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RESEARCH PAPER

Assessment of Water Resources Pollution Carrying Capacity in The Sa Kaeo Special Economic Zone, Thailand

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ABSTRACT

The Phromhot Canal is the only natural water source for consumption and agriculture the Sa Kaeo special economic zone, Thailand. At present, the Phromhot Canal is facing a serious problem with water quality. Our study carried out to analyze and assess the pollution carrying capacity of the natural water resource. The sampling sites were examined 7 stations cut across the downstream areas. All these stations were served as the control station to represent the actual condition of the Phromhot Canal. The results indicated that the water quality of the Phromhot Canal after flowing through the Aranyaprathet Municipality's wastewater treatment plant (AM's-WWTP) was severely contaminated. Effluents from the AM's-WWTP does not meet the effluent quality standard of the Ministry of Natural Resources and Environment, Thailand. In addition, it can flow into the water body up to 6,439.55 m^3/day. The maximum amount of a pollutant (in terms of BOD loading) allowed to enter a water body of the Phromhot Canal should be ≤ 0.08 kg_{BOD}/day (dry period) and 16.52 kg_{BOD}/day (wet period). While the Phromhot Canal has to carry BOD loading up to 51.12 kg_{BOD}/day. For this reason, the Phromhot Canal at after flowing through the WWTP was unable to the pollution carrying capacity. From the field survey, the AM's-WWTP is not suitable for wastewater treatment, which has a capacity of 923.93 m^3/day. Therefore, it is necessary to strictly control the drainage of the wastewater from the Aranyaprathet Municipality's wastewater treatment system, both quantitative and geographic.

Keyword: Water quality; Municipal wastewater; Pollutant emission; BOD loading

INTRODUCTION

In many parts of the world, rapid economic growth combined with worsening climate change puts pressure on water management, especially wastewater pollution (Schindler, 2006; Zhao et al., 2012; Goh et al., 2017). Wastewater pollution is one of the greatest challenges threatening management of rivers worldwide. In addition, wastewater pollution in aquatic ecosystems is also a major cause of today's water quality crisis (Ruprecht, et al., 2021). Despite nearly two-thirds of the world's wastewater produced each year and treated to some degree, but domestic wastewater is a major source of widespread nutrient pollution (Mateo-Sagasta, et al., 2015). This leads to eutrophication and other environmental changes (Wang et al., 2019). Treatment of wastewater before drainage is very important to maintain the quality of natural water sources. Various wastewater treatment technologies such as solvent extraction, membrane filtration (Altaee et al., 2015; Ihsanullah, 2019; Quist et al., 2015), adsorption (Sakulpaisan et al., 2016; Suzaimi, et al., 2019; He, et al., 2019), chlorination (Bao, et al., 2019; Boyd, et al., 2005), and electrocoagulation–flocculation (Akyol, 2012; Yang, et al., 2015) have been developed. However, many wastewater treatment methods are

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quite expensive and cannot treat large volumes of wastewater. Therefore, municipal wastewater treatment systems are the ideal solution to eliminate water pollution, especially in the treatment of domestic wastewater.

In 2014, Thailand has started a special economic zone development policy with the first priority on border areas. At present, there are 10 special economic zone (SEZs) located in the following provinces: Tak, Sa Kaeo, Trat, Mukdahan, Songkhla, Chiang Rai, Nong Khai, Nakorn Phanom, Kanchanaburi, and Narathiwat. The Government of Thailand provides supporting measures and other promotions for the development of basic infrastructure, including tax and non-tax incentives, setting up One Stop Service Center (OSS) and other facilitating measures. Location of all special economic zones in Thailand is shown in Figure 1.

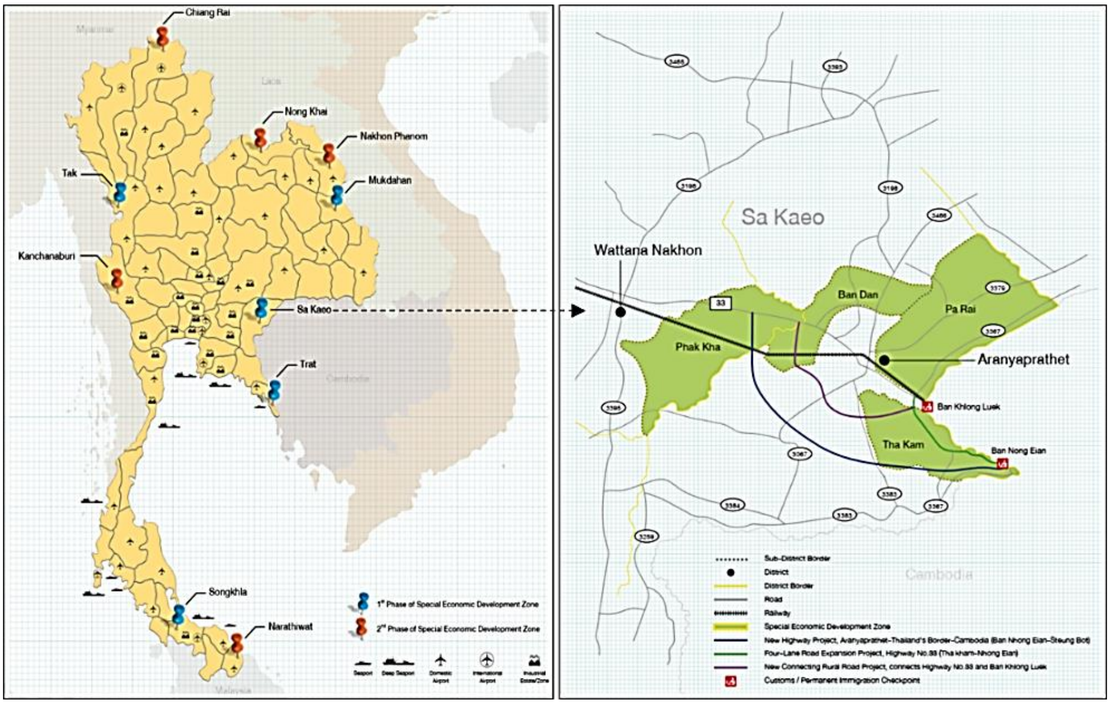

Figure 1. Location of all special economic zones in Thailand and the Sa Kaeo special economic zone (Thailand Board of Investment, 2015).

