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Constructed Wetland with Mixed Mangrove and Non-mangrove Plants for Municipal Sewage Treatment

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Abstract. A constructed wetland wastewater treatment facility with mixed plant species was established successfully in Shenzhen, China. The effluent data indicated that the system was effective in removing pollutants such as COD, NH_4^+-N, TP and heavy metals. With the good growth of mangrove and non-mangrove wetland plants, the constructed wetland not only played an important role in wastewater treatment, but also provided ecological, recreational and educational functions for the local community. This wastewater treatment facility demonstrated to be a favourable supplement to conventional treatment facilities.

Keywords: mangroves, nutrient removal, wastewater treatment

1. Introduction

Constructed wetlands for wastewater treatment have become more and more popular in Asia in recent years. In China, more than 277 constructed wetlands in 24 provinces have been built, among which Guangdong Province is one of the fastest growing regions in promoting constructed wetland technology, with 49 constructed wetlands [1]. The most commonly used wetland plants include *Phragmites*, *Cyperus*, *Canna*, *Disporum*, *Cymbopogon* and *Acorus*, *Arundo*. The removal percentages of chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solid (SS), total nitrogen (TN), ammonium-nitrogen (NH_4^+-N) and total phosphorus (TP) in wastewater averaged 37-90%, 71-94%, 88-98%, 22-62%, 53-90% and 61-96%, respectively [2]. In Hong Kong, the three established constructed wetlands contain mainly *Phragmites*, which act as reed-bed filters to clean storm-water runoff, floodwater or wastewater generated from railway station operations. Most of the plants used in conventional, constructed wetlands are fast growing annual and perennial herbaceous vascular plants, which require frequent harvesting.

Compared to conventional constructed wetlands, the employment of constructed mangrove wetlands for *in situ* wastewater treatment is still lacking, although extensive research has demonstrated their great application potential in this field [3]. Mangroves are perennial woody plants grown in tropical and sub-tropical inter-tidal zones. For wastewater treatment initiatives, mangroves plants prevail over those herbaceous vascular wetland plants. This is because the latter requires frequent harvesting, which is not only labour-intensive and time-consuming, but also leads to poor plant growth and fluctuating treatment performance. Mangrove wetlands are highly efficient in adsorbing and absorbing wastewater-borne pollutants, including nitrogen, phosphorus, heavy metals and toxic organic pollutants [4]-[8]. The removal efficiencies of nutrients and metals from the wastewater in constructed mangrove wetlands ranged from 75 to 98% and 88-96%, respectively [9]. In a small-scale constructed mangrove wetland in Futian National Nature

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Reserve, China, mangrove species *Kandelia obovata*, *Aegiceras corniculatum* and *Sonneratia caseolaris* had good removal-efficiency for COD, BOD_5, NH_4^+-N, TN and TP [8].

The selection of wetland plants for constructed wetlands is important, as different species vary in pollutant removal efficiency. Shi et al. [10] showed that all seven plant species, *Thalia dealbata*, *Phragmites australis*, *Miscanthus sacchariflorus*, *Scirpus tabernacmontani*, *Canna indica*, *Cyperus papyrus* and *Disporum cautoniense*, had satisfactory removal abilities, but the removal was pollutant- and species-specific, with good removal of TN (81%) and NH_4^+-N (82%) by *T. dealbata* but not COD (54%). *C. indica* and *C. papyrus* were efficient in removing COD (70-73%), TN (73-75%) and NH_4^+-N (75-78%). *M. sacchariflorus* had the poorest performance. So far, most constructed wetlands have mono-culture or plants with similar characteristics and few attempts have been made to use mixed plants with different features. The present paper reports the design and construction of a pilot-scale, sub-surface flow wetland system with mixed mangrove and non-mangrove plant species for treating municipal sewage from domestic and industrial sources.

