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Wastewater Treatment in Chinese Rural Areas

Yihuan Deng* and Andrew Wheatley
Civil and Building Engineering Department, Loughborough University, Loughborough, LE11 3TU
✉ y.deng@lboro.ac.uk

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Abstract: In the last 10 years, the extent of wastewater treated in China has increased by 57%, the great amounts of sewage have threatened people's health as well the natural environment. In the last 10 years, the sewage treatment rate has improved, in December 2013, 99.1% of Chinese cities and 82.6% counties have sewage treatment plants. This review paper describes the current situation and has suggestion of how to overcome future sewage problems especially water pollution in China from domestic, agriculture and industrial sectors. It also discusses the urban/rural wastewater for treatment including sewerage systems, treatment plants and water quality standards in China. The paper highlights the challenges of effective wastewater treatment in rural areas as a particular issue due to lack of monitoring and law support. This has led to ineffective management of treatment plants, financial difficulties; inappropriate sewerage, treatment facilities and standards; as well as poor awareness.

Key words: China, rural, wastewater, treatment, challenge.

Introduction

Following the economic reforms in 1979, China has become the world's second largest economy. However, the rapid economic growth has led to environmental issues. Ecological degradation has been quantifiable since 1970s due to deforestation and overgrazing. The reason is that China was struggling to provide sufficient food before the founding of new China in 1949 and agricultural development was the first priority. During this period new agricultural farmlands were created by deforestation and reclaimed wetland areas, but there was still insufficient food for expanding population. Application of agrochemicals was the only way to improve agricultural productivity, also authorities constructed dams and irrigation facilities to strengthen agricultural infrastructure. As a result, the natural environment has been transformed further and self-purification capacity of water environment reduced. Due to poor management, farms have used too much agrochemicals which has led to water quality deterioration. Environmental pollution has been made worse, continued to deteriorate by the new factories established in this period and responsible for discharges of large amounts of waste.

Environmental quality in China has now deteriorated to the point where everyone has become concerned. At the same time, complaints, angry letters and petitions about environmental pollution were increased sharply (Jing, 2010). In order to solve the pollution, China has invested money into reducing environmental pollution and 825.35 billion Yuan was invested which was 1.59% of GDP in 2012. However, the investment is not enough and the trend in environmental pollution is still getting worse.

History of Wastewater Treatment in China

China started recycling water in urban areas in 1970s. Some cities originally used stabilization ponds for

*Corresponding Author

treating urban wastewater with modification such as channels, ponds and wetlands. In this period, China started to import advanced technologies and carried out international technical exchanges to establish the foundation of a future wastewater treatment industry. In 1980s, the Chinese Government adjusted wastewater investment policies to encourage international financial organisations and foreign governments by providing incentives to equipment providers. As a result, large numbers of treatment plants were built in this period and the first large comprehensive wastewater treatment plant (Jizhuangzi plant, Tianjin Province), using activated sludge was built in 1982 and has a capacity of 260,000 m^3 day^{-1}. This plant provided construction and operation experience for dozens of similar projects which were constructed in Beijing, Shanghai, Guangdong, Guangxi, Shannxi, Shanxi, Hebei, Jiangsu, Zhejiang, Hubei and Hunan Provinces (CUWSDRC, 2003). During 1990-1995 period, the investigation showed 64.8% of urban city areas were connected to sewers by this time. By the end of 2010, the treatment rate of Chinese cities, counties and townships had reached 77.5%, 60.1% and <20%, respectively. Figure 1 indicates the number of plants and capacities in the last two decades.

Until 2010, the length of Chinese urban foul sewerage reached 160,000 km, 2,496 treatment plants with total capacity 125 million m^3 (Yan and Zhao, 2008). The majority of these treatment plants used activated sludge process (ASP) and package treatment based on ASP such as Oxidation Ditch, Sequencing Batch Reactors, Anaerobic/Anoxic/Oxic (AAO) and Anoxic-Oxic processes (Guo et al., 2012). Even with this level of construction, there is still a widening gap between wastewater arising and treatment. A theoretical calculation showed that the maximum capacity of whole state was enough for 70% of the discharged amount (MEP, 2012). In addition, some plants do not fully operate or not at all. The survey showed 80% of Chinese treatment plants were under capacity due to unfinished sewerage or too high cost of operation (MOHURD, 2012). Consequently, there are still large amounts of untreated wastewater discharge into rivers with concerns for the environment and a potential risk to human health.