The Sa Kaeo SEZs are in border areas contiguous to Cambodia. There are also 4 sub-districts in the 2 districts of Sa Kaeo Province, including Aranyaprathet District (3 sub-districts including Ban Dan, Pa Rai, and Tha Kham), and Watthana Nakhon (Phak Kha sub-district). In reference to the Government's policy to develop border areas, the targeted industries to promote in the Sa Kaeo can be divided into 12 industries as follows: (1) agriculture, fisheries and agricultural products, (2) textile, and garment, (3) manufacturing of furniture, (4) gems and jewelleries, (5) manufacture of medical equipment, (6) automotive, machinery and parts, (7) electronics and electrical appliances, (8) chemical and plastic, manufacture of plastic, (9) manufacture of medicine, (10) logistic businesses, (11) industrial zones or industrial estates, and (12) businesses that support tourism (Thailand Board of Investment, 2015).

Natural water sources are essential for infrastructure development in all areas of Thailand, including the special economic zone in Sa Kaeo Province. The Phromhot Canal is a local natural water resource which is a river branch of the Tonlé Sap River Basin. It is also a major source of water is the only source that is used for consumption and agriculture of the Sakaeo SEZs. In addition, the Phromhot Canal is considered a natural boundary that divides Thailand

and Cambodia. At present, the Phromhot Canal is experiencing serious problems regarding water quality. One of the main problems is the discharge of wastewater from many sources, both from the community and the industrial plant. There is also a tendency that garbage from the Aranyaprathet Municipality's Landfill can flow into the canal. Because, it is located by the canal (Data from the field surveys). The measurement and analysis of water quality data, types of water pollution, source of water pollution, and carrying capacity to handle the pollution of canal is an essential tool for water management integrated.

Therefore, the objective of this study was to analyze the canal quality status, classify the health of the canal according to Water Quality Index (WQI), assess the possibility of contamination of pollutants from water pollution sources, assess the pollutant emission of water pollution sources, and asses the pollution carrying capacity of the Phromhot Canal.

MATERIALS AND METHODS

The samples were collected in the area of the Phromhot Canal from Aranyaprathet District, Sakaeo Province, Thailand. The Phromhot Canal is one of river branch of Tonlé Sap basin. It is also a major source of water is the only source that is used for consumption and agriculture of the Aranyaprathet sub-district, Sa Kaeo Province. In addition, the Phromhot Canal is considered a natural boundary that divides Thailand and Cambodia (Figure 2).

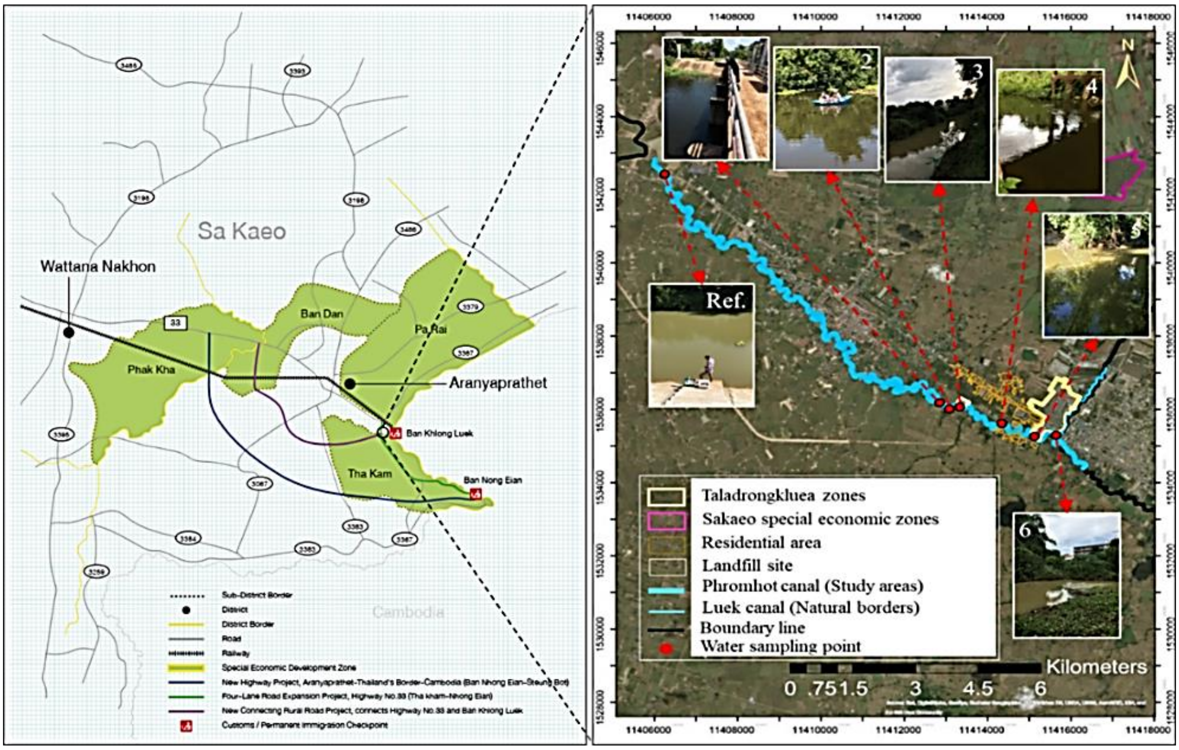

Figure 2. Study area map and locations of selected water sampling point for the study.

In this study, sampling sites had been examined 7 stations cut across the downstream areas. All these stations were served as the control station to represent the actual condition of the Phromhot Canal. In addition, the samplings were conducted during 2 seasons; dry period (June 2018) and wet period (December 2018), representing the characteristics of the canal. The Sample collection locations are presented in detail on Table 1.

Table 1. Sampling sites and their locations.

