Sustainable wastewater management technology for tourism in Thailand: case and experimental studies

W. Liamlaem, L. Benjawan and C. Polprasert

ABSTRACT

Thailand has adopted the concept of eco-tourism as a protocol to protect environmental resources. One of the key factors in enabling the achievement of this goal is the improvement of the quality of effluent from those homestays and resorts which still lack efficient on-site wastewater treatment. This research utilized case studies of subsurface flow constructed wetlands (SFCWs), planted mainly with the Indian shot (*Canna indica* L.), which were designed to treat wastewaters at three resorts located in Amphawa District, Samut Songkram Province in central Thailand. The results showed that the treated effluent was of sufficient quality to meet the building effluent standards Type C, which require the concentrations of biological oxygen demand (BOD), total Kjeldahl nitrogen (TKN) and suspended solids (SS) to be less than 40, 40 and 50 mg/L, respectively. In addition, the first-order kinetic constants for the design and operation of SFCWs were determined. For treating wastewater containing organic substances, with no prior pre-treatment, the first-order kinetic constant of 0.24 1/d can be applied to predict effluent quality. For treating other types of domestic wastewater, a first-order kinetic constant in the range 0.40–0.45 1/d can be used when sizing and operating SFCWs. This research highlights the great potential of SFCWs as a sustainable wastewater management technology.

Key words | *Canna indica* L, decentralized wastewater treatment, resort, subsurface flow constructed wetland (SFCWs), water reuse

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INTRODUCTION

Environmental problems, especially water pollution, have been increasing in Thailand because of rapid population growth, urbanization and tourism. This problem can have negative effects, not only on human health, but also on long-term economic development. The government of Thailand has invested a large sum of money to construct more than 100 wastewater treatment plants, but only about half of them have performed satisfactorily. This is partly because of a lack of personnel skilled in the operation of the treatment plants, and inadequate investment in the essential treatment facilities. In Thailand, the Pollution Control Department (PCD 2019) reported that these wastewater plants can treat only 27% of the entire country's domestic wastewater. Of equal note is that the sewerage network covers only 48% of the urban area (World Bank 2014). The management of wastewater and sanitation in areas without a sewerage system varies, depending on the awareness and attitude of the local population. Besides Thailand, other developing countries in Southeast Asia and elsewhere are also facing similar problems with water pollution.

In these circumstances, an effort has been made to find efficient, sustainable technologies for the management of wastewater, especially for the treatment of wastewater in those areas that do not have a sewerage treatment system. One such technology is decentralized wastewater treatment using natural-based systems. This has the potential to serve those communities that currently do not have any treatment facilities, because the technique can stand alone and does not require any highly technical resources (Crites & Tchobanoglous 1998; Zhang *et al.* 2014). In this context, natural-based systems are those which employ the activities of microbes, soil and/or plants in waste stabilization and resource recovery, without the aid of mechanical or energy-intensive equipment. Examples of these natural systems are: waste stabilization ponds; aquatic weed ponds; constructed wetlands, and land treatment processes. Although they require relatively large land areas, most of

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these natural-based systems could achieve a high degree of waste stabilization and, at the same time, have the potential to produce algal protein, fish, crops and plant biomass from the waste (Polprasert & Koottatep 2017). When designed and operated properly, these natural-based systems can produce treated effluent in terms of biological oxygen demand (BOD_5) and nutrient removal comparable to that from standard conventional wastewater treatment plants, but with much lower construction and operational costs, especially in tropical countries. Furthermore, the treated effluents can be non-body contact re-used in agriculture for growing a variety of crops, whereas in industrial processes (such as cooling water or for cleaning) additional treatment may be required to prevent clogging and biofilm growing in the manufacturing equipment.

Tourism is one of the largest business sectors in Thailand. Various types of tourism, including eco-tourism and homestay, have been promoted by the government as well as the private sector, and so have become popular among local and international tourists. A large number of these tourism areas have been established in many provinces all over the country. Amphawa, located in Samut Songkram Province in central Thailand, is a popular resort district. In this geographic backwater, tourism greatly influences the local people's way of life. The most recent statistical record of Suan Luang (one of 12 sub-districts in Amphawa) states that there are 26 resorts located there, some of which are homestays. Most of them are small-sized resorts (less than 10 rooms), and many are renovated old houses. Consequently, there are no sewerage connections, and pre-treatment facilities are uncommon and basic. Although a few resorts have already installed pre-treatment units such as septic tanks, retention tanks, and oil/grease separators, the quality of treated effluent is still inconsistent and is below the required standards (PCD 2018).