2. Constructed Wetland Treatment System

The constructed wetland treatment system is located in Longgang, about 60 km east of downtown Shenzhen, China. The key parameters of the constructed wetland are summarized in Table 1. Three mangrove species commonly found in Hong Kong and Southern China, namely *Kandelia obovata* (Ko), *Aegiceras corniculatum* (Ac) and *Bruguiera gymnorrhiza* (Bg), and seven non-mangrove species, including *Canna indica* (Ci), *Cyperus alternifolius* (Ca), *Cyperus papyrus* (Cp), *Thalia dealbata* (Td), *Arundo donax* var. versicolor (Ad), *Acorus calamus* (Acc) and *Iris tectorum* (It), based on the wide application and availability in Shenzhen and Southern China, were chosen. The arrangement of different plant species and the assigned area for each species are summarized in Table 2 and Figure 1. Mangrove plants, known to have higher tolerance levels to salts and pollutants than the non-mangrove plants, were placed at the sewage inlet section of the constructed wetland. Among different mangrove species, Bg was found to be most tolerant, followed by Ko and Ac, thus Bg was planted closest to where wastewater was discharged. Previous studies also showed that Bg had the highest tolerance to heavy metal and oil stress and was the best species for wastewater treatment [11]-[13].

Table 1: Key parameters of the constructed wetland

Parameter	Information
Floor area	240 m^2
Treatment capacity	50 m^3/d
Equivalent population size	250 (based on the daily consumption of water of 0.2 m^3/person in urban areas of China)
Type	4-stage tandem-type sub-surface flow
Substrate	0.85 m in depth consisting of three layers (from bottom to top): Gravel (0.15 m), soil (0.35 m), sand (0.35 m)
Vegetation	Mixed culture of mangrove and non-mangrove plants

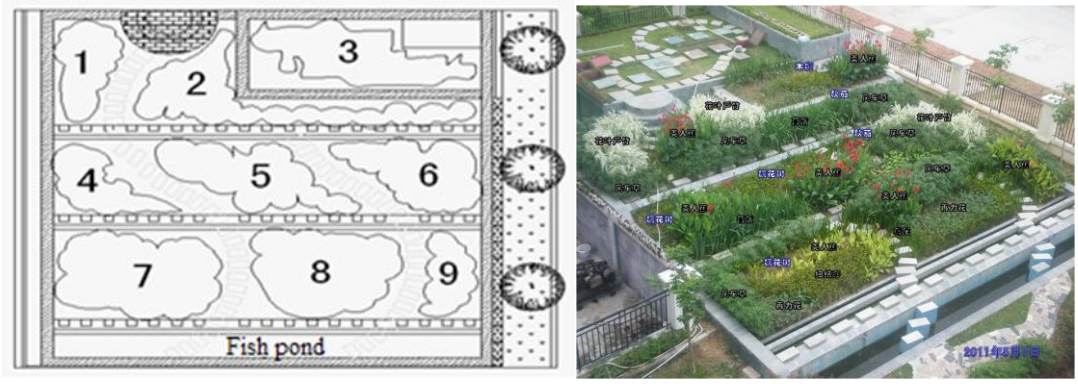

Fig. 1: Area number assigned and their establishment few months later

3. Treatment Efficiency of the Constructed Wetland

The COD concentrations in influent varied from 200 to 400 mg L^{-1} and were stabilized to below 20 mg L^{-1} after treated by the constructed wetland, much lower than the discharge standard 50 mg L^{-1} (Fig. 2A). The average removal percentage of COD was over 90%. The concentrations of NH_4^+-N in sewage were in the range of 30-92 mg L^{-1}, and the fluctuations were due to the seasonal changes in ambient temperatures and sewage production (Fig. 2B). The average effluent NH_4^+-N concentrations were below 3 mg/L, lower than the discharge standard of 8 mg L^{-1}, and the removal was over 95%. Total phosphorus concentrations in the influent ranged from 1.7 to 6.8 mg L^{-1}, and the effluent values dropped to 0.6-1.9 mg L^{-1}, with removal percentages between 40 to 65% (Fig. 2C). Four heavy metals, Ni, Pb, Cu and Cr, were detected in the influent, with mean concentrations of 17.5, 12.5, 12.2 and 12.0 mg L^{-1}, respectively, and the respective ranges of 16.2-18.2, 8.1-17.1, 8.1-16.9 and 8.9-15.6 mg L^{-1}. After passing through the constructed wetland system, all four heavy metals were below detection. These results demonstrated that the constructed wetland was effective in removing organic matter, nutrients and heavy metals. The plants also grew well and some even had flowers, indicating the mangrove and non-mangrove plants mixed well. The system looked like a beautiful garden rather than a sewage treatment system (Fig. 1).

