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Spatial and Temporal Variations of Dissolved Inorganic Nutrients and Relationship with Phytoplankton Density in Coastal Water of Kudat, Sabah, Malaysia

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Abstract

Coastal areas of Kudat are dominated by fisheries activities. Development of infrastructure for fishing facilities like jetty, landing centre and other human activities can increase the loading of nutrients in coastal area. High load of nutrients accelerates the blooming of phytoplankton and in long run creates eutrophication. This study was conducted to determine the temporal and spatial variations of nutrients and relationship of phytoplankton density in coastal water of Kudat. Five stations were selected with three replicated in the study area. Phytoplankton samples, water samples and *in situ* environmental parameters were collected from May 2019 to February 2020 (10 months). The highest concentration of nitrate (NO_3) was observed in May 2019, but the highest concentration of phosphate (PO_4) observed in July 2019. On the other hand, higher concentrations of phosphate (PO_4) were determined than the concentration of nitrate (NO_3) in all stations during study period. The distribution of nutrients is due to monsoonal runoff from surrounding areas as well due to anthropogenic activities. Among the 21 species three of them are from harmful algal species and but dominated by diatoms. Poor relationship observed among the dissolved inorganic nutrients and phytoplankton density, indicates that the relationship does not depend on only nutrients but with favourable environmental parameters. Anthropogenic activity can lead to excessive load of nutrients in Kudat coastal water and in long run cause eutrophication problem in ecosystem with potentially larger economic impacts in a long run period.

Keywords

Nitrate, Phosphate, Monthly Variations, Anthropogenic Activity and Kudat

Coastal Water

1. Introduction

Kudat's coastal water plays an important role in Sabah, largely because most of the community in Kudat are artisanal fishermen. Thus, most of the coastal communities and development are concentrated in this area. The rise in human population and development can increase the rate of nutrients load into the surrounding, which can trigger phytoplankton blooms (Freeman et al., 2019). Phosphate (P), nitrate (N), nitrite, ammonium, and silicate are essential macronutrients in the marine ecosystems (Tavakoly Sany et al., 2019; Anderson el al., 2002). In both freshwater and coastal water, excessive amounts of these nutrients will lead to eutrophication and degradation of the aquatic ecosystem. Nitrogen in water is measured as a common nitrate form that is dissolved in water and readily available in the photosynthesis process. On the other hand, phosphorous in the form of phosphate is essential for the growth of phytoplankton in primary productivity process. Excessively both of these dissolved inorganic nutrients can cause an increase in the growth of aquatic plants, which can disrupt the light, temperature, and oxygen levels in the water below, and lead to eutrophication and hypoxia (low dissolved oxygen) forming a "dead zone" of no biological activity (Cloern, 2001).

Nitrates and phosphorus sources include wastewater treatment plants, runoff from fertilized grassland and agricultural land, defective septic systems, animal manure runoff and industrial waste charge (Carpenter, 1998). In marine and freshwater ecosystem, phosphorus is known the primary limiting nutrient (Paerl et al., 2010). Aquatic ecosystems that are enriching with phosphorus will lead to accelerate the growth of algae blooms or water plants, anoxic events, altering biomass and species composition (Carpenter, 1998).

The abundance and composition of phytoplankton are affected by nutrients, presence of predators, temperature, interaction with other phytoplankton, and light intensity (Li et al., 2020a). The most common limiting inorganic nutrient for phytoplankton growth in marine and freshwater ecosystem is nitrogen and phosphorus respectively (Li et al., 2020b). Certain inorganic nutrients were found to affect phytoplankton growth and chlorophyll-a concentrations with favourable environmental conditions (Ault et al., 2000). Apart from environmental factors, anthropogenic activities were found to lead to reduce density by increasing the concentration of nutrient and organic matter (Zhang et al., 2020). Anthropogenic activities that result in an increase in the water's nitrogen and phosphorus content can alter the composition of the phytoplankton community, more dinoflagellates and phytoflagellates. These are toxic species that may aggregate via active migration and cause visible surface blooms (Ault et al., 2000).

