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ASSESSMENT OF POLLUTION CARRYING CAPACITY IN THE LOWER PART OF MAE KLONG RIVER, THAILAND

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ABSTRACT: Assessment of aquatic environmental impacts, nutrient transfer and the clarification of contaminated sites were conducted based on water quality analysis of the Mae Klong River. Twelve sampling stations were surveyed between April 2015 and April 2016 covering Kanchanaburi, Ratchaburi and Samut Songkhram Provinces. Results showed that aquatic environmental factors varied seasonally. A mathematical model developed using the box modeling method showed that middle (Ratchaburi Province) and lower (Samut Songkhram Province) riverine zones were point source areas. Highest DIN and PO_4^{3-}-P loads were found in Samut Songkhram Province. Results implied that PO_4^{3-}-P levels were higher than the standard criterion for aquaculture (< 1.45 μmol L^{-1}). Levels of PO_4^{3-}-P continued to increase, downriver, particularly in the estuary. Recent PO_4^{3-}-P levels suggest that the number of agroindustry plants discharging waste effluent into the river should be reduced. Monitoring to assess the aquatic status of the Mae Klong River and estuary using the PO_4^{3-}-P database is urgently required to control water quality and reduce contamination levels.

Keywords: Pollution, Carrying capacity, Environmental impact, Mae Klong River

1. INTRODUCTION

The Mae Klong at approximately 140 km long with a catchment area of 22,075 km^2, is the most important river in Western Thailand. The Mae Klong diversion dam is located in the upper zone, about 10 km from the river basin and forms the headworks of the Greater Mae Klong Irrigation Project which divert and distribute water to about 3.0 million rai (1 ha = 6.25 rai) of the cultivated area in 10 irrigation subprojects [1]. The river flows across the lower plain and passes through Ratchaburi Province, before discharging into the Gulf of Thailand in Samut Songkhram Province, where the important estuarine ecosystem supports a residential population as well as various industries [2]. More than 100 industrial factories are located along the banks of the Mae Klong River. Apart from industry and fisheries, other activities supported by the river include intensive agriculture [3].

[4] reported that freshwater inputs to the river depend on rainfall, irrigation control systems, and natural tributaries that flow through agricultural areas. Paddy rice is cultivated in about two-thirds of the area with the other third under sugar cane cultivation [5]. The aquatic environmental parameters, particularly dissolved oxygen and ammonia nitrogen, have deteriorated to critical levels over the past decade [6]. Rapid urbanization and industrial and agricultural development, coupled with inadequate sewerage systems, contribute to elevated material inputs in the water resources, e.g. nitrogen (N) and phosphorus (P) [7].

The abundance of nitrogen and phosphorus compounds causes eutrophication problems [8]. Thus, this study aimed to describe the impacts of aquatic environmental parameter variations. Assessment of non-point source nutrient loads was a major focus, together with clarification of nutrient transfer patterns and a pollution carrying capacity assessment at the impacted sites using a mathematical model. Results will contribute to water quality conservation to maintain acceptable and sustainable utilization management of river ecosystems.

2. MATERIALS AND METHODS

2.1 Sampling sites

Twelve localities along the Mae Klong River were selected as sampling stations (Fig. 1). They were clustered in an 'upper' zone in Kanchanaburi Province (stn. 1-2), a 'middle' zone in Ratchaburi Province (stn. 3-7), and an 'estuarine' zone in Samut Songkhram Province (stn. 8-12).

Water sampling was conducted during two separate time periods to take account of the effects of seasonal variability on nutrient loadings as April 2015 (dry season) and September 2015 (rainy season). Under the influence of monsoon winds, Thailand has three seasons: rainy season (May-September), winter season (October-February) and dry season (March-April) [9].

2.2 Sample collection and analysis

Temperature, dissolved oxygen (DO), salinity and pH of the water samples were measured using a multi-parameter probe (YSI-6600 Sonde Instrument) at the sampling sites (stn.1-12). For nutrient analysis, water samples were pre-filtered through GF/F (Whatman) and then immediately stored at 4 °C before transportation to the laboratory where they were kept at -20 °C until required for analysis.