Therefore, natural-based systems, which are cost-effective, suitable for tropical conditions, and consume less energy, were designed and installed at resorts in Amphawa. Because this district is promoted as being a recreational area, three horizontal surface flow constructed wetlands (SFCWs) were chosen that treated three types of wastewater: (1) grey water (wastewater from human uses except discharges from water closets); (2) black water (liquid sewage from septic tanks); and (3) kitchen wastewater (wastewater from cooking) as SFCWs are simple in terms of operation and maintenance and do not require mosquito control compared to free water surface constructed wetlands. In addition, horizontal SFCWs possess several advantages over vertical SFCWs in terms of their ability to maintain sufficient hydraulic retention time and prevention of liquid short-circuit. The results obtained from studying these SFCWs enabled the identification of design/operation criteria, kinetic constants and process considerations for sustainable wastewater management technology.

METHODS

Experimental design and operation

In this research, SFCWs were studied at three resorts (R1, R2, and R3), treating various types of wastewater generated from the resorts. The systems for the treatment of wastewater at these resorts consisted basically of three major parts: septic tanks (for combined grey and black water) or retention tanks (for grey water only) to remove excess suspended solids and to also serve as an equalization chamber for SFCWs; SFCWs to stabilize organic matter and remove nutrients, and effluent chambers to raise the quality of the effluent in case of suspended solids escaping from SFCWs and to collect the treated water before being discharged or reused. SFCWs were designed to accommodate an organic loading rate of 100 kg BOD_5/ha/day (Crites & Tchobanoglous 1998; Polprasert 2007). Sand and gravel with porosities of 0.384 and 0.475, respectively, were used as media and planted mainly with Indian shot (*Canna indica* L.) and other aquatic plants such as: Bird of Paradise (*Strelitzia reginae* AIT.); Bull-tongue arrowhead (*Sagittaria lancifolia* L.), and Red melon sword (*Echinodorus* × *barthii* H. Muhlberg cv. Double Rojo). These aquatic plants were partly selected for their decorative value, because these SFCWs were located in recreational areas. Other design and operational criteria were taken into consideration, as mentioned in US EPA (2004) and Polprasert (2007). Figure 1 is a flow diagram of the on-site natural system including SFCWs. The three SFCWs are described in Table 1.

Wastewater sources and characteristics

Preliminary investigations revealed that the wastewater at resorts in Thailand can be classified into three major types: (1) grey water from lavatories, sinks, showers and

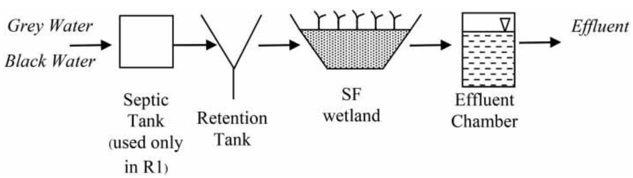

Figure 1 | Schematic diagram of the on-site natural treatment system.

Table 1 | Subsurface flow constructed wetlands at the resorts in Amphawa District

Design and operational criteria	R1	R2	R3
Design organic loading rate (kg BOD_5/ha/day)	100	100	100
Wastewater sources	Liquid from septic tank	Grey water	Grey and kitchen water
Septic tank (m^3)	0.80	–	–
Retention tank (m^3)	0.08	0.10	0.67
BOD_5 (mg/L)	150	100	150
Surface area (m^2)	1.08	3.5	9.4
Media	Sand	Sand + Gravel	Sand and gravel
Media depth (m)	0.5	0.75	0.75
Average hydraulic retention time (days)	4.2	5	5
Slope	1:100	1:100	1:100
Types of constructed wetland	Baffle	Connecting chambers	Baffle
Plants	Indian shot (*Canna indica* L.)	Various plants including: Indian shot (*Canna indica* L.), Bird of Paradise (*Strelitzia reginae* AIT.), *Sagittaria lancifolia* L., and *Echinodorus* × *barthii* H. Muhlberg cv. Double Rojo	Various plants including: Indian shot (*Canna indica* L.), *Pandanus sanderi Sander* ex M.T. Mast, *Philodendron erubescens* K. Koch & Augustin
Effluent chamber (m^3)	0.22	0.17	0.81

laundries; (2) black water or liquid sewage from septic tanks, and (3) kitchen wastewater, mainly from dish washing, which is separated from black water. Wastewater characteristics from the resorts measured according to APHA, AWWA & WEF (1998) are described in Table 2.

