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Phosphorus and Nitrogen Status in the Terengganu River Basin, Malaysia

Y.Y. Hee* and S. Suratman

Institute of Oceanography and Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

*Corresponding author: E-mail: yueyen_yy@hotmail.com

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This study has been carried out in the Terengganu River basin, southern South China Sea (Malaysia), to determine the concentrations of phosphorus (P) and nitrogen (N) based nutrients and their possible sources. The dissolved inorganic nutrients in this river were found to be related to land use, where higher concentrations of dissolved inorganic nutrients were recorded at the stations near to the agricultural activities and urban areas. In contrast, dissolved organic and particulate forms of P and N were generally higher in the largely undisturbed part of the upstream, suggesting that these forms of nutrients can originate from dead organic matter and living organisms, excretion of waste by animals, soil runoff and sewage discharge. When comparing with other selected rivers in the east coast of Peninsular Malaysia, Terengganu river basin showed a relatively higher concentration of P- and N-based nutrients, probably because of the fact that the river had received high impacts of anthropogenic activities. Therefore, a regular monitoring program in this basin is important in order to capture the impact of increasing population densities, land-use changes and social-economic development to the river, which has important implications for the sustainability of Terengganu as well as of Malaysian economy.

Keywords: Phosphorus, Nitrogen, nutrients, Anthropogenic activities, Terengganu River basin.

INTRODUCTION

Human activities have considerably been attributed to the Earth′s environments and landscape modifications and continue to do so. In recent centuries, land-use change has had negative impacts on ecosystems and biodiversity, and might have much greater effects than climate change [1]. One example is the widespread human-induced land-use change in agriculture. Agricultural activity is recognized as one of the significant non-point sources of water pollution, especially for nutrients like nitrogen (N) and phosphorus (P). Leaching of nutrients from fertilized soils is one of the major sources causing eutrophication and harmful algal blooms in many areas around the world [2]. On the other hand, a rapid increase in population growth and urbanisation is also causing land-use changes and triggering the transformation of the environment, especially in urban areas. Nutrient input from urban sources in the form of point source includes untreated sewage, sewage treatment and industrial effluent discharges [3]. The excessive nutrient enrichment of many rivers in the world have led to the occurrence of eutrophication, especially with increasing population density, intensive agriculture practices and industrial activities [3,4]. Even worse, worldwide eutrophication fueled by riverine runoff of fertilizers and sewage had exacerbated primary production in coastal zones, leading to an increase in the formation of hypoxia zones (< 2 mg/L O_2) [5], making the study of the potentially harmful effects of eutrophication to become much more important.

Terengganu River is the largest river in Terengganu state and Kuala Terengganu, a capital city of Terengganu state is situated at the mouth of the Terengganu river. The capital city covers an area of 21,021 hectares with an estimated population of 253,7000 people, which accounts for about 20 % of the total state population [6]. This city has evolved from a fishing village and trading center into a modern city known for its economic center of Terengganu, tourism, modern fishery, marine and creative industries and has continued to modernize since it was elevated to a city status in 2008 [7]. In addition to the urban area, where buildings occupy about 27 % of total land use of Kuala Terengganu district, this city is dominated by agriculture (52 %) [6]. With the rapid development in Kuala Terengganu city and a large area of agricultural land, the river which passes through the populated urban and agricultural area is expected to receive the runoff of nutrients from the agricultural field and direct discharge of domestic wastes.

This study was carried out in the Terengganu River on a monthly interval from July-October 2018, in order to investigate the levels of nutrients in the surface water of Terengganu river basin. The main objective of this preliminary study was to quantify and assess the extent of river nutrient levels, in the hope to provide important baseline data for Malaysian government to help in the future design of the water management and conservation policies of Malaysia′s rivers.

EXPERIMENTAL

Study area: The study was carried out in the Terengganu River basin (Fig. 1) from July to October 2008, covering the dry (July, August and September) and transition monsoon (October) seasons. Ten sampling stations were selected from upstream to downstream, following different land uses including forests, agriculture, commercial plantations, urban settlements, sand mining activities and industry. Stations T1, T2, T3, T4, T7 and T8 were situated in the upstream waters on different tributaries of the Terengganu River; T5, T6 and T9 were situated in the middle reaches of river; while T10 was a downstream station at Kuala Terengganu city. The main stream of Terengganu River is approximately 64.4 km^2, and has a total area of catchment of 4,650 km^2 with an annual river discharge of 10×10^9 m^3 yr^{-1}. The upstream encompasses Kenyir lake in a relatively pristine environmental setting, becoming downstream with urbanized and industrialized settings close to the river mouth, draining into the South China Sea. Population density is concentrated at the towns of Kuala Berang at station T5 and Kuala Terengganu at station T10.