Every phytoplankton species has different optimum environment requirements. In general, the growth characteristics of phytoplankton are constrained by the availability of inorganic dissolved nutrients, as well as by other physical processes. The decrease of dissolved inorganic nutrients concentrations from the river is known as a major factor of the decreasing nutrient level in the coastal water, which is responsible for the phytoplankton to bloom (Azad & Jinau, 2020). However, in recent years, there are an increasing number of studies in tropical waters that reported changes in the phytoplankton biomass throughout the year. During the northeast monsoon, high phytoplankton biomass is often observed, possibly due to heavy rainfall (Gin et al., 2000). Nitrogen and phosphorus concentration affect the phytoplankton species composition (Smayda & Reynolds, 2001). Correlation between phosphorus and abundance further supported the former conclusion that phosphorus is the controlling factor in phytoplankton growth in the Changjiang Estuary where light is not limiting. Based on the relationship between DO, pH and abundance, it is likely that the bloom was caused by rapid *in situ* growth of phytoplankton with high nutrients and sufficient light (Gao & Song, 2004). Information on the distribution of nutrients and its relationship with the phytoplankton communities in estuary around Kudat, Sabah are limited. Besides, peoples are less concern on estuaries, considered estuaries as their best option to discharge their waste due to their belief that the tide can dilute and disperse undesirable substances. This study was carried out to assess the spatial and temporal variations on dissolved inorganic nutrients in the Kudat's coastal area which may vary in phytoplankton species composition and abundance. The outcome of this study can enhance the fundamental knowledge of phytoplankton and nutrients for TMP in Kudat especially in the selected study area.

2. Methodology

2.1. Sampling Site

This study was conducted in Kudat, which is located at the northernmost point of Sabah (**Figure 1**). The samplings were carried out monthly from May 2019 to February 2020 (10 months) during low tide. The southwest monsoon (SWM) is the main cause for the heavy rain which occurs from May to August. However, the heaviest rainfall occurs in September and November which is during the northeast monsoon (NEM). Kudat has a tropical climate with regular temperature, high humidity, and copious rainfall due to its proximity to the equator (Malaysian Meteorological Department, 2014).

Five sampling stations were selected in the study area, based on anthropogenic activities. The location of the sampling stations was marked using the Global Positioning System (GPS). Detail of sampling stations coordinates, and other features were same as described (Romin et al., 2021).

2.2. Sampling and Analysis

Water and phytoplankton samples (in triplicate) were collected from the five stations. Water samples for nutrient were collected at a depth of 0.5 m from the

Figure 1. Location of each sampling stations (bottom) within the coastal area of Kudat, Sabah, Malaysia.

surface of the water using a Van Dorn Water Sampler. For the phytoplankton identification, a phytoplankton net (20 μm mesh size, radius = 0.52 m) was set 0.5 m below the water surface to collect phytoplankton samples. The collected samples were preserved immediately with 5% Lugol's solution for further analysis. The water samples were then poured into labelled polyethylene bottles. One litre of water sample from the Van Dorm water sampler was transferred to a labelled bottle and preserved with Lugol's iodine to analyse the phytoplankton abundance.

Water samples for nutrients (Nitrate and phosphate mg/L) were analysed in the Borneo Marine Research Institution (BMRI) laboratory using standard methods (Parsons et al. 1984). Identifying Marine Phytoplankton was done used standard guidelines (Tomas, 1997). Cell densities were calculated and expressed in terms of cell/L using the Counting Chambers Sedgwick-Rafter Cell technique under a microscope in the laboratory (Aktan et al. 2005).

2.3. Statistical Analysis

SPSS Window Statistical Package (Version 23) was used to conduct the statistical analysis of the data obtained. ANOVA and t-tests were done to test the differences between groups. Pearson Correlation test was done to analyse the correlation between abundance and nutrients. The significance for all the tests was set at $p < 0.05$.

3. Results

Temporal variations of dissolved inorganic nutrients (mg/L)

The nitrate concentrations were determined in the range of 0.017 ± 0.008 to 0.077 ± 0.006 mg/L. The highest and lowest mean concentration of nitrate (NO_3) was observed in May 2019 and September 2019, respectively. On the other hand, concentration of phosphate was recorded the range of 0.224 ± 0.012 to 0.007 ± 0.005 mg/L. The highest mean concentration of 0.224 ± 0.012 mg/L phosphate (PO_4) observed in July 2019 and the lowest of 0.007 ± 0.005 mg/L was recorded in May 2019, as well in the month of February 2020 (Figure 2). Significant differences ($p < 0.05$) were observed in the concentration of dissolved inorganic nutrients (nitrate and phosphate) in during the study period.

Spatial variations of Dissolved inorganic nutrients (mg/L)

The spatial distributions of nitrate and phosphate were observed in the range of 0.024 mg/L ± 0.019 to 0.036 ± 0.019 mg/L and 0.036 ± 0.012 mg/L to 0.056 ± 0.009 mg/L respectively during the study period. Comparatively, higher mean concentrations of phosphate (PO_4) were determined than the concentration of nitrate (NO_3) in all stations from May 2019 to February 2020. In respect of the spatial variation, there found no significant differences ($p > 0.05$) in the concentration of nitrate and phosphate within the stations (Figure 3).

