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Wastewater Treatment Strategies in China: An Overview

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Abstract
Limited water resources and ensuring access to clean water confront the world with critical environmental challenges. In highly industrialized countries, such as china, the rate of water pollution is high, leading to a shortage of fresh water needed for human consumption. In that respect, large scale centralized wastewater treatment systems are considered a characteristic of highly industrialized countries, and for long have been regarded as an extremely successful approach in the wastewater treatment. Despite the availability of this approach in China, the country has continued to experience freshwater shortage and deterioration. This study reviewed freshwater resources and pollution of water resources, the rate of wastewater generation and treatment, wastewater treatment plants and wastewater treatment technologies used in China, especially sanitation conditions and wastewater management in rural China. In addition, the study explored wastewater treatment by the constructed wetlands in China.
Keywords Constructed wetland, China, pollution, wastewater, WWTPs.

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Introduction

Water is an important environmental factor, which influences the health of human populations as well as other living organisms. With the increase of population, the physical and chemical aspects of water quality have become a cause of concern as wastewater from different sources pose a high risk [1]. Worldwide, adequate sanitation and access to safe water is a big problem for billions of peoples [2, 3]. Wastewater is the combination of liquid and water carried wastes originating from household waste, human and animal waste, industrial wastewater and storm runoff [4]. Wastewater from residences, institutions or commercial firms is sewage wastewater [5, 6]. Sewage wastewater is organic as carbon compounds are its main constituents. Besides sewage wastewater, there is the industrial wastewater, which refers to industrial wastes. It is possible to treat sewage wastewater and industrial wastewater using physicochemical or microorganisms because of their organic nature [7]. According to World Health Organization (WHO) about 40 percent of the world's population lacks primary sanitation and this is worst in rural areas [2]. These insufficient sanitation services lead to several waterborne diseases (Fig. 1) [8].

The rapid growth of industries, urban centers and the economy in China are the causes of high amounts of both sewage wastewater and industrial wastewater. Qiu et al. [9] noted that, in the past two decades, industrialization and urbanization are the main causes of surface water degradation. Centralized sewer systems, initially perceived as the optimal solution in water pollution control, did not solve sanitation problems in China [10]. Because of this, the quality of water sources continues to deteriorate. A factor that has facilitated the deterioration is the lack of drainage channels and water treatment facilities in more than 90% of villages in China [11].

In addition, the quality of water sources is worsening, which means that, a large population of the people living in the villages in China consumes polluted water [12]. Currently, wastewater treatment has achieved prioritization in China; hence, there has been adoption of new methods of wastewater treatment. China is on the verge of adoption decentralized wastewater treatment modes, mainly in the villages because wastewater collection in the villages is difficult due to the dispersed layout, small scale and complex geographic conditions [13, 14]. The commonest and newest decentralized method of wastewater treatment is the constructed wetlands. Vyamazal [15] defined constructed wetlands as, "engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewater." The constructed wetlands objective is to take advantage of the processes occurring in natural wetlands, but in a controlled situation. Constructed wetlands for wastewater treatment qualify as an alternate approach for China's small to moderate size cities. Apart from this, constructed wetland is an appropriate alternative because they are cost-effective, and save energy [16]. This study reviews freshwater resources, pollution in water resource, wastewater technologies and in addition the study explores wastewater treatment by the constructed wetlands in china.

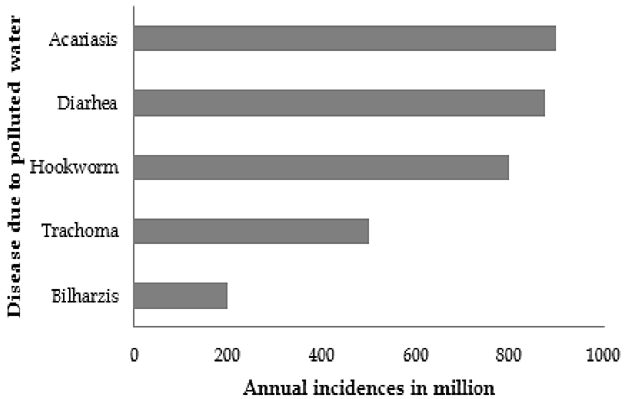

Fig. 1 Annual incidences of water borne disease in the world because of poor sanitation [17].

