Journal of Geoscience and Environment Protection, 2022, 10, 243-258
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Distribution Pattern of Dissolved Inorganic Nutrients and Phytoplankton Diversity in River Estuary, Kota Kinabalu Sabah, Malaysia

Sujjat Al Azad*, Jiney Liow Fui San, Ejria Saleh

Borneo Marine Research Institute, University Malaysia Sabah, Kota Kinabalu, Malaysia
Email: *sujjat@ums.edu.my

How to cite this paper: Al Azad, S., San, J. L. F., & Saleh, E. (2022). Distribution Pattern of Dissolved Inorganic Nutrients and Phytoplankton Diversity in River Estuary, Kota Kinabalu Sabah, Malaysia. *Journal of Geoscience and Environment Protection, 10,* 243-258.
https://doi.org/10.4236/gep.2022.108015

Received: June 29, 2022
Accepted: August 27, 2022
Published: August 30, 2022

Abstract

Nutrients are influenced by anthropogenic activities and consequently change the diversity and density of phytoplankton. The spatial distribution of dissolved inorganic nutrients and phytoplankton diversity and density were determined in river estuary, Kota Kinabalu, Sabah, Malaysia. Samples of water and phytoplankton were collected from six locations of river estuary during the month of May 2019 to October 2019. The highest abundances of 86% diatoms were determined during the study period. This was followed by 13% and 1% of dinoflagellates and Cyanobacteria respectively. The most dominance species of *Skeletonema costatum*, with density of 1186.69 × 10^3 cells/L and *Thalassiosira* sp. (938.01 ×10^3 cells/L) were recorded from Station 1 (upstream) and Station 5 (mangrove area) respectively. The *Chaetoceros* sp. (84.25 × 10^3 cells/L) was the dominated in Station 6 (control site). Station 4 (residential area) accounted the highest diversity of species such as *Skeletonema costatum*, *Thalassiosira* sp., *Peridinium* sp., *Gonyaulax* sp., and *Cylindrotheca* sp. with total cell density of 142.98 × 10^3 cells/L. The high diversity index of 5.2 to 7.09 and evenness index of 1.81 to 2.87 were determined from this river estuary. Very poor relationship was observed with the cell density and dissolved inorganic nutrients, phosphate (R^2 = 0.2437), ammonium (R^2 = 0.301) and nitrate (R^2 = 0.406). The diversity and abundance of phytoplankton in this river estuary not only depend on nutrients, but might be associated with other environmental factors, tidal fluctuations and rate of discharge of nutrient inputs from surrounding areas. This study suggests that long term monitoring not only the nutrients, but discharges and flushing of nutrient during rainfall and tidal fluctuation together with environmental factors should be considered in order to conclude status on the diversity and abundance of phytoplankton in river estuary.

Keywords

River Estuary, Nutrients, Phytoplankton Abundance, Diversity and Evenness

1. Introduction

Growth and diversity in phytoplankton are controlled by various environmental factors, which are influenced by anthropogenic activities. These could result in massive changes in primary productivity global climate change, ozone depletion and pollution in marine ecosystem (Behrenfeld et al., 2006). The diversity and density of algal species could be obtained from water samples that are possibly helpful to detect early signs of eutrophication (Jafari & Gunale, 2006). River estuary is influenced by the freshwater and sea water resulted complex ecosystem for the biodiversity. The three major groups of phytoplankton in freshwater ecosystems such as Bacillariophyta (diatoms), Chlorophyta (green algae), and Cyanobacteria. These groups of phytoplankton take massive growth with optimum level of phyco-chemical factors such as temperature, dissolved oxygen, pH, dissolved inorganic nutrients (ammonia, nitrogen and phosphate) (Muhammad et al., 2005).

The species diversity, biomass and production of phytoplankton are interconnected with nutrients (nitrogen and phosphorus) imbalance and availability in aquatic ecosystem. The unhealthy condition of a river is disturbed by anthropogenic activities which lead to excess nutrient loading. Thus, invariably changing the physicochemical properties of the water. Increasing of total nitrogen, total dissolved nitrogen, dissolved inorganic nitrogen, nitrate and total phosphorus in the river can speed up eutrophication and cause high phytoplankton abundance and diversity. Nitrogen and phosphorus concentration affect the phytoplankton species composition (Smayda & Reynolds, 2001).

Correlation between phosphorus and abundance of phytoplankton suggests that phosphorus is the controlling factor in phytoplankton growth in the 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 et al., 2005). Estuaries trap natural and anthropogenic materials by filtering them from surrounding areas to the open sea. Estuarine systems are exposed to cultural eutrophication, resulting in an increase of productivity and large phytoplankton populations. There are many factors that affect the relative amount of nitrogen in various forms, which are influenced by anthropogenic activities. Phosphorus has been shown to be the production of phytoplankton, while nitrogen is commonly limiting in marine ecosystems (Cloern, 2001). Phytoplankton communities are not only sensitive to various chemical nutrients but also to environmental factors such as temperature, pH, light etc which affect their occurrence, distribution and diversity.