Field sampling and analyses: Prior to field sampling and sample analyses, all high-density polyethylene (HDPE) bottles and glassware were cleaned by a 24 h soaked in 10 % HCl solution, and then thoroughly rinsed with deionized water and lastly, dried before used. On-field, pre-cleaned HDPE bottles were rinsed with the sample prior to filling to minimize cross-contamination. Water samples were then collected directly by immersing the HDPE bottles in the surface water. In laboratory, samples for dissolved inorganic and organic phosphorus and nitrogen analyses were filtered through pre-combusted (450 ºC for 5 h) GF/F glass filter (pore size 0.7 μm) and stored frozen at -20 ºC until analysis.

Analyses of dissolved inorganic nutrients (dissolved inorganic phosphorus (DIP), ammonia, nitrite and nitrate) were based on a standard colourimetric method, involving the chemical reaction of the reagent with nutrients and producing

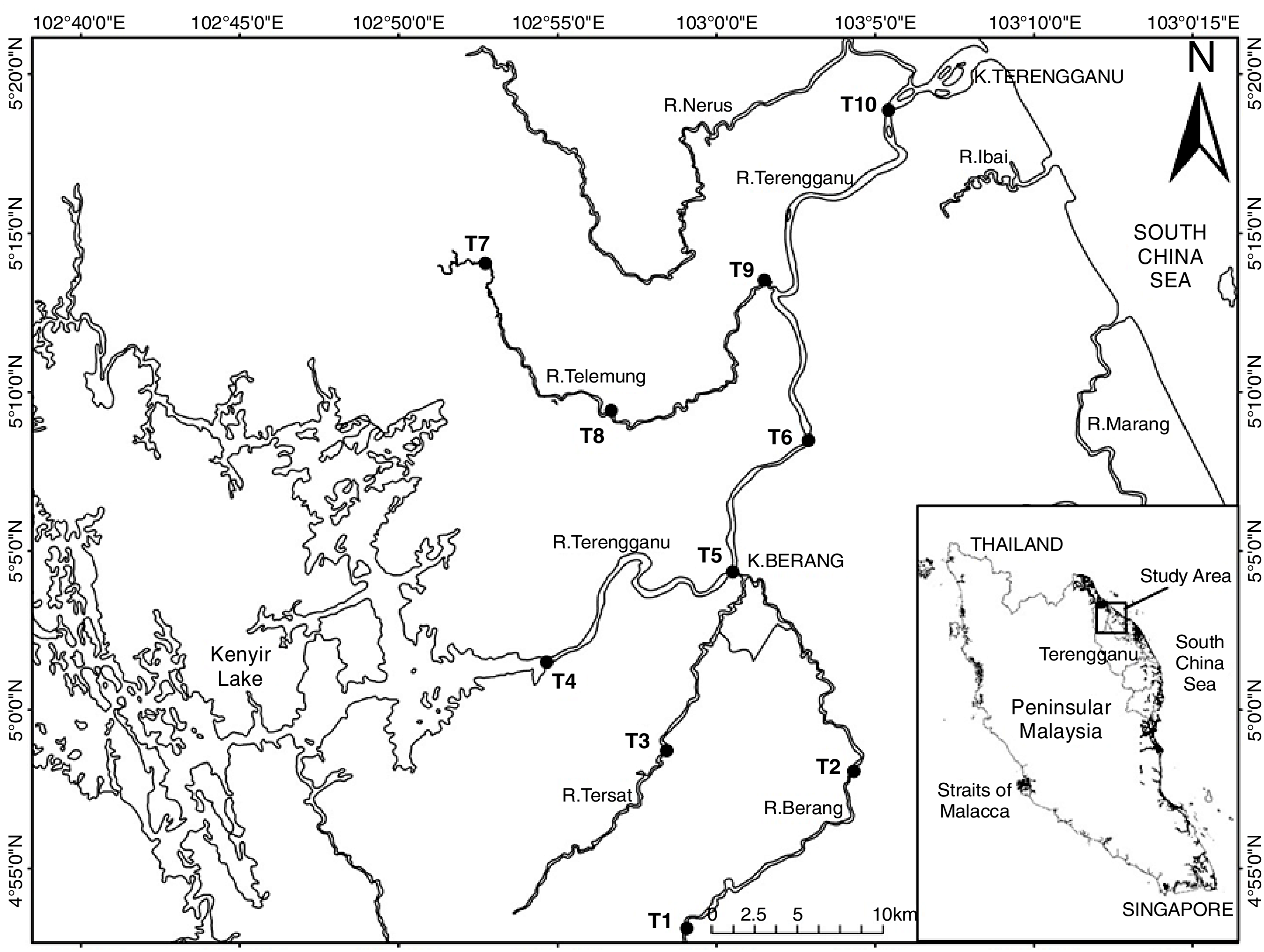

Fig. 1. Sampling locations at the Terengganu River basin, Malaysia

coloured compounds [8]. Dissolved inorganic phosphorus (DIP) was analyzed with the molybdenum blue method, where DIP reacted in an acid medium with ammonium molybdate and antimony potassium tartrate to form an antimony-phospho-molybdate complex, which was then reduced by ascorbic acid to intensely coloured molybdenum blue. The colour measured at 880 nm interference filter was proportional to DIP concentrations. Nitrite and nitrate ions measurements were based on pink azo dye method, in which NO_2^- was reacted with acidic sulphanilamide and *N*-(1-naphthyl)ethylenediamine dihydrochloride to form a pink azo dye and hence give a pink colour complex. The resulting coloured azo dye was detected at 550 nm. This method determines the NO_2^- singly and therefore, NO_3^- was first reduced to NO_2^- by passing through a cadmium redactor. Nitrate (NO_3^-) concentration was then calculated by subtracting the NO_2^- concentrations originally present in the samples. Ammonia was measured *via* the indophenol method, where ammonia reacted in moderately alkaline solution with hypochlorite to monochlromine which, in the presence of phenol, reacted to catalytic amounts of nitroprusside ions and excess hypochlorite, to form indophenol blue. The colour was measured colourimetrically at 630 nm, and the amount of colour developed was proportional to the concentration of ammonia.