Major phytoplankton species (%)

A total of 21 phytoplankton species were identified in the coastal water of

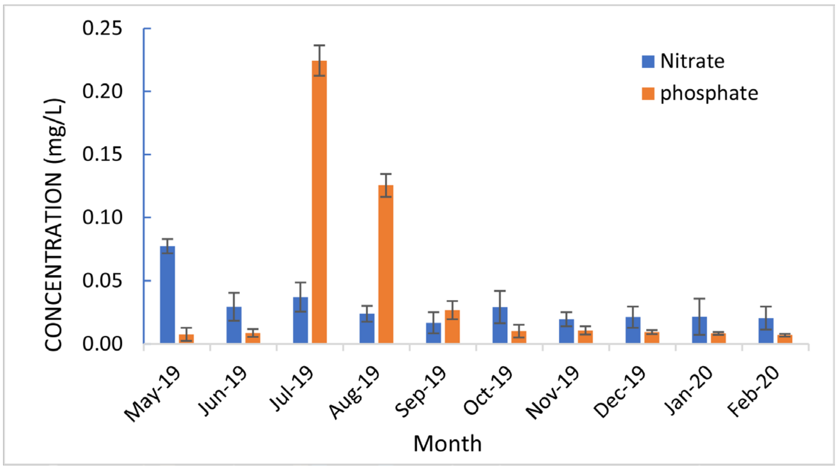

Figure 2. The distribution of dissolved inorganic nutrients, nitrate (NO_3) and phosphate (PO_4) during sampling periods. The values are express as mean ± Sd. Of nutrients from May 2019 to February 2020.

Kudat during the study period (Romin et al., 2021). Detail of temporal and spatial composition of phytoplankton was also published by Romin et al 2021. Diatom was the major dominated group that constituted of 58.74% among the phytoplankton community and followed by dinoflagellate (41.26) during study time. The major dominated species was *Ceratium* sp, composed of 30.46% in phytoplankton community. Other dominated species were *Nitzschia* sp (10.31%) and *Coscinodiscus* sp (7.94%). Phytoplankton other than *Ceratium* sp., *Nitzschia* sp., *Coscinodiscus* sp., *Thalassiothrix* sp., *Thalassionema* sp., *Pleurosigma* sp. and *Peridinium* sp. were categorized under group others (Figure 4).

Relationship of nutrients with phytoplankton density (×10⁴ cell/L)

Negative co-relation was observed between the density of phytoplankton and nutrients (both NO_3 and PO_4). In case of nitrate ($R^2 = 0.0245$) and phosphate ($R^2 = 0.2282$) very poor relationship was determined during study period (Figure 5 & Figure 6).

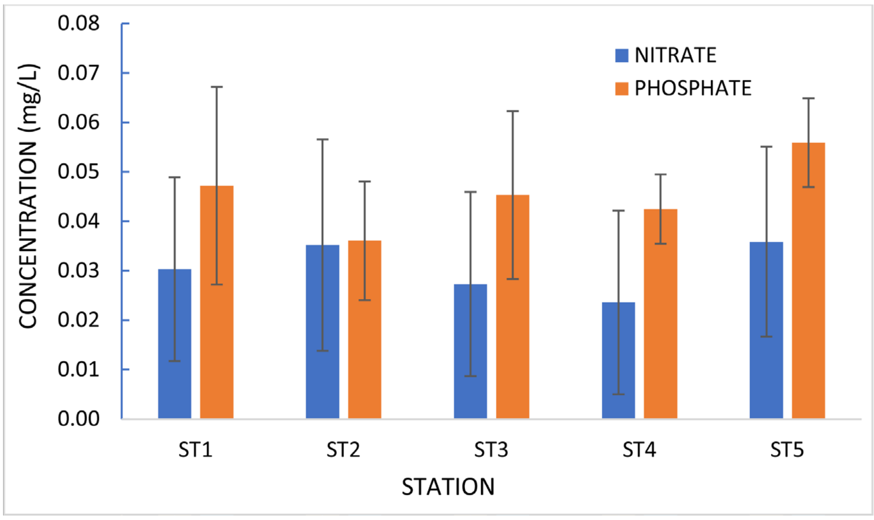

Figure 3. The concentration (mg/L) of dissolved inorganic nutrient nitrate (NO_3) and phosphate (PO_4) at different sampling stations from May 2019 to February 2020. (Values are express as mean ± Sd) in each of station during study period.