In a river system, the current velocity does not allow the planktonic to settle at any place, thus becoming a main limiting factor. Light and nutrients are resources that regulate the quantity, the distribution, and the structure of phytoplankton communities (Diehl et al., 2002). Phytoplankton abundance and diversity are influenced by discharge. The discharges are associated with residence time, channel depth, and dilution rate and affect water transparency and water sedimentation thereby affecting phytoplankton biomass. Information on the distribution of nutrients and its relationship with the phytoplankton communities in riverine estuary around Kota Kinabalu, Sabah is limited. Long term variation on the water quality of Inanam river estuary are documented (Azad, 2021), but the relationship of nutrients with phytoplankton structure of the river estuary are not established in previous study. Thus present study was conducted on riverine estuary of Darau River that mixed with Likas River at the end mouth of the river flowing towards Seppenger Bay. This estuary significantly increasing of nutrients concentration as runoff water of aquaculture lands and urban development are the major environmental concern at the area for many years. Anthropogenic discharges now a day concern on estuaries quality and considered estuaries as their best option to discharge their waste due to the tide that can dilute and disperse undesirable substances. The aim of this study was to determine the spatial distribution of nutrients and phytoplankton diversity and abundance in Kota Kinabalu river estuary.

2. Methodology

2.1. Study Area

The study site is located between latitude 06˚01.189'N and 06˚00.475'N, longitude 116˚07.524'E and 116˚06.335'E. The river estuary is suspected to have high amounts of nutrients concentration due to anthropogenic activities happening at the study area. Six stations were chosen and located based on the source of nutrients as shown in **Figure 1**. It started with upstream of the estuary (S1), construction development (S2), near aquaculture farming where water discharged take place (S3), residential area at Kingfisher (S4), at the estuary of mixing point water of Darau and Likas River (S5) and lastly at control station (S6). The detail co-ordinates of sampling station and attribution at each station are shown in **Table 1**.

2.2. Duration of Sampling

The water samples were taken from May 2019 to October 2019 (six months). Every month water samples were collected from selected stations in triplicate immediately after the start of low tide.

2.3. Collection of Samples for Water Nutrients Analysis

The water samples were collected from each station by using Van Dorn water sampler and immediately stored into polyethylene bottle. The bottles were labelled according to station and preserved in cooler box with ice. All of the samples

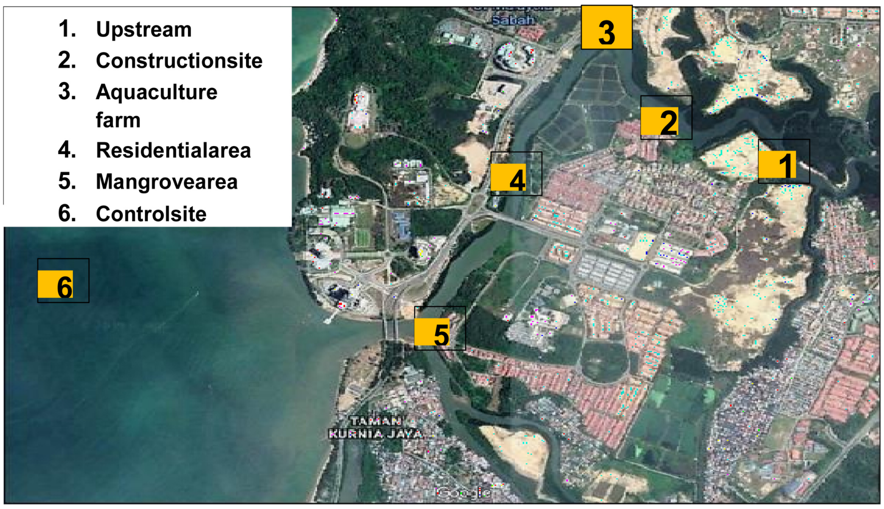

Figure 1. Sampling locations (Sources: Google Earth).

Table 1. Coordinates of sampling and attribution at each station.

Stations	Coordinates	Attributions of Area
1	06˚01.337'N 116˚07.852'E	Upstream of the Darau River
2	06˚01.448'N 116˚07.570'E	Construction area from Alamesra land development
3	06˚01.741'N 116˚07.313'E	Discharges from Aquaculture farm
4	06˚01.369'N 116˚07.109'E	Discharges from residential area at Kingfisher
5	06˚00.800'N 116˚06.850'E	Mangrove area where Darau and Likas water mix
6	06˚00.740'N 116˚06.488'E	Control Site

were brought to Borneo Marine Research Institute Chemical Laboratory for dissolved inorganic nutrients analysis.

2.4. Collection of Samples for Phytoplankton Cell Density Estimation

Water samples were collected using Van Dorn water sampler within a meter depth and pass through phytoplankton net. Amount of water (liter) pass through net were recorded. Then the water samples were poured into three polyethylene bottles and preserved with Lugol's solution before taken to laboratory for the estimation of cell densities per litre

2.5. Collection of Samples for Phytoplankton Species Diversity

A 20 µm mesh size of phytoplankton net was used and towed horizontally in the water for a minute. Flow meter was added with plankton net to record the amount of water pass through net. The water samples were transferred into polyethylene bottles and preserved by using Lugol's iodine for analysis in the lab.