Prior to 1800s, outdoor privy was the main means of disposing human excrement [18]. Sewage treatment systems only emerged after scientists discovered that, borne bacteria were the causes of many infectious diseases. However, during those times, wastewater in most small and medium cities, including villages, was not treated efficiently due to the invariability of treatment facilities [19-21]. With the rapid industrialization and urbanization, however, made China do away with the centralized wastewater treatment strategies and adopted decentralized wastewater treatment methods [22-26]. In China, there is uneven distribution of fresh water resources [27]. The south and the eastern regions of China enjoy rich water resources, whereas the north and western regions have poor water resources [28, 29]. The surface water pollution is extreme and more than half of the freshwater resources are contaminated by industrial, farm or residential wastewater [30]. In addition, around 400 cities out of 669 in China are suffering the shortage of fresh water resources [31]. However, the Southern and Eastern parts of China, which enjoy freshwater resources are among the most urbanized and industrialized parts. A notable factor in these parts is that, the local government has imposed stringent effluent standards, which explains why these parts experience less pollution rates [32]. According to Chen et al. [33], 20% of the Chinese population faced water scarcity and only 52% of the population have wastewater treatment facilities. The main cause of pollution in rivers is untreated wastewater led around 400 Chinese cities to suffer from inadequate access to safe water [34].

Fresh water resources

Fresh water is one of the most precious things of this world. More than 97% water of this planet is saline and unfit for drinking. Only 2.5% water is fresh water. In which 1.72% is locked in glaciers and ice caps, about one-hundredth of that 1% resides in lakes, rivers and other water bodies; the rest is in aquifers beneath the surface as groundwater or trapped in soil as vadoze water.

The average annual water resources volume in china is approximated 2.8 trillion cubic meters [35]. This makes china the fourth largest source of water globally. Nevertheless, it is estimated that the water resource volume per capita in China is 2200 m^3 compare to 8513 m^3 globally. In this regard, China has been rated 88th globally. According to the US Department of Commerce [36], the growing population of china implies that the per capita water resource volume is likely to decrease significantly in the future. The quality of freshwater sources in China is not only poor, but has also continued to decline [37]. China is experiencing shortage of fresh water resources, something which has further been triggered by the rapidly growing population [38]. The high level of wastewater discharge coupled with rapid urbanization has contributed to the water shortage in china, reducing the accessibility of freshwater sources. As the population grows, the level of wastewater discharge has increased rapidly affecting the quality of water and reducing the accessibility of freshwater resources. The resources of fresh water significantly vary throughout China (Fig. 2). In the northern part of China, the volume of water per capita is estimated to be 10% of the global average and a fifth of per capital resource in the Southern China [39].

Wastewater generation

Wastewater is essentially the water supply of the community after it has been fouled by a variety of uses [40]. Commonly the sewage wastewater contains water by mass 99.9% [41], other contamination include suspended solids, biodegradable dissolve organic compounds, inorganic solids, metals and pathogenic microbes. Economic development and improvement of living standards, China's municipal wastewater discharge has been growing faster than industrial wastewater [42]. According to the statistics