In 2010, the Chinese Government has declared the ambition to build a resource-conserving and environment friendly society for the 12th five-year plan (2011- 2015). The article 24 mentioned that solving the water pollution is a priority, and the state council has announced a notice to encourage further wastewater treatment plant construction in 36 key cities which should reach 100%, in cities 85%, in counties 70% and town reach 30%, and the treatment capacity will reach 170 million m^3/day (The State Council, 2012).

The new national strategy to avoid water pollution was released in 2015 by Chinese state council (Ten

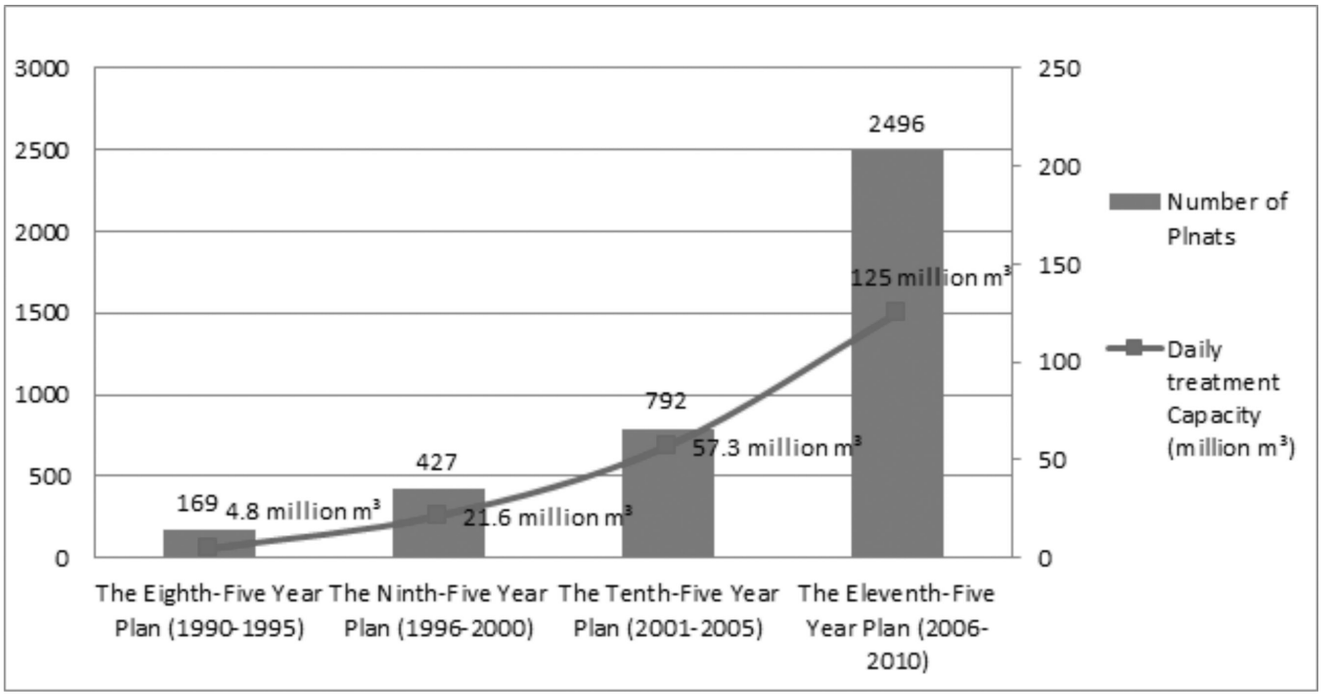

Figure 1: Number of WWTPs and daily treatment capacity in China during 1990-2010.

Water Control Measures). This action plan proposed that Chinese overall water quality should be improved and heavily polluted water basins should be eliminated by 2020. Until 2030, the water ecosystem should be restored preliminarily (The State Council, 2015).