Sampling sites	Locations	GPS coordinates
Reference point	The provincial waterworks authority, Aranyaprathet branch	X 0225751 / Y 1518508
PH-01	Phromhot's weir	X 0232100 / Y 1512395
PH-02.1	Landfills site of the Aranyaprathet Municipality (Before the Phromhot Canal flowing through)	X 0232480 / Y 1512367
PH-02.2	Landfills site of the Aranyaprathet Municipality (After the Phromhot Canal flowing through)	X 0232539 / Y 1512297
PH-03	Watwongchado Security point (Temporary)	X 0233516 / Y 1511858
PH-04	Taladrongkluea, Sakaeo Province (Adjacent to the Tha Kham Subdistrict)	X 0234246 / Y 1511573
PH-05	Thai-Cambodian Border Security Point	X 0234707 / Y 1511563

For water quality analysis, all samples were collected in polyethylene bottles previously cleaned with metal-free detergent and rinsed with deionized water. After collection, samples were promptly transported in a cool-box to the laboratory. The parameter analysis for this research was divided into 3 parts, all of which were used to assess the pollution carrying capacity of the Phromhot Canal. The first part is bacterial parameters. The analysis was conducted as follows: total coliform bacteria (TCB) and fecal coliform bacteria (FCB) were quantified by multiple-tube fermentation technique. All of the bacteriological parameters were performed according to the standard methods (APHA, 2012). The second part is physico-chemical parameters. The analysis was conducted as follows: Dissolved oxygen (DO) was measured using the electrometric measurement method. The 5-day biochemical oxygen demand (BOD_5) test, a method widely used as the standard method for determining the concentration of biodegradable organics in wastewater (Chang et al., 2004), was then carried out. BOD_5 was measured using the azide modification method. Ammonia-nitrogen (NH_3-N) is a measure of the ammonia content by the Nesslerization method. The method quantifies solids, total dissolved solids (TDS) and total suspended solids (TSS), in water or wastewater samples using gravimetric analysis following oven drying. The total nitrogen analysis (Total Kjeldahl Nitrogen; TKN) method is based on the wet oxidation of nitrogen using sulfuric acid and digestion catalyst. The methods for fat, oil and grease (FOG) measurement using hexane as the extraction solvent and gravimetric analysis is now the standard method. All of the physico-chemical parameters were performed according to the standard methods (APHA, 2012). And finally, the third part is the heavy metal parameters. The analysis was conducted as follows: Arsenic (As), Cadmium (Cd), Hexavalent Chromium (Cr^{6+}), Copper (Cu), Total Mercury, (Hg) Lead (Pb) Manganese (Mn), Nickel (Ni), and Zinc (Zn) were determined according to the standard methods (APHA, 2012).

The water quality situation is evaluated in the form of the water quality index (WQI). The WQI is a rating that reflects the influence of different quality variables (Şener et al., 2017). The Thailand WQI was developed by Thailand's Pollution Control Department (PCD) that has been practiced in various countries. The standard methods for the examination of surface water source are used as a tool for guidelines in maintaining Thailand's river water quality (Prakirake et al., 2009). The five water quality parameters include DO, BOD_5, NH_3-N, TCB, and FCB were used to determine WQI. In addition, WQI obtained by Calculator Online (Pollution Control Department, 2016). The computed WQI values are classified into five categories as Table 2.

Table 2. WQI Interpretation.

Rating of water quality [a]	WQI value [a]	Descriptive language [b]
Seriously Polluted	0-30	Unacceptable. Can be used for transportation only.
Poor	31-60	Freshwater resources that are not clean. Consumption requires specific or advanced treatment process before use.
Fair	61-70	Freshwater resources that are medium clean. Consumption requires conventional water treatment process before use.
Good	71-90	Freshwater resources that are very clean. Consumption requires ordinary water treatment process which minor.
Excellent	91-100	Freshwater resources that are extra clean. Consumption can use an ordinary process for pathogenic destruction.

[a] Pollution Control Department (2016); [b] Notification of the National Environmental Board (1994)

Assessment of the possibility of contamination of pollutants from water pollution sources was using observation of sources of water pollution throughout the study area. The survey was conducted from: field trip by boat and geographic photos (obtained from satellite images, and the unmanned aerial vehicle; UAV). After that, assess the possibility of contamination of pollutants from water pollution sources is in accordance with the environmental quality inspection criteria of the PCD (Pollution Control Department, 2004).

In this section, the emission capability of pollution sources was assessed. The analysis was conducted from: the result of water quality analysis, the result of assessment of the possibility of contamination of pollutants from water pollution sources, the amount of pollutant, and the flow rate of pollutant. All data are calculated according to equation (1) (adapted from the Water Quality Management Bureau, 2010; Pollution Control Department, 2009).

$$\text{Pollutant loading} = C_p \times A_p \times D_y \tag{1}$$

Where, C_p is the concentration of pollutants (mg/l), A_p is the amount of pollutant (m^3/d), and D_y is the number of days that pollutants are loaded into water resource (d/y)

The pollution carrying capacity of the Phromhot Canal was assessed in this section. The analysis was conducted by compared BOD loading value with the total maximum daily load (TMDL) value. A TMDL is the calculation of the maximum amount of a pollutant (in terms of BOD loading) allowed to enter a water body so that the water body will meet and continue to meet water quality standards for that particular pollutant (U.S. EPA, 2018). A TMDL are calculated according to equation (2) (Bulsathaporn, 2008; Ugbebor et al., 2012).

$$\text{TMDL} = R_r \times Q \tag{2}$$

$$R_r = K_a\,(C_s - DO) \tag{3}$$

$$K_a = \frac{5.06V^{0.919}}{H^{1.673}}(1.024)^{T-20} \tag{4}$$

$$Q = Q_r + Q_w \tag{5}$$

Where, R_r is the reaeration rate (mg/l/d), Q is the total flow rate (m^3/s), K_a is the reaeration coefficient (d^{-1}), DO is the concentration of measured DO (mg/l), C_s is the concentration of saturated DO (mg/l) at the pressure 1 atmosphere, V is the average stream velocity (m/s), T is the temperature of river (°C), H is the average stream depth (m), Q_r is the flow rate of river (m^3/s), and Q_w is the flow rate of wastewater (m^3/s)

RESULTS AND DISCUSSION

Assess the water quality situation of the Phromhot Canal revealed that tends to deteriorate from the sampling sites at PH-02.2 to the sampling sites at PH-05. The WQI values are 40.5 ± 16.9 and 49.0 ± 12.7, respectively. While the water quality after the sampling sites at PH-02.2 was fair to poor. When considering the depth of each season, it is also known that the water quality of the Phromhot Canal is drastically worse during the dry period which has significant differences at p-value < 0.05 (Table 3).

Table 3. Water quality situation of the Phromhot canal.