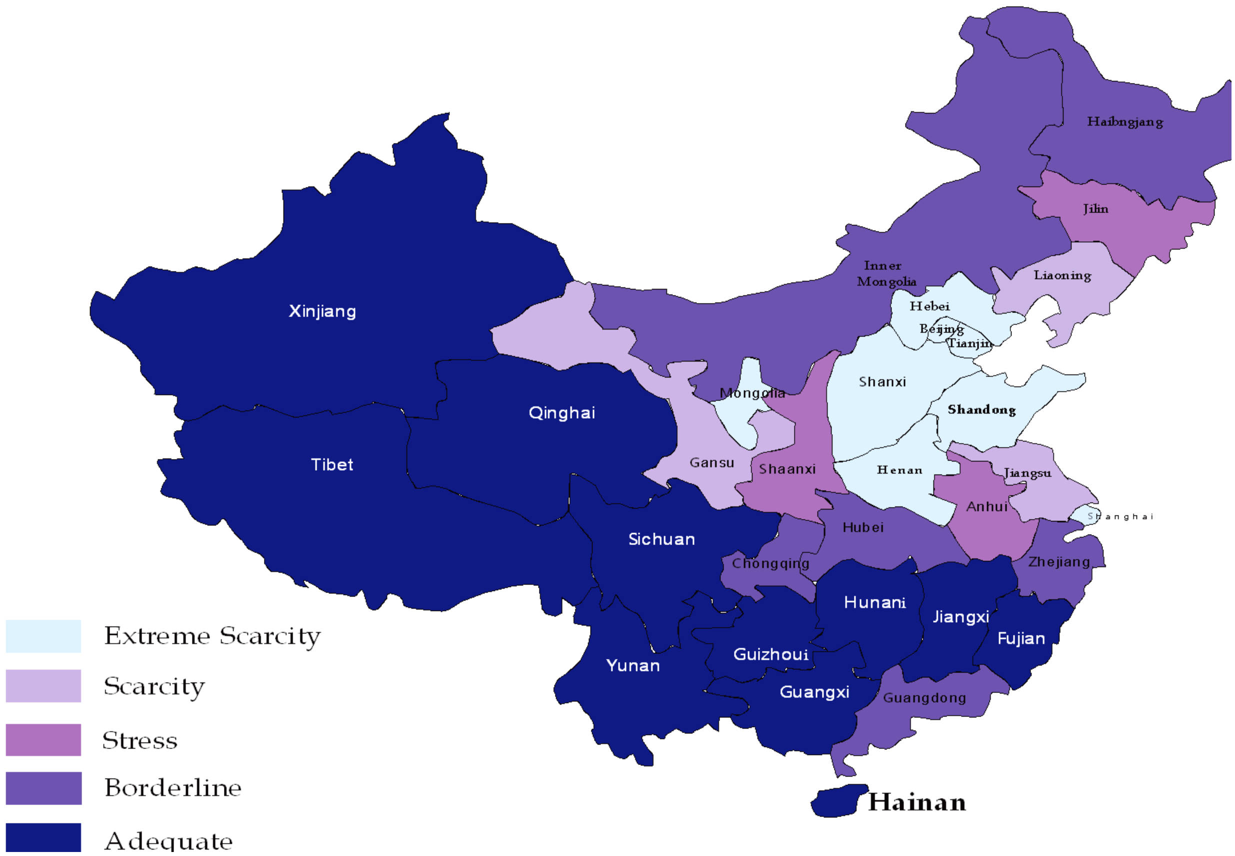

Fig. 2 Freshwater resources of China.

of 2012, China discharged 68.5 billion tons of total wastewater with 24.2 million tons chemical oxygen demand (COD) and 2.5 million tons ammonia nitrogen emission. This quantity is 3.7% greater than the previous year [43]. In this situation, pollutant removal should be main objective [44]. Jiangsu, Zhejiang, Shandong, Guangdong, Fujian and Henan are top wastewater discharging provinces and discharge 45% of total domestic wastewater [45].

