Global J. Environ. Sci. Manage. 10(3): 1-18, Summer 2024, Serial #39

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH ARTICLE

Restructuring of Small-scale constructed wetland systems and treatability of individual household wastewater through natural process

S. Mokatip[1], K. Chunkao[2], W. Wararam[1,*], S. Bualert[1], O. Phewnil[1], T. Pattamapitoon[1], N. Semvimol[1], P. Maskulrath[1], P. Rollap[2], S. Thaipakdee[2]

[1] *Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand*

[2] *The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Chaipattana Foundation, Ban Laem District, Phetchaburi Province, Thailand*

ARTICLE INFO

Article History:
Received 25 October 2023
Revised 30 December 2023
Accepted 08 February 2024

Keywords:
Constructed wetland (CW)
Domestic wastewater
Natural process
Sewer system

DOI: 10.22035/gjesm.2024.03.***

ABSTRACT

BACKGROUND AND OBJECTIVES: Domestic wastewater pollution in Thailand presents challenges due to limited space and a high concentration of point source effluents. This phenomenon often leads to domestic wastewater exceeding the capacity of local treatment systems. This study aims to expand the knowledge gained from The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project by evaluating the treatability of municipal wastewater. It utilizes a constructed wetland system in conjunction with a transfer and point source system. After the implementation of this primary system, the reduction in highly contaminated domestic wastewater could enhance the treatment loading of other secondary treatment systems or even facilitate its release into natural pathways.
METHODS: In the sampling collection process, the dynamics of the collection points were categorized into three different zones: 1) the point sources of domestic wastewater within a municipality, where 15 sample points were selected to represent the municipality; 2) the collection pond within the municipality and the transfer pipeline, comprising three collection points of the system; 3) the constructed wetland treatment system, where five water samples were collected in relation to the length of the existing 100-meter plot. The water samples were collected using four 1-liter polyethylene bottles. The analysis parameters were the biological oxygen demand, total nitrogen, nitrate, total phosphorous and phosphate, and other parameters related to domestic wastewater treatment efficacy.
FINDINGS: This study reveals that the domestic wastewater in Phetchaburi Province initially has a high organic content, leading to a biochemical oxygen demand: nitrogen: phosphorous ratio of 100:2.5:0.2 favoring anaerobic degradation. This ratio shifts in the constructed wetland system, located 18.5 kilometers away, to 100:10.5:2.3, promoting anaerobic treatment. The system shows high efficacy, with 81.4, 50.0, and 58.3 percent removal rates for biochemical oxygen demand, nitrogen, and phosphorus, respectively. This efficacy corresponds to a notable reduction in average biochemical oxygen demand from 740.0 to 9.7 milligrams per liter. Moreover, changes are observed in total nitrogen content, shifting from 20.8 to 2.8 milligrams per liter, in the system's effluent. While lastly, the total phosphorous decreased from 2.75 to 0.60 milligrams per liter
CONCLUSION: This treatment method can be effectively applied to small-scale constructed wetland systems within households. The recommended hydraulic retention time is between 29 and 60 hours under anaerobic conditions and 3 days under aerobic conditions. The changes in the composition of municipal wastewater, which is highly organic, support the use of both degradation processes. The knowledge and application of the constructed wetland system could be suggested for the primary treatment system of domestic wastewater within municipalities, given that this system would provide support to the central wastewater treatment system for enhanced efficacy.

NUMBER OF REFERENCES
61

NUMBER OF FIGURES
6

NUMBER OF TABLES
5

*Corresponding Author:
Email: *watcharapong.warar@ku.th*
Phone: +6690 555 1979
ORCID: 0009-0000-1487-4284

Note: Discussion period for this manuscript open until October 1, 2024 on GJESM website at the "Show Article".

INTRODUCTION

All water resources in the Kingdom of Thailand have been threatened since 1950, causing not only limitations in utilization but also the extinction of aquatic animals and plants. Point sources are presumably accused mainly on communities that settled along riverbanks, accounting for approximately 75 percent (%) of the population, owing to a large group of people staying together. Domestic wastewater can be sourced from households, local fresh markets, and slaughterhouses, in which the daily anthropogenic activities, such as washing, cleaning, cooking, and humans' consumption, are the drivers for its generation (Mohadesi *et al.,* 2024). Scientifically, wastewater contains various organic contaminants owing to the presence of proteins, carbohydrates, fats oils and grease (FOG), and detergents. Increased community wastewater is inevitably created and input into rivers and other natural water sources. The existence of fresh-food markets, local confectionery factories, slaughterhouses, and tourism inside communities and densely populated cities increasingly activate water pollution in rivers as the population increases. Moreover, the increasing residential and settlement areas near riverbanks are directly related to the pollutants, worsening the condition and decreasing the efficiency of water usage (Schwarzenbach *et al.,* 2010). Concerns regarding the decline in the environmental quality due to wastewater pollution have led to the government's attention to recovering the polluted water of all rivers and water sources by setting up a budget of approximately 2,000 million US dollars (USD) per annum for employing high engineering techniques for community or municipal wastewater treatment, including activated sludge (AS), oxidation pond (OP), aerated lagoon (AL), stabilization pond, oxidation ditches, rotating biological contactor, and up flow anaerobic sludge blanket. In the implementation of these technologies, however, the optimized performance of community wastewater treatment techniques for different causes cannot be achieved under the target, causing a loss of budget (Samimi *et al.,* 2024). For instance, one engineering technique was chosen for treating wastewater from a community, but it was never renovated or upgraded to keep up with the increasing sewage content in natural water sources (Chen *et al.,* 2016), which escalates the problems. Various problems, such as maintenance, responsibility, lack of budget, and not seeing the essence of treating community wastewater, interrupt the processes of community wastewater treatment, which can be regarded as the case in Thailand. The common method used in Thailand is AS (Me Maw *et al.,* 2022), and one of the most applicable technologies to resolve this issue is natural technology. A typical method for treating domestic wastewater in tropical areas is using constructed wetland (CW) systems. In this method, photosynthesis drives the addition of oxygen (O) to the wastewater in support of the biodegradation activity, as well as the phytoremediation of submerged plants (Pattamapitoon *et al.*, 2013; Sukchinda *et al.,* 2019). Results from CW systems set up in public parks through subsurface flow CWs (SFCWs) showed 88.9% fecal coliform bacteria removal, 84.9% total nitrogen (TN) removal, 73.3% chemical oxygen demand (COD) reduction, 61.4% biochemical oxygen demand (BOD) reduction, and 14.2% total phosphorus (P) reduction (Vazquez *et al.,* 2023). For carbon (C) sequestration, such systems were a productive carbon dioxide (CO_2) sink in consideration of the ecosystem services contributing to a positive economic sense (Gallanta *et al.,* 2020), and they can enhance soil fertility, act as storm runoff buffers for agriculture, and help mitigate greenhouse gas effects. They also support ecosystems with diverse microorganisms, birds, and plants (Hassan *et al.,* 2021). In terms of ecosystem services, CW systems provide biomass for use in the food and energy industries. They treat various water types, including agricultural, industrial, municipal, stormwater runoff, landfill leachate, and mining water. A literature review identified regulating services such as wastewater treatment, water purification, climate regulation, flood prevention, and erosion control. Supporting services include habitat formation, nutrient cycling, and contributions to the hydrological cycle (Agaton *et al.,* 2023). However, the many applications of CW systems in domestic wastewater treatment encounter a knowledge gap, which, in many cases, leads to excess nitrogen (N) content, causing eutrophication phenomena within many natural regions. In the adoption of CW systems, the uptake of N by plant species plays a key role in controlling excess N (Jitthaisong *et al.,* 2012; Tang *et al.*, 2012; Phewnil *et al.,* 2014; Pitaktunsakul *et al.*, 2015; Chueawong *et al.,* 2019; Phewnil *et al.,* 2024). Natural methods allow for a simple application that requires only local and inexpensive materials and minimal maintenance (Chunkao *et al.,* 2012). A practical landscape design for urban CW was shown to achieve economic and environmental advantages, creating sustainable landscapes and utilizing appropriate engineering landscaping principles (Li *et al.,* 2022). The aim of this study is to examine the potential treatment of the Phetchaburi municipality wastewater from individual point sources (households, local markets, and slaughterhouses), the transfer process, and the wetland treatment to improve the wastewater quality in Phetchaburi, Thailand. The wastewater data were collected in 2021. The results of this study will facilitate the understanding of small-scale wetland systems for household applications. The CW system acts a primary treatment for the reduction of highly organic contaminants before releasing wastewater into the natural rivers or into the treatment system. The output could support other secondary treatment of wastewater contaminants or effluents in natural surroundings. This study was carried out in Phetchaburi Province, Thailand in 2021.

MATERIALS AND METHODS

Study area

The study search was conducted at the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project (LERD) site. The geographic location of the study area in the tropical Laem Phak Bia Sub-district, Ban Laem District, Phetchaburi Province (Universal Trans Mercator 1442725 North and 617774 East), 120 kilometers (km) of Southern Bangkok, Thailand, is shown in Fig. 1. The royal subproject named "Community Wastewater Treatment" has been aimed to treat community (Phetchaburi municipality) wastewater through the natural process along with using CW and OP techniques since 1990 (Fig. 2).

