Seasonal Fluxes of Dissolved Inorganic Nutrients and Suspended Solids at the Mouth of the Prasae River, Eastern Thailand

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ABSTRACT

This study investigates the seasonal fluxes of freshwater, suspended solids, and dissolved inorganic nutrients (ammonia, nitrite, nitrate, phosphate, and silicate) at the Prasae River mouth in eastern Thailand. Water sampling and flux measurements were conducted over eight time points between 2016 and 2017, covering both dry and wet seasons. Water quality and suspended solids showed pronounced seasonal and vertical variations driven by monsoon rainfall and tides, with strong stratification in October 2016 and September 2017. Ammonia spiked to >600 µg N·L^{-1} in June 2016 and ~280 µg N·L^{-1} in September 2017, while nitrite (~10 µg N·L^{-1}) and nitrate (~350 µg N·L^{-1}) peaked in October 2016, reflecting rapid terrestrial input. Phosphate reached ~100 µg P·L^{-1} during peak runoff, and silicate remained high (>1,000 µg Si·L^{-1}), peaking near 3,000 µg Si·L^{-1}. Suspended solids were low at the surface (<40 mg·L^{-1}) but elevated near the bottom, indicating sediment resuspension. River fluxes showed strong monsoonal influence, with peak wet-season exports of nitrate (>2,200 kg N·d^{-1}), phosphate (~480 kg P·d^{-1}), and silicate (~10,000 kg Si·d^{-1}); ammonia and nitrite fluxes were more variable. During the wet season, nutrient exports were mainly discharge-driven, whereas internal processes were more influential in the dry season. TSS fluxes were episodic, indicating alternation between source and temporary sink. Compared with the Rayong, Trat, and Chanthaburi Rivers, the Prasae River shows elevated inorganic nutrient levels.

Keywords: Nutrient flux, Prasae River, Suspended solids flux, Water quality

INTRODUCTION

Estuarine environments are highly dynamic transitional zones that mediate the transfer of materials, such as freshwater, suspended solids, and dissolved nutrients, from terrestrial to marine ecosystems. These fluxes shape the physical, chemical, and biological conditions of coastal waters. Among the most critical constituents transported through riverine systems are suspended sediments and dissolved nutrients, particularly bioavailable forms of nitrogen and phosphorus that directly influence phytoplankton productivity and water quality. Excessive nutrient loading can lead to coastal eutrophication, harmful algal blooms, and oxygen depletion, whereas sediment transport is linked to water turbidity, light penetration, and benthic habitat alteration (Nixon, 1995; Cloern, 2001). Understanding what controls the magnitude and timing of these fluxes is therefore essential, particularly in regions where climatic and land-use variability strongly influences river discharge and material transport.

The magnitude and composition of riverine fluxes are governed by a combination of hydrological, geological, and anthropogenic factors. In tropical

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Southeast Asia, seasonal variation is especially pronounced due to the monsoon-driven climate. During the wet season, increased rainfall and runoff enhance the mobilization of land-derived materials into estuarine and coastal systems. For example, the Mekong River delivers large pulses of sediments and nutrients to the South China Sea during the rainy season, accounting for more than 75% of its annual discharge (Hoang *et al*., 2016). Likewise, research in the Red River Delta, Vietnam, shows that nutrient inputs to estuaries are significantly higher during monsoonal months, primarily due to agricultural runoff and increased river flow (Le *et al*., 2005). These seasonal hydrological pulses have also been observed in the Bang Pakong River in eastern Thailand, where wet-season discharge results in markedly elevated fluxes of dissolved inorganic nutrients and suspended solids into the upper Gulf of Thailand (Yuenyong *et al*., 2023). In contrast, during the dry season, reduced flows allow for greater retention and transformation of materials within estuarine zones. Therefore, capturing seasonal dynamics is essential for understanding the role of rivers in coastal biogeochemical cycles.

Thailand's eastern Gulf coast is home to several small-to-medium rivers that flow into nutrient-sensitive marine ecosystems. The Prasae River Basin in Rayong Province, eastern Thailand, displays a diverse pattern of land use that reflects the interaction between natural features and human activities. Based on Landsat satellite imagery analysis, land use in 2018 was classified into four main categories: vegetation/agriculture (69.08%), community and built-up areas (15.86%), water bodies (1.08%), and bare land (13.26%) (Intacharoen *et al*., 2021). The upper basin is primarily covered by mixed fruit orchards and plantation forests, while the middle basin contains rural settlements and expanding residential zones. In the lower basin, aquaculture ponds and coastal communities dominate, particularly near the river mouth. Mangrove forests, both natural stands and reforested areas, line the coastal fringe, offering ecological services such as sediment retention and nursery habitats. However, the river also receives diffuse sources of pollution, such as fertilizers, organic waste, and suspended solids, making it a potential contributor to downstream and coastal water quality issues (Thaipichitburapa *et al*., 2019).

Although national monitoring programs in Thailand have focused on water quality indices in rivers and coastal zones, there remains limited quantitative information on material fluxes at the river-sea interface, especially for smaller river systems such as the Prasae River. For small-to-medium rivers along the eastern Gulf of Thailand, including the Prasae River, there is a particular lack of process-based, flux-oriented assessments at the estuarine boundary, despite increasing anthropogenic pressures. Understanding both the quantity and variability of these fluxes is essential for regional nutrient budgeting, coastal management planning, and assessing the potential for eutrophication in nearshore waters. This study aims to quantify the seasonal fluxes of suspended sediments and dissolved inorganic nutrients–specifically ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), and silicate (SiO_4^{4-})–at the mouth of the Prasae River. Through repeated field surveys across multiple transects during different monsoonal phases, and by combining discharge data with nutrient concentration measurements, we estimate the total export or retention of these materials at the estuarine boundary. The results of this study provide insights into the role of small rivers in material cycling in the Gulf of Thailand and support evidence-based strategies for integrated watershed and coastal zone management.

MATERIALS AND METHODS

The study was conducted at the Prasae River mouth (Figure 1), located in Klaeng District, Rayong Province, eastern Thailand, where the river discharges into the eastern coast of the Gulf of Thailand. The observation point was situated near coordinates 12°42′1.17″N, 101°42′6.99″E, and the river width at the transect was approximately 140 meters. The average depth range between 5.1–5.7 m. Sampling and measurements were carried out during eight tidal cycles on the following dates: 29–30 January (dry), 4–5 April (dry), 23–24 June (wet), 24–25 August (wet), 17–18 October (wet), and 28–29 December (dry) of 2016, and 8–9 April (dry), 16–17 June (wet), and 16–17 September (wet) of 2017. Each field campaign covered a full tidal cycle (~25 h). It should be noted that Thailand has the Southwest Monsoon (May–October) and the Northeast Monsoon (November–February). In this study, we define the wet season as May to November and the dry season as December to April.