Wastewater treatments

China is experiencing acute water shortage something that have been attributed to both large population, as well as, increased water pollution triggered by the increasing level of economic development with relatively negligible regard for the environmental impacts. The increasing rate of water pollution and the need to protect the environment have prompted China to develop various technologies to ensure efficient treatment of wastewater. There are various technologies that china is currently employing to help in the treatment of wastewater. China, the first large scale municipal wastewater treatment plant was constructed and operated two decades ago [46]. According to the Ministry of Housing and Urban Rural Development of China, by 2012 there were 3340 wastewater treatment plants (WWTPs) with 1.42 × 108 m^3/d treatment capacity [43]. As Fig. 3 shows that the numbers of WWTPs developed by China were increased rapidly because of consciousness about environmental protection. Now China has the world's second largest sewage treatment capacity after the United States. Oxidation ditch, anaerobic/anoxic/oxic (A_2O), and sequencing batch reactor (SBR) are most widely used processes for wastewater treatment account for about 80% of the total treatment quantity and capacity of 29.21%, 25.45% and17.90%, respectively.

Constructed wetlands

Constructed wetlands play an important role in terms of providing wastewater and sludge treatment, runoff treatment, and floodwater retention [47-53]. They are being used all over the world, offering solutions to water quality issues and treating effluents, including domestic sewage, agriculture runoff, urban runoff and industrial wastewater. Constructed wetland can be defined as a man-made engineered, designed area for the purpose of treatment of wastewater by improving the physical, chemical, and biological environment that can occur in natural wetland ecosystems. Constructed wetland can provide economical onsite wastewater treatment that is both effective and aesthetically pleasing [54-56]. Constructed wetlands have only been used for wastewater treatment since the 1970s, which makes them a relatively new treatment technology; however, interest in their use has quickly become widespread [57].

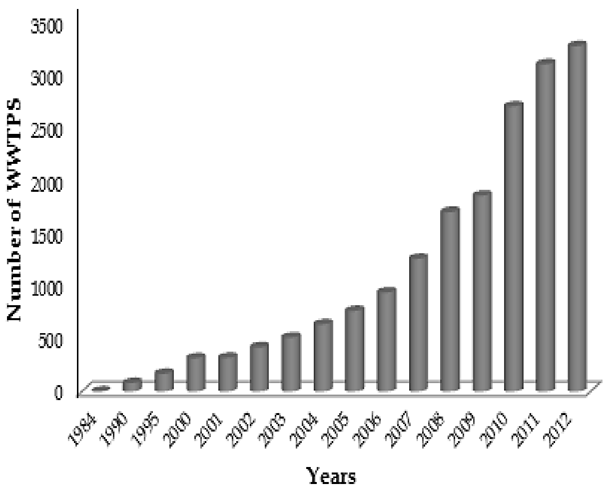

Fig. 3 Number of wastewater treatment plants in China.

Types of constructed wetlands

The most important criteria to categorize constructed wetland is hydrology (surface flow or subsurface flow), vegetation (emergent, submerged, free floating or floating leaved) and flow path (vertical or horizontal) (Fig. 4) [58-60]. Surface flow constructed wetlands are most likely called natural wetlands, those require more land area than a subsurface flow system for the same pollution reduction, but easier and cheaper to design and build [61]. In subsurface flow systems, wastewater flows vertically or horizontally through the substrate, which is composed of sand, soil, rock or any artificial media. In horizontal subsurface flow (HSF) constructed system, water flows horizontally below ground surface. It has greater treatment efficiency. The combination of two or more types of constructed wetland systems called hybrid constructed wetland system. Selection of constructed wetland system depends mainly on the targeted elements for treatment, treatment goals, geographic location, cost and available area [62].

Pollutant removal mechanisms in constructed wetlands

Constructed wetlands are mechanically simple, but biologically complex systems rely on biological, natural microbial, physical, as well as chemical process in the treatment of wastewater [63]. Their rapid emergence has been attributed to the fact that they require low operational cost and investment while at the same time playing an integral role in the provision of higher treatment efficiency coupled with more ecosystem services compared to the conventional wastewater treatment approaches [64-67]. Constructed wetland has been found to be effective in treating biochemical oxygen demand (BOD), total soluble solids (TSS), nitrogen (N) and phosphorus (P) as well as for reducing metals, organic pollutants and pathogens. In any ecosystem, all biotic and abiotic factors are interrelated. So in any type of wetland, any factor can increase or suppress any process. In constructed wetland, a complex interaction exists between plants, microbes and geochemical processes [68]. The removal mechanism takes place in constructed wetland can be abiotic (physical/chemical) or biotic (microbial or plant uptake). The mechanism used for the removal of a contaminant depends on the specific contaminant and site condition. Microbial population has an important role in the removal of biodegradable organic matter. Microbial degradation occurs when organic matter is carried into the biofilms attached on media, soil root system or plant stems. Filtration or gravitational settlement removes suspended solids. Pollutant can be removed by more than one process in constructed wetlands (Fig. 5).

