is discharged into Class II and Class III surface water functional areas according to GB3838 (excluding designated drinking water sources protection zones and swimming areas), Class II seawater functional areas according to GB3097, as well as enclosed or semi-enclosed water bodies such as lakes and reservoirs.</td></tr>
<tr><td>When discharging into water bodies with unclear environmental functions, such as ponds near villages, the water is discharged.</td></tr>
<tr><td>Shanghai</td><td>The effluent is discharged into Class III and higher environmental functional water bodies according to GB3838 (including water bodies within the scope of national and Shanghai designated nature reserves, as well as other key ecological conservation and construction areas)</td><td>The effluent is discharged into other water bodies.</td><td>/</td></tr>
<tr><td rowspan="3">Jiangsu</td><td>Drinking water source protection zone</td><td>Level II and III protection zones of Taihu Lake Basin</td><td rowspan="3">other areas</td></tr>
<tr><td>Level I protection zone of Taihu Lake Basin</td><td>Level I and II protection zones of Tongyu River</td></tr>
<tr><td>National-level ecological protection red line</td><td>Provincial-level ecological protection red line</td></tr>
<tr><td rowspan="2">Anhui</td><td rowspan="2">Rural domestic wastewater treatment and disposal facilities with a capacity greater than or equal to 100m3/d (including), discharging directly into Class I water bodies according to GB3838 (excluding designated drinking water sources protection zones)</td><td>Rural domestic wastewater treatment and disposal facilities with a capacity greater than or equal to 100m3/d (including), discharging directly into Class V water bodies according to GB3838</td><td>Rural domestic wastewater treatment and disposal facilities with a capacity greater than 5m3/d (including) and less than 100m3/d (excluding), discharging directly into Class IV and V water bodies and other water bodies, channels, and natural wetlands without designated water environmental functional zones.</td></tr>
<tr><td>Rural domestic wastewater treatment and disposal facilities with a capacity greater than 5m3/d (including) and less than 100m3/d (excluding), discharging directly into Class III water bodies according to GB3838 (excluding designated drinking water sources protection zones).</td><td>Rural domestic wastewater treatment facilities with a capacity less than 5m3/d (excluding).</td></tr>
</table>

3. Analysis of Control Parameters in Rural Wastewater Treatment Standards in the Yangtze River Delta Region

3.1. Selection of Different Control Parameters in the Standards

There are generally few differences in the selection of control parameters among the local standards of the four provinces (municipalities) in the Yangtze River Delta region. All provinces (municipalities) include pH value, chemical oxygen demand (COD), suspended solids, ammonia nitrogen, total nitrogen, total phosphorus, and animal fats and vegetable oils as control parameters. In addition, Jiangsu Province, Zhejiang Province, and Anhui Province include fecal coliforms as selected control parameters. Shanghai Municipality and Jiangsu Province include anionic surfactants as selected control parameters, mainly for the treatment of rural tourism wastewater.

Table 2. Summary of Control Parameters in Rural Domestic Wastewater Discharge Standards in the Four Provinces (Municipalities) of the Yangtze River Delta Region

Control index	pH	COD	SS	NH_3-N	TN	TP	Animal Fats and Vegetable Oils	LAS	Fecal Coliform
Shanghai	√	√	√	√	√	√	√*	√*	×
Jiangsu	√*	√	√*	√	√	√	√	√*	√*
Zhejiang	√	√	√	√	√*	√	√*	×	√*
Anhui	√	√	√	√	√*	√*	√*	×	√*

*indicates selected control parameters.

To better understand the differences in rural domestic wastewater treatment standards among the four provinces (municipalities) in the Yangtze River Delta region, a comparative analysis was conducted, considering the local standards of the four provinces (municipalities) and the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plants" (GB 18918-2002) and "Standard for irrigation water quality" (GB 5084-2021). The specific results are summarized in Table 3.