During each sampling, vertical profiles of water quality parameters were obtained using a Conductivity–Temperature–Depth sensor (CTD; Rinko-Profiler ASTD102, JFE Advantech Co., Ltd.) and a multi-parameter probe (YSI 6920) to measure temperature, salinity, and pH at surface (~1 m depth) and near-bottom (~1 m above the bed) layers. Water current velocities were measured using an Acoustic Doppler Current Profiler (ADCP; Workhorse Sentinel 600 kHz, Teledyne RD Instruments) mounted on a small boat that transected the river cross-section. Water samples were collected using a 2 L vertical water sampler at the surface and at the bottom depths at the center of the main channel. The samples were immediately filtered through precombusted GF/C filters (pore size 1.2 µm), and the retained material was used to determine total suspended solids (TSS), while the filtrate was analyzed for dissolved inorganic nutrients, including ammonia (NH_3+NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), and silicate (SiO_4^{4-}). Analytical methods followed standard protocols (Table 1).

Table 1. Analytical methods for water quality parameters.

Parameters	Analytical methods
TSS (mg·L^{-1})	GF/C Filter (APHA, 1992)
Ammonia (µg N·L^{-1})	Phenol–hypochlorite (Grasshoff *et al*., 1999)
Nitrite (µg N·L^{-1})	Diazotization (Strickland and Parsons, 1972)
Nitrate (µg N·L^{-1})	Cadmium reduction + Diazotization (Strickland and Parsons, 1972)
Phosphate (µg P·L^{-1})	Ascorbic acid (Strickland and Parsons, 1972)
Silicate (µg Si·L^{-1})	Silicomolypdate (Strickland and Parsons, 1972)
DO (mg·L^{-1})	Winkler titration (Strickland and Parsons, 1972)

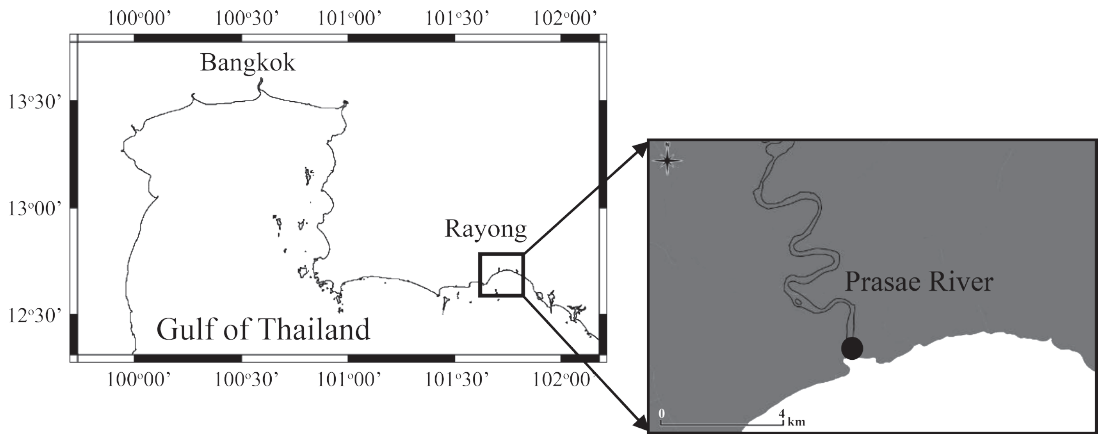

Figure 1. Map of the study area showing the Prasae River mouth in Rayong Province, eastern Thailand. The black circle indicates the sampling station for flux measurements.

Water and material fluxes were calculated based on the cross-sectional integration of current velocities and concentrations using the following equation (Dyer, 1973):

$$F = \frac{1}{T}\int_{t=0}^{T}(Q_s\,C_s + Q_b\,C_b)dt$$

Equation 1

where F is the net flux ($g{\cdot}s^{-1}$), Q_s and Q_b are the water fluxes ($m^3{\cdot}s^{-1}$) in the surface and bottom layers, C_s and C_b are the concentrations ($g{\cdot}m^{-3}$) of the target parameter in the respective layers, and T is the time span of the tidal cycle (25 h). Net fluxes (hereafter "fluxes") were averaged over 11-time intervals during each tidal cycle (every 2.5 h), and replicates (n = 3) were taken to minimize measurement uncertainty.

Statistical analyses–correlation and principal component analysis (PCA)–and their visualizations were conducted in R version 4.5.0 (R Core Team, 2024).

RESULTS AND DISCUSSION

Monthly rainfall in the Prasae River Basin during 2016 and 2017 showed distinct seasonal variability, with precipitation peaking between May and October, corresponding to the southwest monsoon season (Figure 2). The highest rainfall was recorded in June, July, August, and October 2016, each exceeding 350 mm, while the dry season months (November to April) generally received less than 100 mm. Diagonally shaded bars indicate the months in which field sampling was conducted to measure water quality and material fluxes, specifically January, April, June, August, October, and December in 2016, and April, June, and September in 2017. This seasonal rainfall distribution is a key driver of hydrological and biogeochemical processes in this estuarine system.

Water quality parameters at the Prasae River mouth showed clear temporal and vertical variations influenced by seasonal and tidal dynamics (Figure 3). Surface water temperature ranged from approximately 26.7 °C to 32.1 °C, with higher values observed during the summer and rainy seasons (April, August, and October 2016, April and June 2017) and lower values during winter and periods of heavy rainfall (January, June, and December 2016, and September 2017). Salinity showed marked seasonal shifts, particularly in the surface layer. Sharp declines in surface salinity were observed in October 2016 and September 2017, coinciding with periods of high precipitation during the wet season (Figure 2). In these months, surface salinity dropped below 10 psu, while bottom salinity remained relatively high (>25 psu), resulting in strong stratification. This highlights a classic estuarine mixing regime where freshwater overlays