For dissolved organic and particulate forms of phosphorus and nitrogen (DOP, DON, TPP, TPN) analyses, persulphate digestion method with reference to the method by Hansen and Koroleff [8] was first applied to decompose the dissolved and particulate organically bound phosphorus and nitrogen to DIP and NO_3^-. After the digestion process, liberated DIP and NO_3^- were measured by standard colourimetric methods as described above. The digestion performed on the filtered samples yielded the total dissolved phosphorus (TDP) and total dissolved nitrogen (TDN), and on unfiltered samples yielded the total P (TP) and total N (TN). Dissolved organic phosphorus was then calculated as the difference between total dissolved phosphorus and dissolved inorganic phosphorus (DOP = TDP – DIP), while total particulate phosphorus was calculated as the difference between total dissolved phosphorus and dissolved inorganic phosphorus (DIP).

RESULTS AND DISCUSSION

Phosphorus: Fig. 2 shows the histograms based on mean concentrations of P-based nutrients (DIP, DOP and TPP) for four time sampling across the Terengganu River. The results showed that the mean concentrations of DIP, DOP and TPP ranged between 3.94-18.22 µg/L P, 9.02-21.96 µg/L P and 6.63-10.68 µg/L P, respectively. The general trend of DIP was not similar to that of DOP and TPP, where higher DIP mean concentrations were recorded at the downstream stations, while higher DOP and TPP mean concentrations were found at the upper stream areas. Even so, some other higher DIP mean concentrations were also recorded at stations T3 and T5. ANOVA analysis indicates that only DIP concentrations were a significant difference between sampling stations ($P < 0.05$). In comparison to the four time sampling, DIP was again showing a different trend with DOP and TPP, where higher DOP and TPP were recorded in July and October (Fig. 3). With the exception of DIP, ANOVA analysis shows that P-based nutrients had significant differences ($P < 0.05$) among the four sampling results.