2.6. Analytical Parameters

2.6.1. Determination of Water's Analytical Parameters (*In-situ*)

The physical parameters such as Temperature (˚C), Salinity (ppt), pH, Dissolved Oxygen and DO (mg/L) were measured from each six station by using YSI Profesional Plus meter during sampling time.

2.6.2. Laboratory Analysis of Nutrients

The water samples were filtered with 0.45 µm pore-size membrane filter. Concentration of dissolved inorganic nutrients, such as, phosphate (mg/L), nitrate (mg/L), and ammonium (mg/L) were analyzed with colorimetric method, according to the procedure described in APHA (2000).

2.6.3. Phytoplankton Species Composition and Cell Density

All the collected phytoplankton species were identification in the laboratory by using Identifying Marine Phytoplankton book by C.R Tomas (1997) published in. The Sedzwick rafter counting chamber was used to number of phytoplankton using a compound microscope. The total number of cells was counted according to the following formula (Stirling, 1985):

$$N = (A \times 1000 \times C)/(V \times F \times L)$$

N = Number of plankton cells or units per litre of original water A = Total number of plankton counted;

F = Volume of final concentrate of samples in mL L = Volume of original water in litres;

C = Volume of final concentrate of sample in mL.

2.7. Statistical Analysis

The SPSS Window Program (version 23) was used to find significant difference in concentration nutrients among all stations using one-way Analysis of Variance (1-way ANOVA). Simple linear correlation-regression was established for the relationship between nutrient and phytoplankton cell density. One ways ANOVA and significance values were set at $p < 0.05$ used in this study. The Microsoft Excel was used to calculate the phytoplankton diversity index, species richness and equitability index.

3. Results

3.1. Physico-Chemical Water Parameters

The highest temperature of 31.8 (˚C) in station 2 (construction area) and the lowest temperature of 28.2 (˚C) in station 5 (mangrove area) were recorded during the study period. The lowest 14.1 ppt of salinity was recorded at Station 1 and the highest salinity of 32.9 ppt was observed at station 6 (control site). Wider variations (2 - 7 mg/L) in the concentration of dissolved oxygen concentration were recorded during the sampling period. The values of pH were observed in the range of 6.61 to 8.01 during study period in Kota Kinabalu river estuary (**Table 2**). No significant differences were ($p > 0.05$) observed with the physical parameters among the stations except concentration of dissolved oxygen and salinity ($p < 0.05$).

The lowest concentration of phosphate was found in station 6 (0.475 ± 1.042 mg/L). On the other hand, the highest concentration of 0.622 ± 1.161 mg/L of phosphate were recorded at station 2 (**Figure 2**). No significant differences ($p > 1.00$) was observed in the phosphate concentrations among the stations.

The highest concentration of ammonium was recorded in Station 1 (2.075 + 0.296 mg/L) followed by Station 2 (1.745 + 0.443 mg/L) and Station 3 (1.652 + 0.443). The lowest concentration of 0.615 + 0.422 mg/L ammonium was observed at Station 6 (**Figure 3**).

Table 2. Physical parameters in each station during study period at Kota Kinabalu river estuary.

Station	Temperature (˚C)		Salinity (ppt)		Dissolved oxygen (mg/L)		pH	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	30.3	29.0 - 31.6	16.5	14.1 - 20.0	2.5	1.4 - 4.3	7.25	6.61 - 8.01
2	31.3	30.3 - 31.8	21.1	18.3 - 23.6	2.7	1.9 - 4.3	7.46	6.65 - 8.27
3	31.1	30.4 - 31.6	23.4	20.6 - 25.0	3.5	2.3 - 4.6	7.59	6.95 - 8.27
4	31.0	30.0 - 32.0	25.9	24.0 - 27.4	4.1	2.7 - 4.9	7.68	6.85 - 8.25
5	30.6	28.2 - 33.0	26.7	19.2 - 30.3	4.6	2.9 - 5.2	7.67	7.01 - 7.83
6	31.3	30.6 - 32.6	31.2	28.0 - 32.9	6.6	4.8 - 7.6	7.93	7.17 - 8.16