Nitrogen removal

Nitrogen (N) may exist in different forms as ammonia (NH_3 and NH_4), organic N or oxidized N (NO_2^- and NO_3^-). Nitrogen removal can occur through nitrification, denitrification, volatilisation and taken up by plants and become part of plant biomass [69]. A major part of the nitrogen is eliminated from wastewater through denitrification and plant uptake. Nitrogen uptake by plants is important if plants are harvested [70-76].

Phosphorus removal

Phosphorus in constructed wetland occurs as phosphate in the form of organic and inorganic compounds [77-78]. Orthophosphate, dehydrated

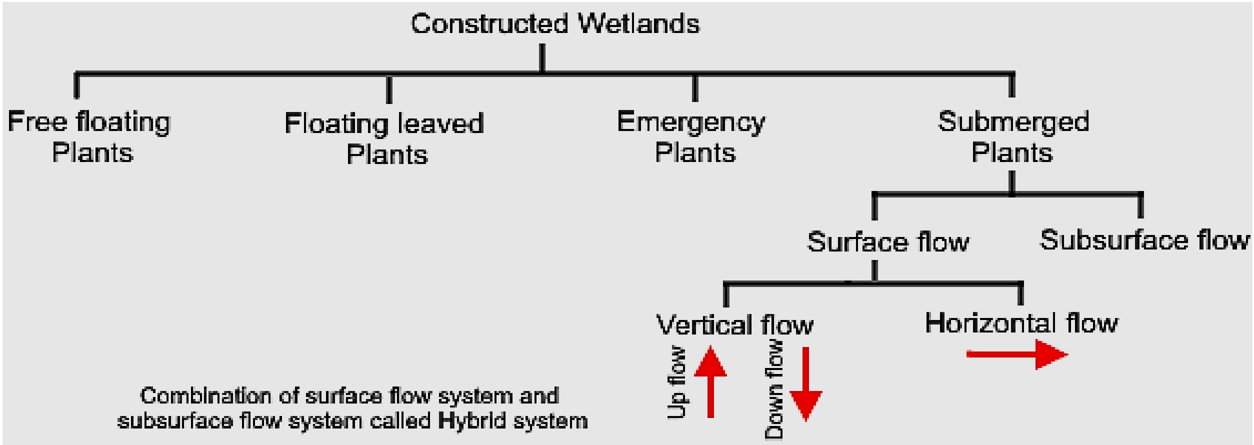

Fig. 4 Classification of constructed wetlands.

orthophosphate (polyphosphate) and organic phosphorus are the main forms of phosphorus [79-80]. Biological oxidation is the main process which causes the conversion of phosphorus to the prthophosphate [81]. Mostly phosphorus component can fix within the soil media. Phosphate removal can be achieved by adsorption, complexation and precipitation reactions involving calcium, iron and aluminium [82-83]. Phosphorous biogeochemical cycle is a sedimentary cycle, involve the transportation of phosphorus through the ground to water therefore phosphorus removal more dependent on plant uptake.

Pathogen removal

Filtration, sedimentation and natural die-off are the main processes for pathogen removal [84].

Metals removal

Metals such as copper and zinc may occur in particulate associated or soluble forms. Physiochemical processes like adsorption, sedimentation, complexation, precipitation, erosion and diffusion, determine the distributions of metals [85]. Metals can accumulate in a bed media by adsorption and complexation with organic material. Plants also can absorb metals.