Table 3. Emission Standards for Pollutants in Rural Domestic Wastewater in the Yangtze River Delta Region

Water Quality Standards	Standard Grade/Class	pH	COD (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TN (mg/L)	TP (mg/L)	Animal Fats and Vegetable Oils (mg/L)	LAS (mg/L)	Fecal Coliform (MPN/L)
Discharge standard of pollutants for municipal wastewater treatment plant①	Class I A standard	6~9	50	10	5(8)[a]	15	0.5	0.5	1	10^3
	Class I B standard	6~9	60	20	8(15)[a]	20	1	1	3	10^4
	Class II standard	6~9	100	30	25(30)[a]	-	3	2	5	10^4
	Class III standard	6~9	120	50	-	-	5	5	20	-
Agricultural Irrigation Standards②	Paddy Field Crops	5.5~8.5	150	60	-	-	-	5	-	40000
	Dryland Crops	5.5~8.5	200	100	-	-	-	8	-	40000
	Vegetables	5.5~8.5	100(60)[a]	60(15)[a]	-	-	-	5	-	20000(10000)[a]
Shanghai③	Class I A standard	6~9	50	10	8	15	1	0.5	1[a]	-
	Class I B standard	6~9	60	20	15	25	2	1.0	3[a]	-
Jiangsu④	Class I A standard	6~9	50	10	5(8)[a]	20	1	0.5	1[b]	10^4
	Class I B standard	6~9	60	20	8(15)[a]	30	3[b]	1	3[b]	10^4
	Class II standard	6~9	100	30	25(30)[a]	-	-	2	5[b]	-
Zhejiang⑤	Class I standard	6~9	60	20	8(15)[a]	20[d]	2(1)[c]	-	3[f]	10000
	Class II standard	6~9	100	30	25(15)[b]	-	3(2)[c]	-	5[f]	10000[e]
Anhui⑥	Class I A standard	6~9	50	20	8(15)[a]	20[b]	1[c]	-	3[e]	10000[d]
	Class I B standard	6~9	60	30	15(25)[a]	30[b]	3[c]	-	5[e]	-
	Class II standard	6~9	100	50	25(30)[a]	-	-	-	5[e]	-

Note 1: The values outside the parentheses represent the control indicators for water temperature >12°C, while the values inside the parentheses represent the control indicators for water temperature ≤12°C.
Note 2: The values outside the parentheses represent the control indicators for processed, cooked, and peeled vegetables, while the values inside the parentheses represent the control indicators for raw vegetables, melons, and herbaceous fruits.
Note 3: The indicator "a" is only applicable to treatment facilities that handle rural tourism wastewater.
Note 4: The values outside the parentheses represent the control indicators for water temperature >12°C, while the values inside the parentheses represent the control indicators for water temperature ≤12°C.
Indicator "b" for animal fats and vegetable oils is only applicable to rural tourism wastewater treatment facilities that provide catering services.
Indicator "c" for total phosphorus is not assessed for decentralized village wastewater treatment facilities with a capacity of ≤2 tons/day.
Note 5: The values inside the parentheses represent the limits for the period from November 1st to March 31st of the following year.
The values inside the parentheses represent the limits for discharging effluent into foul-smelling water bodies.
The values inside the parentheses represent the limits for discharging effluent into enclosed water bodies, semi-enclosed water bodies, and water quality sections with excessive phosphorus at the provincial, municipal, and county levels.
The indicator "d" refers to discharging effluent into enclosed water bodies and semi-enclosed water bodies.
The designation "e" refers to areas designated as controlled by county-level people's governments.
The indicator "f" is for treatment facilities that handle oily wastewater.
Note 6: The values outside the parentheses for ammonia nitrogen represent the control indicators for water temperature >12°C, while the values inside the parentheses represent the control indicators for water temperature ≤12°C.
The total nitrogen indicator is applicable when the facility's effluent is directly discharged into enclosed water bodies such as lakes and reservoirs, or when the excessive factor is total nitrogen in the water.
The total phosphorus indicator is applicable when the facility's effluent is directly discharged into enclosed water bodies such as lakes and reservoirs, or when the excessive factor is total phosphorus in the water.
The fecal coliform indicator is applicable when the facility's effluent meets the Grade A standard.
The animal fats and vegetable oil indicator is applicable to wastewater treatment facilities for rural tourism projects that provide catering services.