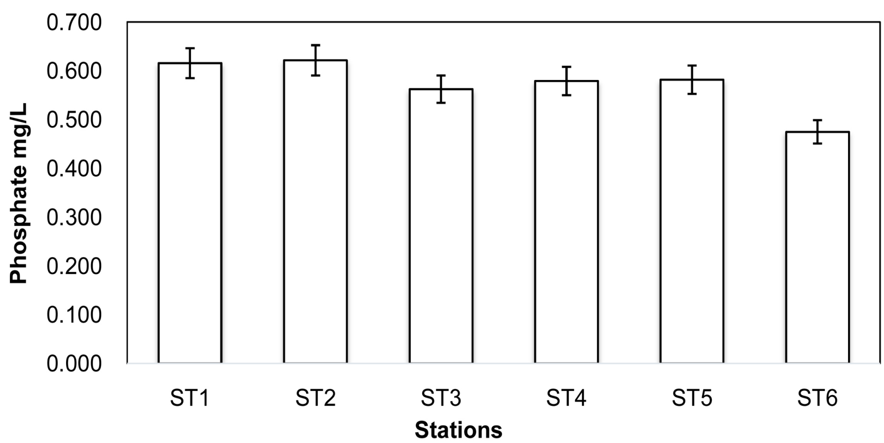

Figure 2. The concentration of phosphate (mg/L) at different stations during the study period in the River estuary. There was no significant difference between PO_4 among the stations ($p > 0.05$) although concentration of phosphate was determined different among the stations.

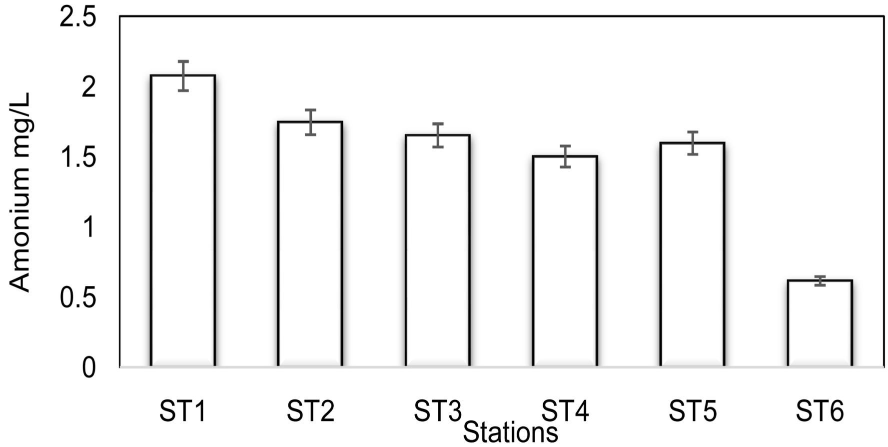

Figure 3. The concentrations of ammonium (mg/L) at different stations during study period in River estuary. There was significant difference between NH_3 among the stations ($p < 0.05$). Tukey post hoc test showed that ST6 was significantly difference than ST1, ST2, ST3, ST4 and ST5.

The concentration of nitrate in Station 2 (0.144 ± 0.298 mg/L) was recorded slightly higher compared to nitrate that was observed at Station 1 (0.141 ± 0.0346 mg/L) while the lowest of 0.042 ± 0.289 mg/L was found at Station 6 (**Figure 4**).

3.2. Major Group of Phytoplankton

Total 25 types of phytoplankton were identified during the study period (May - October) in this River estuary. The most dominated phytoplankton group in the estuary was the Bacillariophyta accounted 86%, 15 species belongs to this group with total density of 2672.72 × 10^3 cells/L. The second most dominated eight species of Dinophyta group (13%) with total density 440.30 × 10^3 cells/L were recorded during sampling period. Only two species of Cyanophyta group was found the with a density of 23.584 × 10^3 cells/L

3.2.1. Abundance (Cell/L) of Phytoplankton in Each Station

The highest phytoplankton abundances with 142.98 × 10^3 cells/L was determined in Station 4, followed by the Station 1 (114.06 × 10^3 cells/L). The lowest of 27.58 × 10^3 cells/L were observed in Station 6 (**Figure 5**).

3.2.2. Phytoplankton Species Diversity Index and Evenness Index

The diversity index of phytoplankton among the stations was observed in the range of 5.2 to 7.09. The highest diversity was observed in Station 4. It indicated that the phytoplankton communities in Kota Kinabalu River estuary were favored with environment conditions for their growth and distribution. As for the Evenness Index, Station 4 had the highest value of 2.87 compared to the evenness value obtained at Station 6 (1.81) assumed that phytoplankton species in Station 6 were not evenly distributed and some other varieties of phytoplankton species are dominating this station than other stations (**Figure 6**).

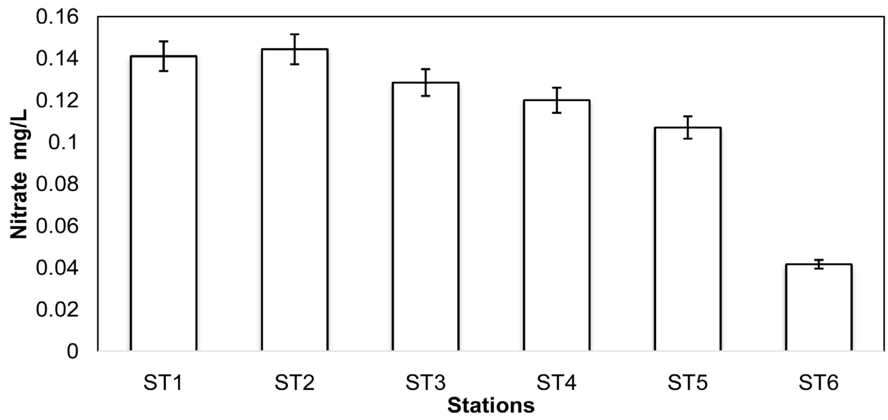

Figure 4. The concentration of nitrate (mg/L) at different stations during study period in Darau River estuary. The concentration of nitrate was significant ($p < 0.00$) among the stations and showed not many differences.