Suspended solids removal

Suspended solids removal from wastewater is very important because it reduces silting and nutrients, which are attached with solids [52]. The main factor for suspended solids removal is suitable time for settling and combines with soil media. The slow flow of wastewater in the system gives time for settling of suspended solids, and plants also can increase sedimentation rate [86].

Applications of constructed wetlands

Wastewater is challenging problem from long time for the world as it contains hygienic hazards as well as organic matter which can cause eutrophication in water bodies, but on the other side they would be valuable for plants as nutrients [86]. The main nutrients in sewage are nitrogen, phosphorus and potassium, and can be utilized for agriculture purpose as fertilizer [87-89]. The first experiment of constructed wetland used to treat wastewater was carried out in Germany in 1950s [90], but the full scale system was built during the late 1960s [91]. From the last several years, constructed wetland is becoming a popular alternative option for wastewater treatment because of its low energy, development and maintenance cost, easy operation, high pollutant removal efficiency, water recycling, and potential for providing significant wildlife habitat [60, 83]. In the beginning, the use of constructed wetland was only for domestic sewage [92-96], but recently constructed wetlands have also been used to treat other types of wastewater such as sludge effluent [97, 98], agricultural wastewater [99, 100], lake/river water [101-104], industrial wastewater [105, 106], oil refinery wastewater [107], storm runoff [108-109], sugar industry wastewater [110], laboratory wastewater [111], landfill leachate [112], hospital wastewater [113], and agricultural runoff [92, 93, 100].

Use of constructed wetlands in China

In China, the first constructed wetland was built during seventh five-year development plan in 1987 [114, 115]. According to the Ministry of Housing and Construction of China, by the end of 2012, only 77.7% counties had wastewater treatment facilities [43]. On

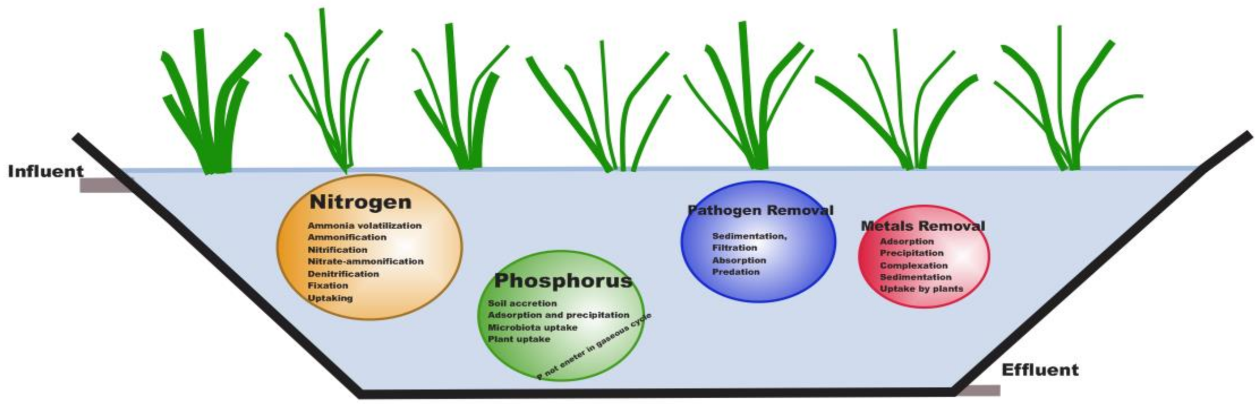

Fig. 5 Performance of different type of constructed wetland in China.

the basis of capacity, there are 4 types of WWTPs in China, small (<1×104 t/d), medium (1×104-1×105 t/d), large (1-3×105 t/d), and super large (>3×105 t/d). There are 3% super large, 13% large, 75% mediumand only 9% small scale WWTPs. Less than 2% WWTPs of China work on constructed wetland technologies and only medium and small scale constructed wetland are working in China. The percentages of constructed wetland WWTPs are 16.4% surface flow system, 29.3% subsurface flow system, and 54.3% vertical flow or Hybrid system [116].