Wastewater collection site

The dynamics of collection points were studied during the dry season from January to April 2021. The selected pathways were categorized into 1) point sources of domestic wastewater within the municipality, totaling 15 points with 3 replicates

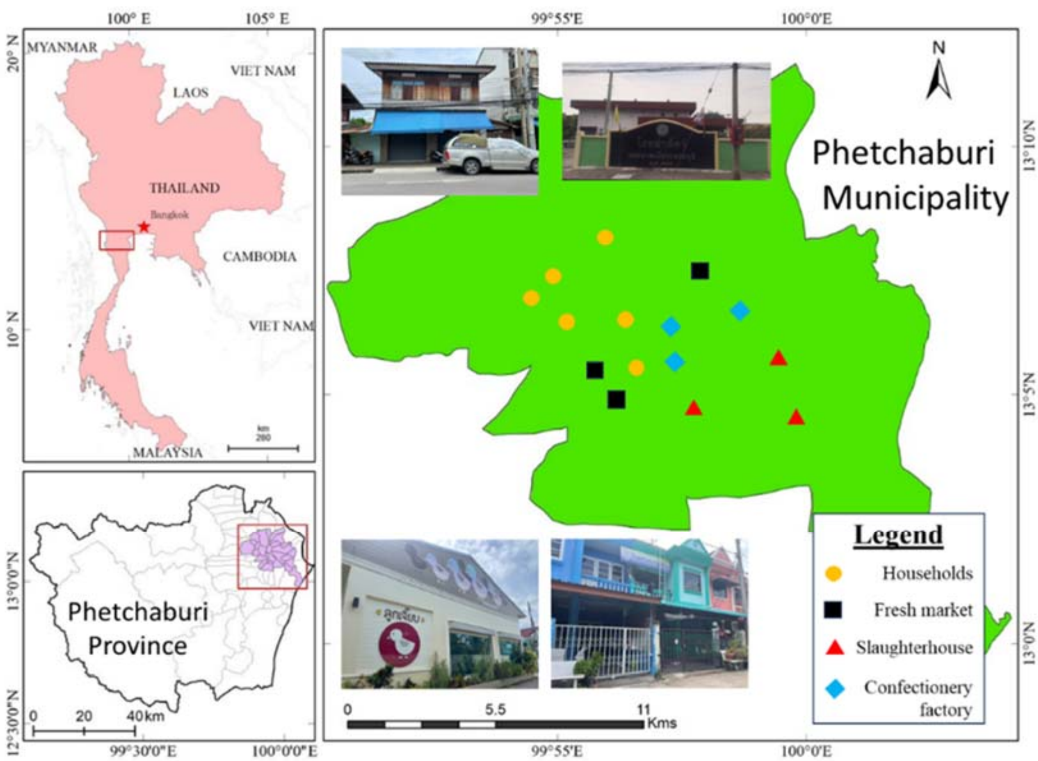


Fig. 1: Geographic location of the study area in the Laem Phak Bia Subdistrict, Ban Laem District, Phetchaburi Province, Southern Bangkok, Thailand

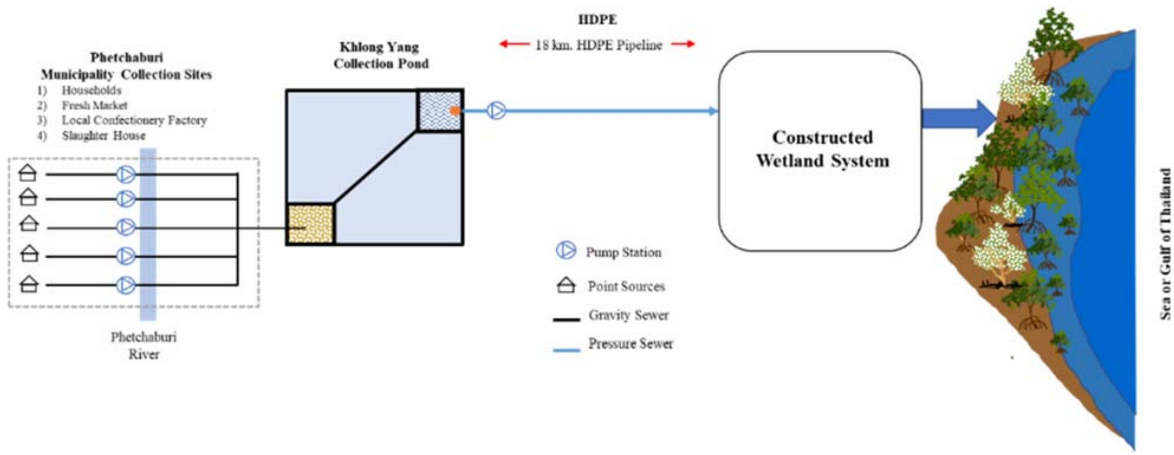


Fig. 2: Study plan: (a) Phetchaburi municipality (community) wastewater collection sites, (b) schematic of Phetchaburi Municipality Sewer Systems from tunnel–pipeline sewer systems through Khlong Yang collection pond and the 18.5 km high-density polyethylene pipeline (HDPE) pipeline, which ends at the LERD site

Table 1: Wastewater collection sites

Collection site	Site location	Remarks
Households	Phetchaburi Municipality	6 collection sites
Fresh market		3 collection sites
Local confectionery factory		3 collection sites
Slaughterhouse		3 collection sites
Klong Yang collection pond	Transferring system	3 collection sites
HDPE Pipeline		
0 m	CW treatment system	5 collection sites
20 m		
40 m		
60 m		
80 m		
100 m		

each, collected at the end of the pipe effluent discharge points; 2) the collection pond within the municipality and the transfer pipeline, consisting of 8 points with 3 replications per point (5 points at the pumping station, 2 points at the Klong Yang collection pond, and 1 point at the high-density polyethylene [HDPE] pipeline); and 3) the CW treatment system, comprising 6 points with 3 replicates per point. Samples were collected at a depth of 15 centimeter (cm) from the water surface at distances in the system of 0, 20, 40, 60, 80, and 100 meters (m). Each point was sampled through grab sampling, with a volume of 3 liters (L), and the samples were kept refrigerated at a temperature of 4 degrees Celsius (°C) until analysis in the laboratory. The collection sites are listed in Table 1 and shown in Fig. 1.

Wastewater analysis

The composition of wastewater from households includes organic substances with C, hydrogen (H), O_2, N, sulfur (S), and P compounds in the form of proteins, fats, carbohydrates, and various suspended

Table 2: Water sample parameters

Parameters	Units	Method(s)	Reference method(s)	Standard
Temperature	°C	Thermometer	APHA, (2017) 23rd edition 2017 part 2550	-
Potential of hydrogen (pH)	-	pH meter		5.5–9.0
Dissolved oxygen (DO)	Milligram per liter	Azide modification	APHA, (2017) 23rd edition 2017	-
Chemical oxygen demand (COD)	mg/L	Close reflux	APHA, (2017) 23rd edition 2017 part 5220	-
Biochemical oxygen demand (BOD)	mg/L	Azide modification	APHA, (2017) 23rd edition 2017 part 5210B	<20.0
Total dissolved solids (TDS)	mg/L	Dried at 103 °C–105 °C	APHA, (2017) 23rd edition 2017 part 2540	-
Fats oils and grease (FOG)	mg/L	Soxhlet method	APHA, (2017) 23rd edition 2017 part 5520	<5.0
Total nitrogen (TN)	mg/L	Total Kjeldahl nitrogen in water	APHA, (2017) 23rd edition 2017 part 4500	<20.0
Total Kjeldahl nitrogen (TKN)	mg/L	Total Kjeldahl nitrogen	APHA, (2017) 23rd edition 2017 part 4500	-
Nitrate nitrogen (NO_3-N)	mg/L	Cadmium reduction	APHA, (2017) 23rd edition 2017 part 4500	-
Ammonia nitrogen (NH_3-N)	mg/L	Phenate method	APHA, (2017) 23rd edition 2017 part 4500-NH_3 C	-
Total phosphorus (TP)	mg/L	Ascorbic method	APHA, (2017) 23rd edition 2017 part 4500-P	<2.0
Phosphate (PO_4^{3-})	mg/L	Vanadomolybdophosphoric acid colorimetric method	APHA, (2017) 23rd edition 2017 part 4500-P	-
Sulfate (SO_4^{2-})	mg/L	Turbidimetric method	APHA, (2017) 23rd edition 2017 part 4500	-
Total sulfide (S^{2-})	mg/L	Iodometric method	APHA, (2017) 23rd edition 2017 part 4500	-
Total bacteria	Colony-forming units per gram (CFU/g)	Heterotrophic bacteria plate count	APHA, (2017) 23rd edition 2017 part 9221	-

solids. Additionally, it contains inorganic substances originating from detergents, with P in the form of orthophosphate. Wastewater was collected at each sampling point following the Standard Methods for the Examination of Water and Wastewater (APHA, 2017) to comprehensively assess water quality, indicative of the characteristics of household wastewater and the efficacy of the studied wastewater treatment system in this research. The suggested parameters are listed in Table 2.