3.2. Analysis of Main Control Indicator Limits

The determination of control indicator limits should consider the discharge of pollutants into water, protection of the ecological environment, and human health and safety. It should be based on the current national, local, and industry standards, taking into account the characteristics of rural domestic wastewater discharge, the construction and management status of wastewater treatment facilities, and wastewater treatment technologies. The pollutant standard limits should be tailored to local conditions and practical considerations to ensure the safe and reasonable discharge of rural domestic wastewater into the environment [17].

Currently, most domestic wastewater treatment systems in China are integrated treatment systems, which are small to medium-sized wastewater treatment facilities that combine sewage pretreatment, secondary treatment, and advanced treatment equipment. Widely used technologies include contact oxidation reactors, moving bed biofilm reactors (MBBR), purification tank systems, and membrane

bioreactors (MBR). Additionally, artificial wetlands, stabilization ponds, and vermifilter systems are also applied in some cases [18].

Figure 1 compares the pollutant emission limits for rural domestic wastewater in the four provinces (municipalities) of the Yangtze River Delta with the "Integrated wastewater discharge standard" (GB 8978-1996), "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002), and "Standard for irrigation water quality" (GB5084-2021). The specific analysis results are as follows (Figure 1):

3.2.1 pH

The pH control requirements for rural domestic wastewater in the four provinces (municipalities) of the Yangtze River Delta are consistent with the "Integrated wastewater discharge standard" (GB 8978-1996) and "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002), which are both within the range of 6 to 9.

3.2.2 COD

The control requirements for COD in rural domestic wastewater in the four provinces (municipalities) of the Yangtze River Delta are consistent with the "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002). The Class I A standard limit is 50mg/L, and the Class I B standard limit is 60mg/L. The Class II standard limit is 100mg/L, which is consistent with the Class I standard limit of the "Integrated wastewater discharge standard" (GB 8978-1996).

3.2.3 SS

Except for Anhui Province, the control requirements for suspended solids in rural domestic wastewater in the other three provinces (municipalities) of the Yangtze River Delta are consistent with the "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002). The Class I A standard limit is 10mg/L, the Class I B standard limit is 20mg/L, and the Class II standard limit is 30mg/L. Anhui Province has more relaxed requirements for suspended solids. The Class I A standard limit is 20mg/L, which is consistent with the Class I B standard in other provinces and municipalities. The Class I B standard limit is 30mg/L, which is consistent with the Class II standard in other provinces and municipalities. The suspended solids limit requirements are stricter than the Class I standard limit of 70mg/L in the "Integrated wastewater discharge standard" (GB 8978-1996).

3.2.4 NH_3-N

The control requirements for ammonia nitrogen in rural domestic wastewater in Jiangsu Province and Anhui Province are consistent with the "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002). For water temperature >12°C, the Class I A standard limit is 5mg/L, the Class I B standard limit is 8mg/L, and the Class II standard limit is 25mg/L. For water temperature ≤12°C, the Class I A standard limit is 8mg/L, the Class I B standard limit is 15mg/L, and the Class II standard limit is 30mg/L. Zhejiang Province does not differentiate based on water temperature but sets stricter control requirements for ammonia nitrogen from November 1st to March 31st each year.

3.2.5 TN

The control requirements for total nitrogen in rural domestic wastewater in the four provinces (municipalities) of the Yangtze River Delta and the "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002) only have control requirements for the Class I standard. Shanghai Municipality has the same Class I A standard limit as the "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002), which is 15mg/L. Jiangsu Province (Class I A), Zhejiang Province (Class I), and Anhui Province (Class I A) have the same control requirements for total nitrogen as the Class I B standard in the "Pollutant Discharge Standard for Urban Wastewater Treatment Plants" (GB18918-2002), which is 20 mg/L. Shanghai Municipality has a Class I B standard limit of 25mg/L, and Jiangsu Province and Anhui Province have a Class I B

standard limit of 30mg/L. Generally, due to the small scale of rural domestic wastewater treatment facilities and the lack of advanced treatment or improper operation and maintenance, the requirements for TN effluent concentration are not very strict.