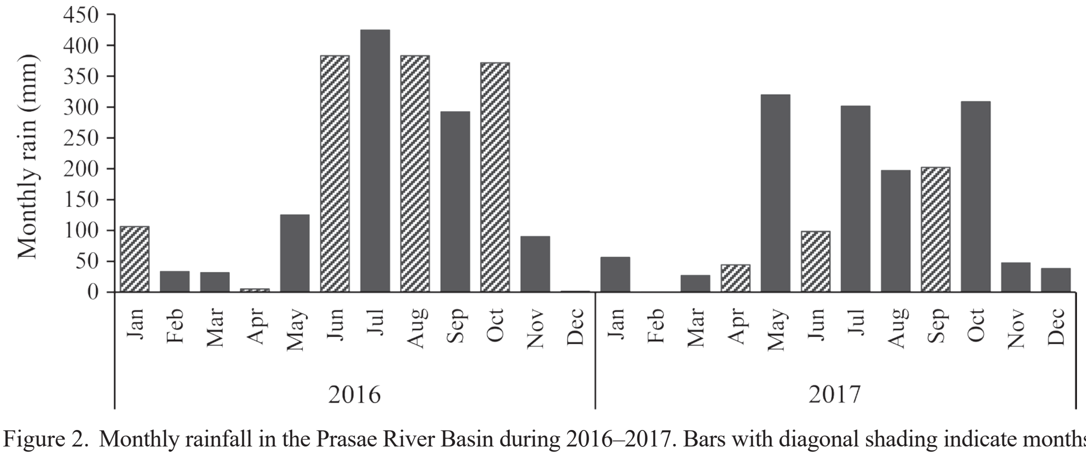

Figure 2. Monthly rainfall in the Prasae River Basin during 2016–2017. Bars with diagonal shading indicate months when field sampling for water quality and material fluxes was conducted.

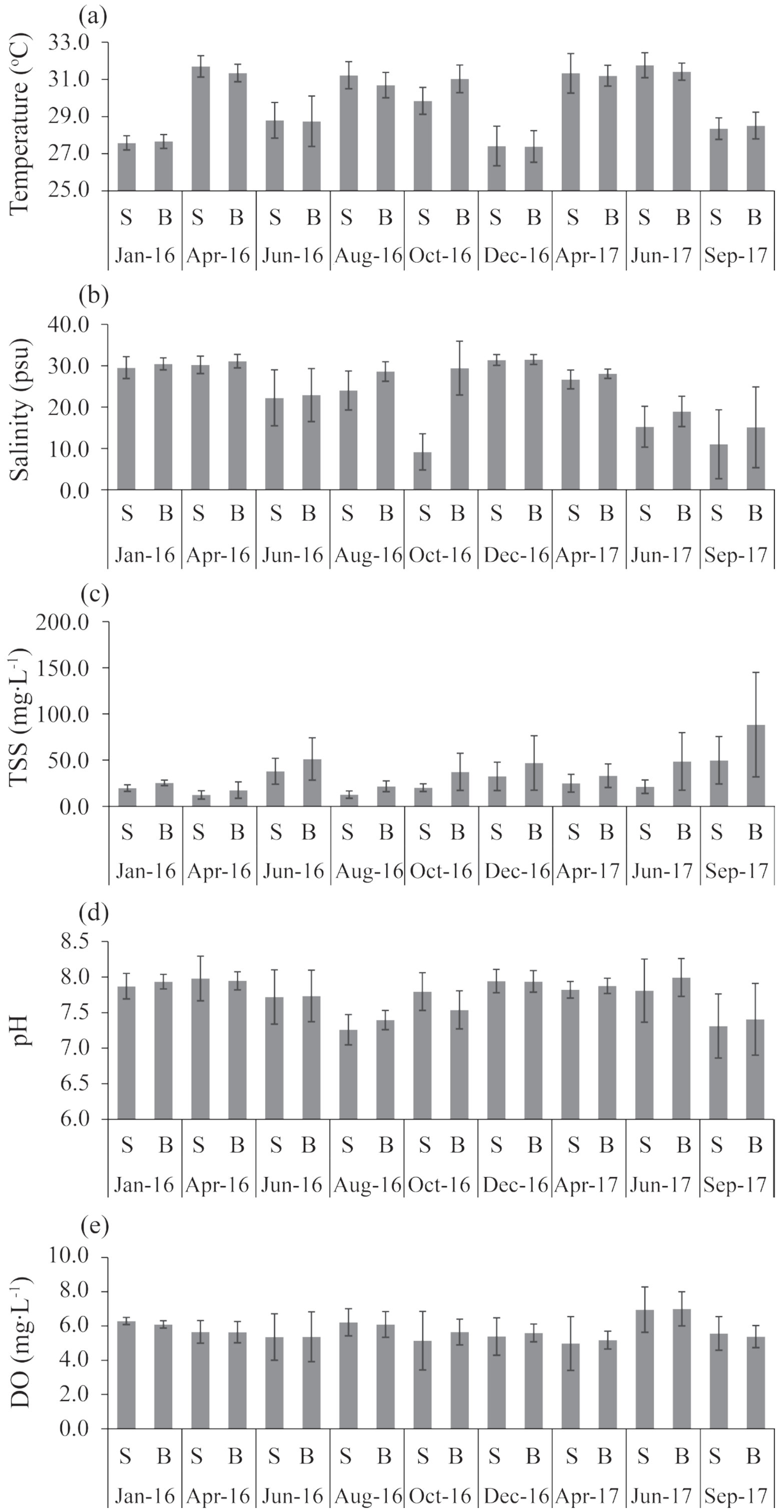

Figure 3. Temporal variations in surface (S) and bottom (B) water quality parameters at the Prasae River estuary during 2016–2017. Panels show (a) temperature, (b) salinity, (c) total suspended solids (TSS), (d) pH, and (e) dissolved oxygen (DO). Error bars represent standard deviations.

saline bottom waters, with potential implications for vertical nutrient transport and oxygen dynamics. The water column in other months appeared to be well-mixed or partially stratified.

Even with heavy rain in June and August 2016, surface salinity remained >20 psu, unlike October 2016 and September 2017 when similar rain led to lower salinity. This deviation from the expected pattern suggests that freshwater discharge at the estuary is not governed solely by local precipitation. Other hydrological factors, such as water retention and delayed runoff within the watershed, soil moisture conditions, upstream reservoir regulation, or groundwater contributions, may influence the timing and magnitude of freshwater inflow to the estuary. Tidal dynamics and estuarine circulation may also contribute to enhanced saline water intrusion during certain months despite high rainfall. This apparent lag between rainfall and surface salinity emphasizes the complexity of freshwater-saltwater interactions in this monsoon-influenced estuarine system.