CW system

The CW system has dimensions of 5x100 m, with cattails planted using shoots of similar age varieties at a height of 30 cm and a spacing of 30x30 cm. These plants are nurtured with irrigation water until they are established. Once established, community wastewater is continuously discharged into the system, maintaining a water level 30 cm above the soil surface with a hydraulic retention time (HRT) of 24 hours (h). The wastewater treatment process occurs through aerobic bacteria, which decompose organic substances (organic N, organic P) present in the wastewater (Samimi and Shahriari Moghadam, 2020). These substances are transformed into nutrients (NO_3^- and PO_4^{3-}) that plants absorb and utilize for growth. Tracking water quality along distances in the CW system, specifically at distances of 0 (influent), 20, 40, 60, 80, and 100 m (effluent), reveals a tendency for organic and inorganic

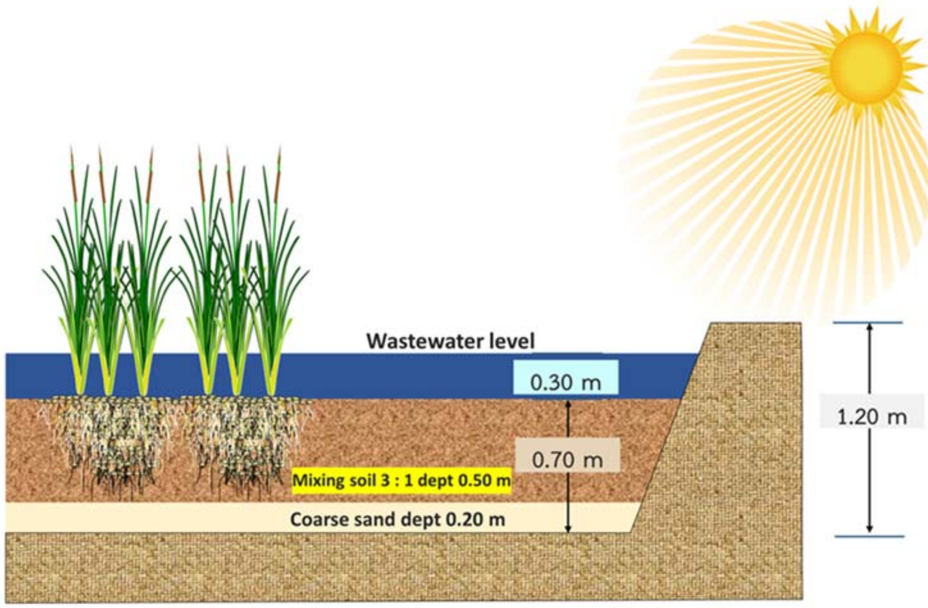


Fig. 3: General characteristics of the CW system on the 1:1000 slope, which is used for treating wastewater using 50.0 cm mixed soil (soil: sand ratio is 3:1) including grown submerged aquatic plants

substances (BOD, TKN, NO_3^-, TP, PO_4^{3-}) to decrease with distance, as depicted in Fig. 3. Cattail trees should be pruned when their growth rate reaches zero or at the age of 90 days to maintain and enhance system efficiency (Chunkao *et al.,* 2014) (Fig. 3). Pruning involves cutting the trees to a height of 40 cm, stimulating the growth of new shoots. This practice ensures the continued efficiency of community wastewater treatment with the CW system. With regard to the species of plants used, *Typha angustifolia Linn*. is a common local species found in the local climate of Thailand and has higher nutrient removal efficiency than other flowering species (Phewnil *et al.,* 2024). *Typha latifolia* and *Phragmites australis* are two species with higher removal efficiency than other species (Parde *et al.,* 2021).

Statistical analyses

All the sampling procedures were executed with three replications for each sample. Subsequently, the collected samples underwent analysis for physical and chemical parameters (Table 2). In the statistical analysis, the data were subjected to analysis of variance, Student's t-test, and Duncan's multiple range test. Least significant differences were calculated when the p-value was significant at the 0.05 level (Moghadam *et al.,* 2022).

RESULTS AND DISCUSSION

Evaluation of point source system structures

In this study, in the classification of wastewater point sources for municipal wastewater, the patterns of land use were classified in accordance with the activities and qualities of water usage. The classification includes households (6 samples), fresh-food markets (3 samples), local confectionery factories (3 samples), and slaughterhouses (3 samples). The influent and effluent wastewater qualities must be sampled to assess treatable tunnel–pipeline sewer systems. In the wastewater system, owing to the high concentration of organic matter content, the source of this wastewater can be from anthropogenic activities. However, within the municipality, small local markets and factories are also present. The production of local foods and desserts in these factories and markets provides a high organic loading in the form of proteins, carbohydrates, and lipids, which contain C, H, O, N, P, and S compounds (Stefanakis and Tsihrintzis, 2012; Pour and Makkawi, 2021). After the selection of point sources, a range of values was found for the BOD, which was the reflection of organic content within the wastewater from the selected point source wastewater. The average BOD concentration was 740 mg/L, which was supported by the high content of organic N in the form of NH_3-N and TKN, as well as P and S^{2-}. The point source concentration found in this study was in parallel with those in cities within the same climate latitudes, where the BOD is in the range of 12–1,328 mg/L (Widyarani *et al.,* 2022). The Phetchaburi municipality covers an area of over 5.4 square kilometers (km^2), with a population of approximately 30,000 persons; the municipality was mostly dense with local markets and cluster household settlements (Thanvisitthpon *et al.,* 2020). In the wastewater transfer process, the average time in the transfer process can be divided into three parts: 1) the transfer from the point source to the Klong Yang collection pond within the municipality, 2) the collection pond and the HDPE pipeline transferring from the collection pond to the CW, and 3) the CW system at the LERD site. The Phetchaburi municipality wastewater sewer system is a closed system with high organic content, and the promotion of anaerobic digestion in the transfer process allowed the ratio of BOD: N: P to be 100.0:2.8:0.3. Under the influence of anaerobic digestion, the BOD concentration decreased rapidly from 740.0 mg/L to 82.4 mg/L, as suggested in the digestion of C compounds (Chen *et al.,* 2008; Penha-Lopes *et al.,* 2012). The decomposition process is supported by many factors, such as the biological stage and a temperature in the range of 27.0 –33.5 °C. These circumstances are in favor of biochemical reaction and promotes anaerobic digestion with the oxidation reduction potential (ORP) values in the negative range (Jinjaruk *et al.*, 2018; González *et al.,* 2022). Jinjaruk *et al.* (2018) found that the transfer time within the pumping station and municipal sewer system was around 2–5 h on average, and this range varied within different transfer locations.

Kong Yang collection and HDPE pipeline

The retention time in the Khlong Yang collection pond sewer system, to which the wastewater from the Phetchaburi municipality was transferred into, was calculated to be 29 h. The water quality results suggested that the water in the Klongyang collection pond was anaerobic, as reflected by low DO levels. A reduction in BOD occurred under anaerobic conditions as C was quickly digested by anaerobic bacteria (Poommai *et al*., 2013; González *et al.,* 2022) (Table 3). The Klong Yang collection pond was contaminated with high organic loading. The ratio of BOD: COD was approximately 0.6, an appropriate biodegradation rate. Noophan *et al.* (2009) suggested the BOD: COD to be more than 0.5. Based on this suggestion, the parameters in Table 3 can be calculated for the BOD:N:P ratio, which was 100.0:15.4:2.7. The oxidation–reduction potential reached -259.5 millivolt (mV), which fell in the range for denitrification and sulfide formation. The low DO concentration of 0.5 mg/L amplified