Nitrogen: The histograms for N mean concentrations (NO_2^-, NO_3^-, ammonia, DON and TPN) present in the water column at each station are shown in Fig. 4. The results showed

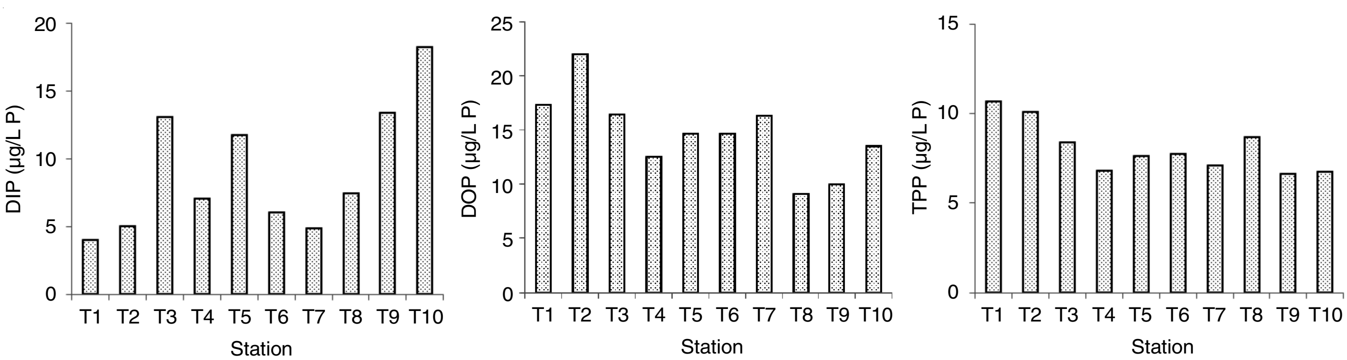

Fig. 2. Spatial variation of mean P-based nutrients concentrations in Terengganu River basin

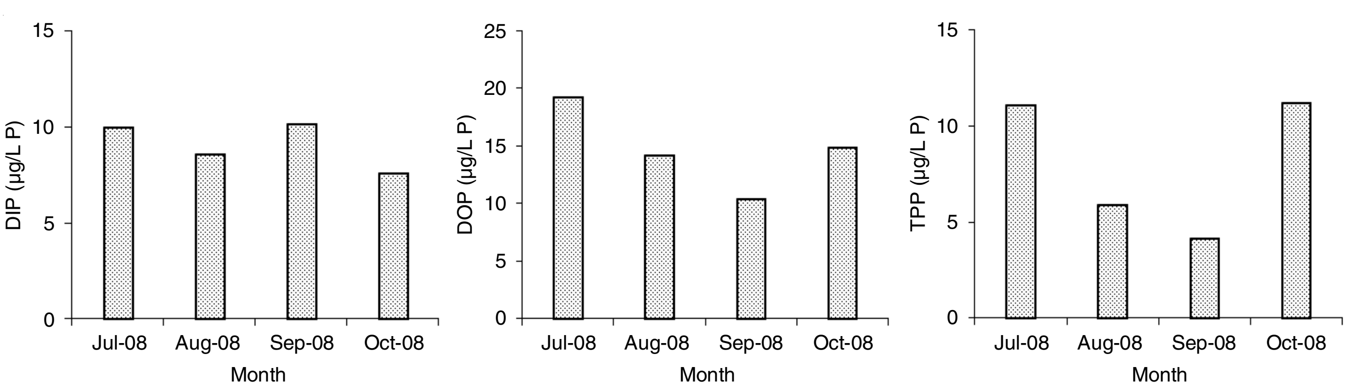

Fig. 3. Monthly variation of mean P-based nutrients concentrations in Terengganu River basin

that mean concentrations of these N compounds ranged between 1.03-2.02 μg/L N, 87.24-208.37 μg/L N, 22.08-122.20 μg/L N, 274-1018 μg/L N and 949-4954 μg/L N for NO_2^-, NO_3^-, ammonia, DON and TPN, respectively. Spatial distribution of N-based nutrients was somewhat similar to P-based nutrients, where mean concentrations of dissolved inorganic N (*i.e.* NO_2^-, NO_3^- and ammonia) were higher at the downstream and middle stream reach of the river, while DON and TPN mean concentrations were higher at the upper stream of the river. However, unlike P-based nutrients, ANOVA analysis shows that N-based nutrients showed significant differences between sampling stations ($P > 0.05$), with the exception of TPN ($P > 0.05$). On comparing the four time sampling, NO_2^-, NO_3^- and TPN show a higher mean concentration in July, while ammonia and DON recorded higher mean concentrations during September (Fig. 5). ANOVA analysis also reveals that most of the N-based nutrients were at a significant difference between sampling periods ($P < 0.05$), with the exception of ammonia ($P > 0.05$).