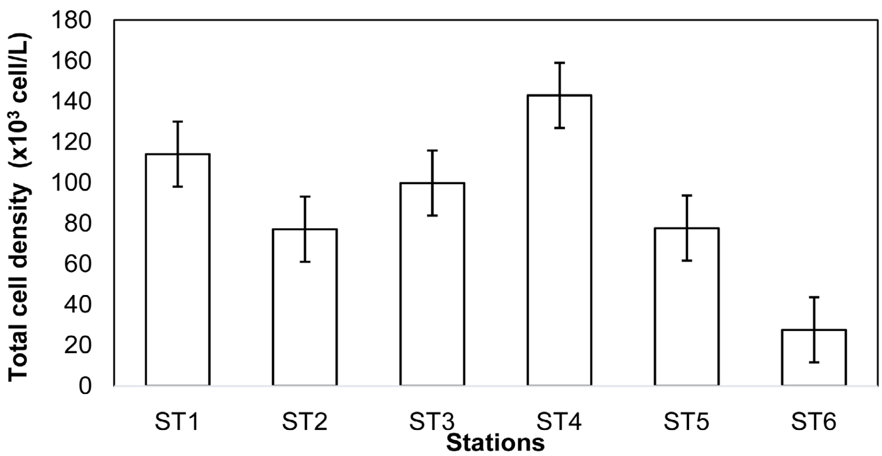

Figure 5. Total cell density of phytoplankton community ($\times 10^3$ cells/L) in different stations during study period in Kota Kinabalu river estuary.

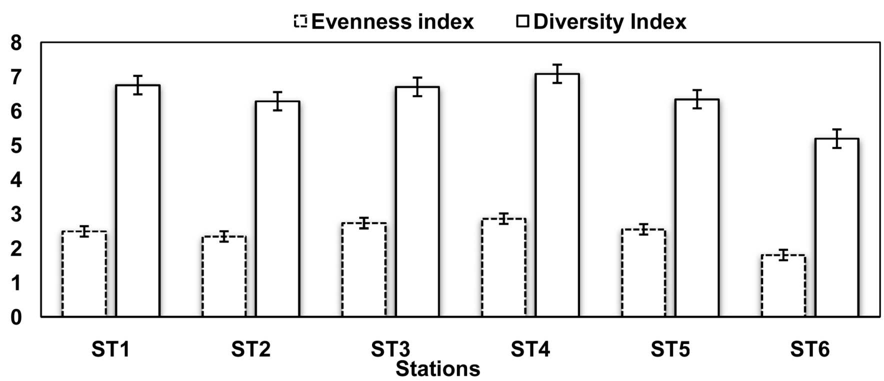

Figure 6. Species diversity and evenness index of phytoplankton communities at each station in Kota Kinabalu river estuary.

3.3. Relationship of Phytoplankton Abundance (Cell/L) with Dissolved Inorganic Nutrients

Weak correlation was found with the cell density and concentrations of nutrients in River estuary as shown in scattered diagram in Figures 7-9.

4. Discussion

4.1. Physical Parameters

Variations in temperature and values of pH among the stations observed negligible except the concentration of dissolved oxygen and salinity. Physical parameters play important roles in the production of phytoplankton productivity if sufficient nutrients are available. In an aquatic ecosystem temperature control the overall metabolic activities in a life process, which are influenced by the wind speed, intrusion of freshwater, tide with an effects on the depth of water and of course of atmospheric temperature (Vajravelu et al., 2018). The upstream of this river estuary is dominated by the freshwater flushing from the spring and also from the surrounding human settlement areas. The recorded water temperature

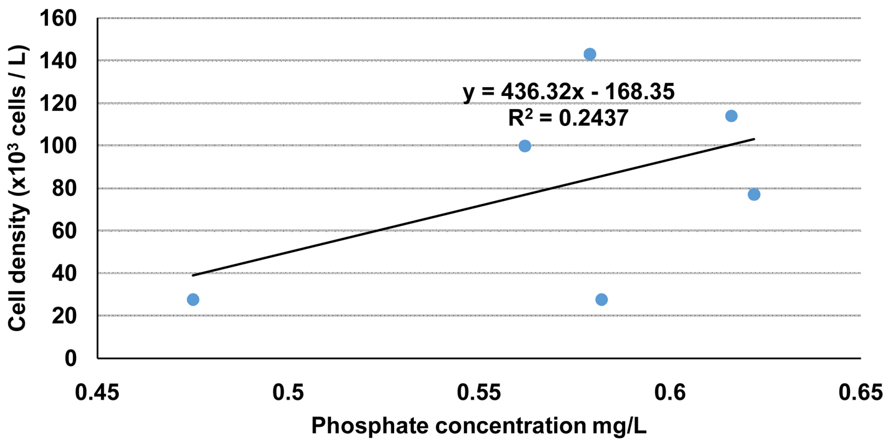

Figure 7. Relationship between Phosphate and phytoplankton cell density in in Kota Kinabalu River estuary. The correlation between concentration of phosphate and phytoplankton cell density was $R^2 = 0.0243$. However slight better correlation was observed with the concentration of ammonium ($R^2 = 0.301$) and nitrate ($R^2 = 0.406$) with phytoplankton cell density.