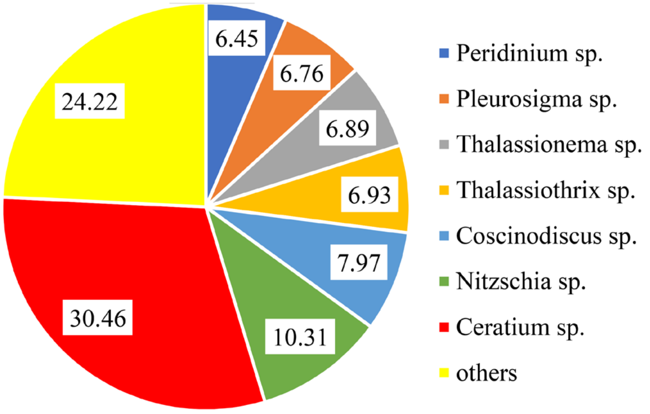

Figure 4. Percentage (%) of species of phytoplankton from May 2019 to February 2020 in Kudat's coastal water.

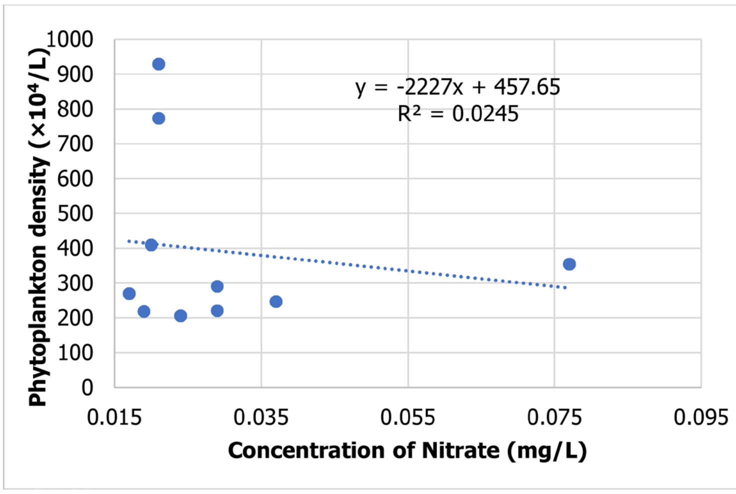

Figure 5. Relationship of Dissolved Inorganic Nutrient nitrate and mean phytoplankton density (×10[4] cell/L) from May 2019 to February 2020.

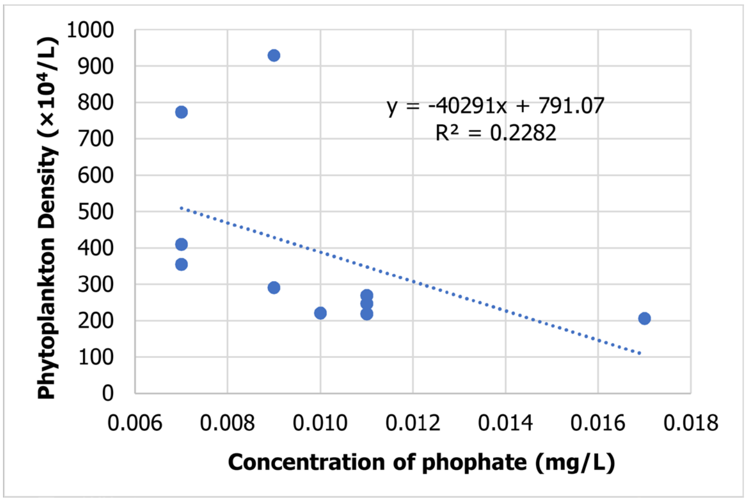

Figure 6. Relationship of Dissolved Inorganic Nutrient phosphate and mean phytoplankton density (×10[4] cell/L) from May 2019 to February 2020.

4. Discussions

Temporal variations of dissolved inorganic nutrients (mg/L)

The distribution of nutrients in the coastal water is influenced by local conditions like rainfall, freshwater inflow, and biological activities (Satpathy et al., 2010) as well as human activities (Chang et al., 2009). Nitrate and phosphate concentrations in the study areas were higher from March to September could be due to heavy rainfall bringing nutrients to the study areas via river run-offs during monsoon season resulted in high nutrients concentration in coastal areas via rivers and land run-offs (Soon & Ransangan, 2016). The range of concentration higher than the concentrations of nitrate, was observed the range of 0.04 to 0.46 mg/L in dry seasons (Rahaman et al., 2013). Typically nitrate concentration in estuaries was higher during monsoon due to freshwater influx (Li et al., 2013). The higher concentrations during monsoon season are attributed to the terrestrial input through riverine discharge into coastal areas (Vijayakumar et al., 2000).