Sampling sites	**WQI**		**The average WQI**
	Dry period	**Wet period**	
Ref.	71.5 ± 0.7	72.0 ± 2.8	71.8 ± 1.7
PH-01	61.0 ± 2.8	68.5 ± 23.3	64.8 ± 14.2
PH-02.1	65.0 ± 10.5	78.0 ± 11.3	71.5 ± 10.5
PH-02.2	26.0 ± 4.2	55.0 ± 1.4	40.5 ± 16.9
PH-03	50.5 ± 7.8	55.5 ± 0.7	53.0 ± 5.4
PH-04	40.5 ± 9.2	50.5 ± 9.2	45.5 ± 9.5
PH-05	42.5 ± 17.7	55.5 ± 2.1	49.0 ± 12.7
The average WQI	51.0 ± 6.9 [a]	62.1 ± 7.3	56.6 ± 10.1

[a] There are statistically significant differences at p-value < 0.05.

In addition, the level of the NH_3-N was likely to increase after the Phromhot Canal flowing through the landfills of the Aranyaprathet Municipality (PH-02.2) to the Thai-Cambodian Border Security Point (PH-05). The contents of the NH_3-N recorded at the waters are between 1.3 ± 1.8 - 2.1 ± 2.8 mg/L. High NH_3-N values were measured at PH-02.2 where pollutants were effective. The continuous increase of NH_3-N can cause nutrient over-enrichment of a water body at elevated concentrations and indirect effects on aquatic life, ammonia causes direct toxic effects on aquatic life (U.S. EPA, 2013; Sener et al., 2013; Debels et al., 2005). NH_3-N is a toxic pollutant often found in landfill leachate and in waste products, such as sewage, liquid manure and other liquid organic waste products. It can also be used as an indicator of the natural health of the body, such as a river or lake or in man-made bodies of water (Aziz et al. 2004; Manios et al. 2002). The optimum value for good water quality is not over 0.5 mg/L of NH_3-N, which ensures healthy aquatic life in a water body (The National Environmental Board, 1994).

In the same way, other parameters (namely; BOD, TCB, and FCB) were likely to increase from the sampling sites at PH-02.2 to the sampling sites at PH-05 when compared with Reference point. The contents of the BOD recorded at the waters are between 2.5 ± 1.0 - 4.3 ± 3.3 mg/L. Generally, the aqueous DO concentration is considered as an overall quality of the aquatic water body, and the increase in aqueous DO concentration usually results from the decrease of oxygen-consuming contaminants in the aqueous phase (Fan et al., 2021). The BOD is a measure of the amount of DO that bacteria will consume while decomposing organic matter under aerobic conditions. Aerobic bacteria decompose these organic materials (natural organic detritus and organic waste) using DO, thus reducing the DO present for aquatic life especially fish (Northeast Georgia Regional Development Center, 2001). In term of bacteriological parameter, the sampling sites at PH-04 was the worst water quality compared with the other parts. The contents of the TCB and FCB recorded at the water is $4.3 \times 10^5 \pm 7.8 \times 1\ 0^5$ and $4.2 \times 10^5 \pm 7.9 \times 10^5$ MPN/100 ml, respectively.

The TCB can be used as indicators of cleanliness and contamination of human and animal waste in water body (Ashbolt et al., 2001; Eleria & Vogel, 2005). Whereas the FCB is found only in feces of warm-blooded animals. Therefore, the FCB was used for good indicator of the risk of contamination of pathogens in the gastrointestinal tract in water body (Ashbolt et al., 2001). Some analysis parameters of water in each of the direction towards the source of the Phromhot Canal are provided in Table 4.

In this section, a survey of water pollution sources around the Phromhot Canal that flows through. There are a total of 13 survey points (SP). The survey found that there is both of the wastewater treatment system and landfills of the Aranyaprathet Municipality between survey points at SP-01 to SP-04. Therefore, there is a high chance of being contaminated with various contaminants. The survey point at SP-01 to SP-04 found that there is a medium chance of being contaminated with various contaminants. Since there are the riverbank community areas. The possibility of pollution contamination from water pollution sources at each survey point of the Phromhot Canal is shown in Figure 3.

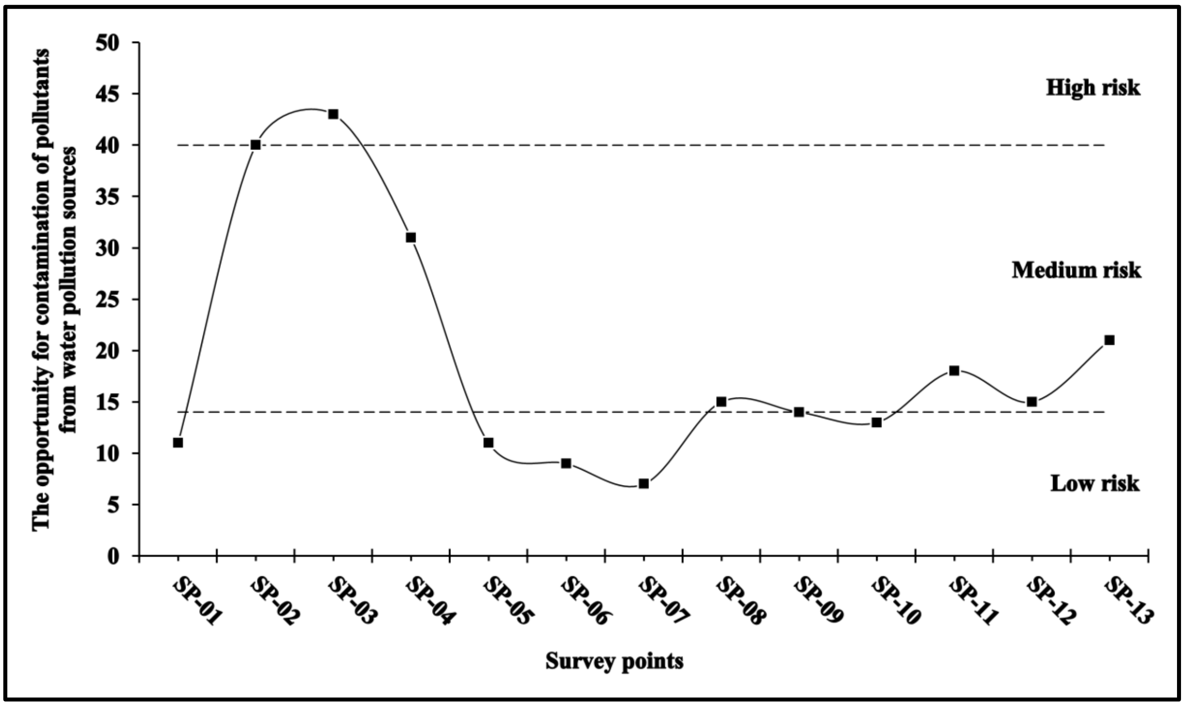

Figure 3. The possibility of pollution contamination from water pollution sources at each survey point of the Phromhot Canal.