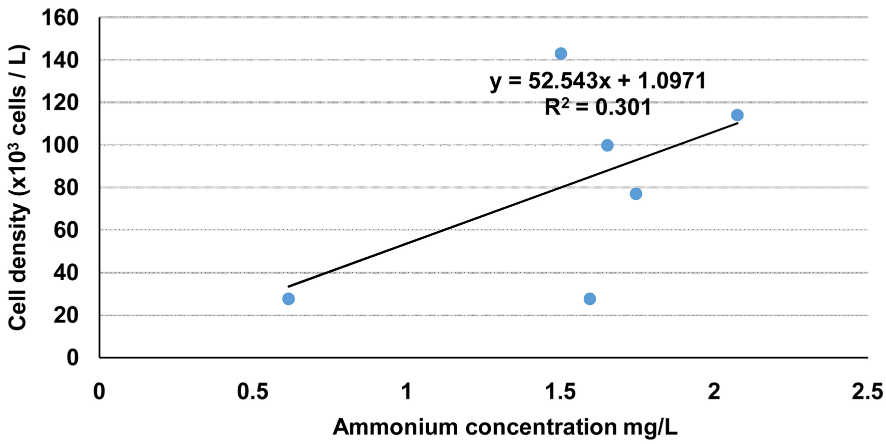

Figure 8. Relationship between concentration ammonium with phytoplankton cell density in Kota Kinabalu River estuary.

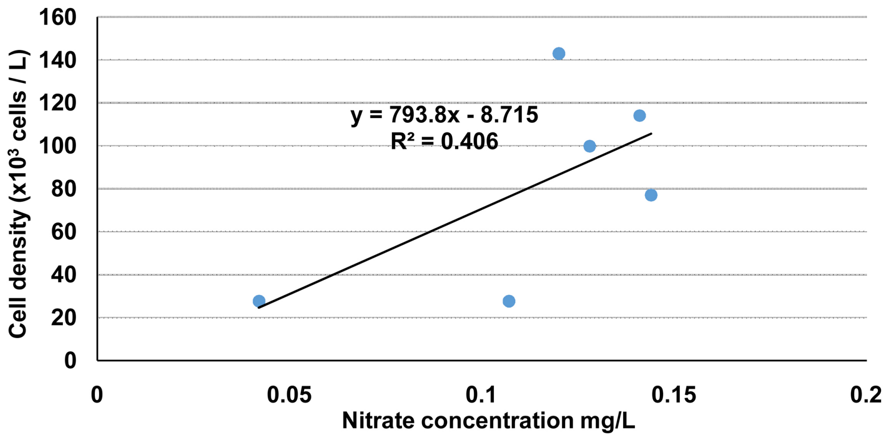

Figure 9. Relationship between concentration of nitrate with phytoplankton cell density in in Kota Kinabalu River estuary.

are not extremely high (31.8˚C) or low (28.2˚C) indicated not poses any threat in this river estuary. The variations in the concentrations of salinity during study period were remarkable, the highest of 32.9 ppt and the lowest of 14.1 ppt. The lowest values in salinity were recorded in the area (upstream), which are diluted with the freshwater. Increase and decrease in salinity in the brackish water also due to influx of freshwater from surface runoff due to heavy rainfall or tidal variations (Srinivasan & Natesan, 2013). However the rainfall data were not recorded during the sampling time. On the other hand the highest salinity of 32.9 ppt recorded in the Station 6, the area completely out of freshwater intrusion. This location is influenced with tidal cycle and relatively weak vertical mixing, leading to an increase in the vertical salinity gradient (Xia et al., 2011) Temperature, salinity (Srinivasan & Natesan, 2013) and primary productivity are directly involved in the changes of dissolved oxygen concentration in aquatic ecosystem.

The wide variation in the concentrations of dissolved makes this river estuary as complex ecosystem. In general the ranges of 2 to 7 mg/L limit the biodiversity of species in this study area. In general the low concentration of dissolved oxygen is the consequences of decaying of organic matter due to rise in temperature and higher microbial activity, which used up oxygen for metabolic process (Eliku & Leta, 2018). The lower values in the dissolved oxygen concentrations in the study period might be due to the environmental condition like lowest tidal fluctuation, which restricted the intrusion from seawater, which resulted in the lowering of salinity and pH (Leidonald et al., 2019). On the other hand the high oxygen values might be the activities of mixing from rainfall and production of phytoplankton biomass, which through the photosynthetic process produces more and more oxygen in River estuary (Aknaf et al., 2017). The variations in the pH values in the range of 6.61 to 8.01 are oblivious due to locations of study areas. In general the lowest values recorded in the stations might be due to the human activities and their settlements around the study areas. The deposition of organic matter and drainage of domestic water might be the major causes of changes in the pH values (Dan-kishiya et al., 2013). Excessive uptakes of carbon dioxide in the primary production process limits the acidic condition consequently the higher values in pH are common phenomena in estuary ecosystem. However the tidal fluctuations and the buffering capacity of the seawater control the sudden changes in pH values in the study area (Srinivasan & Natesan, 2013).