Table 3: Water quality in the Phetchaburi wastewater transfer system

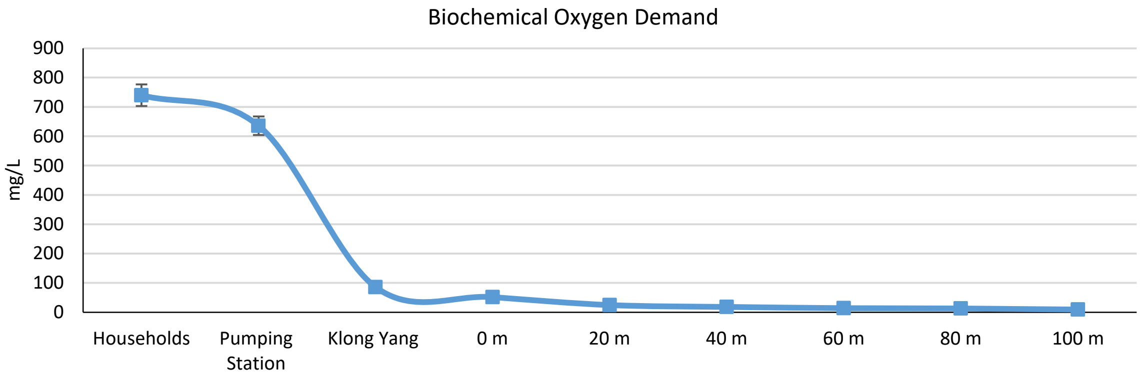
Parameter(s)	Klong Yang collection pond		CW
	Input	Output	Input
Temperature (°C)	30.4 ± 1.47	30.0 ± 1.33	29.8 ± 1.24
pH	7.1 ± 0.41	7.1 ± 0.39	7.2 ± 0.46
DO (mg/L)	0.3 ± 0.27	0.6 ± 1.10	0.5 ± 1.09
TDS (mg/L)	440.0 ± 201.75	467.5 ± 185.03	420.4 ± 123.06
ORP (mV)	-241.0 ± 125.87	-231.0 ± 135.14	-200.0 ± 146.88
BOD (mg/L)	82.4 ± 25.95	62.2 ± 24.21	43.9 ± 13.44
COD (mg/L)	159.8 ± 46.80	142.0 ± 58.34	1208. ± 48.90
PO_4^{3-} (mg/L)	1.5 ± 0.98	1.7 ± 0.96	1.0 ± 0.85
TP (mg/L)	2.25 ± 1.01	2.1 ± 0.86	1.2 ± 0.86
TKN (mg/L)	11.8 ± 6.43	11.3 ± 6.42	12.3 ± 9.07
NO_3^- (mg/L)	0.3 ± 0.75	0.2 ± 0.52	0.2 ± 0.33
TN (mg/L)	12.23 ± 6.30	11.0 ± 6.27	10.4 ± 8.97
NH_3 (mg/L)	5.9 ± 3.74	5.4 ± 3.46	4.4 ± 3.25
S^{2-} (mg/L)	0.7 ± 1.96	0.8 ± 1.03	0.5 ± 0.77
SO_4^{2-} (mg/L)	69.4 ± 64.09	63.5 ± 57.39	67.8 ± 61.79

the process of sulfide formation. The TN found was in the form of organic N as TKN and NH_3-N at 6.20±1.87 and 3.02±1.52 mg/L, respectively. An increase in ammonia within the system occurred with the increase in the ammonification process, supported by low oxygen gas (O_2) levels in the wastewater. Before retaining the wastewater within the system, it was transferred through a closed HDPE pipeline for 18.5 km to reach the LERD site. Owing to the closed nature of the pipeline, only anaerobic processes occurred during the transportation process. As the wastewater travels through the HDPE pipeline, the rate of digestion decreased, particularly after covering a distance of 12 km. The limiting factor for anaerobic degradation during the 18.5 km HDPE wastewater transport was the low availability of C sources (Jinjaruk *et al.,* 2018). However, the high levels of N and P altered the BOD:N:P ratio to approximately 100.0:1.1:0.2, making it favorable for anaerobic processes (Metcalf and Eddy, 2004; Phiwluang and Poonprasit, 2014). As the BOD concentration decreased, the ratio changed primarily because of the increased activity of anaerobic bacteria, which in turn increased the C-to-N ratio (Li *et al.,* 2023). The BOD concentration reaching LERD was found to be 43.9±13.44 mg/L upon entering the CW system. This process would then need to be supported by aerobic conditions. Compared with conventional aerobic technologies based on AS processes, the transfer system had efficacy of 27% – 39% (El-Sonbati *et al.,* 2011).

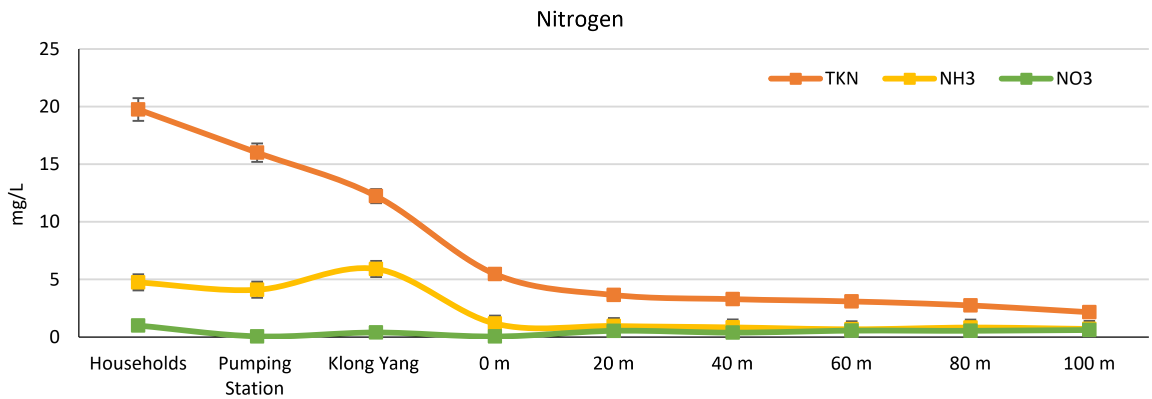
CW system

In the wetland system, the aerobic condition was promoted for the treatment of wastewater. At this point, the wastewater quality was appropriate, with treatment through aerobic degradation with a BOD: N: P ratio of 100.0:10.5:2.3. This ratio supports the hypothesis that aerobic bacteria are responsible for the degradation of organic matter and the nitrification of N in root-zone treatment plants, mediated by microorganisms. The release of O_2 from the roots of macrophytes creates oxidized zones around the roots (Hadad *et al.,* 2006). In these zones, most of the organic content in the wastewater decomposes into CO_2 and water, with O_2 as the terminal electron acceptor. Based on the results given in Table 4, the CW treatment efficacies for BOD, TN, and TP were calculated as 81.4%, 50.0%, and 58.3%, respectively. In addition, NH_3 is oxidized to NO_3^- by nitrifying bacteria in these zones (Gonzalo *et al.,* 2017; Zhang *et al.,* 2018; Seethong *et al.,* 2023). This finding was in parallel with that of a study on the efficiency of a CW system, in which the removal rates were 80%–91% for BOD, 60%–85% for COD, and 80%–95% for total suspended solids. The system also required minimal operation and maintenance (Parde *et al.,* 2021). The organic N was converted into inorganic N(NO_3^-), and the concentration ranged from 0.05 mg/L to 0.62 mg/L, suggesting the uptake by plant species within the CW system (Molle *et al.,* 2008; Cui *et al.,* 2010). The results indicated that BOD and P concentrations gradually decreased with increasing distance. This decrease is a result of bacterial digestion processes under aerobic conditions, with P being oxidized into PO_4^{3-} as it moves further and subsequently taken up by the wetland (Zhao *et al.*, 2017). Soil aerobic bacteria are also suggested as a contributing factor because these bacteria can supply O_2 to heterotrophic microorganisms. The population of heterotrophic bacteria increased from 1.01×10^6 CFU/g to 1.21×10^6, 1.32×10^6, 1.77×10^6, and 1.84×10^6 CFU/g at distances of 20, 40, 60, 80, and 100 m, respectively. As a result, the decreases in BOD, TN, and TP levels match the standards of municipal wastewater treatment systems (Juwarkar *et al.,* 1995) (Fig. 4 and Table 4). In the treatment of S compounds, the SO_4^{2-} output of the CW system was approximately 10.14 ± 4.84 mg/L, showing a reduction from the input of 67.8 ± 61.79 mg/L (Table 4). This reduction in SO_4^{2-} concentration was attributed to the positive oxidation and reduction potential within the CW system, which promoted the oxidation of S^{2-} and subsequent accumulation of SO_4^{2-} by the CW system. Chen *et al.* (2016) suggested that CW utilizes S compounds in wastewater as electron acceptors for sulfide oxidation and for assimilation by plant species and microorganisms (Fig. 4). In studies that assessed nutrient removal by two floating macrophytes (*Lemna minor and Azolla pinnata*), the nitrite (NO_2^-) and NO_3^- levels increased, whereas the NH_3, TP, soluble reactive P, and TN levels decreased across all treatments during the experiment. The inorganic compounds would be later absorbed by the plant species, reaching up to 70%–90% P removal and 63% for BOD (Seguil *et al.,* 2021).

