Fluxes of Dissolved Nutrients and Total Suspended Solids from the Bang Pakong River Mouth into the Upper Gulf of Thailand

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ABSTRACT

Coastal eutrophication is a global environmental concern, primarily driven by nutrient contamination from human and natural sources entering the sea via river mouths. The Bang Pakong River, situated on the eastern coast of Thailand's Upper Gulf, exemplifies this issue. Its watershed, largely dedicated to agriculture, has witnessed rapid urban and industrial growth, contributing to water eutrophication in the Upper Gulf. To address this, a study conducted in 2016 and 2017 analyzed the exchange of dissolved nutrients and total suspended solids at the Bang Pakong River mouth across different seasons. During the rainy season, the concentration of nutrients and suspended solids was high. Hypoxia in near-bottom water occurred. The net flux of these materials depended on seasonal variations in runoff, with higher amounts (71.2×10^6 $m^3\cdot d^{-1}$) being washed into the sea during high runoff periods. In contrast, during the dry season in February, material accumulated in the river due to seawater intrusion, with net water flux (11.6×10^6 $m^3\cdot d^{-1}$) reversing. Significantly, the study found a strong correlation between the net flux of studied materials and average monthly rainfall in the Bang Pakong Basin. This correlation can be valuable in predicting substance transport from the river to the Upper Gulf, aiding in the assessment of nutrient enrichment in the region. Addressing eutrophication is critical for preserving the ecological balance of coastal ecosystems and ensuring the sustainability of these vital environments.

Keywords: Bang Pakong River, Eutrophication, Nutrient fluxes, Total suspended solid fluxes

INTRODUCTION

Land-sea interaction is essential for understanding the mechanisms of eutrophication and red tide in coastal seas. The amount of nutrients from rivers flowing into a coastal sea is very important information that is useful for environmental management to mitigate this environmental problem. In this study, we investigate nutrient and total suspended solid loading in a tropical estuary to understand the mechanism of eutrophication in a coastal sea.

The Bang Pakong River is in the eastern part of central Thailand (Figure 1). It has a total watershed area of approximately 10,707 km^2. The river is formed by the convergence of the Nakhon Nayok River and the Prachinburi River at Ban Sang District, Prachinburi Province. It then flows out into the Upper Gulf of Thailand at Bang Pakong District, Chachoengsao Province, with a total length of 120 km. 66% of the river basin area is used for agriculture, including rice fields, field crops, horticulture, aquaculture and livestock, 18% is a community, industrial and building area, and 16%

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Received 23 July 2023 / Accepted 31 October 2023

is forest (HAII, 2018). Human activities in the basin deteriorate river water quality from upstream to downstream before affecting coastal seas (Bubphamala *et al*., 2010; Senpradit *et al*, 2022). Seawater intrusion is found during the dry season, making it impossible to use water for consumption in this period (Junchompoo *et al*., 2006; Bubphamala *et al*., 2010; Yuenyong *et al*., 2019).

Most contaminated nitrogen and phosphorus compounds in natural water come from water exploited by human activities (Hungspreugs, 1986), while silicon comes from erosion or soil leaching (Mackenzie *et al*., 1967). These substances are commonly found in the form of dissolved organic and inorganic nutrients. If their amount is too high, eutrophication in natural water will result. Conditions where high levels of dissolved nutrients eventually lead to phytoplankton bloom or red tide in rivers, estuaries and coastal seas (Hungspreugs, 1986). When phytoplankton dies, aerobic bacteria use oxygen in decomposition, causing oxygen depletion in the water or hypoxia. Such phenomena affect the aquatic ecosystem, making life unable to survive (Hungspreugs, 1986). Red tide has been frequently reported along the eastern coast of the Upper Gulf of Thailand from the mouth of the Bang Pakong River to Sichang Island, Sriracha District, Chon Buri Province. The most intense blooms occur during the rainy season or from May to September (BIMS, 2006). The phenomenon caused economic damage to coastal farming in the area and tourism in Bangsaen Beach, which is one of the major tourist attractions in Chon Buri Province.

It was reported that the Bang Pakong River had high levels of soluble nutrients and was eutrophic throughout the year (Junchompoo *et al*., 2006). The water quality within the river was categorized as moderate to deterioration (Bubphamala *et al*., 2010). These studies highlight the potential of the Bang Pakong River as a source of nutrients that promote eutrophication in the upper Gulf of Thailand. Our research therefore aims to study the net fluxes of dissolved nutrients and total suspended solids between the Bang Pakong River mouth and the Upper Gulf of Thailand in different seasons.

MATERIALS AND METHODS

The flux measurement point is located at the mouth of the Bang Pakong River at latitude 13°28'11.81"N–13°28'39.11"N and longitude 100°58'33.68"E–100°58'16.79"E (Figure 1).

The study was conducted for a year with periods to cover seasonal changes in 2016 between April 19–20 (summer), July 6–7 (early rainy season), September 21–22 (rainy season), and November 14–15 (early winter), while in 2017 between February 14–15 (late winter) and April 5–6 (summer). An Acoustic Doppler Current Profiler (ADCP) was used to measure the water flux (Q). It was attached to a buoy and towed across the river using a small boat, three repetitions every 2.5 h up to 25 h to cover a tidal cycle. WinRiver II River Discharge Software (RD Instruments Acoustic Doppler Solutions, 2001) was used to control the instrument. Water quality was measured, and water samples were collected at the mid-river each time the water flux was measured. Temperature and salinity were measured using CTDs (Conductivity-Temperature-Depth sensor), including RINKO Profiler, model ASTD102. pH was measured using a Horiba pH meter, model PD110. Water samples were collected using a 2-L sampling cylinder at the upper water level (1 m below the water surface) and the lower water level (1 m above the sea bottom) for analysis of solid dissolved oxygen (DO), total suspended solid in water (TSS) and dissolved nutrients. The dissolved nutrients analyzed are ammonia, nitrite, nitrate, phosphate and silicate, dissolved organic nitrogen and phosphorus, and total dissolved nitrogen and phosphorus. The analytical methods and their references are shown in Table 1. The data were statistically analyzed based on non-parametric independent samples Kruskal-Wallis test and Spearman's Rank correlation coefficient at 95% confidence level or $p<0.05$.

The fluxes of dissolved nutrients and total suspended solids at a river mouth were used to estimate the transfer rates of these substances from the river to the sea or from the sea to the river (Siripong, 1981). The fluxes of dissolved nutrients and total suspended solids (F) are obtained from the product of the water flux (Q) and the concentration of each substance or parameter (C) at that time (t). The water flux data obtained from the ADCP are divided into two depth layers. The values at each depth were then multiplied by the dissolved nutrient and total suspended solids concentrations at each depth to obtain the material flux at the surface (s) and the bottom level (b). They are then summed to get the total fluxes across the river at time t. The net fluxes over a tidal cycle (T) are calculated according to Kjerfve and McKellar (1980) with Equation 1 (adapted from Dyer, 1973).

$$F = \frac{1}{T}\int_{t=0}^{T}(Q_sC_s+Q_bC_b)dt \qquad (1)$$

Table 1. Methods for analyzing dissolved oxygen, total suspended solids and dissolved nutrients.