4.2. Dissolved Inorganic Nutrients

Phosphorus has been considered the primary limiting nutrient for phytoplanktonic organisms, although not a limiting nutrient in marine ecosystem. The lowest concentration of phosphate was found in station 6 (0.475 ± 1.042 mg/L). On the other hand, the highest concentration of 0.622 ± 1.161 mg/L of phosphate was recorded at Station 2, but no significantly different among the stations. Phosphate concentrations around this estuary shows almost similar values as river channel passing through the housing areas, indicating phosphate levels is induced by sewage and wastewater from nearby housing areas. No only human activity, but the distribution of nutrients in the coastal water is influenced by local conditions like rainfall, freshwater inflow, and biological activities (Leidonald et al., 2019). On the other hand human activities around the sampling areas are influences by the discharges waste from residential areas as well runoffs and organic wastes (Soon & Ransangan, 2016) around could be factor in controlling phosphorus in river estuary. The present average phosphate concentration (0.475 - 0.622 mg/L) is comparatively higher the concentration of phosphorus observed in Douala estuary (Fonge et al., 2013) where the concentrations were in the range of 0.03 to 0.04 mg/L. higher values in phosphorus indicating phosphate levels is induced by sewage and wastewater nearby housing areas (Reed et al., 2016). Water nitrogen is found both as inorganic and organic species and in dissolved and particulate forms. Dissolved inorganic nutrients ammonium was recorded in Station 1 (2.075 ± 0.296 mg/L) followed by Station 2 (1.745 ± 0.443 mg/L) and Station 3 (1.652 ± 0.443). The lowest concentration of 0.615 ± 0.422 mg/L ammonium was observed at Station 6. Concentration of ammonioum is much higher than range of concentration of 0.02 to 0.38 mg/l that was determined in Sundarbans mangrove estuarine system of Bangladesh (Rahaman et al., 2013). The Lower concentrations of ammonium indicate the presence of better quality water. High ammonium loads can also enhance the development of primary producers. On the other hand water pH regulates the occurrence of different forms of ammonia in aquatic ecosystem. The higher concentration of ammonium might also be due to wastewater effluents from residential areas and use of fertilizer from agricultural activity nearby land (Lomoljo et al., 2009). Surface run off from surrounding areas and aquaculture activity that uses fertilizers and feed in the fish farm, as well soil erosion might be the factors in the increase of ammonium concentration.

Indeed, the temperature affects the growth rate of bacteria that involved in the nitrification process, with ammonia oxidizers having superior growth rates at high temperatures. In fact, the concentration of nitrate and ammonia derived from the upstream areas are not able to accumulate in the estuary as completely flushed out to the open sea with the high tidal fluctuation. The concentration of nitrate in Station 2 (0.144 ± 0.298 mg/L) was recorded slightly higher compared to nitrate that was observed at Station 1 (0.141 ± 0.0346 mg/L) while the lowest of 0.042 ± 0.289 mg/L was found at Station 6 (control station, not influences by human activity. The lower NO_3–N concentration of is an indication of little human intervention in the river system. Nitrate concentration was higher due to freshwater influx and discharges of organic and inorganic load due to human induced activities (Kumar et al., 2009). Greater concentration of atmospheric N_2 and its continuous mixing in river water through air and surface water interactions might be the reason for the irregular fluctuation in NO_3–N throughout the sampling periods and tide cycles in the study area. In addition biological oxidation of ammonia generate nitrate in aquatic environment with the breakdown of protein. Concentration of nitrate indicates high population pressure and agricultural development, as well as fecal pollution (Adedokun et al., 2008) in aquatic ecosystem. The concentrations of dissolved inorganic nutrients recorded in the present study observed much lower than the Malaysia NWQS (DOE, 2008) acceptable limits that indicates the healthy ecosystem of river estuary.

4.3. Phytoplankton Community

The abundance and distribution of phytoplankton community largely depends on surrounding physico-chemical water quality parameters, although in river estuary productivity hydrodynamics play crucial roles in changes the nature of the water quality. Thus makes ecosystem of river estuary very complex, all factors are interrelated and subsequently contributes in the composition of phytoplankton. A total of 25 species of phytoplankton were identified from present study, on the other hand, 24 genera of phytoplankton were reported from Kota Kinabalu wetland in undulated areas (Azad & Jinau, 2020) and 21 phytoplankton species are identified from Kudat coastal water (Romin et al., 2021). The environment factors that affect the algal species community and limits the availability of certain types of species are manifolds, like temperature, salinity, Secchi depth (visibility), pH, and dissolved oxygen (Huang et al., 2004). In addition concentrations of nutrients are the major factors together environmental parameters might favor some species to blooms (Hastuti et al., 2018). Although poor relationship between nutrients and availability of phytoplankton were observed, which indicates blooming of particular species depends on other environmental parameters.