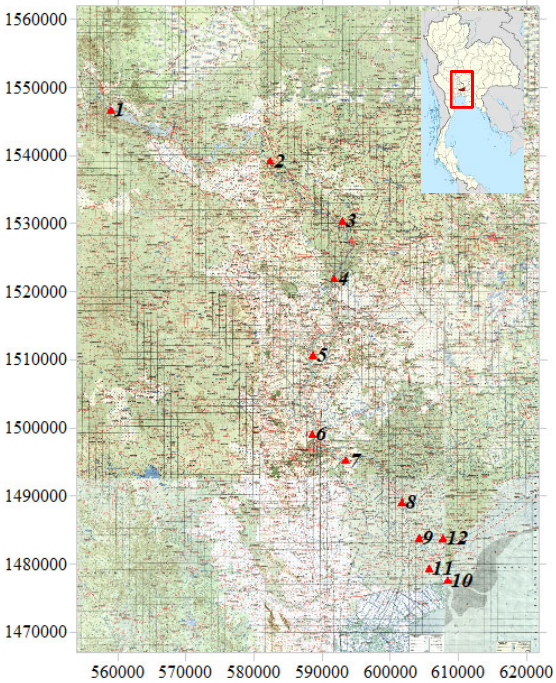

Fig. 1 Sampling stations (UTM; 47P) of the Mae Klong River with the 'upper' zone in Kanchanaburi province (stn. 1-2), a 'middle' zone in Ratchaburi province (stn. 3-7), and an 'estuarine' zone in Samut Songkhram province (stn. 8–12).

Ammonium (NH_4^+), nitrite and nitrate (NO_2^- and NO_3^-), and orthophosphate (PO_4^{3-}) concentrations were determined using a Skalar segmented flow analyzer with corresponding detection limits of 0.70-57.14, 0.70-14.28 and 0.03-3.87 µmol L^{-1}. Specifically, the DIN and P loads were assessed at stn. 1-10 cross-sectional sites using a two-dimensional Surfer model. Nutrient loads were approximated by equation (1)

$$M_i = [Conc]A_iUh_i\Delta t_i \qquad (1)$$

where M_i is the amount of nutrient load (ton/day), Conc is the nutrient concentration (µg L^{-1}), A_i is the cross-sectional area of section *i* (m^2), Uh_i is the flow velocity of section *i* (cm/s) and Δt_i is the length of time (i.e. 1 day) [2].

DIN and P loads were used for making decisions regarding the focus areas for pollution carrying capacity assessment using the mathematical model (Fig. 2). Pollution carrying capacity was conducted at two separate time periods: September 2015 and April 2016.

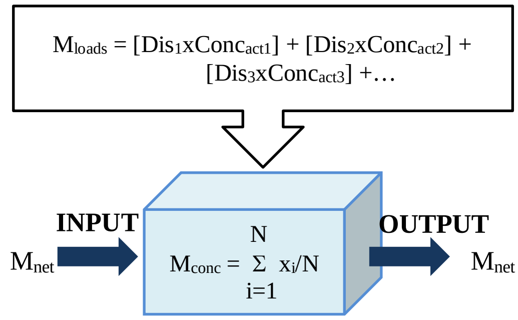

Fig. 2 Mathematical model for pollution carrying capacity assessment of the Mae Klong River.

Nutrient loads were approximated by equation (2), (3) and (4) in Fig. 2,

$$M_{loads} = [Dis_1xConc_{act1}]+[Dis_2xConc_{act2}]+[Dis_3xConc_{act3}]+\ldots \qquad (2)$$

$$M_{conc} = \sum_{i=1}^{N} x_i/N \qquad (3)$$

$$M_{net} = \sum_{i=1}^{25} [Conc]\cdot Uh\cdot A \qquad (4)$$

where M_{loads} is the amount of nutrient discharge (ton day^{-1}) from industrial (Ind.) residential (Res.) and agricultural (Agr.) activity, Dis_1 is the amount of discharge in each activity (L day^{-1}), $Conc_{act1}$ is the average concentration of DIN or PO_4^{3-}-P (µg L^{-1}) M_{cont} is the amount of nutrients within the box (ton/day), x_i is the concentration of DIN or PO_4^{3-}-P (µg L^{-1}) at the present time within the box, M_{net} is the amount of each nutrient load (ton/day), [Conc] is the concentration of DIN or PO_4^{3-}-P (µg L^{-1}) in the time focus (1-25 hrs). Uh is the flow velocity (cm s^{-1}) passing through the section in the time focus, and A is the cross-sectional area (m^2) of the section in focus.

2.3 Data analysis

Physicochemical properties of the water samples associated with both sampling periods (April 2015 and September 2015) were determined using descriptive statistics and presented as means ± standard deviations (SD). T-test was used to verify statistical differences between the two study periods, with $p \leq 0.05$.

3. RESULTS

Table 1 shows the physicochemical characteristics of the water samples for both study periods (rainy and dry seasons). Results revealed that water temperature and salinity varied minimally from season to season ($p \leq 0.05$) and were lower during the rainy season. Sampling locations (stn.1-12) and seasonal variability had no significant impact on pH levels which remained relatively constant throughout.