Parameter	Symbol	Unit	Methods
Dissolved oxygen	DO	$mg\cdot L^{-1}$	Azide modification (Strickland and Parsons, 1972)
Total suspended solids	TSS	$mg\cdot L^{-1}$	GF/F Filter (APHA, 1992)
Ammonia	NH_4^+	$\mu g\ N\cdot L^{-1}$	Phenol-hypochlorite (Grasshoff *et al*., 1999)
Nitrite	NO_2^-	$\mu g\ N\cdot L^{-1}$	Diazotization (Strickland and Parsons, 1972)
Nitrate	NO_3^-	$\mu g\ N\cdot L^{-1}$	Cadmium reduction+Diazotization (Strickland and Parsons, 1972)
Dissolved inorganic nitrogen	DIN	$\mu g\ N\cdot L^{-1}$	Ammonia+Nitrite+Nitrate
Total dissolved nitrogen	TDN	$\mu g\ N\cdot L^{-1}$	Persulphate oxidation+Cadmium reduction +Diazotization (Grasshoff *et al*., 1999)
Dissolved organic nitrogen	DON	$\mu g\ N\cdot L^{-1}$	Total dissolved nitrogen–Dissolved inorganic nitrogen
Dissolved inorganic phosphate	DIP	$\mu g\ P\cdot L^{-1}$	Ascorbic acid (Strickland and Parsons, 1972)
Total dissolved phosphorus	TDP	$\mu g\ P\cdot L^{-1}$	Acid persulphate oxidation+Ascorbic acid (Grasshoff *et al*., 1999)
Dissolved organic phosphorus	DOP	$\mu g\ P\cdot L^{-1}$	Total dissolved phosphorus–Phosphate
Dissolved inorganic silicate	DISi	$\mu g\ Si\cdot L^{-1}$	Silicomolypdate (Strickland and Parsons, 1972)

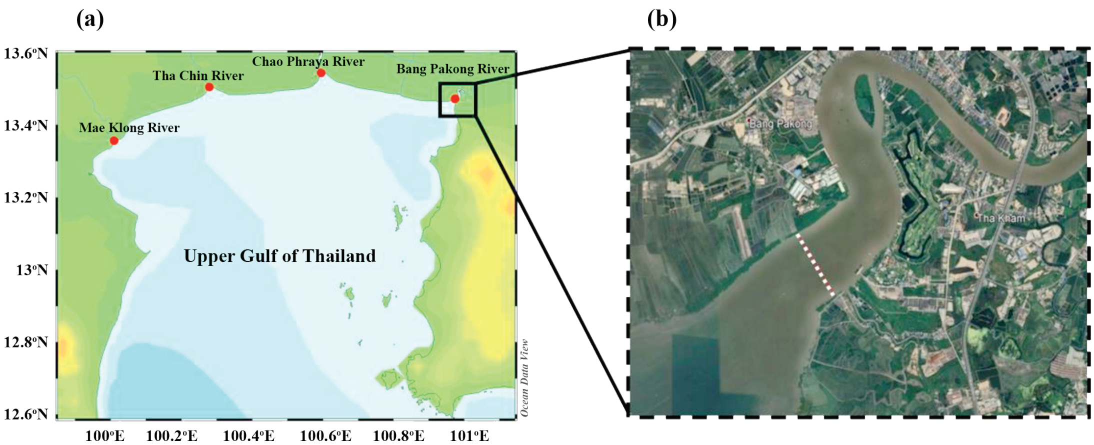

Figure 1. Map of the Upper Gulf of Thailand (a) and the Bang Pakong River estuary (b); The dashed line across the river shows the flux measurement line.

RESULTS AND DISCUSSION

Monthly cumulative rainfall data from the weather stations of the Meteorological Department in the Bang Pakong River basin namely Samut Prakan, Chachoengsao, Chon Buri, Nakhon Nayok and Prachin Buri in 2016–2017 are presented in Figure 2. The data show that the amount of rain differs at every station with a seasonal change. In 2016, the rainfall was low at the beginning of the year and started to increase due to the influence of the southwest monsoon winds in May. The highest average is about 300 mm·month^{-1} from July to September 2016. After October 2016, the amount of rain decreased according to the change in the monsoon wind from the southwest to the northeast monsoon. The average rainfall is lowest in December 2016, which is during the northeast monsoon season. In 2017, the amount of rain increased from March 2017 until the average was higher than 200 mm·month^{-1} from May to October 2017. Monthly cumulative rainfall in most of the Bang Pakong River Basin was highest at the Nakhon Nayok weather station, especially during the rainy season.

General water quality including temperature, salinity, pH, DO and TSS at the Bang Pakong River mouth in 2016–2017 are shown as Box and Whisker plot in Figure 3. Most parameters change seasonally. The average water temperature is highest in April 2016 (32.1±0.4 °C) and lowest in February 2017 (25.7±0.4 °C), respectively, corresponding to the summer and the late winter. Average salinity was high (greater than 30 psu) with a low standard deviation during summer and low with a high standard deviation during the rainy season. The average pH ranged from 6.9 to 7.6, with the lowest in the rainy season and the highest in the early winter. The average DO was below 4.0 mg·L^{-1} from the early rainy season to the early winter of 2016 and during the summer of 2017, with the lowest average during the rainy season (2.8±0.4 mg·L^{-1}) and the early winter (2.9±0.8 mg·L^{-1}), respectively. Averaged TSS was higher at the bottom than at the surface level in all seasons, except during the late winter when the mean values between the two water levels were indifferent. TSS had the highest mean and standard deviation of the year (249.3±116.0 mg·L^{-1}) at the early rainy season.

The results of the dissolved nitrogen group are shown with the Box and Whisker plot in Figure 4. Dissolved inorganic nitrogen (DIN) differs between seasons. Nitrate had the highest average in a year (925.7±220.4 µg N·L^{-1}) at the early rainy season. It declined while ammonia averaged the highest in a year (229.2±45.1 µg N·L^{-1}) in the rainy season. Nitrite was high in the rainy

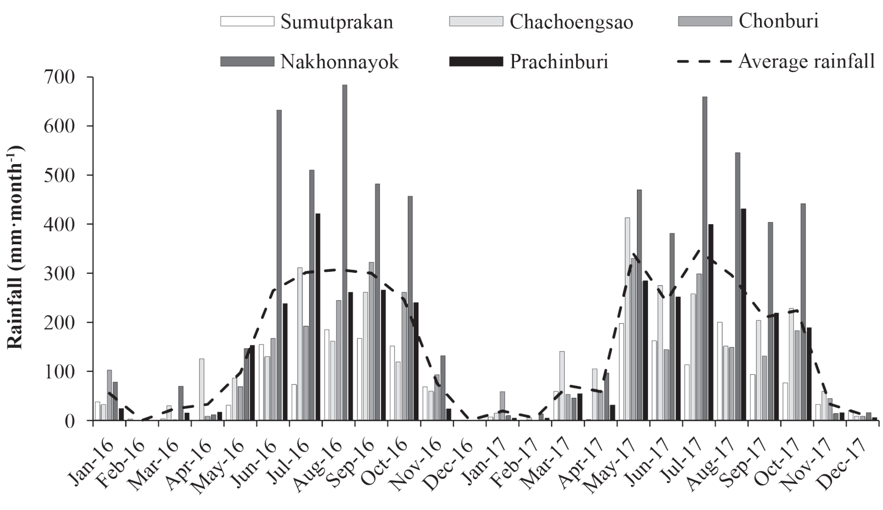

Figure 2. Monthly cumulative rainfall data from the weather stations of the Meteorological Department in the Bang Pakong River basin in 2016–2017.