3.2.6 TP

TP can cause eutrophication in water bodies. The influent TP in the Yangtze River Delta region is generally high, but considering the difficulty of sludge removal in existing facilities, the TP removal efficiency is generally low. Except for Zhejiang Province, the control requirements for TP in the four provinces (municipalities) of the Yangtze River Delta are only for the Class I standard. Jiangsu Province and Anhui Province have the same requirements, with Class I A and Class I B limits of 1mg/L and 3mg/L, respectively. Shanghai Municipality has limits of 1mg/L and 2mg/L. Zhejiang Province has stricter limits of 2mg/L and 3mg/L for the Class I and Class II standards, respectively. Additionally, more stringent limits of 1mg/L and 2mg/L are set for cases where effluent is discharged into enclosed water bodies, semi-enclosed water bodies, and water quality sections with excessive phosphorus at the provincial, municipal, and county levels.

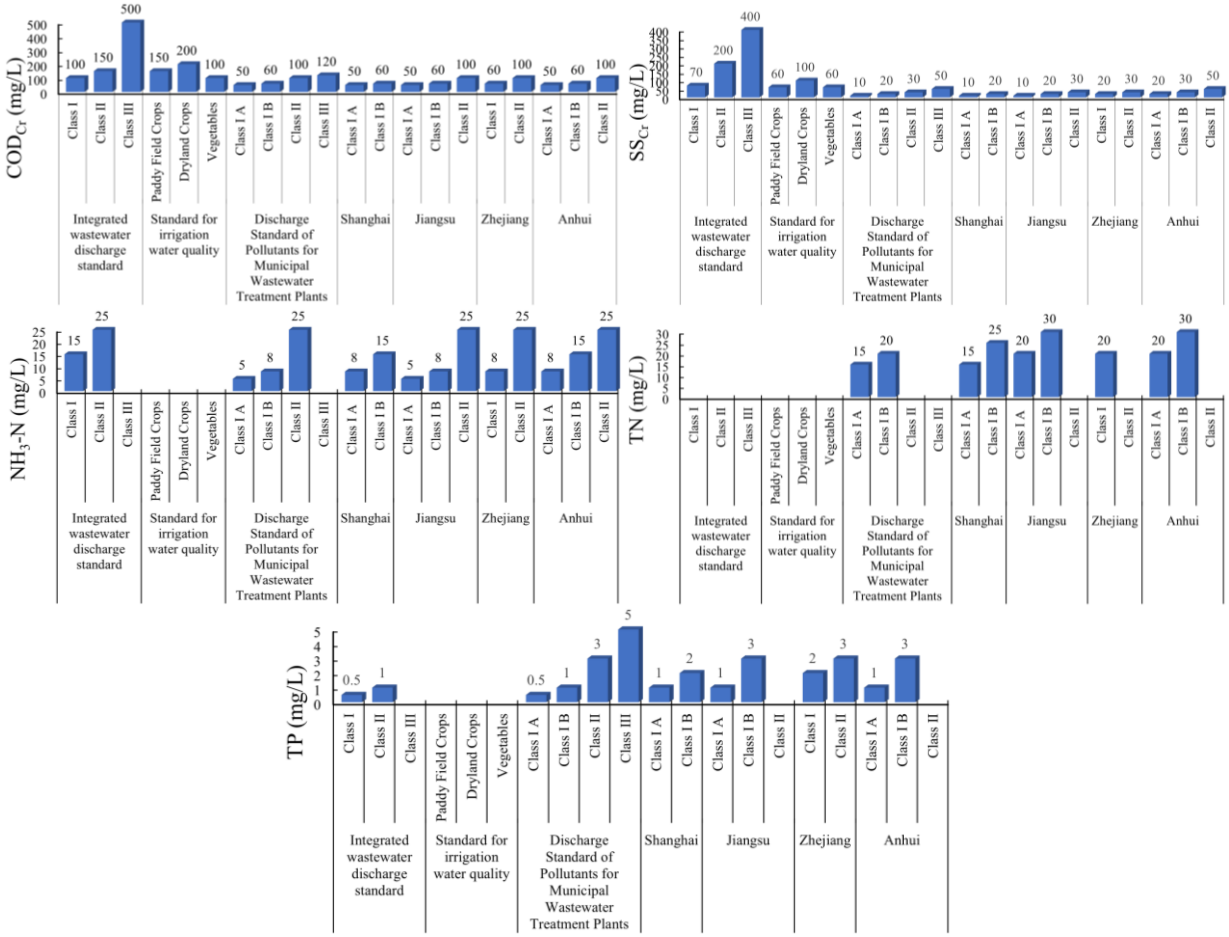


Figure 1. Comparison of Rural Domestic Wastewater Discharge Standards in Various Provinces and Cities in the Yangtze River Delta with Other Standards

3.3. Comparison with Standards for Irrigation Water Quality

In comparison with the standards of the four provinces and municipalities in the Yangtze River Delta region, the "Standard for irrigation water quality" (GB 5084-2021) does not include control indicators for total nitrogen, total phosphorus, ammonia nitrogen, and animal fats and vegetable oils. The analysis focuses on the shared indicators and reveals the following:

For the shared indicators, the first-level control requirements for chemical oxygen demand and suspended solids in the four provinces and municipalities of the Yangtze River Delta region are generally consistent with the classification for vegetables (including raw consumption vegetables,

melons, and herbaceous fruits) in the "Standard for irrigation water quality." However, the emission limits for chemical oxygen demand and suspended solids in paddy crops and dryland crops for agricultural irrigation water quality are significantly higher than the first and second-level limits set by the provinces and municipalities.

The concentration control requirements for anionic surfactants and fecal coliforms are significantly higher in the "Standard for irrigation water quality" compared to the standards for rural domestic wastewater discharge in the four provinces and municipalities. This is mainly because agricultural irrigation water is primarily used for crop irrigation, coming into contact mainly with plant roots and soil, and is not directly used as a source of drinking water for humans.

4. Conclusion and Recommendations