Water Pollution in Chinese Rural Areas

Rural wastewater treatment rates are far behind urban wastewater due to policies, investment and awareness (Xi et al., 2014). Therefore, rural environmental pollution also are a social concern problem. The results showed 50% of complaint letters and 70% petitions about pollution were from rural areas (Wen, 2009). China has 2.79 million villages and 768.8 million villagers represent 57.36% of the Chinese population (Chen, 2012). The rural area plays an important role in the Chinese economy and these diffuse sources of pollution will eventually impact on productivity. Water pollution has a serious impact on Chinese industry, agriculture, water supply and people's heath. A report by Ni and Ma (2010) indicated more than 100 million people drunk polluted water in Chinese rural area. Other investigations showed 88% of Chinese patients and 33% deaths are connected to poor drinking water (Li et al., 2003a). As a result, water pollution has been estimated to cost 3.1% of Chinese GDP (Li et al., 2003b).

Domestic

The rate of water supply has gradually increased and 74.6% of the Chinese rural population had access to piped supply water in 2012 (NHFPC, 2013). This has had a major influence on wastewater amounts because the rural population can more easily consume water and more wastewater will be produced; for example the amount of water consumption could reach 200 Ld^{-1} per person in some affluent villagers. In 2010, the total annual water consumption of China has reached 1.7 billion m^3 in towns and 1.2 billion m^3 in villages (MOHURD, 2010). The amount of rural wastewater is around 4% of the total in China and the trend of rural sewage amount could increase in the future due to increased use of wash machines and flush toilets. Chinese rural wastewater discharge amount and characteristics of different regions were summarised (See Table 1). Majority of rural areas' water consumption was lower than urban region, but large variation (3.0-5.0) in discharge amount was observed. Generally, all the quality parameters of rural sewage contained less pollutants, but in a greater range (Zhang et al., 2008). Wang (2008) and Liao et al. (2011) suggested that this was due to socio-factors (e.g. different customer, economic level and geography) and sewage characteristics were different and affected by local industries.

Agriculture

China represents 7% of world arable land, but has 22% of the world population, which requires an intensive use of inorganic fertiliser and pesticides (Li and Zhang, 1999). In 2011, China has used 58.39 billion tonnes of chemical fertiliser and 1.81 billion tonnes pesticides (Ma et al., 2012). The intensive use of fertiliser and pesticides improved Chinese food production (detail see Figure 2), but it caused pollution in the environment. The majority amount of chemicals was not taken up by the plants and was discharged to ecosystem, polluting both surface and groundwater. At the same time, intensive animal breeding is a third source of pollution including N and P via run off and infiltration. Recent data showed 85.2% of lakes and reservoirs were eutrophic or hypertrophic, and 70.6% of rivers were polluted with pesticides (Wang and Li, 2007; MEP, 2013).

Industrial

A water pollution survey showed 43% of villagers polluted by industries (Tang and Zuo, 2008). Township and Village Enterprises (TVEs) was the main industry body in countryside and have increased sharply since 1978. After three decades of development, TVEs produced one third of GDP and half the value of the industrial output of China (Ministry of Agriculture, 2011). Many of the TVEs however directly discharge wastewater into water courses and the major source of industrial pollutants in the rural environment because of substandard facilities and poor management.

In 1995, of the total industrial wastewater discharged by TVEs only 40.1% was treated (MEP, 1998). After further five years, the discharge amount reached 41.1% and 36.1% of total COD discharged, but the rate of treatment rate has not improved to the same extent (MEP, 2001). Those wastewater contained high hazard substances while there was very little information. The health of local residents have been affected and higher rates of acute and chronic diseases are reported, potentially teratogenic and mutagenic toxicity (Dong et al., 2000; Zhang, 2001; Sun, 2009). Currently,TVEs was a major source of rural water pollution.