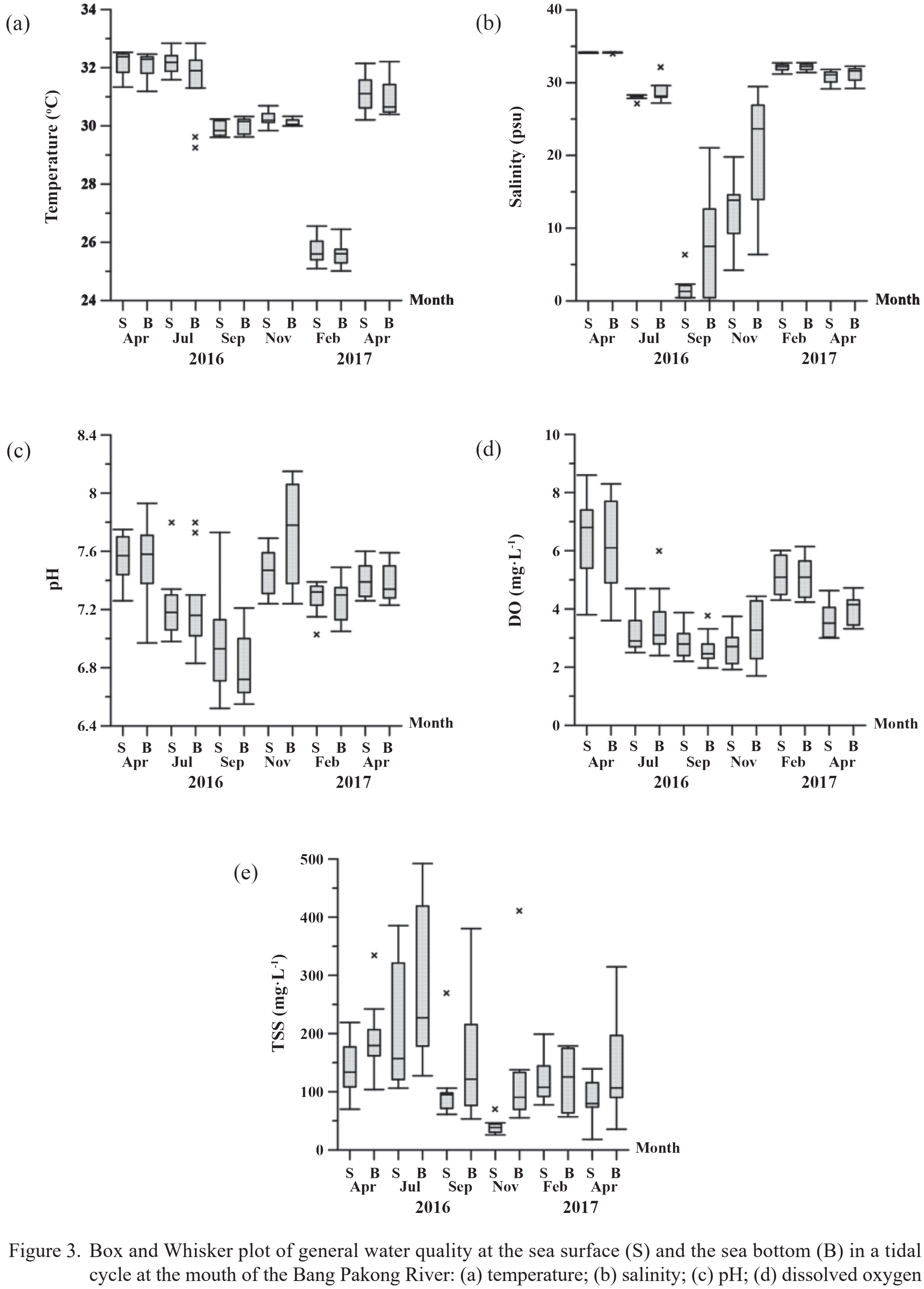

Figure 3. Box and Whisker plot of general water quality at the sea surface (S) and the sea bottom (B) in a tidal cycle at the mouth of the Bang Pakong River: (a) temperature; (b) salinity; (c) pH; (d) dissolved oxygen (DO); (e) total suspended solid (TSS).