Table 4. Bacteriological and physicochemical parameters of the Phromhot Canal.

Parameter	Sampling sites							Std. [1/]
	Ref.	PH-01	PH-02.1	PH-02.2	PH-03	PH-04	PH-05	
Temperature (C°)	32±2.8	30.6±1.5	30.5±1.2	30.8±1.7	30.1±2.0	29.9±1.3	29.5±1.3	N
pH	7.2±0.3	7.5±0.6	7.4±0.7	7.3±0.5	7.2±0.3	7.4±0.6	7.0±0.3	5-9
Turbidity (NTU)	25.4±14	21.2±23.1	20.0±17.0	22.8±14.7	20±20.6	22.3±18.3	22.8±10.5	NS
Conductivity (µS/cm)	530±415.7	218.9±75.4	788.3±676.6	865±593.2	593.8±599.6	335.3±210.5	632.3±547.3	NS
Salinity (ppt)	0.3±0.2	0.1±0.1	0.4±0.3	0.5±0.3	0.3±0.3	0.2±0.1	0.3±0.3	NS
DO (mg/l)	5.2±1.3	4.5±0.6	6.1±1.4	4.6±2.9	4.5±2.4	3.4±1.4	3.75±1.8	≥2.0
BOD (mg/l)	1.3±0.5	1.5±1.0	1.8±1.5	4.3±3.3	2.5±1.0	2.8±0.5	2.8±2.4	≤4.0
TSS (mg/l)	16.5±11.7	17.3±18.4	16.2±15.4	15.6±13.7	17.2±14.2	19.5±14.4	26.4±12.3	NS
TDS (mg/l)	98.5±78.4	168.0±32.8	157.5±20.0	205.5±57.7	214.5±58.9	232.5±86.5	224±111.1	NS
NH_3 – N (mg/l)	0.4±0.2	0.4±0.2	0.4±0.2	2.1±2.8	1.4±2.1	1.5±2.1	1.3±1.8	0.5
FOG (mg/l)	1.3±0.5	1.4±0.5	1.6±0.4	1.8±0.4	1.6±0.3	1.7±0.5	1.7±0.6	NS
TCB (MPN/100 ml)	$3.9x10^2±2.7x10^2$	$13.0x10^4±4.5x10^4$	$2.7x10^3±4.2x10^3$	$1.1x10^5±1.3x10^5$	$1.0x10^4±6.3x10^3$	$4.3x10^5±7.8x10^5$	$6.0x10^4±4.8x10^5$	$≤2.0x10^4$
FCB (MPN/100 ml)	$0.9x10^2±0.2x10^2$	$6.2x10^3±1.1x10^4$	$5.8x10^2±4.9x10^2$	$8.9x10^4±1.4x10^5$	$7.1x10^3±5.3x10^3$	$4.2x10^5±7.9x10^5$	$2.8x10^4±1.7x10^4$	$≤4.0x10^3$

N = Be natural; NS = Not specified; [1/] = Water quality standards in surface water sources (Notification of the National Environmental Board, 1994)

From this study, the source of pollution that is important in area are the wastewater treatment system and landfill of the Aranyaprathet Municipality. Therefore, the research team has measured and analyzed the amount of pollutants in both pollution sources. The most of pollutants are detected in the wastewater of the pollution sources (Table 5).

Table 5. The measurement and analysis of pollutants from the point source of water pollution.

Parameter	The point source water pollution		Std. 1/
	Wastewater	Leachate	
Temperature (C°)	29	30	NS
pH	7.0	8.2	5.5 – 9.0
Turbidity (NTU)	3.69	112	NS
Conductivity (µS/cm)	743	12,900	NS
Salinity (ppt)	0.4	7.4	NS
DO (mg/l)	1.7	0.5	NS
BOD (mg/l)	4	56	≤20
TSS (mg/l)	100	255	≤30
TDS (mg/l)	184	8,456	NS
TKN (mg/l)	12.6	6.3	≤20
FOG (mg/l)	2.4	6.3	≤5
TCB (MPN/100 ml)	$4.0x10^3$	$3.0x10^3$	NS
FCB (MPN/100 ml)	$4.0x10^3$	$2.7x10^2$	NS
As (mg/l)	0.0003	0.0074	NS
Cd (mg/l)	0.006	0.006	NS
Cr^{6+} (mg/l)	0.006	0.006	NS
Cu (mg/l)	0.006	0.355	NS
Total Hg (mg/l)	0.0005	0.0009	NS
Pb (mg/l)	0.031	0.031	NS
Mn (mg/l)	0.616	2.34	NS
Ni (mg/l)	0.020	0.230	NS
Zn (mg/l)	0.007	0.772	NS

NS = Not specified; 1/ = Standards for quality control of wastewater from wastewater treatment systems (Ministry of Natural Resources and Environment, 2010)

When evaluating the potential for pollutants contamination from both pollution sources. It revealed that the wastewater treatment system is a major pollution source. While pollutants from the landfill are unlikely to be contaminated into the Phromhot Canal. Since it has a small amount of pollution. Since it is a little sump (Figure 4) and away from the canal about 25 meters. In addition, the landfill site is still on a clay layer, with the Cation exchange capacity (CEC) of 39.8 and 40.7 cmol/kg soil, respectively. The CEC values in the soil indicate the ability to absorb pollutants (Darunsontaya et al., 2018). Therefore, causing sedimentation of pollutants in the soil rather than flowing into the Phromhot Canal.

(A) (B)

Figure 4. The characteristics of (A) a little sump inside the landfill and (B) the color of leachate.