Wastewater Treatment in Chinese Rural Areas

The wastewater treatment rate in cities, towns and villages was 78%, 15% and 6% respectively. The 6%

Table 1: The characteristic of Chinese rural domestic sewage in different regions

Provinces	*Concentration (mg/L)*							*Water demand (p/l/d)*	*Remarks*	*Reference*
	pH	*SS*	*COD*	*BOD_5*	*NH_3^+-N*	*TP*	*TN*			
Sichuan	6-9	100-500	62-314	-	3.6-40.5	0.5-12.1	-	70-110		Zhang et al., 2008a
Jiangsu	6.4-8.9	10-507	30-1460	-	1.6-868.9	0.8-70.8	-	55		Duan et al., 2013
Hubei	-	43	91	28	24.3	2.33	27.3	50-60		Sun, 2010
Jiangsu	6-9	250	600	280	-	2.75	38	25-70		Xu et al., 2007
Beijing	-	458-2520	135-628	-	-	2.1-7.6	20.2-48.1	95		Fong et al., 2009
Yunnan	6.7-8.3	251-969	270-1629	118-342	-	2.1-37.9	24-238	-	In Dian lake region	Yuan et al., 2010
Anhui	-	-	800-1200	-	10	4-6	20-40	26	In Cao lake region	Sun, 2010
Fujian	-	-	-	-	11.8	2.1	20	54		Chen et al., 2004
Chongqing	-	-	44-456	-	-	9.9-72	0.9-9.8	-		Fang et al., 2009
Guangdong	-	59-107	182-350	-	0.3-14.3	1.9-2.3	-	71		Ling et al., 2009
Zhejiang	6.8-7.4	-	63	18	-	0.023-0.034	0.06-0.13	-	Polluted river	Yao et al., 2013
Qinghai	-	-	523.34	-	4.7	4.6	18.7	-	Only grey water	Ding et al., 2012
Jiangxi	-	-	17-107		0.3-18.9	0.1-6.0	1.2-40	-	Polluted river	Zou et al., 2012
Guangxi	-	72-160	42-296	-	6.8-44.7	2.1-5.2	10.3-51.8	-	May mixed with rainwater	Zhao et al., 2014
Taiwan	6.1-7.1	-	14-383	5-194	0.5-0.9	0.03-4.47	2.1-55.1	-	Samples from three villages	Chen et al., 1999
Shandong	-	337	398	-	-	9.94	125	-	Samples from two villages	Gao et al., 2010
Hunan	-	-	100-500	60-300	15-43	1.8-3.5	29-52	-	Huanglong village	Yang et al., 2009
Shaanxi	-	-	334-488	92-201	37-50	4.6-5.5	-	-	Polluted river (Zao river)	Yu et al., 2011
Guizhou	-	-	77-694		1-17	0.5-6.4	5.5-28.6	-	Hongfeng lake basin	Zhang et al., 2013
Ningxia	6.5-8.5	200-300	300-600	150-350	30-80	30-80	5-8	1-10		Wang, 2013
Hebei	6.8-8.4	-	16-99	35-64	2-28	1-4	1.7-28.9	12-28	Xibeipo region	Song et al., 2014