TSS revealed one of the most striking patterns among all parameters. While surface TSS remained relatively low and stable across most months (<40 $mg \cdot L^{-1}$), bottom TSS peaked sharply in September 2017, reaching values >140 $mg \cdot L^{-1}$. This suggests intense resuspension of bottom sediments, possibly driven by strong estuarine circulation or runoff events. pH remained within a moderately alkaline range (7.0–8.2), with slightly lower values in the surface layer during high-discharge months, likely influenced by dilution with fresh river water and reduced buffering capacity. The temporal pattern of pH did not exhibit abrupt shifts, suggesting the system retained relative chemical stability. DO levels were generally high across all sampling events (6.0–8.5 $mg \cdot L^{-1}$), indicating overall well–oxygenated conditions.

Ammonia was markedly elevated in June 2016 and September 2017, with both surface and bottom waters exceeding 600 $\mu g\ N \cdot L^{-1}$ and 280 $\mu g\ N \cdot L^{-1}$, respectively (Figure 4). These two peaks represent the early and mid-phases of the wet season, respectively. Nitrite concentrations remained relatively low across most sampling events (2–10 $\mu g\ N \cdot L^{-1}$) but peaked in October 2016. Nitrate showed the most pronounced peak among all nutrients, reaching nearly 350 $\mu g\ N \cdot L^{-1}$ in surface water during October 2016. This suggests a strong pulse of terrestrial nitrogen input, likely from upstream runoff during the peak of the wet period (Figure 2). The sharp temporal spike followed by rapid decline implies transient external loading rather than continuous in situ production.

Phosphate was moderate throughout the study period (generally <100 $\mu g\ P \cdot L^{-1}$), with highest values occurring in October 2016 and September 2017 (Figure 4). These coincided with peak runoff months and high sediment resuspension, indicating both watershed input and benthic release as probable sources. An interesting observation is the elevated phosphate concentration in April 2017, which occurred during the dry season when runoff is typically low. This may be attributed to internal loading mechanisms, such as the release of phosphate from bottom sediments under enhanced remineralization of organic matter in the water column. During prolonged low-flow periods, water residence time increases, promoting the accumulation of nutrient-rich bottom waters and allowing sufficient time for sediment–water exchange processes.

Silicate concentrations were consistently high compared to other nutrients, with concentrations frequently exceeding 1,000 $\mu g\ Si \cdot L^{-1}$ and peaking near 3,000 $\mu g\ Si \cdot L^{-1}$ in October 2016. Elevated silicate concentrations are likely derived from weathering of upstream silicate minerals and delivery of suspended particulate matter during high-discharge periods.

Water flux was predominantly seaward (positive) throughout most of the study period, with values ranging from approximately +0.3 to $+4.9 \times 10^6\ m^3 \cdot d^{-1}$, indicating sustained freshwater discharge toward the coastal zone (Figure 5). Only two months-August and December 2016-exhibited net landward (negative) water flux, with respective values of -3.56 and $-0.71 \times 10^6\ m^3 \cdot d^{-1}$. The net landward flow recorded in August 2016, despite high regional rainfall during that period, suggests that elevated precipitation does not always translate into increased seaward discharge.

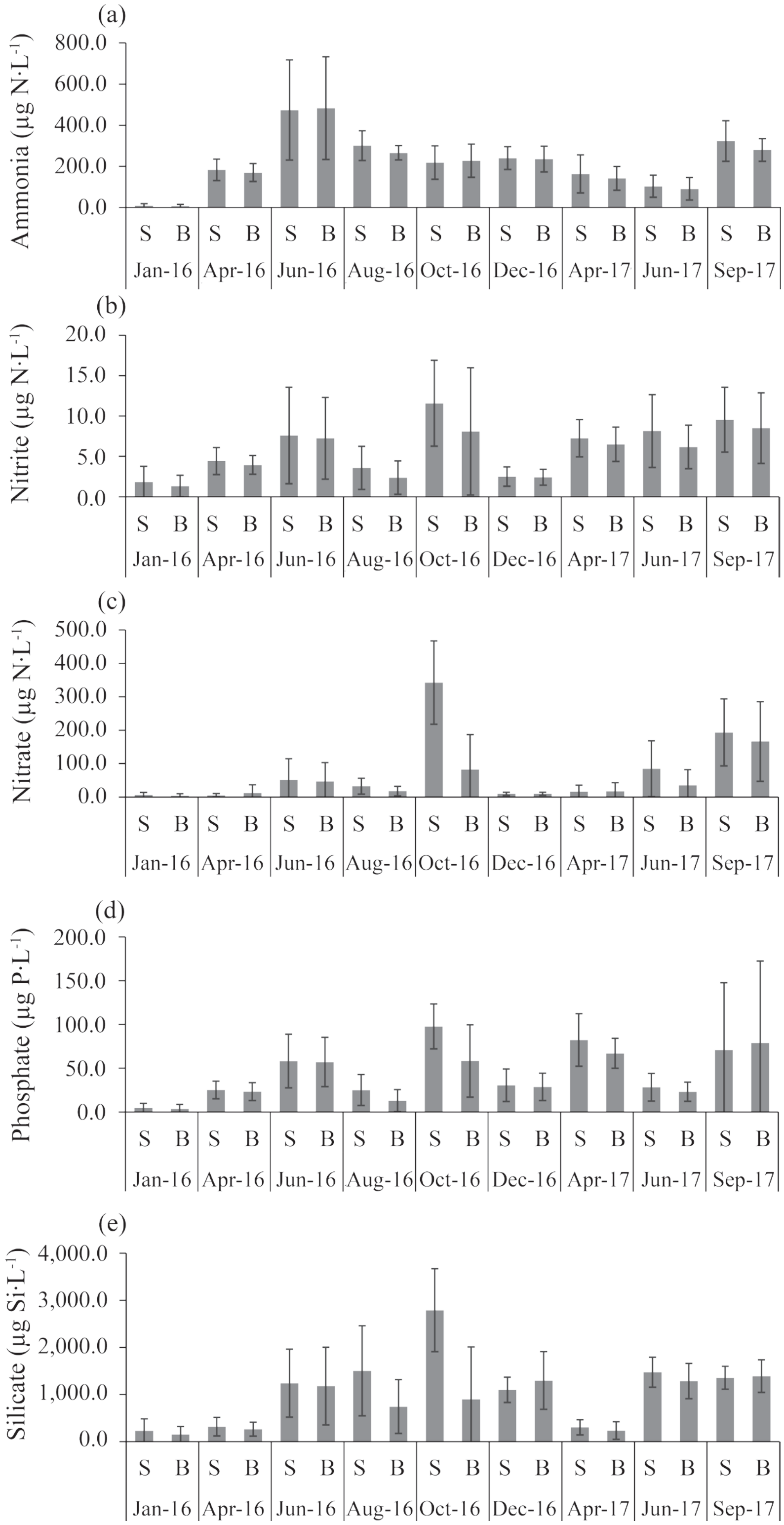

Figure 4. Concentrations of dissolved nutrients in surface (S) and bottom (B) waters at the Prasae River estuary during 2016–2017: (a) ammonia, (b) nitrite, (c) nitrate, (d) phosphate, and (e) silicate.

