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Assessment of Nutrients and Sediment Loading in a Tropical River System in Malaysia

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Abstract. A detailed study has been carried out on the Pinang river, a tropical river system in Penang Island, to identify the physical and chemical characteristics of the water and to evaluate the relative contributions of anthropogenic activities to the river's pollution. The results indicated that sites closer to the most-urbanized and agricultural areas are severely impaired. The river water was found to vary considerably in terms of chemical and physical properties. High nutrient load, especially nitrate (31.6 $\pm$ 2.9 kg/day), was found elevated at the lower part of the river, suggesting the occurrence of anthropogenic activities. Nutrients and sediments were found to be the most frequent cause of river pollution. The river pollution has reached to such a high level that it has devastated the aquatic ecosystem in most exposed sections of the river.

Keywords: anthropogenic activities, physical and chemical parameters, nutrients and sediment loading

1. Introduction

The development of water resources has often been used as an index for socio-economic and health status of many nations worldwide. However, the consequences of such development around a river ecosystem often leads to deterioration of the river water quality. Penang, an island on the northern part of Peninsular Malaysia, is currently experiencing vast development. With the ever-expanding population in Penang Island, there is an urgency for proper conservation and efficient utilization of freshwater bodies for sustainable development. The population pressures in the island accelerates the progressive deterioration of water quality because of increased domestic, municipal, agricultural, and industrial activities including discharging of effluents into water bodies, leading to increased environmental degradation resulting from urbanization and deforestation.

As an example, Pinang river in Balik Pulau has been heavily subjected to various anthropogenic activities. The river is an important source of water supply for the western part of the island. The major environmental concerns are erosion, siltation and discharge of various pollutants such as garbage, human wastes and excreta, and effluents from aquaculture and agriculture, into the river.

A previous study by Nurul-Ruhayu [1] revealed that Pinang river is categorized as class III and IV under Interim National Water Quality Standards for Malaysia (INWQSM). Due to intensified agricultural and aquaculture activities, Pinang river is considered one of the most polluted rivers in the country [2]. This paper aims to assess the nutrients and sediment loadings in the river in relation to anthropogenic activities along the river basin.

2. Materials and Methods

2.1. Study Area

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The Pinang river basin lies between latitude 5^o 23’26.71”N 100^o10’40.62”E and 5^o 24’12.79”N 100^o13’36.01”E (Figure 1). It is a shallow river with a depth of 0.18 – 3.03 m and a width of 1.8 – 121.0 m. The upper part of this river is surrounded with orchard plantations. As the river flows, it passes through a few villages without proper sewage and sanitary treatment systems. Thus, it receives a large amount of effluents from agriculture, aquaculture as well as domestic wastewater.

The economic activities in the catchment area include cultivation of crops such as durian and coconuts, as well as raising of livestock, and fishing. The communities around the river use the water extensively for drinking and other domestic purposes after prior treatment by the Penang Water Authority.

2.2. Sampling and Field Work

Three sampling stations were located at the upper, middle and lower part of the river. The sampling was carried out twice a month from October 2007 to October 2008 during both spring tides and neap tides at low and high tides. The sampling covered both wet (i.e. March – April and July – October) and dry seasons (i.e. May – June and November – February).

Surface water samples for nutrient analyses were collected at depths of 30 cm and directly stored into clean 1 litre polyethylene bottles. Bottom water samples were collected at depths of 0.5 m above the river bed using water sampler. All the samples were stored in an icebox at 4 ^oC and transported immediately to the laboratory for further analyses. Measurement of parameters such as dissolved oxygen (DO), temperature, electrical conductivity (EC), salinity, and *p*H, were done *in-situ* at the sampling stations. The collected data for DO and the temperature of the water samples were measured using a DO Meter YSI Model 52. Dissolved salts and ions for water EC level were determined by a Conductivity Meter TDS (Total Dissolved Solids) Meter (HACH). Salinity and *p*H were measured using a hand refractometer (ATAGO) and a portable battery-operated *p*H meter (EUTECH Instruments), respectively.

2.3. Laboratory Analysis

The nutrients (nitrite, nitrate, ammonium, and ortho-phosphate) were analyzed according to the procedures outlined in the *Standard Methods for the Examination of Water and* Wastewater [3]. Total suspended solids (TSS) were measured gravimetrically after drying in an oven to a constant weight at 105^{o}C. The results in mg/l were converted into loads using mean discharges, and concentrations were measured. The formula used is outlined by Tilrem [4] as:

L= kCQw, where L= loads in t day-1, k= 0.0864, C= Concentration in mg/l, and Qw = Water discharge in m^3s^{-1}.

The mean discharges at three stations were used in the computation of the loads to kg day^{-1} for nitrate, nitrite, ammonium, ortho-phosphate, and TSS.

3. Results and Discussion

A summary of the results of means of physico-chemical analyses and nutrient loadings is presented in Table 1.