Average water usage by tourists at resorts in Amphawa ranges from 80 to 120 L/capita/day (Benjawan *et al.* 2017a, 2017b). However, water usage and wastewater characteristics vary dramatically depending on tourist seasons and holidays. The results from this preliminary investigation were used as primary data for sizing SFCWs and their components.

Table 2 | Wastewater characteristics from the resorts

Parameter	Grey water	Black water	Kitchen wastewater
pH	7.53–8.12	8.34–8.43	6.48–7.59
COD (mg/L)	39–209	102–339	281–630
BOD (mg/L)	9–150	57–165	150–383
SS (mg/L)	8.5–82	16–31	38–113
TKN (mg/L)	2.03–16.6	45–63	5.1–26.5
TP (mg/L)	0.06–0.96	4.5–4.8	0.4–4.6

Process kinetics

When designing SFCWs, the two major parameters to be considered are hydraulic retention time and process kinetics. However, the exact hydraulic retention time is difficult to determine, because the flow regimes inside the SFCWs depend on the porosity of the media. Furthermore, several mechanisms are involved in the stabilization of organic substances and the reduction of nutrients. Normally, the flow pattern of an SFCW would be somewhere between 'completely mix' and 'plug flow' hydraulic regimes. Therefore, integrated models with specific assumptions were developed (WEF 2001; Polprasert & Khatiwada, 1998). However, considering the complex reactions occurring in the SFCWs, the integrated models developed so far are often unable to always predict the treatment efficiencies of constructed wetlands. When designing SFCWs to treat wastewater from resorts, the common first-order kinetic reaction for BOD_5 removal can be applied as follows:

$$\frac{C_e}{C_o} = e^{-k_T t} \quad (1)$$

where,

C_e = Effluent BOD_5, (mg/L)
C_o = Influent BOD_5, (mg/L)
k_T = first order kinetic constant, (1/day) at liquid temperature, T(°C)
t = hydraulic retention time in SFCW, (days)

The process kinetic constant (k) varies greatly according to temperature and other factors, such as reactor configuration, media and types of plant. The value of k can be obtained experimentally and used for the subsequent design and operation of SFCWs.

Laboratory and statistical analysis

During this study, wastewater samples from resorts, influent and effluent samples from each SFCW were collected once a week on Wednesday afternoon. These samples were preserved at a temperature of 4–8 °C during 2-hr transportation before being analyzed in the laboratory. The parameters analyzed were: pH; turbidity; chemical oxygen demand (COD); BOD_5; total Kjeldahl nitrogen (TKN); total phosphorus (TP); suspended solids (SS); total dissolved solids (TDS); and coliform bacteria. The values of pH, EC and turbidity were obtained by using onsite electronic meters, and other parameters were measured based on *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA & WEF 1998): COD (close reflux); BOD (azide modification); TKN (digestion and distillation); TP (digestion and colorimetric); SS (gravimetric); TDS (gravimetric); and coliform bacteria (most probable number: MPN). Due to inflow and quality variation, the results were presented as arithmetic means ± standard deviations, and statistical analysis was done using Microsoft Excel 2016.

RESULTS AND DISCUSSION

The SFCWs in the three resorts were in operation over 150 days (March–September), treating wastewater from various sources equivalent to per-capita BOD_5 loading ranking from 2.5–40 $gBOD_5$/capita/d. The performance of each SFCW was evaluated by analysing its influent and effluent. The first 30 days were a period of start-up, to allow plant growth and fine tuning of the operational and environmental conditions. Thereafter, the remaining time was meant to be a period of operation at full capacity. However, because the system received actual wastewater directly from the guest rooms in each resort, each SFCW had to accommodate wide variations in flow rate and organic loadings entering the system. This increased the amount of time taken for the SFCWs to reach the steady state condition.

BOD_5 and other pollutant removal

Analysis of the influent and effluent of the three SFCWs, over their entire period of operation, yielded the data contained in Table 3. Weekly results of BOD_5 from R1, R2, and R3 are illustrated in Figure 2.