Table 1 Physicochemical properties of water samples (mean±SD)

Parameters	Study period	
	April 2015 (dry)	September 2015 (rainy)
Temp (°C)	31.85±0.71[a]	29.19±0.72[b]
DO (mg L^{-1})	5.62±2.26[a]	5.47±1.11[a]
Salinity (psu)	2.79±5.19[a]	0.39±0.62[a]
pH	7.63±0.22[a]	7.18±0.19[a]
NH_4^+ (μmol L^{-1})	8.57±8.41[a]	5.13±2.08[a]
NO_2^-+NO_3^- (μmol L^{-1})	26.83±13.34[a]	11.55±3.76[b]
PO_4^{3-} (μmol L^{-1})	1.31±1.90[a]	1.77±1.18[a]

The DO varied in response to seasonal variability ($p > 0.05$) at alarmingly higher than Thailand's minimum threshold of 4 mg L^{-1}. Average levels of NH_4^+ and NO_2^-+NO_3^- also varied significantly ($p \leq 0.05$) with the season. Minimum and maximum concentrations of NH_4^+ and PO_4^{3-} associated with dry and rainy seasons were respectively 1.73 and 28.92 μmol L^{-1}, and 0.10 and 5.23 μmol L^{-1}. Observations also revealed that NH_4^+ and NO_2^-+NO_3^- were high during the dry season.

Table 2 shows the cross-sectional area, water volume and current velocity associated with the 10 cross-sectional sites (stn. 1-10). During the dry season (April), stn. 10 exhibited the highest volume and velocity of 78.49 x 10^6 ton day^{-1} and 39.7 cm s^{-1}, respectively. Meanwhile, stn. 2 recorded the lowest volume (3.09 x 10^6 ton day^{-1}) and stn. 7 had the lowest velocity (12.5 cm s^{-1}).

Nutrient loads (DIN and P) associated with stn. 1-10 were estimated using (1). Results indicated that the DIN and P loads were respectively in the range of 2.09-31.00, and 0.03-5.25 ton day^{-1}. The highest DIN and P loads were registered at stn. 10, 31.00 ton day^{-1} and 5.25 in the dry season (Table 3).

Nutrient (DIN and P) transport analysis implied that the major contaminated sites were around Samut Songkhram Province. Results of nutrients loads indicated that the lower zone (Samut Songkhram Province) should focus on a point source area in the Mae Klong River.

Table 2 Water volume and velocity of the 10 cross-sectional sites during the dry (April 2015) season

Zone	St n.	Section area (m^2)	Volume (10^6 ton day^{-1})	Velocity (cm s^{-1})
Upper	1	1,217.05	31.34	29.8
	2	196.58	3.09	18.2
Middle	3	253.98	4.37	19.9
	4	536.14	10.84	23.4
	5	531.77	10.93	23.8
	6	564.10	9.07	18.6
	7	732.09	7.91	12.5
Lower	8	747.91	10.15	15.7
	9	1,213.72	26.95	25.7
	10	2,288.23	78.49	39.7

Table 3 DIN and P transport (ton day^{-1}) at three cross-sectional sites during the dry season (April 2015)

Zone	Sectioned codes	DIN (ton day^{-1})	PO_4^{3-}-P (ton day^{-1})
Upper	St1	9.80	0.13
	St2	2.09	0.03
Middle	St3	3.22	0.04
	St4	3.36	0.10
	St5	3.35	0.11
	St6	4.71	0.12
	St7	4.54	0.11
Lower	St8	5.97	0.13
	St9	12.64	0.44
	St10	31.00	5.25

Table 4 Parameters for calculating the mathematical model in the lower area (Samut Songkhram Province) of the Mae Klong River

Type of waste water	Waste water volume	No.	Levels of concentration (μg/l)	
			DIN	PO_4^{3-}-P
Industry *	5 x10^5 Lday^{-1}	80 factory	23.6 x10^3	4.45 x10^3
Domestic	342 L$cap.^{-1}day^{-1}$	194,069 cap.	10.9 x10^3	1.4 x10^3
Shrimp pond	1.9 x10^4 L$Rai^{-1}day^{-1}$	1,613 Rai	2.7 x10^3	43.1
Rice field	2.3 x10^3 L$Rai^{-1}day^{-1}$	-	3.6 x10^3	49.6

DIN and P transport for pollution carrying capacity were calculated using the equations shown in Fig. 2, with primary and secondary data collected from government officials (Table 4).

Results revealed that DIN and P transport during the rainy season were higher than levels in the dry season. However, output levels of DIN and P loads in both seasons were lower than input levels (Fig.3). To improve self-remediation of the river, especially during the dry season, high DIN and P levels in the box require larger recharge from the Mae Klong River in the dry season and imposition of restrictions on the discharge of wastewater into the river.