Reservoir regulation upstream–such as controlled water storage or delayed releases-could have attenuated freshwater discharge to the estuary during the observation period. Wind forcing associated with the southwest monsoon may also have contributed to enhanced saline water intrusion. These combined processes highlight the complexity of estuarine hydrodynamics, where net water movement reflects interactions among rainfall, catchment retention, tidal forcing, wind stress, and anthropogenic flow control.

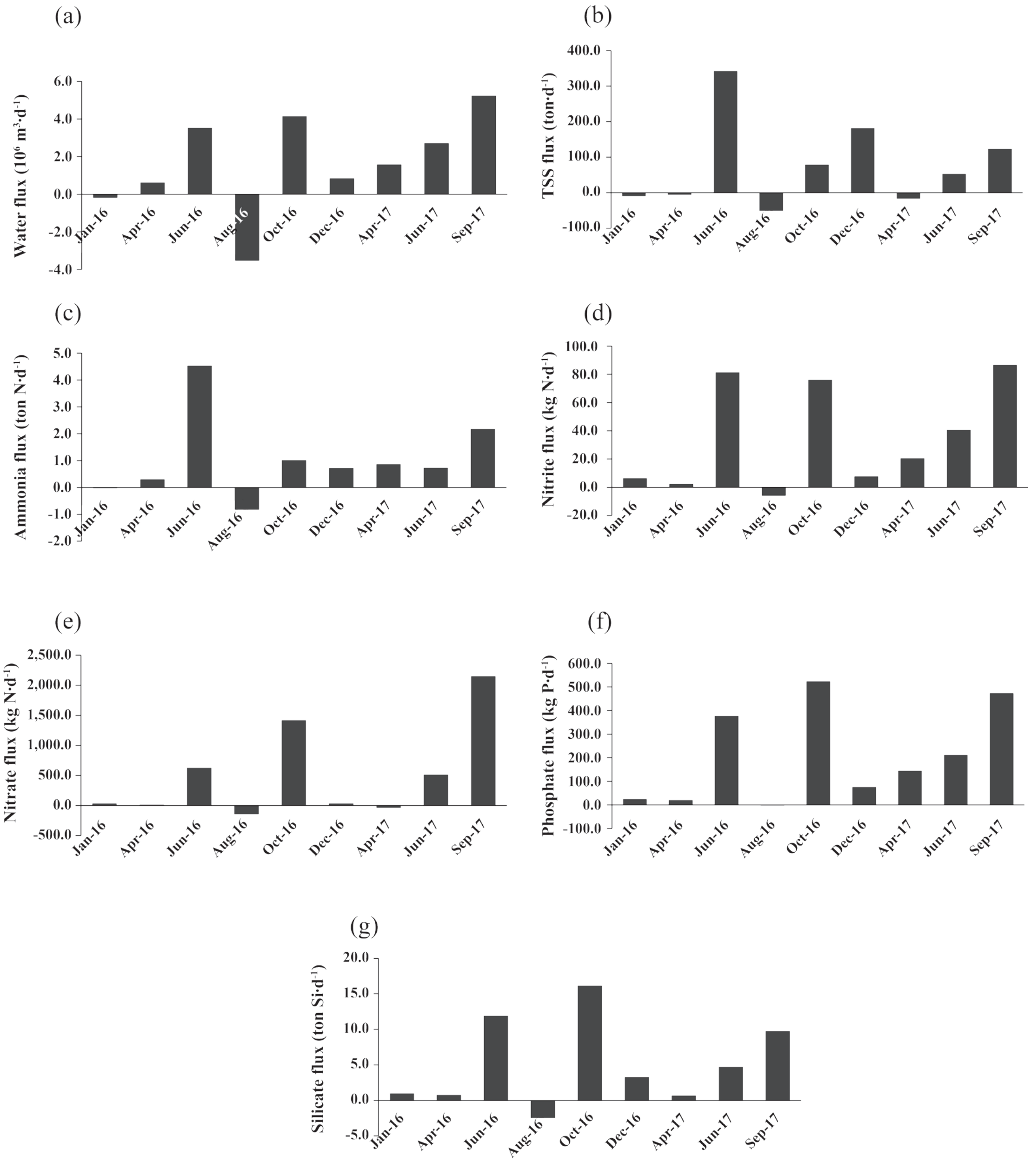

Figure 5. Monthly fluxes of (a) water, (b) total suspended solids (TSS), (c) ammonia, (d) nitrite, (e) nitrate, (f) phosphate, and (g) silicate at the Prasae River mouth from January 2016 to September 2017. Positive values represent net export to the coastal waters, while negative values indicate net import.

TSS fluxes exhibited episodic peaks, with the highest export observed in June 2016 (~350 $t \cdot d^{-1}$), consistent with strong river flow and sediment mobilization during the early monsoon onset. Additional TSS export events occurred in December 2016 and September 2017, though at lower magnitudes, reflecting contributions from late-season runoff and estuarine mixing. In contrast, several months-including January, April, and August 2016 and April 2017-showed small but measurable landward (negative) TSS fluxes, suggesting episodic sediment import from coastal waters into the estuary. These occurrences, although lower in magnitude, may reflect dynamic sediment–water column interactions near the river mouth, such as tidal pumping, resuspension, or bottom boundary layer exchange. The bidirectional nature of TSS fluxes highlights the transitional role of the estuary not only as a source but also as a temporary sink for suspended sediments, depending on the timing of discharge, tidal phase, and local circulation. Landward TSS fluxes have also been reported in the Weru Estuary (Buranapratheprat *et al*., 2018) and the Bangpakong River (Yuenyong *et al*., 2023).