The amount of waste water flowing into the treatment system: The volume measurement of wastewater shows that the wastewater flows into the wastewater treatment system at 6,439.55 m^3/day. Field survey also found that the total amount of wastewater flows into the Phromhot canal at sampling sites PH-02.2. The reason is that the size and form of the current wastewater treatment system (Figure 5) is not suitable for carrying the amount of wastewater, which has a capacity of only 923.93 m^3 (Table 6).

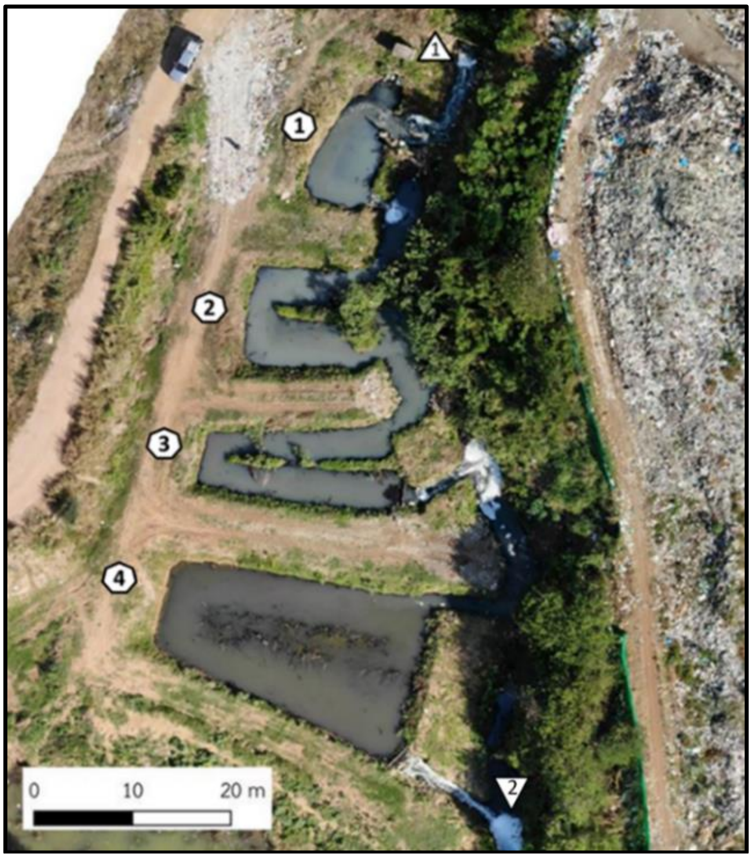

Figure 5. The details of the wastewater treatment system;
Influent, Wastewater treatment systems, and Effluent.

Table 6. Measurement and evaluation of the capacity of the wastewater treatment system.

Pond	Base area (m^2)	Average depth (m.)	Pond capacity (m^3)
1	70.14	1.00	**72.95**
2	89.40	2.80	124.90
3	123.20	2.40	149.90
4	388.67	1.50	**576.20**
Total	**671.41**	-	**923.95**

For the water pollution emission, the various pollutants that can be discharged into the Phromhot Canal per year shown in Table 7. The survey also found wastewater come from the Aranyaprathet Subdistrict. The most pollutants in wastewater are in the form of organic substances, which can be decomposed by aerobic bacteria. The amount of organic matter in water is commonly measured by the Biochemical Oxygen Demand (BOD). When the BOD in the water is high. It shows that there are a lot of organic matter and putrid conditions will easily occur (Water Quality Management Bureau, 2017). According to a study by Fan et al. (2021) found that BOD must be significantly reduced to maintain water quality within specified water quality criteria.

Table 7. The amount of water pollution emission into the Phromhot Canal.

Parameter	The pollutants loading	
	(Kg/day)	(Kg/year)
BOD	51.52	18,803.50
TSS	48.94	17,863.32
TDS	2,704.61	987,183.72
TKN	81.14	29,615.51
FOG	15.45	5,641.05
As	0.00	0.71
Cd	0.04	14.10
Cr^{6+}	0.04	14.10
Cu	0.04	14.10
Total Hg	0.00	1.18
Pb	0.20	72.86
Mn	3.97	1,447.87
Ni	0.13	47.01
Zn	0.05	16.45

In addition, factors that influence a domestic wastewater quality include: (1) a daily activity of people living in the community and (2) the wastewater in each sub-community has a primary treatment process before flowing into the municipal waste water treatment system. This factors directly affect the efficiency of wastewater treatment. While the characteristics of the wastewater system and methods of treatment play an important role in the treatment process. (Panswad, 1994). Similar to a study of Cao et al. (2020) found that the water quality of the Huangtian River is poor, mainly due to the abundance of production sewage, domestic sewage, and garbage being poured into the river, especially in the dry season. In addition, Angriani et al. (2018) revealed that increasing population rates around the Kuin River, Banjarmasin, South Kalimantan, Indonesia has resulted in serious degradation.

Assessment of the pollution carrying capacity of the Phromhot Canal is comparison between a BOD loading with a total maximum daily load (TMDL). The results found that the Phromhot Canal (since sampling point at PH-02.2) is unable to receive pollutants flowing from the wastewater treatment system because the BOD loading value is greater than the TMDL value (Table 8). The contents of the TMDL recorded at the is ≤ 0.08 kg_{BOD}/day in dry period and 16.52 kg_{BOD}/day in wet period, respectively. In 2015, the Water Quality Management Bureau has proposed to use the TMDL to control the water quality by using the TMDLs as the determination of wastewater both quantitative and spatial, such as the use of a permit system (Water Quality Management Bureau, 2015).

Table 8. The assessment of the pollution carrying capacity of the Phromhot Canal.

The water resources	Type of water resources [2/]	Std. BOD [2/] (mg/L)	BOD Loading (kg_{BOD}/day)	TMDL (kg_{BOD}/day)	
				Dry period	Wet period
The Phromhot Canal [1/]	4	3.0	51.52	≤ 0.08 [3/]	16.52

1/ The interval between the sampling site at PH-02.1 and the sampling site at PH-02.2

2/ The standard for effluent controlling from community wastewater treatment system (Ministry of Natural Resources and Environment, 2010)

3/ One of the important variables in calculating TMDL is the velocity of the currents. The researchers measured the velocity of the currents in the Phromhot Canal at the highest during the drought period at 0.04 m/s. As the velocity of the currents in many parts of the Phromhot Canal is not flow, which the TMDL value should be less than or equal to 0.08 kg_{BOD}/day.