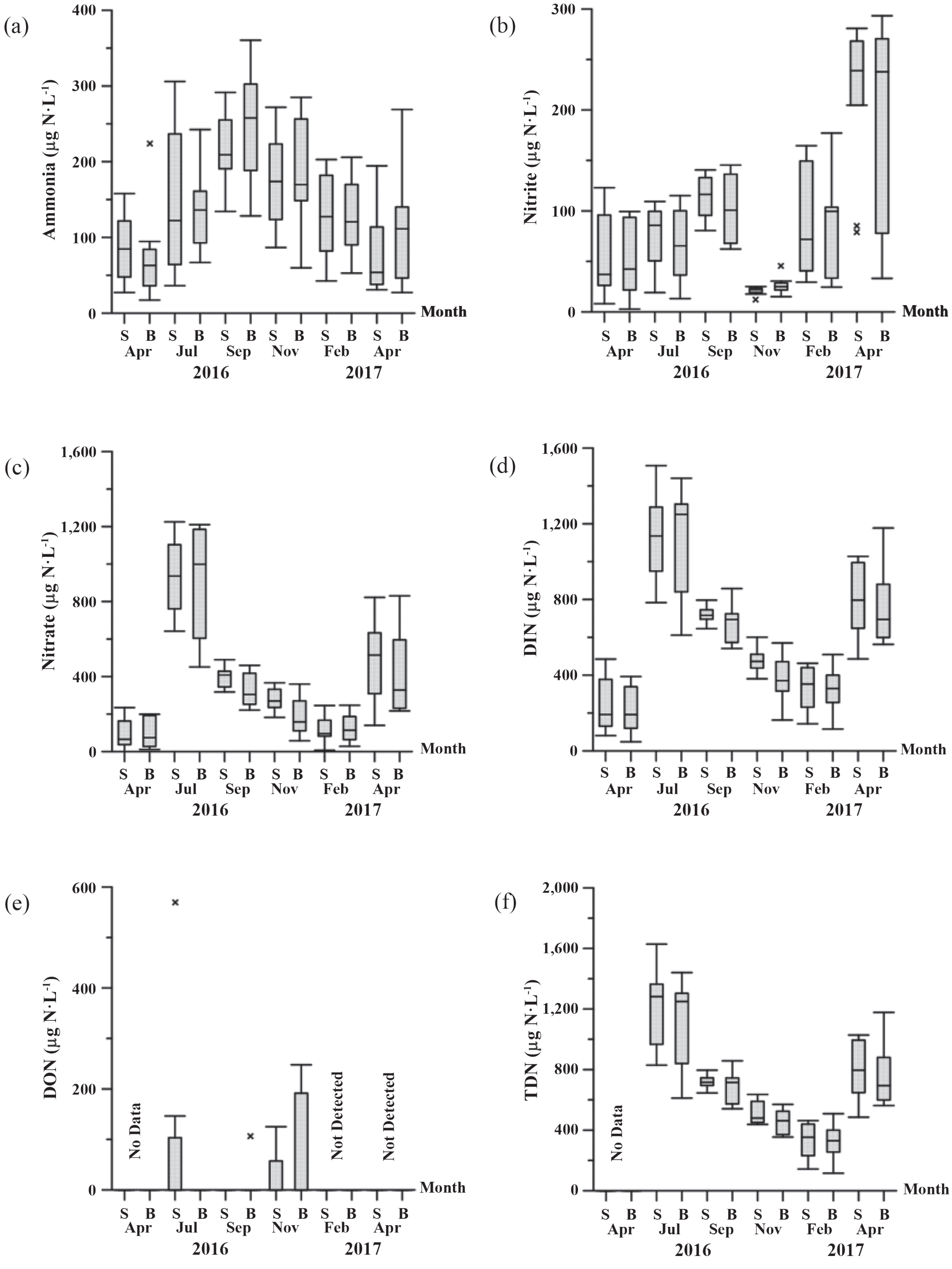

Figure 4. Box and Whisker plot of dissolved nitrogen nutrients at the sea surface (S) and the sea bottom (B) in a tidal cycle at the mouth of the Bang Pakong River: (a) ammonia; (b) nitrite; (c) nitrate; (d) dissolved inorganic nitrogen (DIN); (e) dissolved organic nitrogen (DON); (f) total dissolved nitrogen (TDN).

season as was ammonia, with the highest (217.5±71.7 µg N·L^{-1}) in the summer of 2017. Total dissolved nitrogen (TDN) at the early rainy season was highest in the year (1,174.0±252.4 µg N·L^{-1}), as well as nitrate and DIN (1,133.8±234.1 µg N·L^{-1}). Dissolved organic nitrogen (DON) was high in the early rainy season (40.1±85.0 µg N·L^{-1}) and the early winter (46.8±46.9 µg N·L^{-1}) and was very low (ND) in the late winter and the summer in 2017. Statistical tests showed that most dissolved nitrogen nutrients were not significantly different between depth but in a tidal cycle and the season.

Most of the total dissolved phosphorus (TDP) in the form of dissolved inorganic phosphate (DIP) had the highest mean at the early rainy season (240.6±101.0 µg P·L^{-1}) (Figure 5). Average dissolved organic phosphorus (DOP) was highest in the rainy season (13.5±7.5 µg P·L^{-1}) and lowest to undetectable at the early rainy season and the early winter. The statistical test showed that most of the dissolved phosphorus nutrients were not significantly different with depth but in a tidal cycle and season. The DIN:DIP mole ratio averaged in a tidal cycle was greater than 16 only during the rainy season. Most

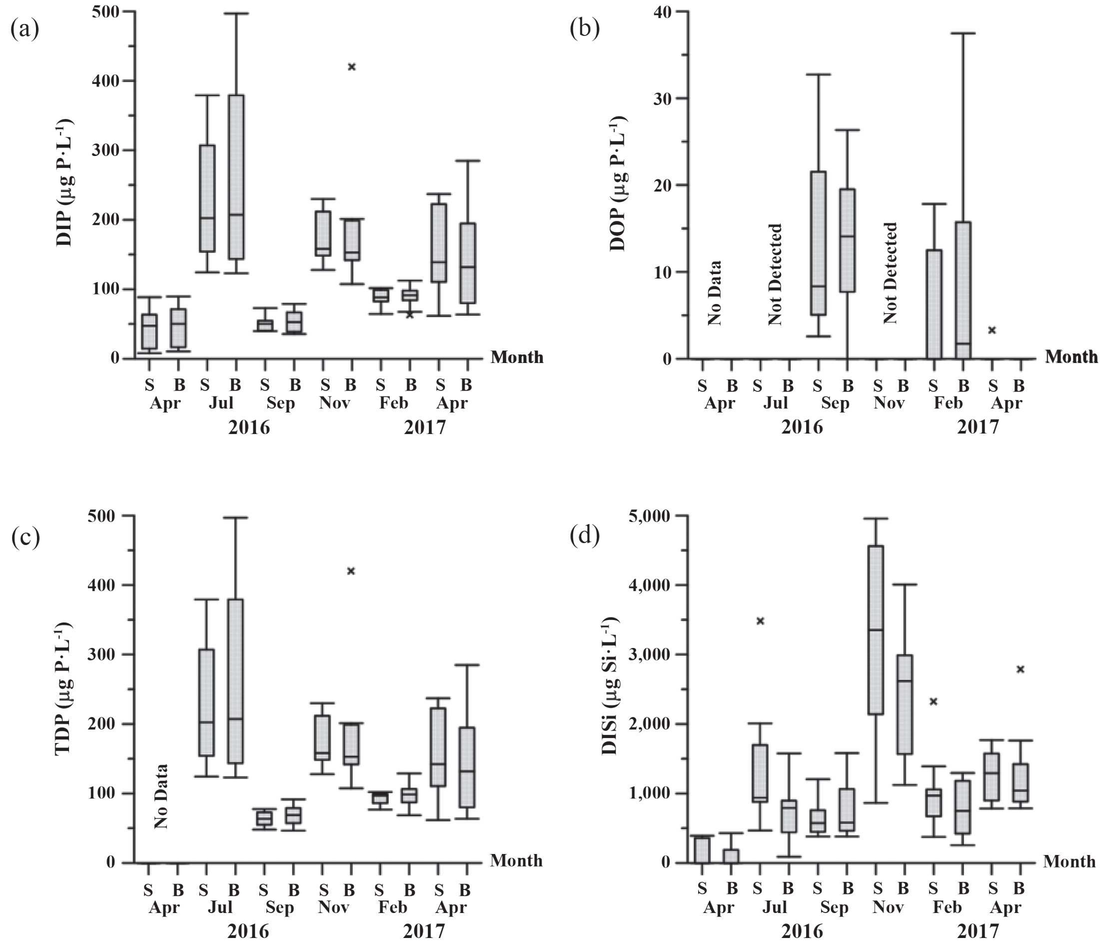

Figure 5. Box and Whisker plot of dissolved phosphorus and silicate nutrients at the sea surface (S) and the sea bottom (B) in a tidal cycle at the mouth of the Bang Pakong River; (a) dissolved inorganic phosphorus (DIP); (b) dissolved organic phosphorus (DOP); (c) total dissolved phosphorus (TDP); (d) dissolved inorganic silicate (DISi).

dissolved inorganic silicate (DISi) was high at the surface and low at the bottom. The mean DISi was high at the early rainy season and in the summer of 2017 and highest in the early winter (2,859.0± 949.6 µg Si·L^{-1}). Most DISi was not significantly different with depth and in a tidal cycle but between seasons.

The net water flux flowed toward the sea during the summer, the early and the rainy season, and the early winter in 2016 and in the summer of 2017 in the amount of 7.5×10^{6} m^{3}·d^{-1}, 43.4×10^{6} m^{3}·d^{-1}, 71.2×10^{6} m^{3}·d^{-1}, 14.3×10^{6} m^{3}·d^{-1} and 15.6× 10^{6} m^{3}·d^{-1}, respectively, with the highest value in the rainy season (Figure 6). The net water flux of 11.6×10^{6} m^{3}·d^{-1} was directed into the river during the late winter of 2017, this change of discharge is consistent with the monthly rainfall in the Bang Pakong River Basin, as shown in Figure 2. The net total suspended solids flux flowed towards the sea in a high amount at the early rainy season at the highest peak in the rainy season for 13.1×10^{3} t·d^{-1}. The net total suspended solids flux was low and directed towards the sea during the summer and into the river during the late winter.