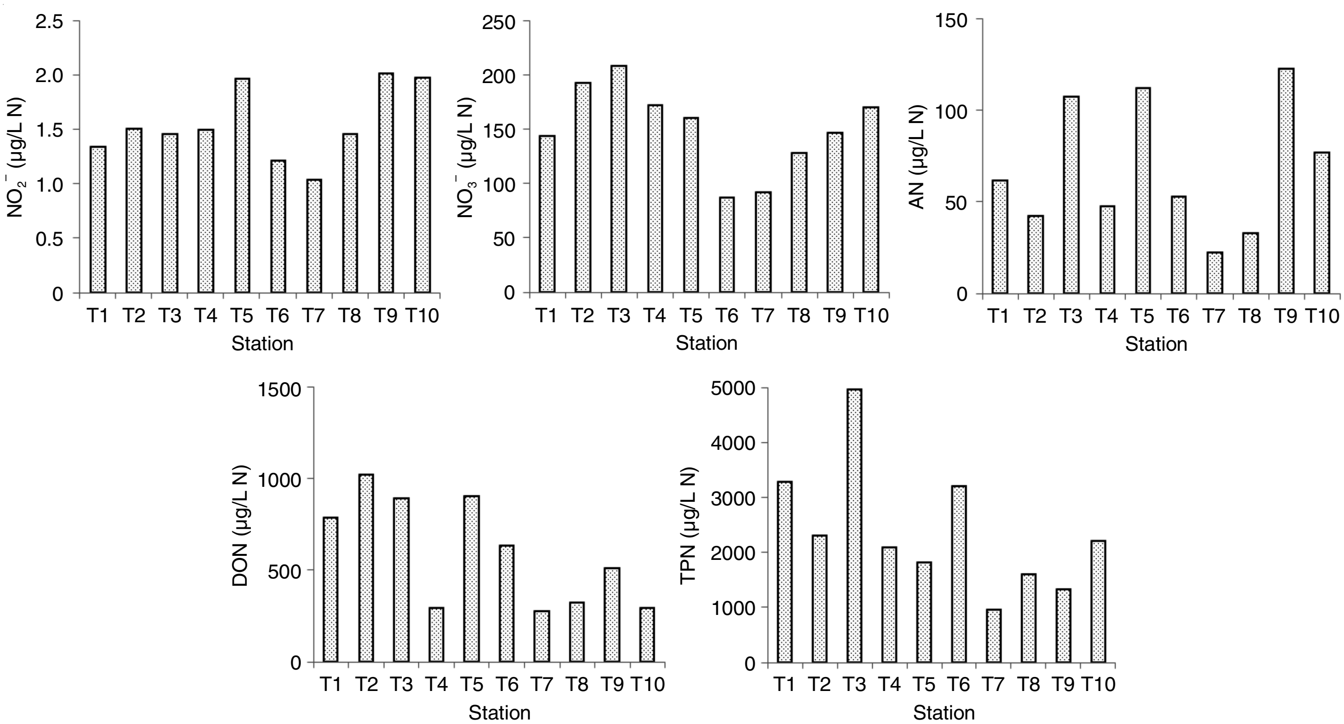

Fig. 4. Spatial variation of mean N-based nutrients concentrations in Terengganu River basin