Table 3 | Influent and effluent quality of constructed wetlands treating resort wastewater

	R1			R2			R3			
Parameter	**Inf***	**Eff***	**% rem***	**Inf**	**Eff**	**% rem**	**Inf**	**Eff**	**% rem**	**Eff Std****
pH	7.96 ± 0.4	8.19 ± 0.8	–	7.71 ± 0.7	8.35 ± 0.7	–	6.47 ± 0.5	7.62 ± 0.6	–	5–9
COD (mg/L)	87 ± 48	46 ± 29	46 ± 20	97 ± 55	24 ± 11	46 ± 20	519 ± 257	125 ± 95	75 ± 13	–
BOD (mg/L)	32 ± 22	15 ± 10	51 ± 21	46 ± 32	6 ± 4	51 ± 21	340 ± 142	78 ± 68	76 ± 17	<40
TKN (mg/L)	54 ± 21	30 ± 23	48 ± 32	12 ± 6	2 ± 1	48 ± 33	19 ± 6	13 ± 4	30 ± 21	<40
TP (mg/L)	6.1 ± 1	2.6 ± 2	58 ± 29	0.6 ± 0.3	0.1 ± 0.1	58 ± 29	3.3 ± 1.2	1.9 ± 1.0	40 ± 26	–
SS (mg/L)	32 ± 30	12 ± 8	48 ± 26	27 ± 12	8 ± 5	48 ± 26	92 ± 42	18 ± 11	78 ± 16	<50
TDS (mg/L)	447 ± 211	387 ± 141	31 ± 22	451 ± 329	375 ± 174	31 ± 22	1,106 ± 357	1,067 ± 339	20 ± 20	
Turbidity (NTU)	19 ± 25	26 ± 36	–	31 ± 23	4 ± 3	82 ± 16	98 ± 61	49 ± 42	57 ± 31	–

*Inf = Influent, Eff = Effluent, and % rem = % removal.
**Building Type C, Effluent standard (PCD 2018).

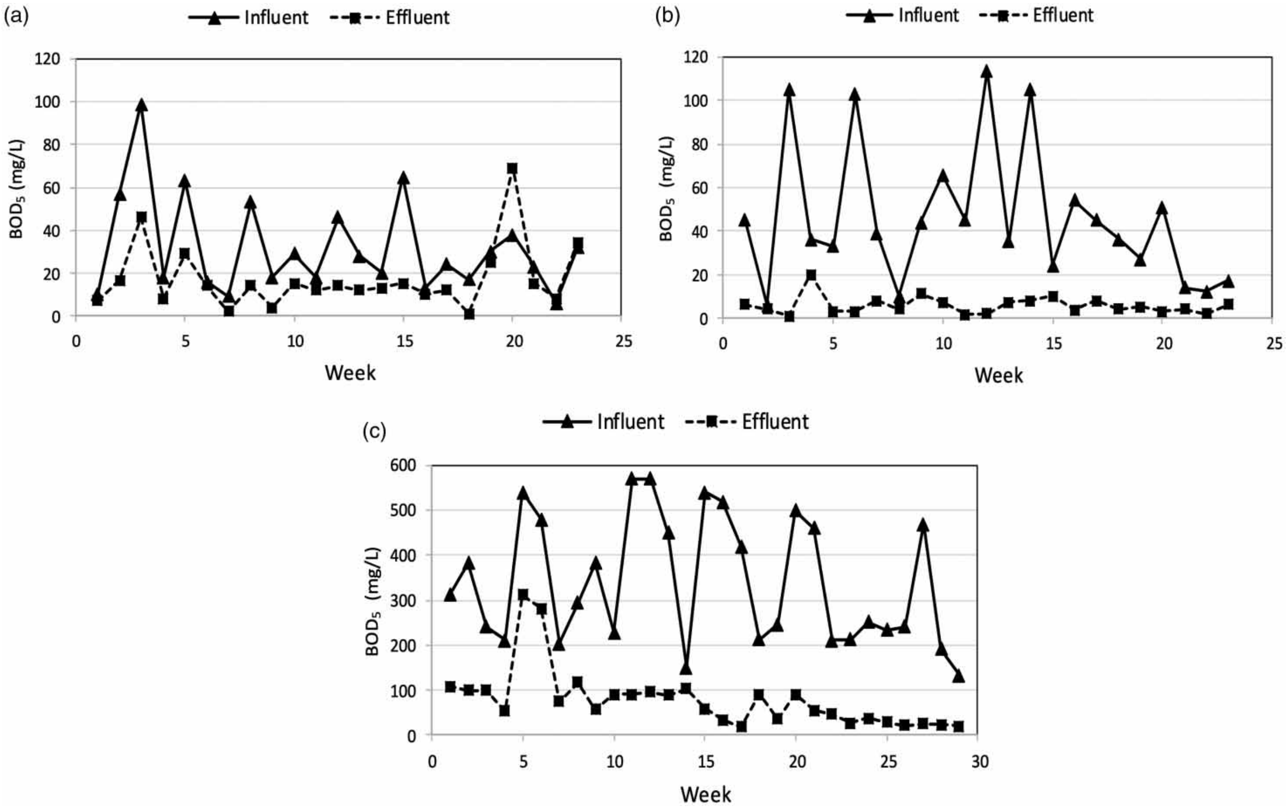

Figure 2 | Influent and effluent BOD_5 removal by SFCWs in three resorts.