For investigating the treatment efficiency of different constructed wetland systems in China, data from previous published literature was obtained [117-140]. We compared free water surface constructed wetlands (FWS), vertical subsurface flow constructed wetlands (VSSF), horizontal subsurface flow constructed wetlands (HSSF) and Hybrid systems. Fig. 6 shows that overall performance of hybrid systems is better than other systems, especially for total suspended solids (TSS), BOD (biological oxygen demand) and TP, but for NH_4-N removal is poor. HSSF system showed better efficiency compared to VSSF for all parameters. For nitrogen and NH_4-N, HSSF efficiency is higher, indicating that the HSSF systems are probably better at nitrification compare to other systems in China. The treatment performance of constructed wetland is not only related to the constructed wetland system, but also depend on the hydraulic loading rate (HLR) and hydraulic retention time (HRT).

Rural China and decentralized of wastewater treatments

According to 2007 data, 727 million peoples live in rural areas which comprise 55% of the total China population. This rural population is scattered over 20,000 townships and 18,000 township-level village clusters, which, in turn, consist of 720,000 administrative villages. Poor sanitation conditions with undeveloped basic infrastructure are common in most of the rural areas. Most of villages have no sewage treatment system, only 3% rural villages have wastewater treatment facility [141]. Limited water resources and ensuring access to clean water confront rural China with critical environmental challenges. Over the past several decades, the Chinese government has made significant strides to improve water supply in rural areas; however, over 300 million rural Chinese residents still do not have access to safe drinking water and proper sanitation [142]. Rural water issues range from shortage or scarcity to severe contamination and related public health problems. Regional and temporal shortage of water resources, contaminated water resources and increased threat of diseases related to inadequate water supply, sanitation and hygiene, inefficient water resources management, and lack of appropriate and sustainable waste management technologies are major water related problems. The fresh water quality sources are deteriorating and more than 100 million people consume polluted water [143]. Environmental degradation and pollution exacerbate poverty in China's countryside, while also threatening the health of vulnerable rural populations, particularly children. Diarrhea is still a leading cause of child death in rural areas. Although social and economic development is improving from last decade, but more than 90% villages in China lack proper drainage channels or sewage treatment facility. Effective wastewater treatment for rural area is essential to stop further deterioration of freshwater quality.

Rural wastewater management is fundamentally different from urban sewerage system management in terms of policies, regulations, standards, financing, designs, operation and maintenance, and beneficiary community involvement and participation. Implementing sustainable and appropriate sanitation and wastewater management practices in rural China is a priority to address the environmental and public health issues in rural areas. Adopting simple, low-cost decentralized and small centralized wastewater management schemes is fundamental to effectively manage and in some instances reuse wastewater for the benefit of rural populations [144-147].

Decentralized system is a good option for rural areas, where wastewater collection is difficult because of the small scale, complicated geographic situation and dispersed layout [148]. In a centralize wastewater management system, 60% budget is utilized for collecting wastewater [149]. Decentralized treatment mood keeps the collection component of the wastewater management system as minimal as possible but mainly focus on basic treatment. Centralize wastewater treatment mood requires piping material, pumps and energy which increase cost of system [150, 151]. According to the United States Environmental Protection Agency's (USEPA), decentralized mood is most cost effective and appropriate for the scattered population than centralized systems. Wastewater treatment facilities in rural China are very low, and higher proportion of the total population residing in rural area tends to discharge greater volume of sewage led to serious freshwater pollution [152]. The absence of infrastructure, dispersed population, geographic condition and low economic activities create the demand for the decentralized mood of wastewater treatment structures. The constructed wetland is a best option for rural wastewater management.