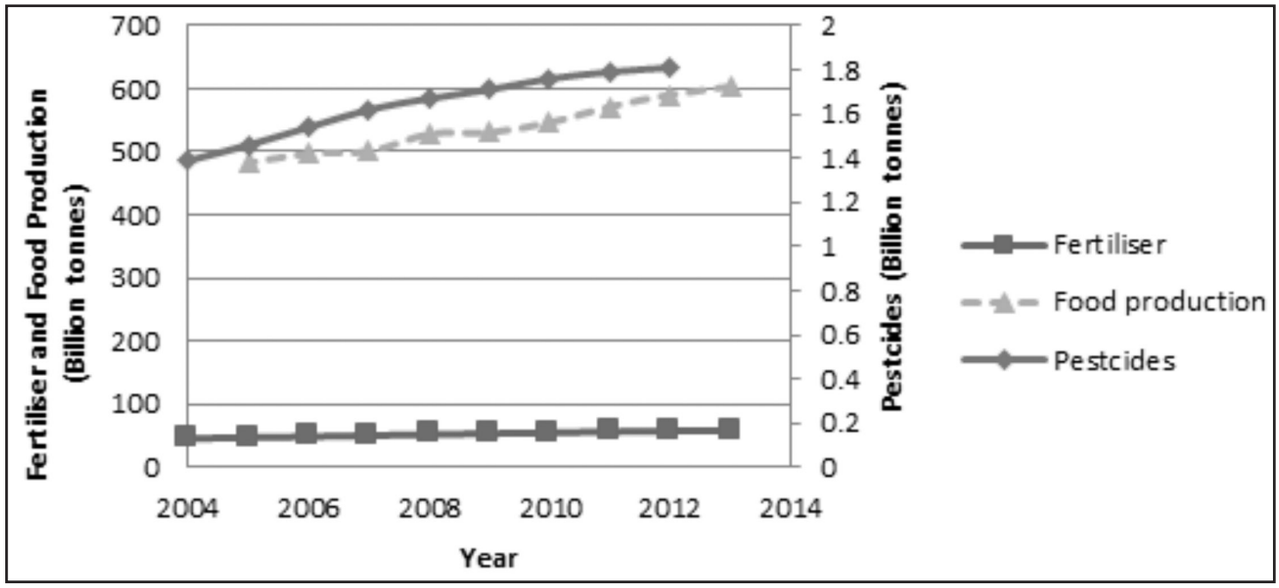

Figure 2: Consumption of fertiliser, pesticides and food production in China.

of rural treatment plants were concentrated in five provinces (Shanghai, Jiangsu, Zhejiang, Guangdong and Shandong), which means that large parts of Chinese rural area have no wastewater treatment (Ju, 2012). Due to lack of wastewater infrastructure, rural sewage normally is dumped into farmland or river course. Results show that the rural area discharge about 50% of major water pollutants of whole country, such as 43% of chemical oxygen demand (COD), 57% of the total nitrogen and 67% of total phosphorus (MEP, 2010). The authorities have considered this problem and taken action (details shown in Table 2). In 2015, they indicated that the town sewage treatment should reach 30% and has given financial support to achieve this target. This is the first planning for treatment in rural areas. For the new 2015-2030 plan, the target is to treat 85% of sewage in the country and manage agricultural pollution, particularly pollution discharge from livestock farms, pesticides and chemical fertiliser (The State Council, 2015).

Until 2010, China had 1,625 sewage treatment plants in rural areas, 945 distributed in four major provinces (Jiangsu, Zhejiang, Shandong and Guangdong) and another 680 plants distributed in 27 provinces. The total rural treatment capacity reached 9.54 million m^3/day (Ju, 2012). Even so however there is still a gap compared with extent and quality of urban treatment.

Sewer System

There are three levels of sewerage in Chinese rural. The largest and priority villages are connected to a centralized sewer system, the next is a cluster system of villages and for the smallest are onsite system (detail see Table 3). Normally, rural sewerage was built from concrete open channels and pipes. Currently, they are gradually being replaced by UPVC material due to light weight, no corrosion and low cost over the long-term view, lower friction factor, potentially long service life and easy replacement. The rural wastewater sewerage has been studied by He (2007), Li (2010) and Fang (2012). They suggested 200 mm diameter pipe could be used for most sub-main and main pipes within villages, and 300 mm diameters for outside of villages. Blockage was the most carrion complaint and inspection chambers are recommended at pipe junction points. Prefabricated U shaped flumes for chambers could be used instead of traditional trapezoid flumes, and UPVC pipe would be modified on site as the bottom of U flume. The traditional Inspection chamber covers of cast iron were not suitable for rural areas due to cost and risk of pilferage. Steel-fibre reinforced concrete covers were recommended a best selection.

Treatment Plants

Currently, there are various wastewater treatment processes in rural China and reported by many researches (Chen, 2006; Lv et al., 2006; Liang and Ni, 2007; Cao and She, 2009; Ling et al., 2009; Shen et al., 2009; Tan et al., 2011; Wei et al., 2012; Ye, 2013). Septic tanks were most widely used. 97% of areas used them due to the inexpensive and their simple operation. Anaerobic treatment was promoted by a national rural

Table 2: Relevant projects for rural wastewater management

Name of Ministry	*Project*	*Total investment*	*Notes*	*Reference*
Ministry of housing and urban-rural development	Village renovation projects	10 billions Yuan	-	(Ju, 2012)
Ministry of environmental protection	Comprehensive control of the rural environment project	13.5 billion Yuan	57 million inhabitants benefit	MEP, 2009; 2010; 2011; 2012
Ministry of agriculture	Rural biogas project	23 billion Yuan	1100 villages benefit	Li et al., 2010
Ministry of health	Rural toilet improvement project	-	Sanitary toilets reached 72% about 187.3 million households	Ministry of Health, 2012