The net flux of nitrate toward the sea was highest at the early rainy season at 44.3 t N·d^{-1} different from the net fluxes of ammonia and nitrite which were highest in the rainy season in the

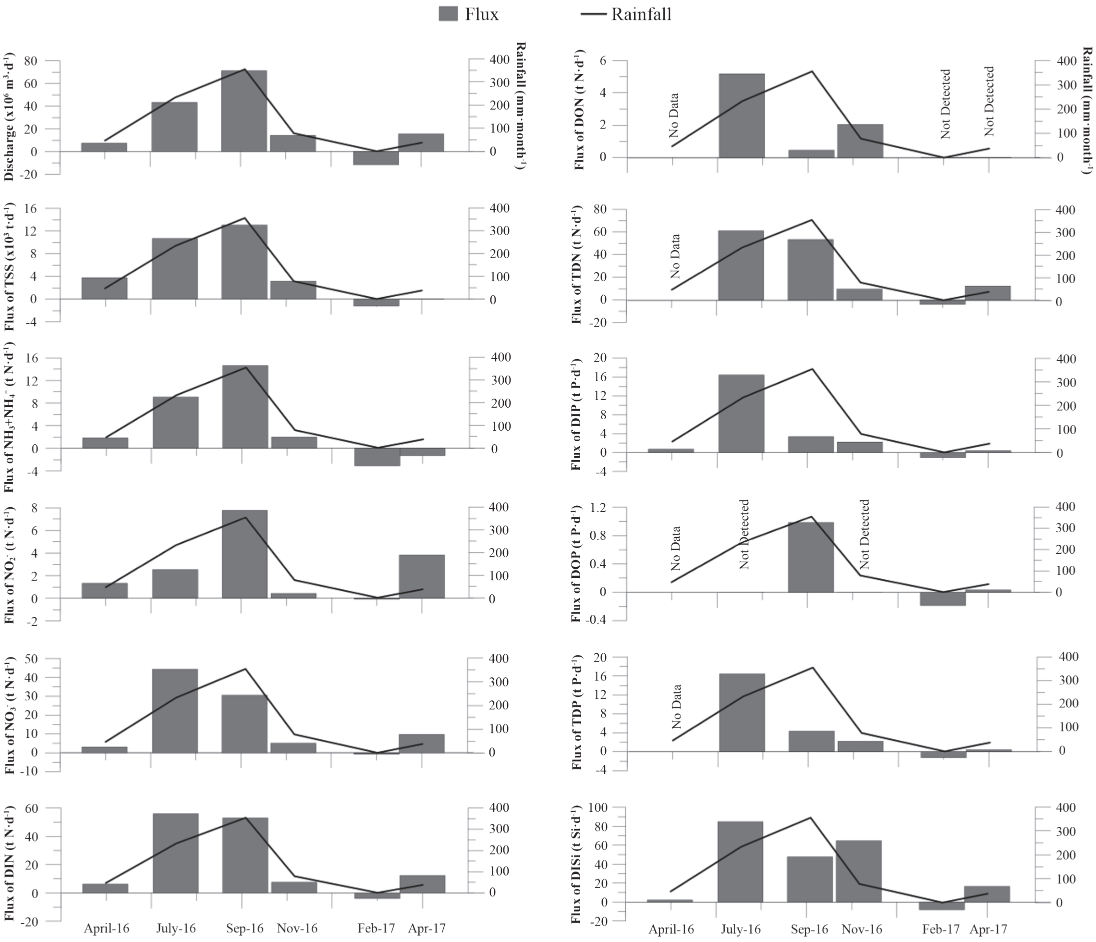

Figure 6. Monthly cumulative precipitation, the net fluxes of water, total suspended solids and dissolved nutrients at the Bang Pakong River Mouth in each season (April 2016–April 2017).

amount of 14.6 t $N{\cdot}d^{-1}$ and 7.8 t $N{\cdot}d^{-1}$, respectively, out to the sea. When included as a net DIN flux, it was high both at the early and the rainy season with the direction toward the sea in the amount of 55.9 t $N{\cdot}d^{-1}$ and 52.9 t $N{\cdot}d^{-1}$, respectively. The net flux of DON was found to be relatively low compared to DIN with the highest value of 5.2 t $N{\cdot}d^{-1}$ to the sea at the early rainy season. The DON flux was undetectable neither in the late winter nor in the summer of 2017. The net flux of TDN had the highest outflow direction at the early rainy season at 61.1 t $N{\cdot}d^{-1}$.

The net flux of TDP (DIP) was highest at the early rainy season at 16.4 t $P{\cdot}d^{-1}$ toward the sea. The net flux of DOP during the rainy season was 1.0 t $P{\cdot}d^{-1}$ in the seaward direction. DOP fluxes were not observed during the early rainy season and the early winter in 2016. The net flux of DISi was highest at the early rainy season as with other nutrients. It flowed out to the sea in the amount of 84.7 t $Si{\cdot}d^{-1}$. The net silicate flux decreased in the rainy season and increased again in early winter.

All water qualities changed seasonally. During summer (April), when the monsoon wind changes from the northeast to the southwest, the weather is hot resulting in high water temperatures. The rainfall is low, so the net water flux (outward direction) in the summer is also low. Due to the intrusion of seawater into the Bang Pakong River (Yuenyong *et al.*, 2019), the salinity and pH of the water are therefore high. The rainfall is high in the river basin during rainy season in June to October. The high cumulative rainfall from June to August and water flow delay cause the highest net water flux outflow to the sea in September. The drop in water temperature results from the heavy rainfall throughout the area. The interior of the Bang Pakong River is fresh due to large amounts of runoff pushing all the salt water out to the sea (Yuenyong *et al.*, 2019). During the late winter (February), the influence of the northeast monsoon wind makes Thailand cool and dry. The rainfall is lowest, thus the net water flux is low and direct from the sea into the river.

Dissolved oxygen changed significantly with the salinity and pH of the water (Figure 7). During the rainy season, the dissolved oxygen content was lower than 4.0 $mg{\cdot}L^{-1}$, below the coastal water quality standard (PCD, 2017). In summer and winter, the pollutants at the estuary are diluted by seawater, which is more dominant than runoff resulting in high DO. Total suspended solids at the Bang Pakong River Mouth come from various sources, such as the leaching of sediments into the river, resuspension on the riverbed, or the current convergence that causes sediment accumulation (Turbidity maxima). Total suspended solids were highest at the early rainy season. Statistical tests showed a positive correlation between total suspended solids and salinity. This indicates that most total suspended solids at the Bang Pakong River Mouth may come from offshore sediment resuspension. It is then transported into the area during high tide.