Dissolved nutrient fluxes were similarly influenced by seasonal hydrology. Ammonia flux peaked sharply in June 2016 (~4.5 $t\ N \cdot d^{-1}$) and September 2017 (~2 $t\ N \cdot d^{-1}$), coinciding with elevated in situ concentrations and runoff-driven loading. Nitrite fluxes peaked at around 80 $kg\ N \cdot d^{-1}$ in June and October 2016, and again in September 2017. Moderate fluxes were observed in April (~20 $kg\ N \cdot d^{-1}$) and June 2017 (~40 $kg\ N \cdot d^{-1}$), while near-zero fluxes occurred during January, April, and December 2016. A slight negative flux was recorded in August 2016. Nitrate also varied substantially over time, with major export in October 2016 and September 2017, reaching approximately 1,400 and 2,200 $kg\ N \cdot d^{-1}$, respectively. Moderate export (~600–700 $kg\ N \cdot d^{-1}$) was also observed in June 2016 and June 2017. In contrast, fluxes during January, April, and December 2016, as well as April 2017, were minimal.

Among the three inorganic nitrogen forms, ammonia and nitrate fluxes were comparatively high in magnitude, with strong seasonal peaks during the wet season. Nitrite flux also followed this seasonal pattern but at much lower levels. Despite two sharp peaks in June 2016 and September 2017, ammonia flux remained persistently high at about 1 $t\ N \cdot d^{-1}$ across several months from October 2016 to June 2017, indicating continuous inputs near the river mouth. Negative fluxes of all measured materials in August 2016 corresponded with the landward direction of water flux during the same period. Nitrate and nitrite shared similar seasonal trends, while ammonia responded more strongly to early monsoon conditions.

Phosphate fluxes showed distinct peaks during the wet season, with the highest values in October 2016 (~530 $kg\ P \cdot d^{-1}$), followed by September 2017 and June 2016. Moderate exports occurred from April to June 2017, while fluxes in January and April 2016 remained low. Silicate fluxes exhibited a similar seasonal trend, with major peaks in June and October 2016, reaching up to ~16 $t\ Si \cdot d^{-1}$. Both nutrients showed strong export during high-discharge months, consistent with runoff-driven inputs.

Seasonal differences in both water quality parameters and material fluxes were evaluated using the Wilcoxon rank-sum test (Figure 6). This non-parametric test was applied because the data did not follow a normal distribution. Among all parameters, silicate concentration, nitrate concentration, and nitrite flux showed statistically significant differences ($p \leq 0.05$) between seasons. Silicate and nitrate concentrations were higher during the wet season, with elevated silicate levels likely associated with increased soil erosion in the watershed during periods of intense rainfall, and higher nitrate concentrations driven by enhanced agricultural and urban runoff, thereby increasing nutrient loading to the estuarine system. In contrast, nitrite flux was significantly higher in the dry season, potentially reflecting greater benthic nitrification/denitrification activity or reduced water column flushing during periods of lower river discharge.

The correlation matrix confirms that most dissolved nutrients at the Prasae River mouth are negatively correlated with salinity, indicating a strong freshwater influence (Figure 7). Nitrite ($r = -0.72$), nitrate ($r = -0.66$), silicate ($r = -0.67$),

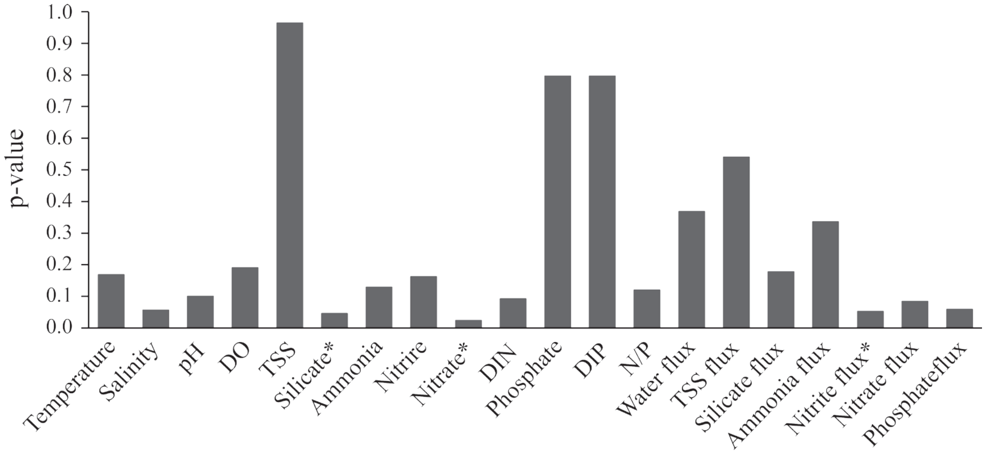

Figure 6. p-values from the Wilcoxon rank-sum tests comparing dry and wet seasons for each water quality parameter and nutrient flux. An asterisk (*) on labels along the horizontal axis indicates significant differences at p≤0.05.