Table 3: Three types of Chinese sewer collection system

Condition	Within 5 km of urban sewer system	Long distance, high costs and geography obstacle to connect with centralized	Individual or few households
Sewer collection system type	Connecting to centralized sewer system	Cluster system	On site system

Zhang et al., 2008b, Wang, 2008a, Jiang and Liu, 2006

biogas reactor construction plan. Two thirds of the cost was covered by government subsidy and the villagers paid rest. It was reported in 2000, China had 40 billion biogas reactors and covering about 30% of the rural population (Chen et al., 2010). Any form of secondary treatment processes was not common, less than 30% of areas used oxidation tank, biofilm reactor, constructed wetland or engineered soil treatment. Standard activated sludge was rarely used even in rich villages with large populations (Dong et al., 2012; Guo et al., 2014).

Standards

The Chinese government has published several standards for rural wastewater treatment in recent years (Table 4). Currently, rural wastewater effluent discharge has adopted GB18918-2002 (Second class) (see Table 5). However, these standards were primarily developed for urban plants and to pressure the urban water environment and they are higher than European standards. Therefore, rural plants struggled to meet these standards due to scale, operation, technical and economic differences. Dong et al. (2012) have reported even with secondary treatment, rural areas cannot satisfy the requirements. Creating new standards for all rural plants is critical. Urban standards could be the starting reference, but factors should also be based on the economic, geographic, climatic and human activity.

Challenges of Wastewater Treatment in Rural Area

Lack of Monitoring and Law Support

China has relevant regulations and laws for environmental pollution, such as water law, water pollution control regulation and environmental protection law, but they mainly focused on industrial and city areas, and very few consider rural areas. The environmental protection law of China states that MEP is the leader of national environmental protection. However, in rural sewage treatment there is no chain of liability for managing. The wastewater cycle and the status of government departments in the management of rural sewage is not clear (Gao, 2009). None of the Ministries are uniform in their approach to rural pollution because there are no specific regulations to cover this field (Wu et al., 1999). For example, the planning of an urban treatment plant follows the sequence of approval by local Development and Reform Commission, and during construction, the plants are under the bureaus of housing construction. The environmental protection bureaus (EPB) only monitor effluent quality after the construction finished and have no influence on design. In addition, the power of EPB is limited because of insufficient resources. The results showed EPB has 13,225 agency branches with 205,334 staff. There are 1877 town agencies which

Table 4: Chinese rural wastewater treatment relevant standards

Categories	*Name*	*Standard No.*	*Notes*
Relevant effluent standards for rural area	Integrated wastewater discharge standard	GB8978-1996	Effluent directly discharged to water body
	Discharge standard of pollutants for municipal wastewater treatment plant	GB18918-2002	Effluent directly discharged to water body
	Standards for irrigation water quality	GB5084-2005	Effluent reused for irrigation
	Water quality standard for fisheries	GB11607-89	-
	The reuse of urban recycling water—Water quality standard for scenic environment use	GB/T18921-2002	-
	The reuse of urban recycling water—Quality of farmland irrigation water	GB20922-2007	Effluent reused for irrigation
Relevant standards for rural treatment facilities	Technique code for village rehabilitation	GB50445-2008	Guideline for sewer and treatment plants
	Technical specification of wastewater engineering for town and village	CJJ124-2008	-
	Small complete equipment for domestic wastewater treatment	CJ/T 355-2010	-
	Technical specification of wastewater treatment facilities for village	CJJ/T163-2011	-

Table 5: Chinese and EU discharge standard of main pollutants for municipal wastewater treatment plant

Parameters (mg/L)	*First Class*		*Second Class*	*Third Class*	*EU Standard*
	Grade A	*Grade B*			
COD	50	60	100	120	125
BOD_5	10	20	30	60	25
SS	10	20	30	50	35(TSS)
TN	15	20	-	-	10
TP	0.5	1	3	5	1
NH_3-N	5	8	25	-	-
Colour	30	30	40	50	-
pH			6-9		-
Number of fecal coliforms (number/L)	1000	10000	10000	-	-

means one agency take care of 22 townships (MEP, 2013).