Generally, the TMDL system has been recognized as an effective strategy for pollution mitigation in addition to the concentration-based control measures of each country (Fan et al., 2021). The TMDL system has become an attractive option for improving water quality since the enforcement of effluent discharge standards may not be as effective as expected (Lai et al., 2013; Leveque & Burns, 2017).

CONCLUSION

According to the results of the study, the effluents from the Aranyaprathet Municipal Wastewater Treatment Plant (AM's-WWTP) is the main cause of water quality changes in the Phromhot Canal. The effluents can also flow into the water body up to 6,439.55 m3/day. For the assessment of the pollution carrying capacity, the Phromhot Canal (since flowing through the AM's-WWTP) is unable to receive pollutants because the BOD loading value is greater than the total maximum daily load (TMDL) value. The TMDL value allowed to enter a water body of the Phromhot Canal should be ≤ 0.08 kgBOD/day (dry period) and 16.52 kgBOD/day (wet period). While the Phromhot Canal has to carry BOD loading up to 51.12 kgBOD/day.

This research puts forward the following suggestions to provide effective basis for the reduction of the water pollutants: (1) develop an integrated wastewater management strategy by the local government organization (LGO) to be the main unit for coordinating operations with relevant agencies, (2) the LGO must support the improvement of municipal wastewater treatment systems to increase efficiency in treating wastewater treatment systems, (3) the LGO should involve local people in wastewater management through the collection of wastewater treatment fees, and (4) Encourage the private sector to invest in the wastewater treatment business. In addition, financial institutions should provide loans at low interest rates certified by the LGO. To create incentives for the private sector to play a greater role in investment in environmental protection.

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CONFLICT OF INTEREST

The authors declare that there is not any 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 has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Akyol, A. (2012). Treatment of paint manufacturing wastewater by electrocoagulation. Desalination., 285; 91–99.

Altaee, A., Sharif, A., Zaragoza, G. and Ismail, A. (2015). Evaluation of FO-RO and PRO-RO designs for power generation and seawater desalination using impaired water feeds. Desalination, 368; 27–35.

Angriani, P., Sumarmi, Ruja, I. N. and Bachri, S. (2018). River management: The importance of the roles of the public sector and community in river preservation in Banjarmasin (A case study of the Kuin River, Banjarmasin, South Kalimantan – Indonesia). Sustain. Cities Soc., 43; 11-20.

APHA, 2012. Standard methods for the examination of water and wastewater, 22nd edition edited by Rice, E. W., Baird, R. B., Eaton A. D. and Clesceri, L. S. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), Washington, D.C., USA.

Ashbolt, N. J., Grabow, W. O. K. and Snozzi, M. (2001). Indicators of microbial water quality. In Fewtrell, L., and Bartram, J. (eds.) Water quality: Guidelines, Standards and Health. Assessment of risk and risk management for water-related infectious disease. London, UK: IWA Publishing, pp. 289-316.

Aziz, H. A., Adlan, M. N., Zahari, M. S. M. and Alias, S. (2004). Removal of ammoniacal nitrogen ($N\text{-}NH_3$) from municipal solid waste leachate by using activated carbon and limestone. Waste Manage. Res., 22; 371-375.

Bao, X., Wu, Q., Shi, W., Wang, W., Yu, H., Zhu, Z., Zhang, X., Zhang, Z., Zhang, R. and Cui, F. (2019). Polyamidoamine dendrimer grafted forward osmosis membrane with superior ammonia selectivity and robust antifouling capacity for domestic wastewater concentration. Water Res., 153; 1–10.

Boyd, G. R., Zhang, S. and Grimm, D. A. (2005). Naproxen removal from water by chlorination and biofilm processes. Water Res., 39; 668–676.

Bulsathaporn, A. (2008). The application of mathematical models for an environmental flow assessment and total maximum daily load (TMDL) of prachinburi–bangpakong river. Dissertation, Mahidol University, 165p.

Cao, F., Lu, Y., Dong, S. and Li, X. (2020). Evaluation of natural support capacity of water resources using principal component analysis method: a case study of Fuyang district, China. Appl. Water Sci., 10: 192.

Chang, I. S., Jang, J. K., Gil, G. C., Kim, M., Kim, H. J., Cho, B. W. and Kim, B. H. (2004). Continuous determination of biochemical oxygen demand using microbial fuel cell type biosensor. Biosens. Bioelectron., 19(6); 607-613.

Darunsontaya, T., Jaroenpong, C., Jindaluang, W.and Jaroenchasri, R. (2018). Potassium adsorption characteristics of sugarcane growing soils in Sa Kaeo province. KHONKAEN AG R.J., 46(2); 277-288. [Thai]

Debels, P., Fýgueroa, R., Urrutia, R., Barra, R. and Niell, X. (2005). Evaluation of water quality in the Chilla'n river (Central Chile) using physicochemical parameters and a modified water quality index. Environ. Monit. Assess., 110; 301-322.

Eleria, A. and Vogel, R. M. (2005). Predicting fecal coliform bacteria levels in the Charles River, Massachusetts, USA. J. Am. Water. Resour. Assoc., 41(5); 1,195-1,209.

Fan, C., Chen, K-H., and Huang, Y-Z. (2021). Model-based carrying capacity investigation and its application to total maximum daily load (TMDL) establishment for river water quality management: A case study in Taiwan. J. Clean. Prod., 291; 125-251.

Goh, P. S., Matsuura, T., Ismail, A. and Ng, B.C. (2017). The Water-Energy Nexus: Solutions towards Energy-Efficient Desalination. Energy Technol., 5; 1136–1155.

He, X., Yang, D.-P., Zhang, X., Liu, M., Kang, Z., Lin, C., Jia, N. and Luque, R. (2019). Waste eggshell membrane-templated CuO-ZnO nanocomposites with enhanced adsorption, catalysis and antibacterial properties for water purification. Chem. Eng. J., 369; 621–633.

Ihsanullah, I. (2019). Carbon nanotube membranes for water purification: Developments, challenges, and prospects for the future. Sep. Purif. Technol., 209; 307–337.