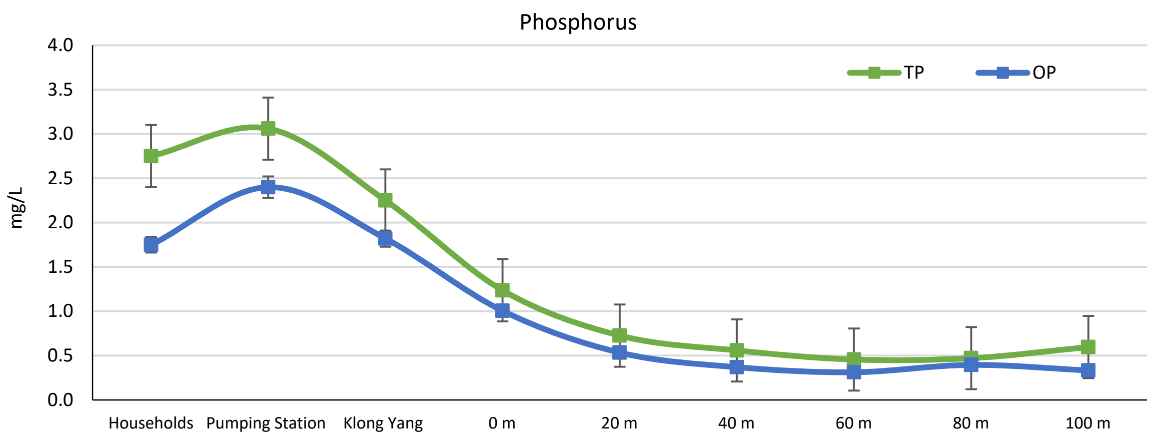
From Fig. 4, wastewater from household sources



(a)



(b)



(c)

Fig. 4: Water quality changes from the point source to the treated CW system (a) Biochemical Oxygen Demand; (b) Nitrogen; (c) Phosphorus

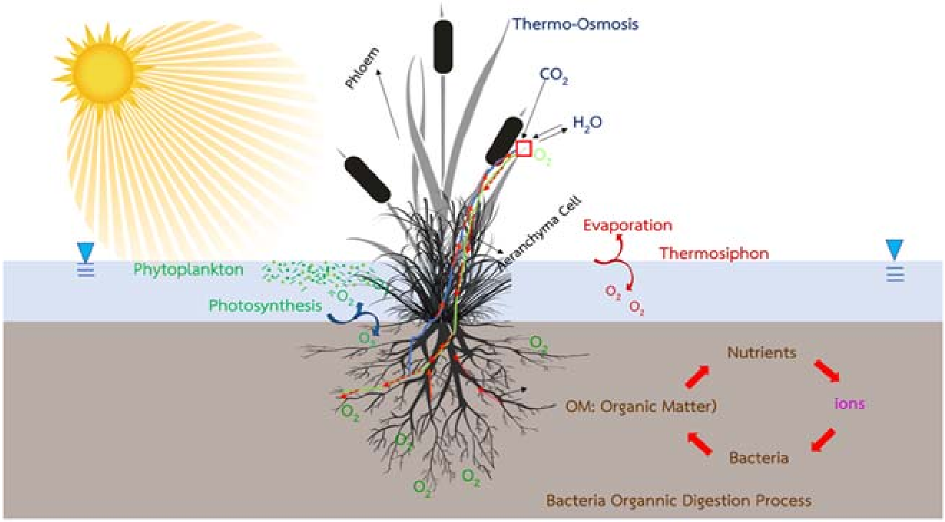


Fig. 5: CW treatment concept

Table 4: Water quality in the CW system at the LERD site

Indicators	Distance in the CW system						
	0 m	20 m	40 m	60 m	80 m	100 m	Standard*
BOD (mg/L)	52.2	24.8	18.4	14.4	12.9	9.7	<20.0
COD (mg/L)	196.8	110.2	83.1	64.6	40.2	36.4	
pH	6.8	7	7.1	7.2	7.2	7.3	5.5-9.0
DO (mg/L)	0.5	2.51	3.06	4.54	4.56	5.25	-
TKN (mg/L)	5.41	3.65	3.29	3.097	2.74	2.15	-
TN	5.54	4.12	3.63	3.69	3.4	2.77	<20.0
NH_3-N (mg/L)	1.16	0.96	0.84	0.67	0.82	0.79	-
NO_3-N (mg/L)	0.04	0.51	0.38	0.55	0.54	0.61	-
TP (mg/L)	1.27	0.76	0.55	0.45	0.47	0.53	<2.0
PO_4^{3-} (mg/L)	1.06	0.53	0.36	0.31	0.39	0.33	

*Notification of the Ministry of Natural Resources and Environment Re: The standard effluent discharge from a domestic wastewater treatment system, B.E. 2553

exhibits a high organic content, detected in the form of BOD at 740 mg/L, TKN at 19.75 mg/L, and TP at 2.75 mg/L. Inorganic substances are also present, with NH_3 measured at 4.75 mg/L, NO_3^- at 1.0 mg/L, and PO_4^{3-} to 1.75 mg/L. The transformations occurring from households to the transfer system (pumping station, Klong Yang collection pond, and HDPE pipeline) predominantly involve the anaerobic digestion process (Masharqa *et al.,* 2023; Migdal *et al.,* 2023; Thakur *et al.,* 2023; Ma *et al.,* 2024). As a result, BOD decreases rapidly, stabilizing at 52 mg/L at the point where water enters the artificial wetland system. The decomposition of organic matter continues within the artificial wetland system, but this process involves aerobic decomposition. With the bacterial group around the *Typha* roots, organic substances (TKN, TP) are decomposed and converted into inorganic substances (NO_3^-, PO_4^{3-}), serving as plant nutrients. The plants in the artificial wetland system absorb these nutrients for growth, thereby enhancing the quality of treated wastewater. From the measurement of the water quality at the effluent point of the artificial wetland system (100 m), BOD was 9.7 mg/L, which is below the standard threshold of 20 mg/L.

Adaptability of the CW system

The system has been constructed for over 30 years

Table 5: Wastewater quality of different municipality sources

Indicators	Households			Fresh-food market			Local confectionery factory			Slaughterhouse		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
BOD (mg/L)	740	50	1,830	2,410	1,770	3,600	4,260	1,140	9,900	2,300	1,590	3,360
DO (mg/L)	4	0	8	0	0	0	1	0	4	5	4	5
Temperature (°C)	28	26	30	26	24	28	30	29	32	30	30	30
TDS (mg/L)	511	214	1,032	1,823	1,770	1,880	477	288	742	381	338	439
pH	6	5	7	7	7	8	7	5	8	9	7	10
TN (mg/L)	26	6	74	81	21	175	288	56	734	164	117	207
TKN (mg/L)	26	6	74	81	21	175	285	52	731	163	117	207
NO_3-N (mg/L)	0	0	0	0	0	0	2	0	4	2	2	3
NH_3-N (mg/L)	0	0	1	7	1	13	2	1	3	16	14	20
TP (mg/L)	3	0	6	21	19	25	11	6	19	12	11	12
PO_4^{3-} (mg/L)	3	0	5	20	17	23	11	6	19	11	11	11
FOG (mg/L)	71	4.5	165	642	428	1668	402	352	3,187	736	583	10,982

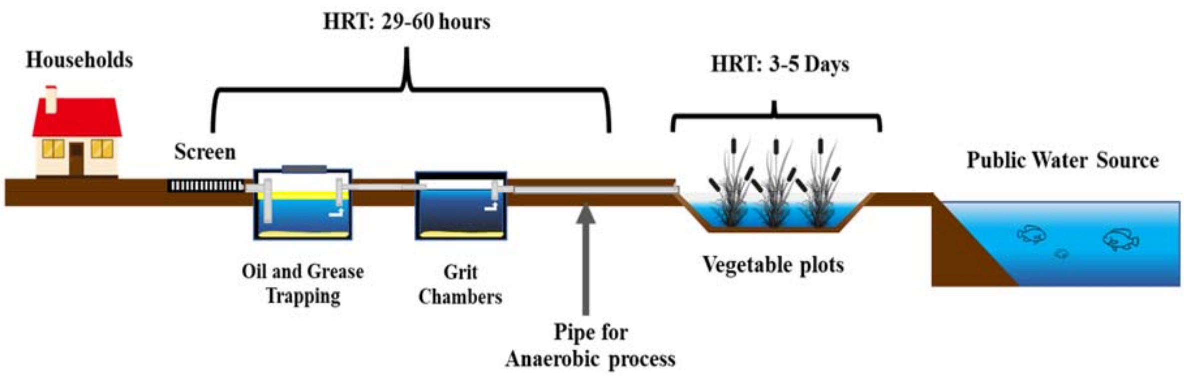


Fig. 6: Hypothetical adaptability of a small-scale CW system to individual households

and has been suggested for maintenance every 5 years (Wongsrikaew *et al.,* 2018). The inefficacy of the closed system would decrease the anaerobic digestion within the sewer system and reduce the overall efficacy of the treatment. The adaptability of the system makes it available to households. In dealing with different complex issues in terms of C, N, and P contents, under different point sources, diverse treatment durations are required for the concentration differences in wastewater. The advantage of vertical-flow CW ecosystems over horizontal-flow CWs is the requirement for smaller space for installation (Dissanayaka *et al.,* 2019). CW ecosystems employ certain soil texture and thickness for filtering and absorbing contaminants in wastewater together with the bacterial organic digestion process. The wastewater from point sources is the key factor for specifying the area size of CW ecosystems (Konnerup *et al.,* 2011): a large size for municipal and densely populated settlements, a medium size for industrial factories, a small size for municipal and low-populated settlements, and a small size for household estates, hospitals, and shopping centers (Borkar and Mahatme, 2011; Gikas and Tsihrintzis, 2012). Compared with other CW systems globally, the combination of septic tanks with CWs is proved effective for single-family wastewater treatment, with high BOD and COD removal rates and moderate P and N removal rates. This system also requires a low operation cost, as supported by the data collected from field studies and questionnaires in Songore wetland, Zimbabwe, which showed that wetland resources contributed about 50% to annual household income, varying among villages (Mahlatini *et al.,* 2020; García-Ávila *et al.,* 2023). Small-scale CW systems are expected to remove contaminants from household and housing estate wastewater, which are distributed around the county (Soroko *et al.,* 2007).