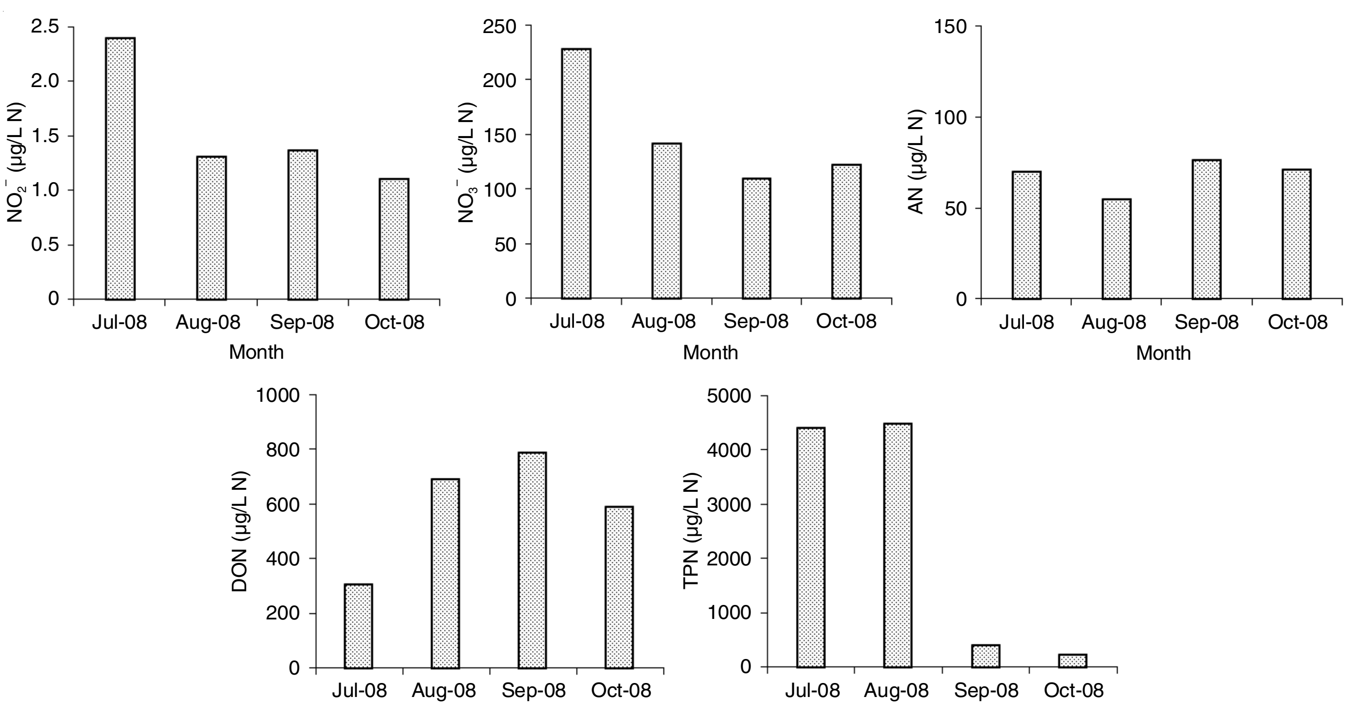

Fig. 5. Monthly variation of mean N-based nutrients concentrations in Terengganu River basin

Spatial and temporal distributions of P- and N-based nutrients: The results showed that dissolved inorganic nutrients (*i.e*. DIP, NO_2^-, NO_3^- and ammonia) tend follow a pattern similar to each other, with higher mean concentrations occurring at Terengganu River middle reach and downstream stations of town and agricultural areas. Considering that the areas for agriculture dominated the land use cover of Kuala Terengganu, especially its lowland areas provide the district with suitable areas for plantation such as paddy, palm oil trees and rubber trees [9], diffuse agricultural sources were therefore likely to be a major contribution to the higher dissolved inorganic nutrients at the downstream station. Washout of fertilizers not utilized by target plants are primarily attributed to anthropogenic dissolved inorganic nutrient sources [10]. One example study from Yangtze river reported a similar finding that dissolved inorganic nutrient concentrations had increased greatly since fertilizer application peaked after 1980s [11].

Additionally, sewage is another major source of phosphorus and nitrogen to the rivers and this point source generally influences the phosphorus and nitrogen concentrations in the river column. Many Malaysian rivers continue to suffer from sewage pollution [12], and it has been reported that sewage from urban areas has contributed to higher dissolved nutrient concentrations, as per the previous study of Malaysian rivers [13]. Kuala Berang (station T5) and Kuala Terengganu (station T10) are the two major and high population density towns along the Terengganu river, where domestic sewage could possibly contribute to the higher concentrations of dissolved inorganic nutrients in the river. In addition to a higher local population density of Kuala Terengganu, increasing tourism in this city could also likely have resulted in the increased discharge of sewage into the river, thereby causing the rise up of the river dissolved inorganic nutrient concentrations.