3.1. Physico-chemical Parameters

The river water was in normal *p*H range (pH 6.6 $\pm$ 0.4 – 8.1 $\pm$ 0.1) and was unaffected by seasonal variations. The *p*H was within the range of 6.5 – 9.5, which is stipulated for drinking and domestic purposes [5]. The DOE [2] also sets protection limits of *p*H from 6.5 to 8.5 for fisheries and aquatic life. Based on these guidelines, the *p*H of the Pinang river water would not adversely affect its use for domestic and recreational purposes, and the aquatic ecosystem. The well buffered nature of the Pinang river water can be attributed to the nature of deposits over which it flows [6]. Water temperatures ranged from 24.8 $\pm$0.5 ^oC to 30.3 $\pm$0.5 ^oC, which are within the temperature ranges experienced in the basin.

EC values varied between 21.2$\pm$6.1 µMHOS/cm and 39,611.1 $\pm$2,770.6 µMHOS/cm. The lower part of the river recorded the highest EC of 39,611.1 $\pm$2,770.6 µMHOS/cm. Generally, the EC of a river is lowest at the freshwater source, and as it flows towards the sea, it leaches ions from the soils and organic materials [7]. The average value of EC for unpolluted rivers without tidal influence is approximately 350 µMHOS/cm [8].

As Pinang river experienced tidal fluctuation, the salinity recorded at the middle part of the river was high at 16.0 ± 2.1 psu during high water at spring tide.

Pristine surface waters are normally saturated with DO, but such DO can be rapidly removed by the oxygen demand of organic wastes. The management of DO provides a broad indicator of water quality [9]. DO concentrations in unpolluted water are normally about 8 – 10 mg/L at 25 ^{o}C [9]. Concentrations below 5.0 mg/L adversely affect aquatic life. The concentration of DO in the river ranged from 6.6 ± 0.6 mg/L – 7.8 ± 0.4 mg/L and thus, the river water is suitable for use in the aquatic ecosystem.

Elevated TSS (138,433.8 ± 13,076.5 mg/L) at the lower part of the river indicated a zone of sedimentation. Soil erosion and runoff from agriculture activities contributed to high TSS in the river water. TSS is a common indicator of polluted waters. A river with high sedimentation would decrease light penetration into the water column and hence, reduce photosynthesis.

3.2. Nutrient Loadings

Generally, nutrient loadings exhibited low concentrations under the sheltered environment of the flowing upstream. However, in Pinang river, high nutrients load occurred during the wet season due to surface runoff and erosion (Table 1). Few studies found that anthropogenic activities such as agriculture, dominate the upstream at higher altitudes, resulting in increased nitrate levels [10,11]. In addition, domestic discharge without water treatment [12] and fertilizers leaching through groundwater [13] enter the river system, thereby, increasing the concentration of nitrate.

3.3. Statistical Analysis

From the correlation analysis, nitrate was found to be negatively correlated with temperature ($r = -0.621$), EC ($r = -0.666$), and salinity ($r = -0.699$) at $\alpha = 0.01$, $n = 442$. The *p*H, DO, and nitrate concentration ($p < 0.05$, $df = 406$, $n = 408$) are significantly higher during the wet season compared to the dry season. Meanwhile, the salinity and TSS ($p < 0.05$, $df = 406$, $n = 408$) were significantly higher during the dry season. High nitrate concentration reflected that leaching is the most important mechanism of transporting nitrogen in the form of nitrates from the terrestrial to the aquatic environment during heavy rains.

4. Conclusion

The study has provided information about the water quality status of Pinang river. The results indicated that *p*H and DO were all within their natural background levels of 6.5 – 8.5 and 5.0 – 7.0, respectively. Nutrients load in the Pinang river were derived mainly from domestic, agricultural, and commercial activities. In general, the distribution of TSS, nitrite, nitrate, ammonium, and ortho-phosphate were very distinct at the middle-stream, where wastewater from houses, small cottage industries, oil palm plantations, and aquaculture ponds were directly discharged into the river. The accumulation of nutrients from various sources would eventually flow into the river estuary and out to the sea. The impact of anthropogenic activities in Pinang river could lead to water quality deterioration and loss in its aesthetic value.