In treating wastewater from resorts, the major pollutants were found to be organic substances and nutrients, as described by BOD_5 and TKN. Other potential pollutants (SS, TP, and TDS) were not found at significant levels. It was apparent that the performance of the SFCWs was affected by wide variations in influent organic loading (in terms of BOD_5 and flow rate), especially during the start-up period. The SFCW at R1, which received the combined wastewater from septic tanks, had large fluctuations in effluent quality because its influent had a high content of organic substances and nutrients (as indicated by TKN and TP). A similar level of performance was also observed by the SFCW at R3 in treating a combination of grey and kitchen wastewaters. After continuing operation over 20 weeks, the R3 system showed consistent and acceptable performance, although there was still great variation in its influent. This was due to it maintaining a normally longer hydraulic retention time than R1, as the effluent concentrations of pollutants were significantly influenced by hydraulic retention time and increased over time Zhang *et al.* (2014) For R1, at week 20, there was an organic shock load as wastewater collection was done once a week, while hydraulic retention time was maintained at 4.2 days. Hence, the effluent characteristic exhibited higher contaminant levels than the influent. Efficient removal of BOD_5 and other pollutants was observed at the SFCW at R2, which was fed only by grey water from guest rooms. Zhang *et al.* (2014) revealed that constructed wetlands treating municipal wastewater with a constant hydraulic loading rate in developing countries performed efficient SS, COD, and total nitrogen removal up to 94, 86, and 67%, respectively, while BOD removal of 89% was achieved in SFCWs. This can be used as an upper limit of conventional constructed wetland operation. The quality of that effluent even met the general requirement of $BOD_5 < 20$ mg/L. This indicated that SFCWs can cope with wastewater containing medium to low levels of organic matter and nutrients, but that black water and kitchen wastewater require either a large land area or pre-treatment units before entering SFCWs. Although a combination of various aquatic plants was used as described in Table 1, the major species (over 80%) planted was Indian shot (*Canna indica L.)* as it is one of the most common vegetation species found in the study area. Furthermore, Indian shot can withstand a high organic loading rate comparing to other aquatic plants and would be beneficial in terms of decoration at resorts. In addition, different vegetation species have different capacities for nutrient uptake and accumulation of heavy metals (Tanner *et al.* 1995) but there was no significant difference in terms of organic substance removal efficiency while treating domestic wastewater. Another option is to upgrade these conventional SFCWs, for example by replacing the existing media with more efficient materials. An experiment was conducted to investigate the efficiency of volcanic rocks in improving water quality and their use as media in SFCWs (Yammanas & Tuwicharanon 2016). Due to their high porosity and iron content, these volcanic rocks (with biofilm growing in the pores) were able to reduce COD by more than 60%, suggesting their suitability to be used as media in SFCWs for effective treatment of wastewater. Moreover, the SFCWs in these resorts also demonstrated efficient removal of nutrients, when compared to another biological wastewater treatment system. At the end of the experimental period, the quality of the effluents from all three SFCWs met the building effluent standards Type C, which require the concentrations of BOD, TKN and SS to be less than 40, 40 and 50 mg/L, respectively. However, it was found that all SFCWs yield low fecal coliform removal. This was due to the operational condition of these reactors, as pathogen inactivation cannot be achieved under the ambient temperature ($30 \pm 5\,^{\circ}$C) and hydraulic retention time $\leq$5 days (Feachem *et al.* 1983; Polprasert 2007).In addition, the effluents from some SFCWs were found to be suitable to be re-used for non-body contact purposes (US EPA 2004). The above results demonstrate the potential of natural systems, such as constructed wetlands, as a sustainable wastewater management technology that is low-cost in construction, operation and maintenance, but yet still effective in wastewater treatment for non-body contact reuse or disposal to non-sensitive receiving zones.