In contrast to dissolved inorganic forms of nutrients, dissolved organic and particulate forms of phosphorus and nitrogen were generally higher in the largely undisturbed part of the upstream (stations T1, T2 and T3), suggesting that there were other sources of dissolved organic and particulate nutrients in Terengganu River. In rivers, these nutrients could have originated from photosynthetical organisms (*e.g*. algae and plants), excretion of waste by animals, soil runoff and sewage discharge, as well as dead organic matter and living organisms, as these act as sources for particulate nutrients [14-16]. Therefore, in the undisturbed upstream of Terengganu River (stations T1, T2 and T3), the higher concentration of these nutrients was probably derived from natural sources and biological matter, although not all upstream stations were showing an identical trend of higher concentrations.

The role of monsoonal season is associated with rainfall amount has been found to influence the concentration of river nutrients on the east coast of peninsular Malaysia. Some of the previous studies carried out in the rivers of Terengganu state showed a seasonal pattern of higher nutrient concentrations in the wet season as a result of soil leaching, land runoff from agricultural land [17,18]; while another study in Kelantan River showed an opposite trend, where lower P- and N-based nutrients mostly occurred in the wet season due to the dilution effect by heavy rainfall [19]. In the current study, however, no general trend of higher P- and N-based concentrations has been observed in a particular month, probably because of the fact that most of the sampling time occurred in the dry season and October is considered as a transition season; therefore, the effect of the rainy season on nutrient distribution was not observed in this study, leading to a single seasonal observation and hence the results were mostly not significantly different between months in this study.

Comparison with selected rivers on the east coast of Peninsular Malaysia: While the focus of this article is on P- and N-based nutrients in the Terengganu River basin, comparing the data obtained in this study with the same river system on the east coast Peninsular Malaysia is useful in providing information of different land-use effects on nutrient distribution of rivers that have a broadly similar topography and geography (Table-1). Flowing through the largest cities in Terengganu and Kelantan states, Terengganu and Kelantan Rivers recorded comparable dissolved inorganic nutrient concentrations, and the majority of them were higher than those in Besut, Setiu and Kemaman Rivers. According to Suratman and Hee [19], higher concentrations of dissolved inorganic nutrients in Kelantan River occurred at the middle reaches and downstream of the river, where Kuala Krai twon and the capital city of Kota Bharu are located. They suggested that urban areas also contributed the higher concentrations of dissolved inorganic nutrients in the Kelantan River, which is somewhat similar to this current study. Both Terengganu and Kelantan Rivers also recorded a higher concentration of DOP (but not DON for Kelantan River). Overall, Terengganu river showed a relatively higher concentration of all three forms (dissolved inorganic, organic and particulate) of phosphorus and nitrogen compounds in the surface water, probably because the river received the impacts from both urban areas and agricultural activities.

Conclusion

The present study of nutrients carried out in Terengganu River basin showed that relatively higher concentrations of dissolved inorganic nutrients were found in agricultural and

TABLE-1
COMPARISON OF P- AND N-BASED NUTRIENTS WITH SELECTED RIVERS ON THE EAST COAST OF PENINSULAR MALAYSIA

River	Phosphorus (µg/L P)			Nitrogen (µg/L N)					Ref.
	DIP	DOP	TPP	NO_2^-	NO_3^-	AN	DON	TPN	
Terengganu	3.9-18.2	9.0-22.0	6.6-10.7	1.03-2.02	87-208	22-122	274-1018	949-4954	Present study
Kelantan	2.3-5.8	9.8-16.7	23.8-54.2	0.88-2.06	204-279	150-318	186-363	NA	[19]
Besut	0.3-7.3	NA	2.3-19.3	NA	88-323	26-81	NA	50-1033	[20]
Setiu	3.2-7.0	5.6-12.1	9.2-119.4	0.01-6.48	49-216	6-13	11-28	NA	[17,18]
Kemaman	1.3-7.0	0.3-11.3	4.9-468.3	1.47-6.28	31-496	NA	427-2502	143-1652	[21]

NA = Not available

urban areas. The diffuse agricultural sources of fertilizer as well as a point source from sewage effluent input, has been suggested as the major sources of phosphorus and nitrogen to the river, increasing the dissolved inorganic phosphorus and nitrogen concentrations in the water column. In contrast to dissolved inorganic nutrients, dissolved organic and particulate forms of phosphorus and nitrogen were generally higher in the largely undisturbed part of upstream, suggesting that these nutrients can originate from dead organic matter and living organisms, excretion of animal wastes, soil runoff and sewage discharge. In comparison with other selected rivers on the east coast of peninsular Malaysia, Terengganu River basin showed relatively higher concentrations of nutrients.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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