5. Acknowledgement

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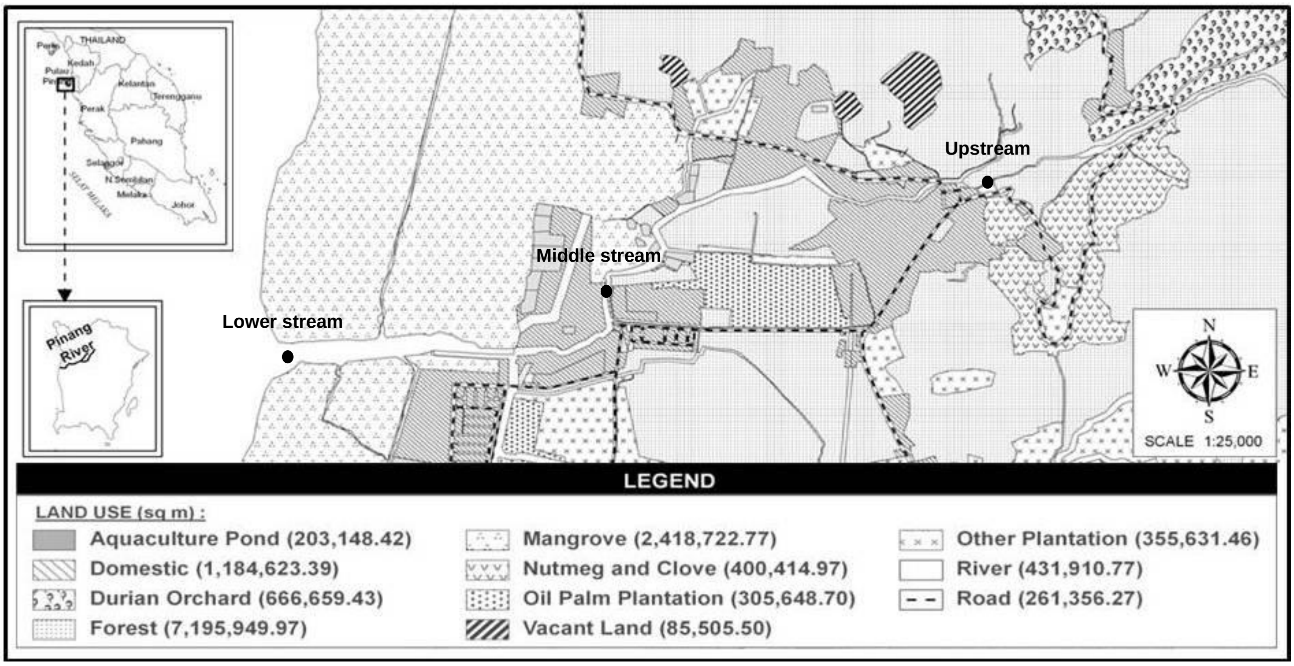

Fig. 1: Map of Pinang river showing sampling points and land-use activities (Mapping of ArcGIS 9.3)

Table 1: Mean value of measured physico-chemical parameters and nutrient loadings at the upper, middle and lower parts of Pinang river during neap and spring tides at dry and wet seasons.

Physico-chemical Parameters	**Upstream (freshwater source)**		**Middle Stream**				**Lower Stream**			
			Neap		**Spring**		**Neap**		**Spring**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
*p*H	6.6±0.4	6.8±0.8	7.1±0.2	7.3±0.1	7.4±0.1	7.8±0.2	8.0±0.1	7.7±0.2	7.8±0.0	8.1±0.1
Temperature (^{o}C)	24.9±0.9	24.8±0.5	26.8±0.4	26.9±0.1	29.3±0.4	28.1±0.2	28.6±0.2	29.2±0.3	30.3±0.5	29.7±0.3
EC (µMHOS/cm)	23.3±4.6	21.2±6.1	7,973.3±4,974.0	8,433.3±3,056.0	30,300.0±4,778.9	18,336.2±6,980.7	31,027.8±7,551.8	28,104.8±1,764.5	39,611.1±2,770.6	31,986.2±2,594.4
Salinity (psu)	0.0	0.0	5.3±4.2	4.3±0.8	16.0±2.1	9.4±4.3	21.7±4.1	17.7±1.5	27.0±2.9	20.8±3.9
DO (mg/L)	7.8±0.4	7.5±0.5	7.3±0.5	7.2±0.2	6.9±0.3	7.0±0.5	6.6±0.1	6.6±0.6	7.3±0.4	6.8±0.8

TSS (kg/day)	33.3±10.4	30.5±5.2	10,686.2 ±5,405.5	8,988.1± 2,533.5	1,036.3± 218.2	1,251.3± 450.1	2,353.4± 403.9	2,312.0± 459.2	138,433.8 ±13,076.5	104,615.0 ±14,651.3
Nitrite (kg/day)	0.0	0.0	7.0±0.5	8.5±1.0	0.6	0.5±0.1	0.2	0.4	13.3±2.8	4.4±0.5
Nitrate (kg/day)	0.8±0.1	0.8±0.1	29.0±3.0	31.0±3.2	2.4±0.3	2.4±0.2	2.0±0.3	2.2±0.1	15.3±4.7	31.6±2.9
Ammonium (kg/day)	0.0	0.0	7.0±0.5	7.6±0.5	0.5	0.7	0.3	0.4	13.4±1.3	7.9±0.7
Ortho-phosphate (kg/day)	0.0	0.0	11.0±0.6	17.1±1.8	1.3±0.3	1.0±0.1	0.9±0.1	0.9±0.1	18.9±2.2	13.8±1.2