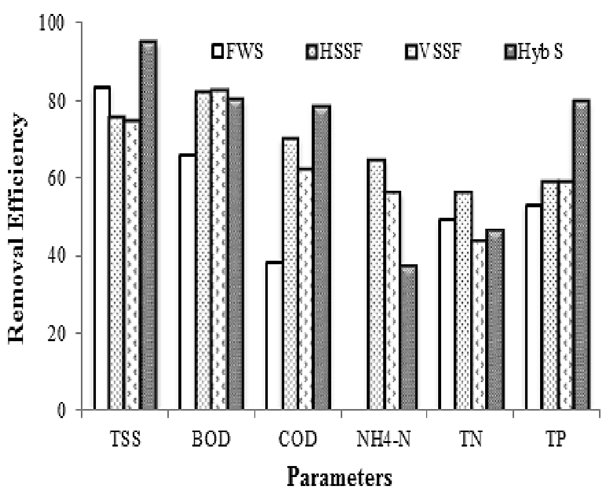

Fig. 6 Performance of different type of constructed wetland in China. Surface constructed wetlands (FWS), vertical subsurface flow constructed wetlands (VSSF), horizontal subsurface flow constructed wetlands (HSSF) and hybrid systems (Hyb S).

The conventional systems need large capital investments and operating costs, on the other hand constructed wetlands are effective and low-cost alternatives [153]. Constructed wetland need one third to one half cost of conventional systems. According to Wang et al. [154] and Akratos and Tsihrintzis [155], for treatment of one ton wastewater, building cost of a constructed wetland is 1000 to 2800 ¥ as compared to 1500 to 4000 ¥ for conventional treatment system in China. Moreover, constructed wetland systems have approximately 0.05 to 0.20 ¥ per ton of wastewater operation and maintenance cost that is very low. Constructed wetlands are requiring more space of land than that for conventional wastewater treatment mood [156, 157]. The high land requirement is the main barrier for constructed wetlands to expand the application. China urban is highly dense, but in rural china land is available and affordable. China possesses number one aquaculture industry in the world and treating wastewater is another challenge [158], and constructed wetlands hold potential for this type of treatment [159]. Constructed wetlands can provide additional ecosystem service benefits, such as biomass production, carbon sequestration, seasonal agriculture, reusable water supply, regional climate regulation, habitat conservation, and educational and recreational usage [160].

Conclusions

This paper has reviewed the wastewater problems of China, the strategies used in the treatment of wastewater and the use of constructed wetlands to treat wastewater. This study established that China is experiencing severe water shortages, which has resulted from growing population, as well as water pollution caused by the rapid economic development in the country. During the last decade, China government made great efforts to build WWTPs especially in urban China, but still rural China situation is not good. Initially, China employed centralized methods in wastewater treatment. Anaerobic/anoxic/oxic, sequencing batch reactor and oxidation ditch processes are the major processes for wastewater treatment. However, centralized methods are not good options for rural China to achieve the intended objective of maximum wastewater treatment.

Implementing sustainable and appropriate sanitation and wastewater management practices in rural China is a priority to address the environmental and public health issues in rural areas. Adopting simple, low cost decentralized management schemes are fundamental to effectively manage and in some instances reuse wastewater for the benefit of rural populations. China is a large and physically and culturally diverse country. Adopting sustainable, long-term sanitation and wastewater management programs will not occur at the national level, but will depend on the ability of many municipal, county and village governments to formulate cohesive and realistic wastewater management programs. Constructed wetlands have gained popularity across the world; including China.

Constructed wetlands are cost-effective and energy saving. Apparently, Constructed wetlands come in different designs, which have weaknesses and strengths. As such, there have been innovations, mainly in the combination of two or more constructed wetlands to achieve maximum output, such combinations brought about hybrid constructed wetlands. Sustainable development is the basic goal for every country as well as China; in this regard constructed wetland wastewater treatment methods will probably be the primary technology for reducing freshwater pollution and shortage. The application of constructed wetlands to treat rural wastewater treatment is highly helpful, and still need further research, policy decisions, public awareness and management training to promote the development of constructed wetland methods for wastewater treatment in China.

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