Given the variations in water quality, the small-scale CW system, as designed for LERD, may not be suitable. The design of the CW for LERD indicated an average daily water requirement of 75 cubic meters. The initial calculations showed that the BOD loadings per square meter ranged from 20.6 kilogram per day (kg/d) to 27.8 kg/d. Thus, the minimum HRT required in LERD's CW would be 3 days. The HRT for the CW system was designed to be 3–5 days (Fig. 6). Regarding the treatability of CW in small units within the municipality, the BOD concentration should not exceed 100 mg/L, as calculated from the LERD site, making the household unit adaptable (Fig. 6). In the case of anaerobic treatment systems, the use of anaerobic digestion would promote the decrease and thus change the BOD: N:P ratio to an appropriate value (Merino-Solís *et al.,* 2015), which can be calculated for anaerobic treatments lasting at least 24–60 h. The FOG tap is necessary. For different point sources within the Phetchaburi municipality, the FOG concentration in households was 71.0 mg/L on average. However, in the design of the LERD transfer system, an underflow method was used, trapping the majority of the FOG within the Klong Yang collection pond. Conversely, in the application to household usage, installation of a FOG tap is recommended, which would allow for a decrease in the FOG on the water surface to promote a better treatment effect and enable the exchange of O_2 in the air and CW soils where the FOG concentration within the households can be seen. In the system, the recommended volumetric removal rate should be employed alongside the theoretical HRT (Sperling *et al.,* 2023), which, in this study, is recommended to be between 29 and 60 h. These findings supported the preference for the site-specific approach in design. Besides the support of the municipal treatment system, the successful application system for attenuating the pollutant concentration in a crude oil wastewater pit in Pakistan was presented to remove organic concentration up to 2.63 × 10 kg, while the C sequestration was 2.11 × 10 kg. In economic translation, the treatment system's initial cost per treatment volume was USD 0.0184 per cubic meter (Arslan *et al.,* 2023).

CONCLUSION

For determining and realizing the suitability of restructuring small-scale CW systems and their effectiveness in treating individual household wastewater through a natural process, their applicability to wastewater from single households, combined households, villages, and communities should be considered. This consideration includes scenarios with debris and large amounts of organic materials. To achieve this objective, fundamental data on water quality and quantity must be established, and the organization of a wastewater flow system is essential for the implementation of a CW design. In this study, the experimental design was divided into separated sampling and analysis sections of the point source in the municipality, the transfer system, and the CW system at LERD. From the result, the high organic concentration from the Phetchaburi municipality was quickly degraded by the promotion of anaerobic digestion through a closed pipeline that allowed the ratio of BOD:N:P to be 100.0:1.1:0.2. At 12 km, the HRT in this transfer process was approximately 29-60 h, reducing the municipality (point source) BOD from 740.0 to 86.0 and 52.0 in the Klong Yang collection pond and the anerobic digestion process. Supported by the aerobic process, the effluent of the CW system was reduced to 9.7 mg/L. The TN decreased from 20.8 mg/L to 2.8 mg/L. The majority of N compounds from the initial point source (municipality) was in their organic form. During the treatment process, they were converted into an inorganic form, which was then absorbed by the CW system. The ratio of BOD: N: P ratio of 100.0:10.5:2.3 suggested further aerobic digestion, indicating the adaptability of the CW system for wastewater treatment. With a proper anaerobic management system, CW could be adopted in household applications. This study also examined various properties of domestic wastewater in different regions of Thailand. It emphasizes the necessity for a pretreatment process, which is recommended for individual households. This pretreatment process includes using a screening dish, sedimentation through grit chambers, and the trapping of FOG before initiating the bacterial organic digestion process within the wetlands. Meanwhile, the knowledge on CW is proven scientifically; the system would be implemented through an environmental education program that the local government would provide to local communities for adoption in individual households. This approach would help reduce the high contamination loading in domestic wastewater effluent, thus supporting the overall treatment process and addressing issues related to domestic water treatment facilities.

AUTHOR CONTRIBUTIONS

S. Mokatip contributed to the literature review, experimental design, material preparation, data collection, data analysis and interpretation, and manuscript preparation. W. Wararam helped in the study conception, experimental design, material preparation, data collection and analysis, and manuscript preparation and editing. T. Pattamapitoon collected the transfer pipeline anaerobic wastewater data and interpreted the data. N. Semvimol collected the CW system wastewater data and interpreted the data. O. Phewnil performed a chemical analysis of the water samples together with the overall analysis of the system. P. Rollap performed land use and land cover mapping for the municipality, and K. Chunkao contributed to the conceptual design. S. Bualert assisted in the experimental design, and S. Thaipakdee performed imaging and mapping of the collection sites. P. Maskulrath participated in the material preparation, data collection, and manuscript preparation and editing.

ACKNOWLEDGMENT

The authors are thankful to the staff of The King's Royally Initiative Laem Phak Bia Research and Development Project for their support. The authors are also grateful to the Chaipattana Foundation for funding this study. Furthermore, the authors would like to thank the Department of Environmental Science, Faculty of Environment, Kasetsart University for providing personnel and laboratories.

CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

%	Percent
°C	Degree Celsius
ANOVA	Analysis of variance
AS	Activated sludge
AL	Aerated lagoon
BOD	Biochemical oxygen demand
BOD:N:P ratio	Biochemical oxygen demand: nitrogen: phosphorus ratio
C	Carbon
CFU/g	Colony-forming units per gram
cm	Centimeter
C:N ratio	Carbon-to-nitrogen ratio
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CW	Constructed wetland
DMRT	Duncan's multiple range test
DO	Dissolved oxygen

FCB	Fecal coliform bacteria
FOG	Fats oils and grease
h	Hour
H	Hydrogen
HDPE	High-density polyethylene
HFCW	Horizontal-flow constructed wetlands
HRT	Hydraulic retention time
kg	Kilogram
km^2	Squared Kilometer
km	Kilometer
LERD	The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project
m	Meter
mg/L	Milligram per liter
mV	Millivolts
N	Nitrogen
NO_2^-	Nitrite
NH_3-N	Ammonia nitrogen
NO_3-N	Nitrate nitrogen
N:P ratio	Nitrogen: phosphorus ratio
O	Oxygen
O_2	Oxygen gas
OD	Oxidation ditches
OP	Oxidation pond
ORP	Oxidation reduction potential
pH	Potential of hydrogen
PO_4^{3-}	Phosphate
PVC	Polyvinyl chloride
RBC	Rotating biological contactor
S	Sulfur
S^{2-}	Sulfide
SO_4^{2-}	Sulfate
SP	Stabilization pond
SFCW	Subsurface flow-constrained wetland
STD	Standards
TDS	Total dissolved solids
TKN	Total Kjedahl nitrogen
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
USD	United States dollar
VFCW	Vertical-flow constructed wetland

REFERENCES

Agaton, C.B.; Guila, P.M.C., (2023). Ecosystem services valuation of constructed wetland as a nature-based solution to wastewater treatment. Earth, (4): 78-92 (**5 pages**).

APHA, (2017). Standard Method for the Examination of Water and Wastewater, 23rd. Ed. America Public Health Association, Washington DC.

Arslan, M.; Siddique, K.; Müller, J.A.; Tahseen, R.; Iqbal, S.; Islam, E.; Abbasi, S.A.; Usman, M.; El-Din, M.G.; Afzal, M., (2023). Full-scale floating treatment wetlands in Pakistan: from performance evaluation to public acceptance. ACS EST Water, 3(11): 3516-3525 (**10 pages**).

Borkar, R.; Mahatme, P.J., (2011). Wastewater treatment with vertical flow constructed wetland. Int. J. Environ. Sci., 2(2): 590-603 (**14 pages**).

Chen, Y.; Wen, Y.; Zhou, Q.; Huang, J.; Vymazal, J.; Kuschk, P., (2016). Sulfate removal and sulfur transformation in constructed wetlands: the roles of filling material and plant biomass. Water Res., 102: 572-581 (**9 pages**).

Chen, Y.; Cheng, J.J.; Creamer, K.S., (2008). Inhibition of anaerobic digestion process: a review. Bioresour. Technol., 99(10): 4044-4064 (**20 pages**).

Chueawong, O.; Prabuddham, P.; Phewni, O., (2019). Dual roles of soils on landfill leachate treatment and their soils carbon sequestration. Environ. Asia, 12(3): 23-31 (**9 pages**).