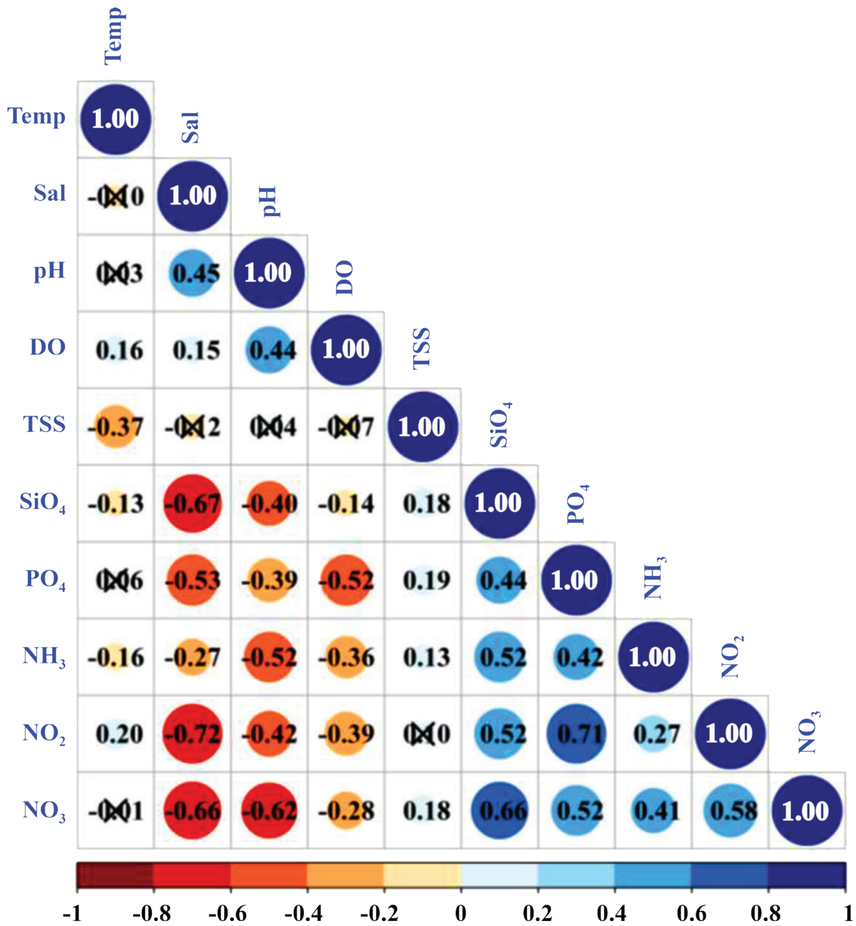

Figure 7. Spearman correlation matrix of environmental and nutrient parameters at the Prasae River estuary. Circle size and color represent the strength and direction of correlation. Crosses (×) indicate correlations that are not statistically significant (p>0.05).

and phosphate (r = -0.53) all show strong negative correlations with salinity, suggesting that these nutrients are primarily introduced by terrestrial runoff. Ammonia (r = -0.27) also shows a negative correlation with salinity, albeit weaker, implying a partial freshwater origin, likely from anthropogenic sources such as domestic wastewater or aquaculture effluents. Moreover, ammonia shows moderate positive correlations with phosphate (r = 0.42) and silicate (r = 0.52), indicating shared sources and possibly concurrent release through sediment-water interactions. These patterns reinforce the interpretation that nutrient concentrations in the estuary are largely driven by seasonal freshwater input, with local biogeochemical processes contributing to spatial variability.

The PCA biplot shows a clear contrast between two major groups of water quality variables (Figure 8). Water parameters-including nitrate, nitrite, ammonia, phosphate, silicate, and TSS-appear closely grouped, indicating they tend to vary together across the samples. In contrast, salinity, pH, and DO form a separate group, suggesting they are inversely related to nutrient levels. Temperature and the N/P ratio, defined as the molar ratio of dissolved inorganic nitrogen (DIN = ammonia+ nitrite+nitrate) to dissolved inorganic phosphorus (DIP = phosphate), show weaker associations. The first principal component (PC1) explains 48.5% of the total variance, while the second component (PC2) accounts for 17.4%. Together, they explain 70.4% of the total variation, indicating that the biplot effectively captures the main gradients in water quality within the dataset.

The PCA biplot of flux-related variables shows that the first two principal components explain 84.5% of the total variance (PC1 = 71.9%, PC2 = 12.6%) (Figure 9). Most variables–including nitrate, phosphate, nitrite, silicate, water discharge, and rainfall-are grouped in a similar direction, suggesting they tend to co-vary across the samples. Ammonia and TSS follow the same general trend but with slightly different orientations, indicating minor differences in their dynamics. This pattern likely reflects the influence of freshwater inflow and rainfall on nutrient export, as increased water volume during high-flow conditions can enhance the transport of dissolved and particulate nutrients from the watershed to the estuary. The separation of ammonia and TSS from the main group may be due to additional local factors, such as sediment resuspension, organic matter decomposition, or

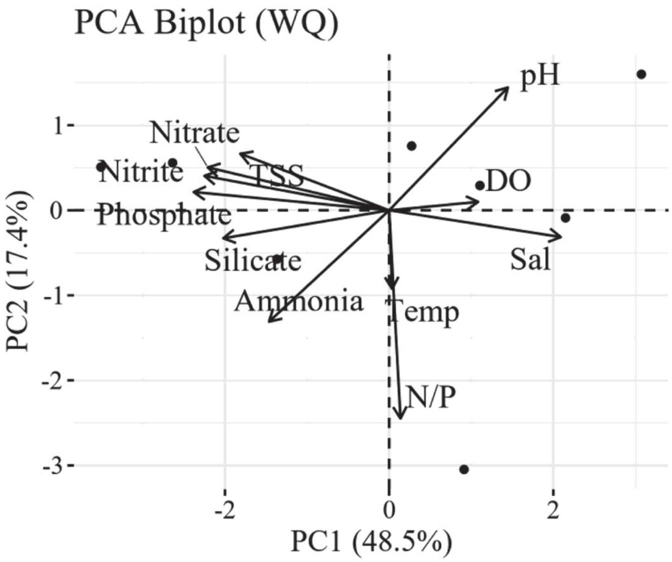

Figure 8. PCA biplot of water quality parameters at the Prasae River estuary, showing grouping of nutrients and TSS opposite to salinity, pH, and DO along PC1 (48.5%) and PC2 (17.4%).

point-source inputs, which can cause variability in their fluxes independent of hydrological conditions. The overall structure therefore highlights the dominant role of hydrological forcing in controlling nutrient fluxes, while also suggesting that some parameters respond to more complex or localized processes.

N/P ratio provides critical insight into nutrient dynamics and potential limitation of phytoplankton growth in estuarine systems. Figure 10 shows temporal changes in N/P molar ratios at the Prasae River mouth. The N/P molar ratios varied substantially, ranging from below 10 to over 50. According to the Redfield ratio, values higher than 16 indicate phosphorus limitation in April, June, August, and December 2016, often associated with runoff dominated by nitrogen-rich fertilizers (Bennett *et al*., 2001; Elser *et al*., 2007). In contrast, ratios lower than 16 in January and October 2016, and April, June, and September 2017 suggest potential nitrogen limitation. Such

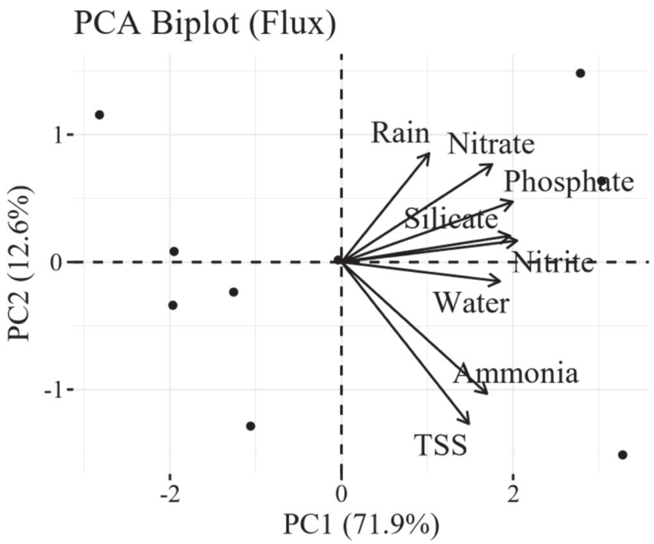

Figure 9. PCA biplot of flux-related variables showing co-variation of rainfall, water discharge, and dissolved nutrient fluxes along PC1 (71.9%) and separation of ammonia and TSS along PC2 (12.6%).