Spatial variations of Dissolved inorganic nutrients (mg/L)

The highest concentration of both phosphate and nitrate were recorded from station 5 which is an area with many squatting houses. So, nutrients loaded from wastes from the residential areas. Nitrate and phosphorus loading are dependent on land use, fertilizer application, population density, and other anthropogenic activities. The additional source nutrients could be due to anthropogenic activities such as direct wastes from the fish landings as well domestic sewages from surrounding areas. The addition of nitrates as non-conservative nutrients due to anthropogenic activities increases the concentrations in Wanquan River estuary, China (Li et al., 2013). The global transport of dissolved inorganic nutrients in rivers has increased due to anthropogenic activities (Wen et al., 2008) In general dissolved inorganic nutrients nitrogenous species carried in river waters were transported out to the coastal ocean frequently used up in the primary productivity process, while dissolved phosphates sink in the estuary. This is thought that large amount of waste input and the organic material and phosphate minerals carried by water entering the coastal water in Kudat could have profound impacts coastal ecosystem.

Major phytoplankton species (%)

This estuary area was dominated by diatoms (58.74%) and followed by dinoflagellate (41.26%) species. Among the dinoflagellates few dominated harmful algal species (*Peridinium* sp., *Prorocentrum* sp. and *Dinophysis* sp. also observed during study period. The emergence of extremely serious toxic phytoplankton blooms in long run nearshore waters may create eutrophication problems (Aktan et al., 2005). Due to seasonal variations, the distribution and abundance of phytoplankton in tropical waters are considerably varies. The most relevant macronutrients for most phytoplankton species are nitrate and phosphate, although diatoms additionally require silicate for constructing their frustules (Ramos et al., 2017). Because of different nutrient utilisation strategies, species occurrence and succession in phytoplankton communities frequently result from resource competition (Litchman et al., 2006). Nutrient availability is directly related to the productivity of the water body. A shortage of nutrients causes the water body to be unproductive. An excess of nutrients causes eutrophication by algal bloom and makes the water toxic. Dissolved inorganic nitrogen is the primary limiting factor for phytoplankton bloom in the coastal environment (Cloern, 2001). Nutrient concentrations are not the only factor affecting the phytoplankton blooms, but the changing environmental parameter might favour some species to blooms. Factors like temperature, salinity, Secchi depth (visibility), pH, and dissolved oxygen are resultant for the succession or limit the growth of certain groups of algae (Huang et al., 2004).

Relationship of nutrients with phytoplankton density (No. of Cells 10^4/L)

The relationship between phytoplankton and dissolved inorganic nutrients in this study were observed very poor. Negative co-relation was observed between the density of phytoplankton and nutrients (both NO_3 and PO_4). If nitrogen concentration control phytoplankton biomass in water ecosystem, then it is possible to establish a good relationship between nitrogen concentration and Secchi depth, analogous to the models established for the relationship between Secchi depth and phosphorus concentration (Jeppesen et al. 1997). As mentioned before the phytoplankton bloom is not only controlled by dissolved inorganic nutrients, but also vitally necessary for favorable environmental conditions in the areas. Due to the wide range of concentrations of nutrients some might have low nutrients levels while others might be high in concentrations. These concentrations often fell in the low levels that were not supportive in the bloom of phytoplankton. In such situations negative or poor correlations between salinity with both nitrogen and phosphorus indicate the surface runoff as well nutrients of anthropogenic activities (Nielsen et al., 2002). The roles of anthropogenic activities are the consequences of nutrients availability in the selected stations of this study. The predicated poor relationship of nutrients and phytoplankton density in this study might be due to low levels in selected parts of areas or times, as observed in the spatial and temporal distribution of nutrients in Kudat coastal areas.

5. Conclusion

The spatial and temporal concentrations of dissolved inorganic nutrients were quite variables. This study has identified that the coastal water of Kudat was dominated with diatoms followed by dinoflagellates by 58.74% and 41.26% respectively with few harmful algal blooming species. The relationship of nutrients and phytoplankton density was poorly established, as blooming also depends on other environmental parameters. Surface runoff after heavy precipitation is believed to be the results in accumulation of nutrients (nitrate and phosphate) in the study area as well as anthropogenic activities near the sampling site. Continuous anthropogenic activities in a long run could lead eutrophication problems in the Kudat coastal waters. The increase in the concentrations of nutrients due to anthropogenic activity remains complex due to hydrological factors, which need to study critically to establish the nutrients dynamics towards phytoplankton bloom.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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