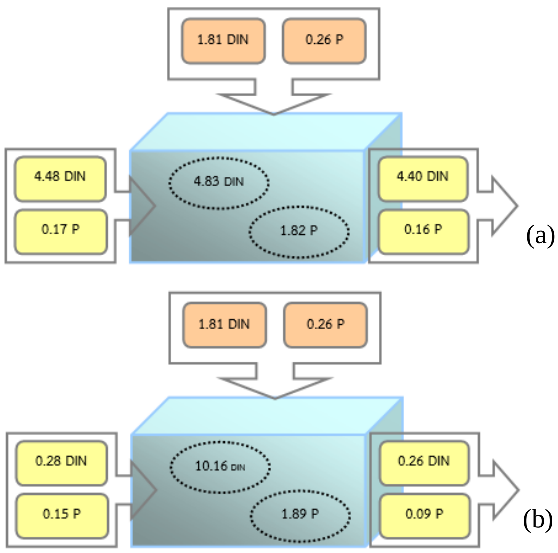

Fig. 3 DIN and P transport (ton day^{-1}) for pollution carrying capacity assessment using the mathematical model in the rainy (September 2015) and dry (April 2016) seasons in the lower part of the Mae Klong River.

4. DISCUSSION

Research results indicated that temperature and salinity of the river water varied minimally with seasons, while pH levels also remained relatively constant throughout. According to [2], freshwater inflow and precipitation-induced drainage influence the salinity level. Findings also revealed that dissolved oxygen (DO) was higher than Thailand's minimum threshold of 4 mg L^{-1}, rendering the water unfit for aquatic animals [10].

Furthermore, high DIN and P nutrient concentrations suggested anthropogenic contamination from the high population density along and near both sides of the river. Nutrient loads from the major areas revealed the impact of anthropogenic activity, while water flow characteristics influenced water quality in those areas [2]. Generally, nutrient loadings in a river are linked to natural and anthropogenic sources, e.g. runoff from urban areas and plantations, and inflow through organic-rich ground [11]. In addition, non-point sources e.g. storm water runoff and runoff from agricultural and urban areas contribute significantly to riverine biogeochemistry [12].

In water quality assessment, NH_4^+ is an important determinant [13]. The NH_4^+ levels in water bodies should be below 1 mg L^{-1} (or 71.4 μmol L^{-1}) [14], and the PO_4^{3-} levels below 1 μmol L^{-1} to avert eutrophication [2]. The PO_4^{3-} levels in the Mae Klong River were in excess of the limit.

Anthropogenic activity and water mass transfer direction of the Mae Klong River, especially in the lower zone (Samut Songkhram Province), contributed to high DIN and P loads. Nutrient input-outputs were high in the dry season when nutrient loads were excessive. High nutrient load have to be focused on the reduction of diffuse sources, particularly the nitrogen and phosphorus emissions by drainage systems have to be reduced [15]. [11] reported that nutrients in water could be diluted or enhanced in response to areas that the water flows through, and that nutrient concentrations influence the self-remediation of the waterways.

[16] also suggested that the potential for nutrient reduction may be greatly enhanced by the discharge of large pulses of water. An opposite effect from a decrease in the flow velocity in the middle zone due to the river's morphology could I water and, thus, nutrient accumulation could be enhanced. In addition, land use contributes to nitrogen enrichment in the river [17], while phosphorus emission from wastewater is prevalent in highly populated areas [18]. Nutrient contamination in surface waters can pose a health risk for humans and aquatic life. In addition, runoff from urban and agricultural land uses can contribute to nutrient fluctuation and consequentially water quality [19].

The mathematical model for pollution carrying capacity of the area (lower zone) was positive, indicating adequate self-remediation and nutrient input-output balance. However, nutrient loads should be monitored, especially during the dry season. The levels of these nutrients were affected by the water velocity. The results revealed that the estuarine zone had higher loaded volumes when compared to the middle zones of the river. High loads found in the lowest zone could imply that either intermittent loads or estuarine upward functions had impacted on the aquatic ecosystem [2].

5. CONCLUSION

Effects of seasonal variability (rainy and dry seasons) and nutrient transfer patterns on the anthropogenic nutrient loads (DIN and P) and the self-remediation of the Mae Klong River in Thailand were investigated. Findings revealed maximum DIN and P loads of 31.0 ton day^{-1} and 5.25 ton day^{-1}, respectively during the dry season in the lower part of the river.

The predominantly positive nutrient transport for DIN and P indicated adequate self-remediation with subsequent nutrient input-output still in balance. To address self-remediation in the area requires enhanced recharge from the Mae Klong River during the dry season. Observations also indicated that water mass transfer direction influenced drainage, nutrient dilution and nutrient accumulation in the area.

6. ACKNOWLEDGMENTS

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