All dissolved nutrients were negatively correlated with salinity (Figure 7), indicating a runoff source. Most dissolved nutrients were found in the form of inorganic. Nutrients in the group of nitrogen and phosphorus come mainly from human activities. The concentration was highest in the early rainy season (July 2016), associated with the high rainfall onset during this time. Land use data show that 66% of the basin area comprises agricultural, rice fields, field crops and horticulture (HAII, 2018). These activities use fertilizers containing nitrate and phosphate to stimulate agricultural productivity. Fertilizer residues in the soil are leached into the river in high concentrations, but low volume, during the dry season. When the runoff increases at the early rainy season, they are carried out to the river mouth in higher concentrations than in other periods. Although DIN was high, the N:P mole ratio (Redfield, 1958) suggests that nitrogen be limited for phytoplankton growth in all seasons except in the rainy season. Phosphorus was limited due to the large increase in nitrogen in this season.

In addition to its source from soil erosion and leaching, DISi may be increased by the desorption from total suspended solids in the presence of salinity in the estuary (Mackenzie *et al.*, 1967; Wilke and Dayal, 1982). Therefore, silicate concentrations were highest in the early winter (November 2016), the first phase when salinity begins to dominate the runoff and penetrates the Bang Pakong River. The silicate release process from the suspension may occur above the study point and be blown out to sea during low tide.

The net flux of all substances released into the sea in large quantities from the early to the middle of the rainy season (July to September 2016) was consistent with the red tide season in the east of the Upper Gulf of Thailand. BIMS (2006) reported the strong red tide phenomenon along the coast of Chon Buri Province, located in the northeast of the Upper Gulf of Thailand, during the southwest monsoon season or from May to September every year. This report is consistent with Munhapon *et al*. (2022) who found that this area was most affected by runoff from the Bang Pakong River during the southwest monsoon season. As the net flux of various substances was found to be high during this period, this study supports factors that promote the phytoplankton bloom in coastal areas of Chon Buri Province previously reported. In the winter, it was the period when the net flux of all substances flowed into the Bang Pakong River, so there were no reports of red tide in this coastal area.

The net flux of water, total suspended solid and all dissolved nutrients have a statistically significant relationship with monthly cumulative rainfall, which can be used to create linear regression equations as shown in Table 2. The obtained equations can be used to forecast the net flux of water, total suspended solids and dissolved nutrients from the monthly cumulative rainfall data during 2011–2020 as shown in Figures 8 and 9.

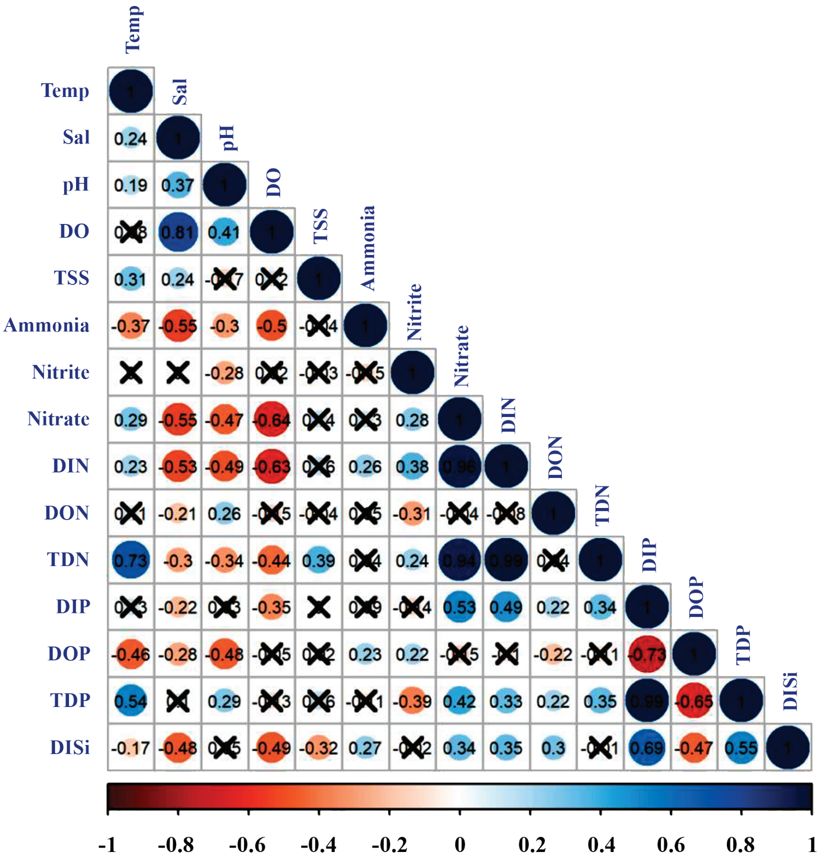

Figure 7. The relationship (shown as correlation coefficient, r) between physical and chemical water qualities at the Bang Pakong River Mouth in a tidal cycle from all observations during 2016–2017.

Note: r values marked with “×” are non-significant (p>0.05, 2-tailed) and ones without marks are significant (p< 0.05, 2-tailed); Abbreviations as shown in Figure 3–5

Table 2. Linear regression equations between net fluxes at the Bang Pakong River Mouth (y) and monthly cumulative rainfall in the river basin (x).

y	Linear equation	r^2
Flux of water ($\times 10^6$ $m^3 \cdot month^{-1}$)	y = 6.129x-77.538	0.885
Flux of TSS ($\times 10^3$ $t \cdot month^{-1}$)	y = 1.228x-8.531	0.910
Flux of NH_3+NH_4^+ (t $N \cdot month^{-1}$)	y = 1.404x-63.006	0.888
Flux of NO_2^- (t $N \cdot month^{-1}$)	y = 0.449x+21.572	0.491
Flux of NO_3^- (t $N \cdot month^{-1}$)	y = 3.926x-38.872	0.920
Flux of DIN (t $N \cdot month^{-1}$)	y = 5.779x-80.305	0.985
Flux of DON (t $N \cdot month^{-1}$)	y = 0.277x+6.082	0.332
Flux of TDN (t $N \cdot month^{-1}$)	y = 6.196x-115.429	0.983
Flux of DIP (t $P \cdot month^{-1}$)	y = 1.121x-31.300	0.578
Flux of DOP (t $P \cdot month^{-1}$)	y = 0.064x-4.468	0.427
Flux of TDP (t $P \cdot month^{-1}$)	y = 1.208x-42.549	0.620
Flux of DISi (t $Si \cdot month^{-1}$)	y = 6.372x+232.231	0.585