Chunkao, K.; Nimpee, C.; Duangmal, K., (2012). The King's initiatives using water hyacinth to remove heavy metals and plant nutrients from wastewater through Bueng Makkasan in Bangkok, Thailand. Ecol. Eng., 39: 40-52 (**8 pages**).

Chunkao, K.; Tarnchalanukit, W.; Prabuddham, P.; Phewnil, O.; Bualert, S.; Duangmal, K.; Pattamapitoon, T.; Nimpee, C., (2014). The King's Royally initiated LERD project on community wastewater treatment through small wetlands and oxidation pond in Phetchaburi, Thailand. Mod. Appl. Sci., 8(5): 233-246 (**13 pages**).

Cui, L.; Ouyang, Y.; Lou, Q.; Yang, F.; Chen, Y.; Zhu, W.; Luo, S., (2010). Removal of nutrients from wastewater with Canna indica L. under different vertical-flow constructed wetland conditions. Ecol. Eng., 36(8): 1083-1088 (**6 pages**).

Dissanayaka, D.; Jayaneththi, J., (2019). Small-scale wetland units for domestic greywater treatment. in Proceedings of the 11th annual research symposium, Faculty of Agriculture, Sri Lankan J. Agric. Ecosyst., 1(1): 52-60 (**9 pages**).

El-Sonbati, M.A.E.; Hegazy, T.; AL-Asmar, A.; Salem, M., (2011). Environmental studies of domestic wastewater treatment using integrated anaerobic/aerobic system. J. Am. Sci., 7: 485-492 (**8 pages**).

Gallanta, K.; Witheya, P.; Riskb, D.; Cornelis van Kooten, G.; Spafford, L., (2020). Measurement and economic valuation of carbon sequestration in Nova Scotian wetlands. Ecol. Econ., 171: 10661 (**7 pages**).

García-Ávila, F.; Zhindón-Arévalo, C.; Valdiviezo-Gonzales, L.; Sánchez-Alvarracín, C.; Criollo-Bravo, J.; Albuja-Arias, D.; Vivar-Martínez, E., (2023). Domestic wastewater treatment at the single-family level using a septic tank and constructed wetland system: a scientometric and systematic analysis. ARPN J. Eng. Appl. Sci., 18(13): 1573-1584 (**12 pages**).

Gikas, G.D.; Tsihrintzis, V.A.; (2012). A small-size vertical flow constructed wetland for on-site treatment of household wastewater. Ecol. Eng., 44: 337-343 (**7 pages**).

González, R.; Peña, D.C.; Gómez, X., (2022). Anaerobic co-digestion of wastes: reviewing current status and approaches for enhancing biogas production. Appl. Sci., 12(17) (**30 pages**).

Gonzalo, O.G.; Ruiz, I.; Soto, M., (2017). Integrating pretreatment and denitrification in constructed wetland systems. Sci. Total Environ., 584-585: 1300-1309 (**10 pages**).

Hadad, H.; Maine, M.; Bonetto, C.J.C., (2006). Macrophyte growth in a pilot-scale constructed wetland for industrial wastewater treatment. Chemosphere, 63(10): 1744-1753 (**10 pages**).

Hassan, I.; Chowdhury, S.R.; Prihartato, P.K.; Razzak, S.A., (2021). Wastewater treatment using constructed wetland: current trends and future potential. Processes, 9: 1917 (**27 pages**).

Jinjaruk, T.; Chunkao, K.; Pongput, K.; Choeihom, C.; Pattamapitoon, T.; Wararam, W.; Maskulrath, P., (2018). HDPE pipeline length for conditioning anaerobic process to decrease BOD in municipal wastewater. Environ. Asia, 11: 31-44 (**14 pages**).

Jitthaisong, O.; Dhanmanonda, P.; Chunkao, K.; Teejuntuk, S., (2012). Water quality from mangrove forest: The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Phetchaburi Province, Thailand. Mod. Appl. Sci., 6(8).

Juwarkar, A.; Oke, B.; Juwarkar, A.; Patnaik, S.J., (1995). Domestic wastewater treatment through constructed wetland in India. Water Sci. Technol., 32(3): 291-294 (**4 pages**).

Konnerup, D.; Trang, N.; Brix, H., (2011). Treatment of fishpond water by recirculating horizontal and vertical flow constructed wetlands in the tropics. Aquaculture, 313: 57-64 (**8 pages**).

Li, T.; Jin, Y.; Huang, Y., (2022). Water quality improvement performance of two urban constructed water quality treatment wetland engineering landscaping in Hangzhou, China. Water Sci. Technol., 85(5): 1454-1469 (**16 pages**).

Li, G.; Xu, F.; Yang, T.; Wang, X.; Lyu, T.; Huang, Z., (2023). Microbial behavior and influencing factors in the anaerobic digestion of distiller: a comprehensive review. Fermentation, 9.

Ma, R.; Duan, J.; Xue, L.; Yin, A.; Petropoulos, E.; Suo, Q.; Yang, L., (2024). Treatment of nitrogen and phosphorus from sewage tailwater in paddy rice wetlands: concept and environmental benefits. Environ. Monit. Assess., 196:174 (**11 pages**).

Mahlatini, P.; Hove, A.; Maguma, L.F., Chemura, A., (2020). Using direct use values for economic valuation of wetland ecosystem services: a case of Songore wetland, Zimbabwe. GeoJournal. 85: 41–51 (**11 pages**).

Masharqa, A.; Tardeh, S.A.; Mlih, R.; Bol, R., (2023). Vertical and hybrid constructed wetlands as a sustainable technique to improve domestic wastewater quality. Water, 15: 3348 (**21 pages**).

Me Maw, M.; Kitpati Boontanon, S; Jindal, R., Boontanon, N.; Fujii, S., (2022). Occurrence and removal of microplastics in activated sludge treatment systems: a case study of a wastewater treatment plant in Thailand. Eng. Access., 8(1): 106-111 (**6 pages**).

Merino-Solís, M.L.; Villegas, E.; Anda, J.D.; López-López, A.J.W., (2015). The effect of the hydraulic retention time on the performance of an ecological wastewater treatment system: an anaerobic filter with a constructed wetland. Water, 7(3): 1149-1163 (**15 pages**).

Metcalf, L.; Eddy, H.P., (2004). Wastewater Engineering: Treatment and Reuse. 4th. Ed. McGraw-Hill, New York.

Migdal, K.; Józwiakowski, K.; Czekala, W.; Sliz, P.; Tavares, J.M.R.; Almeida, A., (2023). Application of the Monte-Carlo method to assess the operational reliability of a household-constructed wetland with vertical flow: a case study in Poland. Water, 15: 3693 (**18 pages**).

Moghadam, H.; Samimi, M., (2022). Effect of condenser geometrical feature on evacuated tube collector basin solar still performance: Productivity optimization using a Box-Behnken design model. Desalination, 542: 116092 **(8 pages).**

Mohadesi, M.; Gouran, A.; Darabi, F.; Samimi, M., (2024). Sunflower seed pulp ash as an efficient and eco-friendly adsorbent for Congo red uptake: characteristics, kinetics, and optimization. Water Pract. Technol., 19(1): 228-240 **(12 pages)**.

Molle, P.; Prost-Boucle, S.; Lienard, A.J., (2008). Potential for total nitrogen removal by combining vertical flow and horizontal flow constructed wetlands: a full-scale experiment study. Ecol. Eng., 34(1): 23-29 (7 pages).

Noophan, P.; Paopuree, P.; Kanlayaras, K.; Sirivithayapakorn, S.; Techkarnjanruk, S., (2009). Nitrogen removal efficiency at centralized domestic wastewater treatment plants in Bangkok, Thailand. Environ. Asia. 2: 30-35 (**6 pages**).

Parde, D.; Patwa, A.; Shukla, A.; Vijay, R.; Killedar, D.J.; Kumar, R., (2021). A review of constructed wetland on type, treatment, and technology of wastewater. Environ. Technol. Innovation, 21: 101261 (**6 pages**).

Pattamapitoon, T.; Sirirote, P.; Pakkong, P.; Chunkao, K., (2013). Nature of solar radiation as encouraged to produce an increment of dissolved oxygen and hydrogen peroxide in oxidation ponds for community wastewater treatment at H.M. The King's LERD Project, Phetchaburi Province, Thailand. Mod. Appl. Sci., 7(6): 26-41 (**16 pages**).

Penha-Lopes, G.; Flindt, M.R.; Ommen, B.; Kristensen, E.; Garret, P.; Paula, J.J., (2012). Organic carbon dynamics in a constructed mangrove wastewater wetland populated with benthic fauna: A modelling approach. Ecol. Model., 232: 97-108 (**12 pages**).

Phewni, l.O.; Chunkao, K.; Pattamapitoon, T.; Intaraksa, A.; Chueawong, O.; Chantrasoon, C.; Boonprakong, T., (2014). Choosing aquatic plant species for high wastewater treatment efficiency through small wetland. Mod. Appl. Sci., 8(4): 187-194 **(8 pages).**

Phewnil, O.; Chunkao, K.; Prabhuddham, P.; Pattamapitoon, T., (2024). Application of different aquatic plants in an alternated fill and drain wetland system of Phetchaburi municipal wastewater treatment in Thailand. Environ. Sci. Pollut. Res., 31(1): 1304-1313 (**10 pages**).