Lai, Y. C., Tu, Y. T., Yang, C. P., Surampalli, R. Y. and Kao, C. M. (2013). Development of a water quality modeling system for river pollution index and suspended solid loading evaluation. J. Hydrol., 478; 89-101.

Leveque, J. G. and Burns, R. C. (2017). A structural equation modelling approach to water quality perceptions. J. Environ. Manag., 197; 440-447.

Manios, T., Stentiford, E. I. and Millner, P. A. (2002). The removal of NH_3-N from primary treated wastewater in subsurface reed beds using different substrates. J. Environ. Sci. Health, A., 37(3); 297-308.

Mateo-Sagasta, J., Raschid-Sally, L. and Thebo, A. (2015). Global Wastewater and Sludge Production, Treatment and Use (Chapter 2). In Drechsel, P., Qadir, M. and Wichelns, D. (eds.) Wastewater: economic asset in an urbanizing world. Springer, pp. 15-38.

Northeast Georgia Regional Development Center. (2001). Guidebook for Local Governments for Developing Regional Watershed Protection Plans. Water Resources Branch, Georgia Environmental Protection Division, USA.

Panswad, T. (1994). Waste and rainwater drainage system design guide, 4th edition. The Engineering Institute of Thailand Under H.M. and The Environmental Engineering Association of Thailand, Bangkok.

Pollution Control Department (2016). Inland Water Quality Information System (IWIS). Retrieved April 21, 2021, from https://bit.ly/2SO3gOS.

Pollution Control Department. (2004). A guide to simple environmental quality checks. Ministry of Natural Resources and Environment, Bangkok.

Pollution Control Department. (2009). A guideline for estimating emission of pollution into the environment, 1st edition. Ministry of Natural Resources and Environment, Bangkok.

Prakirake, C., Chaiprasert, P. and Tripetchkul, S. (2009). Development of specific water quality index for water supply in Thailand. Songklanakarin J. Sci. Technol., 31(1); 91-104.

Quist-Jensen, C. A., Macedonio, F. and Drioli, E. (2015). Membrane technology for water production in agriculture: Desalination and wastewater reuse. Desalination., 364; 17–32.

Ruprecht, J. E., Birrer, S. C., Dafforn, K. A., Mitrovic, S. M., Crane, S L., Johnston, E. L., Wemheuer, F., Navarro, A., Harrison, A. J., Turner, I. L. and Glamore, W. C. (2021). Wastewater effluents cause microbial community shifts and change trophic status. Water Res., 200; 117206.

Sakulpaisan, S., Vongsetskul, T., Reamouppaturm, S., Luangkachao, J., Tantirungrotechai, J. and Tangboriboonrat, P. (2016). Titania-functionalized graphene oxide for an efficient adsorptive removal of phosphate ions. J. Environ. Manag., 167; 99–104.

Schindler, D. W. (2006). Recent advances in the understanding and management of eutrophication. Limnol. Oceanogr., 51 (1part2); 356-363.

Sener, S., Davraz, A. and Karagüzel, R. (2013). Evaluating the anthropogenic and geologic impacts on water quality of the Eðirdir Lake, Turkey. Environ. Earth Sci., 70; 2,527-2,544.

Sener, S., Sener, E. and Davraz, A. (2017). Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). Sci. Total Environ., 584-585; 131-144.

Suzaimi, N. D., Goh, P. S., Malek, N. A. N. N., Lim, J.-W. and Ismail, A. F. (2019). Performance of branched polyethyleneimine grafted porous rice husk silica in treating nitrate-rich wastewater via adsorption. J. Environ. Chem. Eng., 7; 103235.

Thailand Board of Investment. (2015). A Guide to Investment in the Special Economic Development Zones. [Electronic version]. Retrieved April 21, 2021, from https://www.nesdc.go.th/ewt_dl_link.php?nid=5197.

The Ministry of Natural Resources and Environment. (2010). Effluent Standard for Sanitary Wastewater Treatment Systems. In Notification of the Ministry of Natural Resources and Environment dated April 7, B.E. 2553 (2010) was issued under the Enhancement and Conservation of National Environmental Quality Act, B.E. 2535 (1992) and published in the Royal Gazette, Vol. 127, Special Part 69D dated June 2, B.E. 2553 (2010).

The National Environmental Board. (1994). Surface Water Quality Standard in Thailand In Notification of the National Environment Board No.8, B.E.2537 (1994) was issued under the Enhancement and Conservation of National Environmental Quality Act B.E. 2535 (1992) dated January 20, B.E.2537(1994), which was published in the Royal Government Gazette, Vol.111, Part 16D, dated February 24, B.E. 2537(1994).

U.S. Environmental Protection Agency (EPA). (2013). Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater. Washington, DC, USA.

U.S. Environmental Protection Agency (EPA). (2018). Overview of Total Maximum Daily Loads (TMDLs). [Electronic version]. Washington, DC, USA. Retrieved April 21, 2021, from https://bit.ly/2XHs6a0.

Ugbebor, J. N., Agunwamba, J. C. and Amah, V. E. (2012). Determination of reaeration coefficient K_2 for polluted stream as a function of depth, hydraulic radius, temperature and velocity. Niger. J. Technol., 31(2); 174 - 180.

Wang, X., Daigger, G., de Vries, W., Kroeze, C., Yang, M., Ren, N.-Q., Liu, J. and Butler, D. (2019). Impact hotspots of reduced nutrient discharge shift across the globe with population and dietary changes. Nat. Commun., 10(1); 2627.

Water Quality Management Bureau. (2010). A guide for collecting water from domestic wastewater treatment systems. Pollution Control Department, Bangkok.

Water Quality Management Bureau. (2015). A training workshop “The pollution carrying capacity of water resource”. Pollution Control Department, Bangkok. Retrieved April 21, 2021, from https://bit.ly/2TcTBVJ.

Water Quality Management Bureau. (2017). A guide of Community Wastewater Treatment System. Pollution Control Department, Bangkok.

Yang, T., Qiao, B., Li, G.-C. and Yang, Q.-Y. (2015). Improving performance of dynamic membrane assisted by electrocoagulation for treatment of oily wastewater: Effect of electrolytic conditions. Desalination., 363; 134–143.

Zhao, S., Zou, L., Tang, C.Y. and Mulcahy, D. (2012). Recent developments in forward osmosis: Opportunities and challenges. J. Membr. Sci., 396; 1–21.