Financial Difficulty

The funding of rural plants need to be solved urgently. Unlike urban BOT (Build-operate-transfer) projects, the initial construction cost of rural treatment plants is normally covered by regional or provincial government, while the villages undertake the operational costs. Central government has no specific funding for rural plants. Normally, sewage treatment funding was a part of overall village/town renewal or expansion schemes. Therefore, in common with other regions of the world, funding available always was often allocated to more visible prestigious development such as road and water supply. Wastewater treatment project was not in priority

in current stage. Moreover, authority always focused on construction and ignored funding operation and maintenance. Village governments do not charge the local inhabitants income tax and it is hard to ensure regular operation and maintenance after construction finished for the poor villages.

Poor Management of Treatment Plants

Because lack of consistency in the management of rural sewage treatment, poor operation and management were the obvious reported problems for rural sewage plants. The government monitoring system showed that only 50% of rural treatment plants were under regular operation. Other investigation results confirmed this and explained the reason why the operation rate was relatively low. The results showed only 5% of rural plants run by trained staff, 69% of plants were not supervised or with part-time maintenance and 26% were run by 1 or 2 full-time operators (Ju, 2012).

Inappropriate Collecting System, Treatment Facilities and Standards

There are two major technical problems in rural plants: ineffective sewage collection and poor performance of works. Currently, sewage was collected by combined open channels. This method has obvious benefit such as easy maintenance and lower costs, but it includes influent of plants containing lower organic concentration. In additions, the rural sewer systems collected majority of grey water, because the Chinese septic tank performed no effluent treatment and infiltrate into ground (Nie et al., 2010). As a result, the COD concentration of influent was lower than 100 mg/l in some plants, which already met discharge standards (Gao et al., 2010). Due to these reasons, the performance of plants were poor. Moreover, as noted sewage treatment standards used in rural areas have been adopted from urban ones and not suitable for villages. Normally, rural plants have to achieve the 2nd grade discharge standard (GB18918-2002), but in some cases it was shown most cannot achieve this standard even after the secondary treatment (Dong et al., 2012).

Poor Awareness

The rural people are the primary stage of environmental protection, their main targets are to keep environment clean and tidy. An investigation showed the majority of rural population was not informed about the wastewater threat because they thought they can access pipe water (Kan, 2008). Currently, most of treatment project rely on government leading and investment. People are passive cooperation, because they thought the projects were pure government task and not related to themselves. Therefore, the facilities were abandoned soon without resident support.

In current stage, some parts of Chinese rural areas are still in a poor condition and to increase people's income is the first priority. Recently, the urban areas have introduced strict discharge standard to push heavy polluted industry out of cities. Rural or less developed areas become a best choice. Rural leadership thought the factories could create more jobs for local people to maintain social stability and pay considerable tax for local government. Therefore, the local government protect these highly polluting factories, even when they discharge wastes exceeding the standards. Without local government support and public participation, rural water pollution was hard to mitigate or terminate (Hu and Wang, 2008; Zhu, 2007).

Conclusion and Recommendation

The Chinese wastewater treatment industry has been significantly developed in the last 20 years. Treatment rate has increased from 30% in 1998 to 93% in 2012. However, the majority of treatment plants have been built in urban areas. The rural areas have been ignored. In the technical aspect, the quality of rural environment has got worse due to growth in amounts of sewage and lack of treatment. In the strategy aspect, it is due to lack of long-term mechanism and not identify the responsibility and duty of each administration. In this case, developing a well controlled strategy could reduce rural water pollution. There some actions need to be taken.

In the short-term view, it is an urgent issue to produce a more practicable rural effluent discharge and design and standard guide monitoring standards. The UK/European classification system for areas could be introduced for example depending on the sensitivity of receiving area. The easiest tests could be used for guiding sewage plants daily operation (e.g. turbidity). In order to break local protectionism, it is important to keep the media and non-government organisations active in supervision of water pollution (Xue et al., 2006).

In the long-term view, rural wastewater management plans at national level are needed. Marketization and partnerships are the only way to solve the shortage of rural plants and ensure their good operation. The village committees can play an important role in rural water environmental protection by encouraging villagers to participate and understand whole operation

from planning to operation (Pan, 2004; Zhang, 2009). Moreover, EPB need to become core agencies for charging not only wastewater pollution but also solid, and collaboration of other government bodies work.

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