Process kinetic determination

In terms of the practical design approach of SFCWs, the efficiency of BOD reduction is essentially a volume-based hydraulic retention time model. The degradation of organic substances in SFCWs can be described by first-order kinetics, as shown in Equation (1). Crites *et al.* (2006) and Polprasert (2007) suggested the process kinetic constant (k) for SF constructed wetlands: $k_{20} = 1.104$ (at $20\,^{\circ}$C). This value varies with respect to temperature, so that k at any temperature (k_T) is given by: $k_T = k_{20}(1.06)^{T\text{-}20}$. However, this kinetic constant may not be applicable in all cases. In this study, first-order kinetic constants were determined for the three SFCWs treating various type of wastewater. The values of these process kinetic constants are shown in Table 4.

The mean values of process kinetic constants from the SFCWs treating liquid from septic tanks (R1), grey water (R2), and a combination of grey and kitchen water (R3) were found to be 0.240 1/d, 0.431 1/d, and 0.421 1/d, respectively. These values are relatively low when compared to the one suggested by Crites *et al.* (2006) and Polprasert (2007), while the determination of the first-order reaction rate from a constructed wetland treating landfill leachate, which is difficult in terms of biological degradation, showed that 0.201 1/d was attained under the same climate condition (Sawaittayothin & Polprasert 2006). Furthermore, process kinetic greatly depends on temperature; higher temperature generally results in higher k_T. Song *et al.* (2009) investigated seasonal performance variation and found that during winter a full-scale constructed wetland displayed lowest COD, ammonia, and phosphorous removal efficiencies. The extremely low kinetic constant of 0.240 1/d was found at the SFCW treating wastewater containing organic substances (R1), although the BOD_5 concentration of its influent was not as high as the influent of R3. It is seen from Table 3 that the influent at R1 had a high nitrogen content compared to carbon: TKN of 54 ± 21 mg/L and BOD_5 32 ± 22 mg/L. This was the main reason why the value of the first-order kinetic constant obtained from R1 was much lower than those obtained from R2 and R3. According to Polprasert (2007), the initial C/N ratio should be in the range of 20/1–40/1 (this being the optimum for biological processes).

Therefore, when designing and operating SFCWs in a tropical climate (ambient temperature 30–35 °C), first-order

Table 4 | Process first-order kinetic

Parameter	R1	R2	R3
Wastewater sources	Liquid from septic tanks	Grey water	Grey and kitchen water
Influent BOD_5 (mg/L)	32 ± 22	46 ± 32	340 ± 142
Ambient temperature (°C)	30 ± 5	30 ± 5	30 ± 5
Process kinetic, k_T (1/d)	*0.240*	*0.431*	*0.421*

kinetic constants need to be adjusted. It is suggested that, for treating wastewater containing high organic substances (such as the liquid from septic tanks, with no prior pre-treatment), a first-order kinetic constant of 0.240 can be applied to predict the quality of the effluent. In addition, in order to produce good and consistent effluent quality, a longer hydraulic retention time (e.g. 10–15 days) is strongly recommended for organic removal and pathogen inactivation (Feachem *et al.* 1983). For treating other types of domestic wastewater such as grey water, it is recommended that a first-order kinetic constant in the range 0.40–0.45 is used. These first-order kinetic constants can be used as references in 'future–sizing' SFCWs at homestays or resorts that are located in areas that do not have a sewerage system and so require a sustainable wastewater management technology.

CONCLUSIONS

Case studies on the application of constructed wetlands to treat wastewaters were carried out at resorts located in Amphawa District, Samut Songkram Province in central Thailand. These resorts employed SFCWs, planted mainly with Indian shot (*Canna indica* L.), to treat their wastewaters. The results of these case studies showed that the quality of the treated effluent met the building effluent standards Type C, which require the concentrations of BOD, TKN and SS to be less than 40, 40 and 50 mg/L, respectively. This study also determined appropriate first-order kinetic constants for the design and operation of SFCWs. It is suggested that, for treating wastewater containing high organic substances (such as sewage), with no prior pre-treatment, a first-order kinetic constant of 0.240 can be used to predict the effluent quality. In addition, in order to produce effluent of consistent quality, and which corresponds to more stringent standards, a longer hydraulic retention time is strongly recommended. A first-order kinetic constant in the range 0.40–0.45 can be used when sizing and operating SFCWs that treat other types of domestic wastewater, such as grey water or low organic content wastewater. These natural systems are expected to play an important role, both for Thailand and other developing countries, in reducing water pollution and promoting sustainability.

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