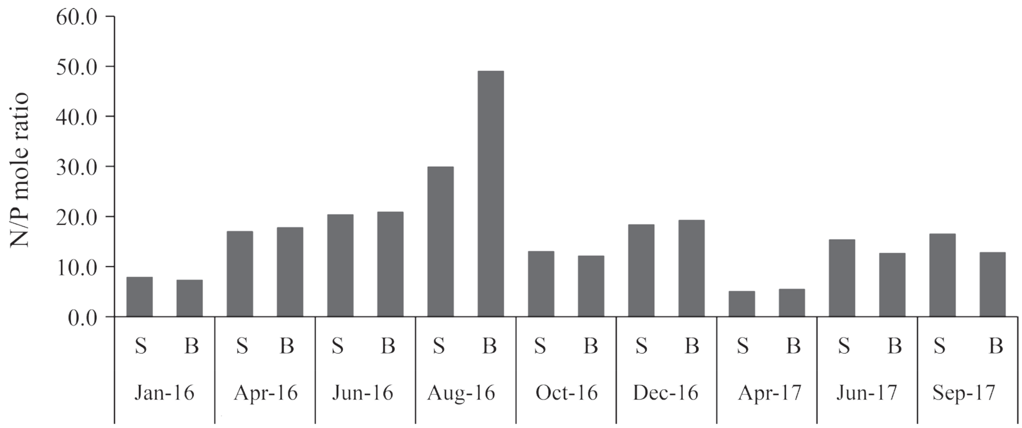

Figure 10. N/P mole ratios in surface (S) and bottom (B) waters at the Prasae River estuary during 2016–2017.

conditions may arise from decreased nitrogen delivery or from increased phosphate inputs through the resuspension of bottom sediments releasing pore water phosphate into the water column, especially under prolonged residence times. The alternating patterns of nitrogen and phosphorus limitation highlight the complex nutrient dynamics in the Prasae estuary, influenced by both watershed inputs and in situ biogeochemical processes.

Seasonal variation in nutrient fluxes-particularly during the wet season-differs significantly among key river systems in eastern Thailand (Table 2). The Chanthaburi River showed the highest nutrient export, reflecting extensive runoff from a large and agriculturally active watershed (Kan-atireklarp *et al*., 2015a). The Trat River ranked second, largely driven by high freshwater discharge while maintaining water quality within acceptable standards (Meesub *et al*., 2021). The Prasae River followed, with strong exports indicating moderate enrichment from seasonal inputs. The Rayong River, while showing lower overall fluxes, exhibited a sharp seasonal increase, reflecting the influence of rapid runoff from urban and industrial land uses (Kan-atireklarp *et al*., 2015b). These comparisons emphasize the varying hydrological and land-use controls on nutrient fluxes in the region, positioning the Prasae River as moderately enriched during the wet season, between the heavily productive Chanthaburi and the lower-export Rayong system.

The estuarine and coastal waters at the mouth of the Prasae River present a dynamic ecologically sensitive environment. Water quality in this region generally aligns with Thailand's Type 3 (for aquaculture) and Type 6 (for community) marine water standards, which define thresholds such as DO≥4 $mg \cdot L^{-1}$, nitrate (NO_3^-–N) ≤60 μg $N \cdot L^{-1}$ and phosphate (PO_4^{3-}–P)≤45 μg $P \cdot L^{-1}$ (NEB, 2006). Field measurements taken between 2016 and 2017 at the Prasae River mouth recorded DO levels consistently within 6.0–8.5 $mg \cdot L^{-1}$, indicating well-oxygenated conditions. However, nitrate and phosphate levels often exceeded the national thresholds during the wet season. These elevated concentrations suggest episodic nutrient enrichment driven primarily by watershed runoff during the monsoon months. A recent report by Thailand's Department of Marine and Coastal Resources documented a red tide event near the Prasae estuary in August 2019 (DMCR, 2023).

This study was conducted during 2016–2017 and reflects the water quality conditions and riverine fluxes of the Prasae River during that period. Although no recent Land Use/Land Cover (LULC) assessment is available for the Prasae watershed, the projections by Intacharoen *et al*. (2021) provide an indication of possible changes. Their model suggests that between 2018 and 2023, vegetation and agricultural areas may decrease by approximately 0.94%, while community and built-up areas may increase by about 1.49%. Water bodies and bare land remains relatively stable. These projected LULC shifts imply a potential deterioration in water quality in the Prasae watershed, associated with increasing human activities and land development. This highlights the need for continuous monitoring and integrated watershed-coastal management to mitigate future degradation and maintain the ecological integrity and productivity of the Prasae estuarine system.

Table 2. Summary table of wet-season nutrient fluxes for selected rivers on Thailand's eastern coast.

River	Nitrate flux ($kg\ N \cdot d^{-1}$)	Phosphate flux ($kg\ P \cdot d^{-1}$)	Silicate flux ($kg\ Si \cdot d^{-1}$)	Reference
Chanthaburi	7,900	360	>170,000	Kan-atireklarp *et al*. (2015a)
Trat	3,190	500	87,890	Meesub *et al*. (2021)
Rayong	970	100	17,400	Kan-atireklarp *et al*. (2015b)
Prasae	>2,200	480	10,000	This study

CONCLUSION

This study demonstrates that the Prasae River exports significant amounts of suspended sediments and dissolved nutrients to the coastal sea, particularly during the wet season. Nitrate was the dominant nitrogen form, followed by ammonia and nitrite, while phosphate and silicate also showed strong seasonal export patterns. The fluxes were primarily driven by monsoonal discharge, with local hydrodynamics and sediment interactions playing secondary roles. Compared to other rivers in eastern Thailand, the Prasae River shows moderate nutrient export-higher than Rayong but lower than Trat and Chanthaburi-indicating a watershed under moderate nutrient enrichment pressure.

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