(1) The pollutant control indicators of the rural domestic wastewater treatment discharge standards in the four provinces and municipalities of the Yangtze River Delta are consistent with the Discharge standard of pollutants for municipal wastewater treatment plant. The concentration control requirements for pollutants are also generally consistent with the pollutant concentration limits for urban wastewater treatment plant discharge. However, some indicators, such as total nitrogen and total phosphorus, are more lenient compared to the discharge standards for urban wastewater treatment plants.

(2) Among the four provinces and municipalities in the Yangtze River Delta, the rural domestic wastewater treatment discharge standards in Zhejiang Province, Jiangsu Province, and Anhui Province are applicable to centralized treatment facilities with a capacity smaller than 500 m3/d, while the standard for Shanghai is applicable to facilities with a capacity smaller than 300m3/d.

(3) The standards promulgated by the four provinces and municipalities in the Yangtze River Delta for rural domestic wastewater discharge are mainly based on the differences in the drainage destination, treatment facility scale, and discharge mode of rural domestic wastewater. The standards are developed in a hierarchical manner. The requirements for direct discharge are stricter than those for indirect discharge. The higher the environmental function of the receiving water body and the larger the treatment facility scale, the more stringent the control requirements.

(4) Except for Shanghai, the other three provinces in the Yangtze River Delta have specified the corresponding reuse standards for water discharged for resource utilization. The control values for chemical oxygen demand, suspended solids, anionic surfactants, and fecal coliforms in the standards at various levels in the four provinces and municipalities of the Yangtze River Delta can be applied to the water quality requirements for farmland irrigation, excluding fresh vegetables, melons, and herbaceous fruits.

(5) The development of resource utilization of rural domestic wastewater is the current trend and also aligns with China's dual carbon strategy. The Yangtze River Delta region has a high level of economic development and strong environmental awareness, and the practice of rural wastewater treatment has been at the forefront. The local standards of the four provinces and municipalities fully reflect the transformation from high-standard discharge of rural wastewater to resource utilization. Therefore, it is necessary to develop facilities that meet the existing standards according to local conditions and establish a long-term management mechanism as the next step in the rural wastewater treatment in the Yangtze River Delta region.

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