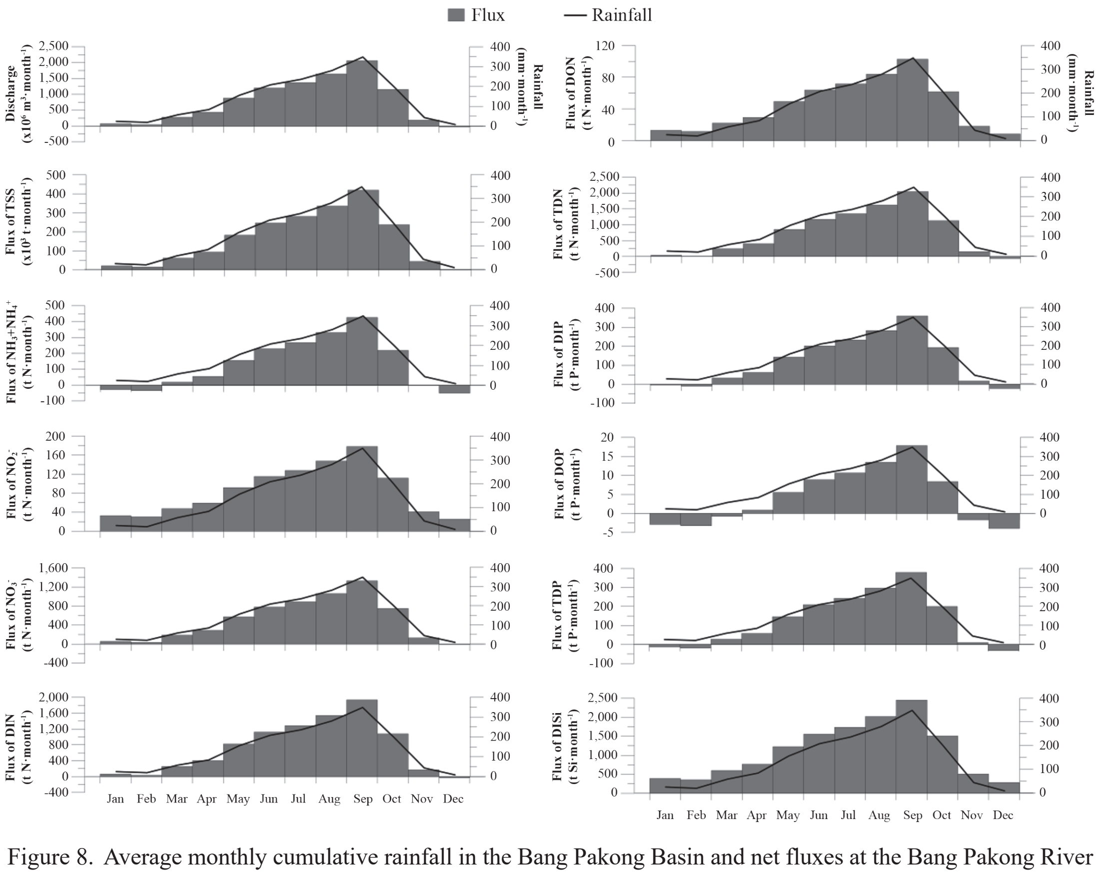

Figure 8. Average monthly cumulative rainfall in the Bang Pakong Basin and net fluxes at the Bang Pakong River Mouth during 2011–2020.

Note: Abbreviations as shown in Figure 3–5

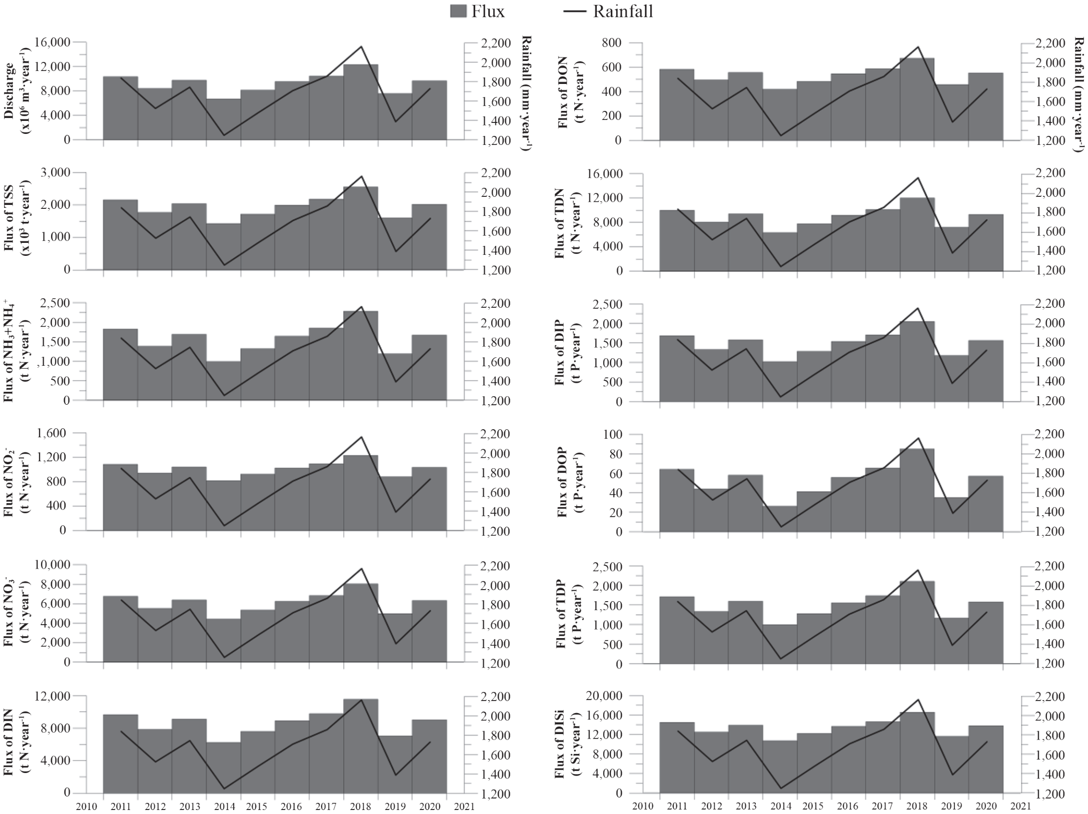

Figure 9. Average yearly cumulative rainfall in the Bang Pakong Basin and net fluxes at the Bang Pakong River Mouth during 2011–2020.
Note: Abbreviations as shown in Figure 3–5

The average monthly cumulative rainfall in the Bang Pakong River Basin from 2011 to 2020 shows little rainfall from November to February. The lowest rainfall is in December for 8.5 mm·$month^{-1}$, while the highest one is in September for 348.6 mm·$month^{-1}$ (Figure 8). The fluxes of total suspended solids and dissolved nutrients were estimated flowing to the sea during March and October. The largest fluxes occur in September, similar to the rainfall variation. From November to February, the net fluxes are low, and some flow into the river. According to the annual forecast (Figure 9), 2014 and 2019 are the periods when the net fluxes of all substances are smallest while 2018 has the largest fluxes in 10 years. The equations based on rainfall data to forecast the net fluxes of materials at the Bang Pakong River Mouth should be used carefully for some parameters. R^2 of the net flux equations of nitrite, DON and DOP is less than 0.5, indicating that the accuracy of the predicted values is less than 50%.

Fluxes of dissolved inorganic nitrogen (DIN = Ammonia+Nitrite+Nitrate), phosphorus in terms of phosphate (DIP) and silica in terms of silicate (DISi) of the Bang Pakong River were compared with other rivers including the Mekong River, the Red River Delta in Vietnam, the Tha Chin River and the Trat River in Thailand. The net fluxes of all substances flowing out to the sea vary according to the watershed, the larger the watersheds, the higher the fluxes (Figure 10). When the proportion of the fluxes per watershed area is compared, the values of the Mekong River are relatively low although the net fluxes are the largest among them. This is related to land uses in the Mekong watershed, which has relatively moderate agriculture, high forest, and low urban areas (Table 3). Forest absorbs while agriculture and urban release nutrients into natural water. The nutrient fluxes per watershed area are largest in the Red River Delta (Luu *et al*., 2012) because of high urban, and low forest with moderate agriculture areas.