Phiwluang, W.; Poonprasit, M.J., (2014). Potential of using natural materials as support media in anaerobic filter for tapioca wastewater treatment. Adv. Mat. Res., 931: 687-692 (**6 pages**).

Pitaktunsakul, P.; Chunkao, K.; Dampin, N.; Poommai, S., (2015). Vertical-flow constructed wetlands in cooperating with oxidation ponds for high concentrated COD and BOD pig-slaughterhouse wastewater treatment system at Suphanburi-provincial municipality. Mod. Appl. Sci., 9(8): 371-385 (**15 pages**).

Poommai, S.; Chunkao, K.; Dumpin, N.; Boonmang, S.; Nimpee, C., (2013). Determining the in-pipe anaerobic processing distance before draining to oxidation pond of municipal wastewater treatment. Int. J. Environ. Sci. Dev., 4(2): 157-162 (**6 pages**).

Pour, F.H.; Makkawi, Y.T., (2021). A review of post-consumption food waste management and its potentials for biofuel production. Energy Rep., 7: 7759-7784 (**26 pages**).

Samimi, M.; Shahriari Moghadam, M., (2020). Phenol biodegradation by bacterial strain O-CH1 isolated from seashore. Global J. Environ. Sci. Manage., 6(1): 109-118 (10 pages).

Samimi, M.; Moghadam, H., (2024). Modified evacuated tube collector basin solar still for optimal desalination of reverse osmosis concentrate. Energy. 289: 129983 **(8 pages).**

Schwarzenbach, R.P.; Egli T.; Hofstetter, T.B.; Gunten, U.; Wehrli, B., (2010). Global water pollution and human health. Annu. Rev. Environ. Resour., 35: 109-136 (**28 pages**).

Seethong, K.; Chunkao, K.; Dampin, N.; Wararam, W., (2023). Using benthos a bioindicator to assess the efficiency constructed wetland community wastewater treatment system. Global J. Environ. Sci. Manage.,: Eco-Friendly Sustainable Management. 9(SI): 47-60 (14 pages).

Seguil, P.Y.; Vilchez Garay, L.; Cortez Matencios, C.; Cornejo Tueros, J.; Camargo Hinostroza, S.; Canales Guerra, V., (2022). Systematic review of the efficiency of aquatic plants in the wastewater treatment. IOP Conference Series: Earth Environ. Sci., 1009: 012004 (**12 pages**).

Soroko, M., (2007). Treatment of wastewater from small slaughterhouse in hybrid constructed wetlands systems. Ecohydrol. Hydrobiol., 7: 339-343 (**5 pages**).

Sperling, M.V.; Wallace, S.D.; Niva, J., (2023). What is the best design approach for estimating effluent concentrations from horizontal flow treatment wetlands: the use of volumetric (kV) or areal (kA) removal rate coefficients? Water Sci. Technol., 88(2): 502-515 (**14 pages**).

Stefanakis, A.I.; Tsihrintzis, V.A., (2012). Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands. J. Chem. Eng., 181: 416-430 (**15 pages**).

Sukchinda, S.; Bualert, S.; Phewnil, O.; Pattamapitoon, T.; Srichomphu, M., (2019). Effect of solar radiation on cyanobacteria bloom in oxidation ponds community wastewater treatment at The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Phetchaburi, Thailand. Environ. Asia, 12(3): 54-61 (**8 pages**).

Tang, X.; Wu, M.; Yang, W.; Yin, W.; Jin, F.; Ye, M.; Scholz, M., (2012). Ecological strategy for eutrophication control. Water Air Soil Pollut., 223(2): 723-737 (**15 pages**).

Thanvisitthpon, N.; Shrestha, S.; Pal, I.; Ninsawat, S.; Chaowiwat, W., (2020). Assessment of flood adaptive capacity of urban areas in Thailand. Environ. Impact Assess. Rev., 81 (**11 pages**).

Thakur, T.K.; Barya, M. P.; Dutta, J.; Mukherjee, P.; Thakur, A.; Swamy, S.L.; Anderson, J.T., (2023). Integrated phytobial remediation of dissolved pollutants from domestic wastewater through constructed wetlands: an interactive macrophyte-microbe-based green and low-cost decontamination technology with prospective resource recovery. Water, 15: 3877 (**50 pages**).

Vazquez, A.M.; Samudio-Oggero, A.; Nakayama, H.D.; Cantero-García, I., (2023). Sub-surface flow constructed wetland for the treatment of sewage generated in a municipal park. Global J. Environ. Sci. Manage., 9(3): 545-558 **(14 pages).**

Widyarani; Wulan, D.R.; Hamidah, U.; Komarulzaman, A.; Rosmalina, R.T.; Sintawardani, N., (2022). Domestic wastewater in Indonesia: generation, characteristics and treatment. Environ. Sci. Pollut. Res., 29: 32397-32414 (**18 pages**).

Wongsrikaew, O.; Pattamapitoon, T.; Chunkao, K.; Poommai, S.; Janyasuthiwong, S., (2018). Physical and chemical changes of the soil in constructed wetland treating municipal wastewater: A case study of Laem Phak Bia environmental research and development project. in Proceedings of the 2nd international conference on environment, livelihood andservices (ICELS 2018).

Zhang, X.; Jing, R.; Feng, X.; Dai, Y.; Tao, R.; Vymazal, J.; Cai, N.; Yang, Y., (2018). Removal of acidic pharmaceuticals by small-scale constructed wetlands using different design configurations. Sci. Total Environ., 639: 640-647 (**8 pages**).

AUTHOR (S) BIOSKETCHES

Mokatip, S., Ph.D. Candidate, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand.
- Email: Sakonwan.mo@ku.th
- ORCID: 0009-0000-2253-3228
- Web of Science ResearcherID: NA
- Scopus Author ID: NA
- Homepage: https://www.lerd.org/

Chunkao, K., Ph.D., Professor, The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Chaipattana Foundation, Ban Laem District, Phetchaburi Province, Thailand.
- Email: *prof.kasemc@gmail.com*
- ORCID: 0009-0002-8035-4732
- Web of Science ResearcherID: NA
- Scopus Author ID: 54683551800
- Homepage: https://www.lerd.org

Wararam, W., Ph.D., Assistant Professor, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand.
- Email: *watcharapong.warar@ku.th*
- ORCID: 0009-0000-1487-4284
- Web of Science ResearcherID: NA
- Scopus Author ID: 57096032600
- Homepage: https://envi.ku.ac.th

Bualert, S., Ph.D., Associate Professor, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand.
- Email: *surat.b@ku.th*
- ORCID: 0000-0003-1385-792X
- Web of Science ResearcherID: NA
- Scopus Author ID: 6504138469
- Homepage: https://envi.ku.ac.th

Phewnil, O., Ph.D., Assistant Professor, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand.
- Email: *onanong.p@ku.th*
- ORCID: 0000-0001-9616551X
- Web of Science ResearcherID: NA
- Scopus Author ID: 56252364600
- Homepage: https://envi.ku.ac.th

Pattamapitoon, T., Ph.D., Assistant Professor, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand.
- Email: *thanit.pa@ku.th*
- ORCID: 0009-00051664450X
- Web of Science ResearcherID: NA
- Scopus Author ID: 55822416300
- Homepage: https://envi.ku.ac.th

Semvimol, N., Ph.D., Assistant Professor, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand.
- Email: *noppawan.sem@ku.th*
- ORCID: 0000-0002-9581-1986
- Web of Science ResearcherID: NA
- Scopus Author ID: 57096067300
- Homepage: https://envi.ku.ac.th

Maskulrath, P., Ph.D., Lecturer, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand.
- Email: *parkin.ma@ku.th*
- ORCID: 0000-0002-1352-4247
- Web of Science ResearcherID: NA
- Scopus Author ID: 57202060728
- Homepage: https://envi.ku.ac.th

Rollap, P., M.Sc., Instructor, The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Ban Laem District, Phetchaburi Province, Thailand.
- Email: *pongisara.lerd@gmail.com*
- ORCID: 0009-0002-6855-4459
- Web of Science ResearcherID: NA
- Scopus Author ID: NA
- Homepage: https://www.lerd.org/

AUTHOR (S) BIOSKETCHES (continued)

Thaipakdee, S., M.Sc., Instructor, The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Ban Laem District, Phetchaburi Province, Thailand.

- Email: *thaipakdee1027@gmail.com*
- ORCID: 0009-0005-1679-0152
- Web of Science ResearcherID: NA
- Scopus Author ID: NA
- Homepage: https://www.lerd.org/

HOW TO CITE THIS ARTICLE

Name, N., (2024). Title. Global J. Environ. Sci.Manage., 10(3): 1-18.

DOI: 10.22035/gjesm.2024.03.***

URL: ***