Table 2: Plant species and vegetated area (m^2) in the constructed wetland. The assigned area # is shown in Figure 1

	Vegetated	Non-mangrove species								Mangrove species		
Area #	area	Ca	It	Ci	Ad	Acc	Td	Cp		Bg	Ko	Ac
1	10	5	-	-	3	-	-	-		1	-	1
2	20	4	2	2	4	-	2	-		4	2	-
3	15	-	1.5	3	-	1.5	3	3		3	-	-
4	10.8	3.6	1.8	1.8	-	1.8	-	-		-	-	1.8
5	15	3	-	3	-	1.5	1.5	3		-	-	3
6	10.8	3.6	-	-	3.6	1.8	-	-		-	1.8	-
7	15	5	-	5	-	1.2	1.3	2.5		-	-	-
8	16	4	-	2	-	2	4	4		-	-	-
9	5	2.5	-	2.5	-	-	-	-		-	-	-
Total	**117.6**	**30.7**	**5.3**	**19.3**	**10.6**	**9.8**	**11.8**	**12.5**		**8**	**3.8**	**5.8**

Ca, *Cyperus alternifolius*; It, *Iris tectorum*; Ci, *Canna indica*; Ad, *Arundo donax* var. versicolor; Acc, *Acorus calamus*; Td, *Thalia dealbata*; Cp, *Cyperus papyrus*; Bg, *Bruguiera gymnorrhiza*; Ko, *Kandelia obovata*; Ac, *Aegiceras corniculatum*

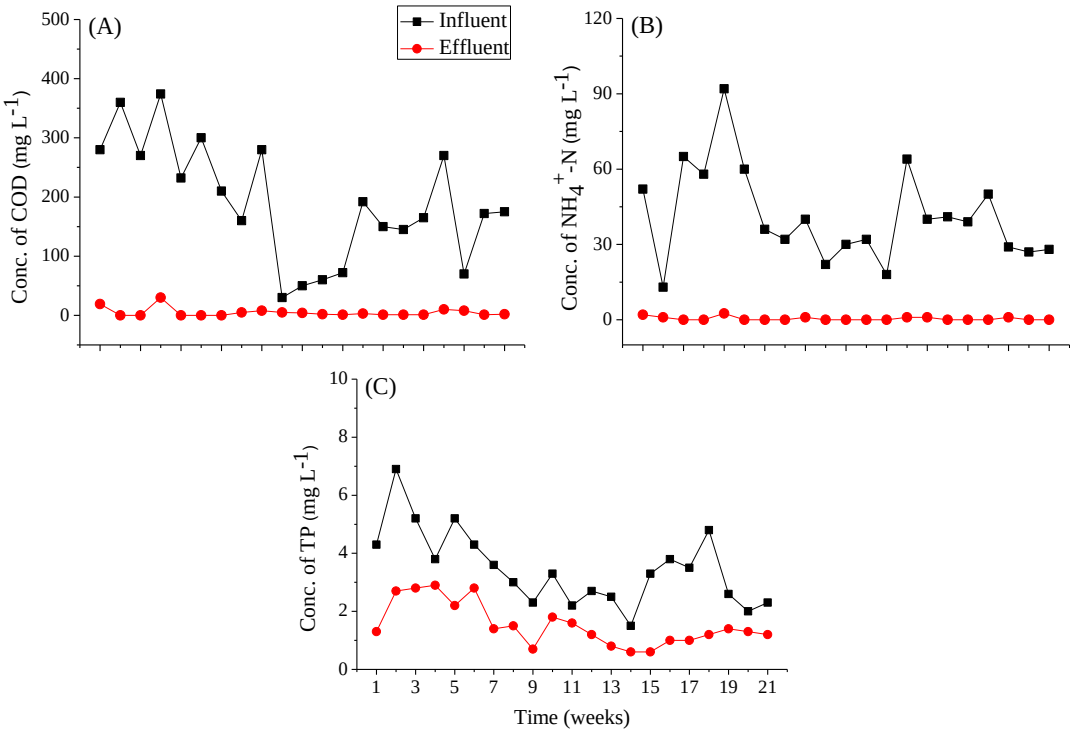

Fig. 2: Concentrations of organic matter (A), ammonium nitrogen (B) and Total phosphorus (C) in influent and effluent

4. Acknowledgements

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