Table 3. Comparison of land use between the Bang Pakong River and other rivers.

River	Watershed Area (km^2)	Discharge ($km^3 \cdot year^{-1}$)	Land use (%)					
			Agriculture	Forest	Urban	Wetland	Unused	Total
MKR[1,2]	760,000	467.0	49	42	5	2	3	100
RRD[3]	14,312	99.2	51	13	21	8	7	100
TCR[1,4]	13,492	22.6	76	9	9	3	3	100
BPR[1]	10,707	9.5	66	16	11	2	5	100
TR[5]	1,557	2.1	55	32	4	4	5	100

Remarks: [1]HAII (2018); [2]Manaka *et al*. (2015); [3]Luu *et al*. (2012); [4]Thaipichitburapa *et al*. (2010); [5]LDD (2016)

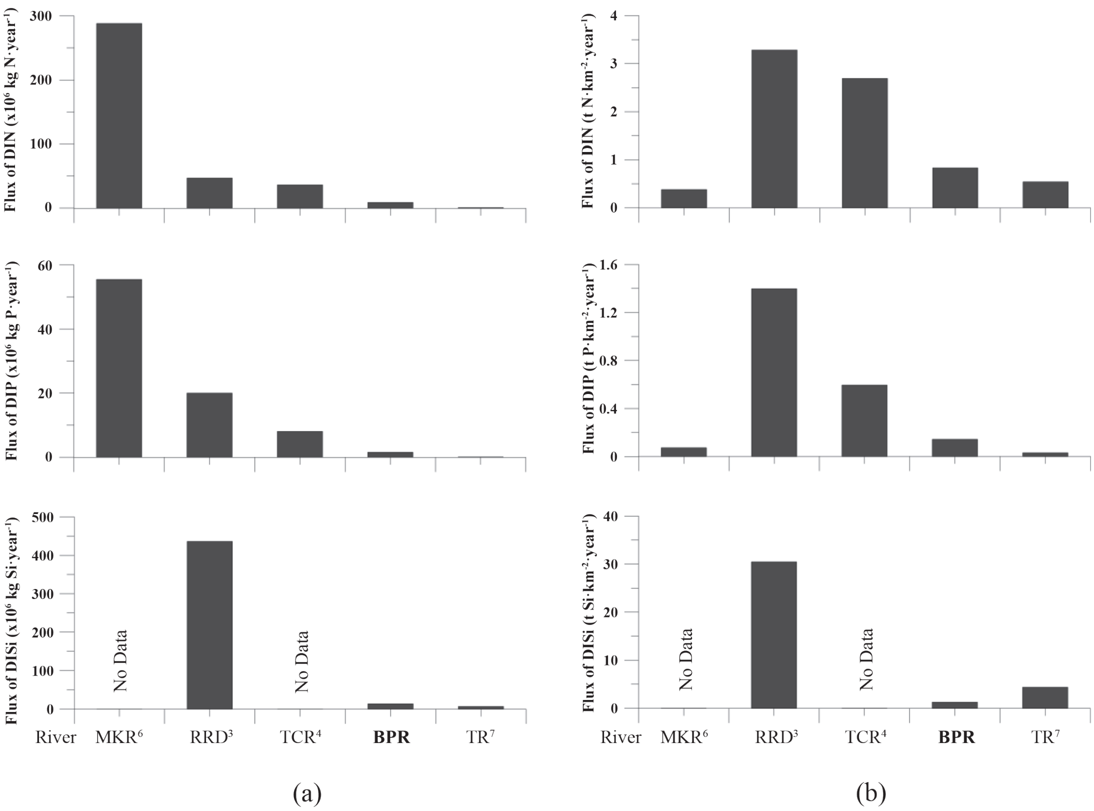

Figure 10. Comparison of: (a) yearly net fluxes of DIN, DIP and DISi between the Bang Pakong River and other rivers; (b) the net fluxes per watershed area.

Note: Flux of DIP in the MKR using TDP (total dissolved phosphorus); MKR = Mekong River; RRD = Red River Delta; TCR = Tha Chin River; BPR = Bang Pakong River; TR = Trat River

Remarks: [6]Liljeström *et al*. (2012); [3]Luu *et al*. (2012); [4]Thaipichitburapa *et al*. (2010) and [7]Meesub *et al*. (2021)

The Tha Chin River basin also released high nutrients per basin area among other Thailand rivers due to high aquaculture and low forest. However, because of low urban areas, the released nutrients per watershed area are lower than in the Red River Delta. According to HAII (2018), most of the activities in the Tha Chin River are agriculture (76%), which is about 10% more than the Bang Pakong River. Thaipichitburapa *et al*. (2010) reported that the population of the Tha Chin River watershed is mainly engaged in rice farming and farmland. The demand for large quantities of agricultural products, therefore, leads to the use of more fertilizers and pesticides. The basin of this river is also an important livestock area in the country. The high amount of waste discharged into the waterways by these activities also contributes to the high value of the net DIN and DIP fluxes flowing into the sea.

The majority of the Trat River basin is 55% of agriculture, with only 4% of the community land (LDD, 2016). This results in less net fluxes per watershed area of DIN and DIP than the Bang Pakong River for approximately 1.6 times and 4.8 times, respectively. The Bang Pakong River had a watershed area about 6.9 times wider than the Trat River, but the DISi net flux was about 3.3 times lower than the Trat. According to a study by Meesub *et al*. (2021), the upstream area of the Trat River has a high slope causing erosion and leaching of minerals from the soil surface, especially nutrients with high silicon content, into natural water sources. Thus, the amount of silicate in the water source is much higher than in the Bang Pakong River despite the much smaller watershed area.

CONCLUSION

The study of the net flux of total suspended solids and dissolved nutrients in the Bang Pakong River mouth during 2016–2017 showed that seasonal changes affected the physical and chemical water quality in the Bang Pakong River. The influence of the southwest monsoon season results in the leaching of substances into the water source, resulting in the net water fluxes of total suspended solids and nutrients flowing into the sea. The highest fluxes occur during the early to the middle of the rainy season (July to September 2016). During the northeast monsoon, the fluxes decreased until the flow directed into the Bang Pakong River resulted from seawater intrusion (February 2017). The net fluxes of all substances were significantly correlated with the monthly precipitation in the watershed, and which could be used to predict the net fluxes of water, total suspended solids and dissolved nutrients for Bang Pakong River.

ACKNOWLEDGEMENTS

Thank you to the Eastern Marine and Coastal Resources Research Center, the Department of Marine and Coastal Resources Mr. Supawat Kan-atireklap and Mrs. Suthida Kan-atireklap for supporting the instruments for the field observations, the Department of Aquatic Sciences Faculty of Science, Burapha University for all research facilitation, and Ms. Siraporn Tong-U-dom, Mr. Parattagon Phromkot, Mr. Dudsadee Leenawarat and other students in Oceanography group for helping with data collection and water quality analysis. This research was partially funded by revenue from the Thai government grant (National Budget) Fiscal Year 2016 (Additional), Burapha University through the National Research Council of Thailand, contract number 31/2559. This study was conducted in collaboration under the Core-to-Core Program (B. Asia-Africa Science Platforms) and JSPS KAKENHI Grant Number 26302001 of JSPS and is partially supported by JSPS Core-to-core CREPSUM JPJSCCB20200009.

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