The highest phytoplankton abundances with 142.98×10^3 cells/L was determined in Station 4, followed by the Station 1 (114.06×10^3 cells/L). The lowest of 27.58×10^3 cells/L were observed in Station 6 (**Figure 5**). The highest cell densities in station 4 might be due discharges of nutrients from aquaculture farm located nearby the location. Aquaculture farm generally uses feed to fed fishes, which are rich in nitrogen and phosphorus, together the metabolic waste product from like faeces and excreta, basically are nitrogenous product also discharges in nearby location (Romin et al., 2021). On the hand the lowest cell densities was observed in the Station 6, which are limited with the nitrogenous sources in marine environment. Cell density of algal bloom in Kota Belud coastal area in Sabah was associated with nitrate is limiting factor rather than phosphate in Kota Belud's coastal water (Azad et al., 2016). In addition to that heavy rainfall brings nutrients to the study areas via river run-offs during rainy season (Soon & Rangsangan, 2016), although rainfall data was not observed in this study. However poor this study also reported poor relationship between nutrients and abundance of phytoplankton density (R^2 values for phosphate, ammonium and nitrate were 0.2437, 0.301, 0.406 respectively). Composition and abundance of phytoplankton population serve as indicator in changing the nutrients in marine, which act as important component in the determination of eutrophication in marine ecosystems (Hastuti et al., 2018). The composition, abundance and growth of phytoplankton species are mainly affected by the physical and chemical parameters of the specific marine environment in which they are located (Vajravelu et al., 2018).

The diversity index and species evenness were observed in the range of 5.2 to 7.09 and 1.81 to 2.87 respectively. The observed values were comparatively higher in present study than that of mean Shannon-Weaver's diversity index (H') of 2.56 and Pielou evenness index (J') of 0.84 (Romin et al., 2021) and also the diversity index of 2.35 with evenness index of 0.83 (Fatema et al, 2014). It indicated that the phytoplankton communities in Kota Kinabalu River estuary were favored with environment conditions for their growth and distribution. On the other hand, low diversity index values generally due to low species diversity or might also be due to blooming of certain types of species that dominate in ecosystem (Coelho et al., 2007). The relationship between diversity index and evenness are positive and strong. In certain circumstances such as competition, predation, and succession of blooming species changes the diversity index with the alteration in evenness without any change in species richness (Stirling & Wilsey, 2001). The abundance (Cells/L) of phytoplankton in this study observed higher together with a better diversity index indicate the healthy productive this river estuary. The evenness of the species diversity shows the dominance of certain opportunistic phytoplankton communities, which need further study to look to identify the succession of the species in river estuary. Man-made stressors have affected the density of phytoplankton in the study area.

5. Conclusion

Alteration in nutrients and water quality were the major reasons of changes in phytoplankton species diversity and abundances. The household area and aquaculture activity around this estuary have the highest abundances of nutrients with due to emissions of effluent from the residential sewage nearby during the study period. Thus, Kota Kinabalu river estuary might undergo eutrophication due to high input of nutrient loading in the areas such as nitrogen and phosphorus by anthropogenic activities for examples land degradation, development aquaculture and agriculture practices. Frequent sampling and long term monitoring on the discharges of nutrients by human induced activity are essentially important to achieve sustainable healthy ecosystem or to avoid eutrophication process in this river estuary.

Conflicts of Interest

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

References

Adedokun, O. A., Adeyemo, O. K., E. Adeleye, E., & Yusuf, R. K. (2008). Seasonal Limnological Variation and Nutrient Load of the River System in Ibadan Metropolis, Nigeria. *European Journal of Scientific Research, 23,* 98-108

Aknaf, A., Akodad, M., Moumen, A., Ben Chekroun, K., Elhamouti, C., Bailal, A., & Baghour, M. (2017). Study of the Spatial and Temporal Variation of Physical-Chemical Parameters Characterizing the Quality of Surface Waters of the Lagoon Marchica—North-East Morocco. *Journal of Materials and Environmental Sciences, 8,* 3216-3225.

APHA [American Public Health Association and Water Pollution Control Federation] (2000). *Standard Methods for the Analysis of Water and Wastewater* (15th ed.). American Public Health Association and Water Pollution Control Federation.

Azad, S. A. (2021). Chapter 2. Long Term Variations of Water Quality in the Inanam River Estuary of Kota Kinabalu, Sabah, Malaysia. In T. Yoshida, & B. M. Manjaji-Matsumoto (Eds.), *The Marine Ecosystem of Sabah* (pp. 18-29). Penerbit University Malaysia Sabah, Jalan UMS.

Azad, S. A., & Jinau, V. J. (2020). Spatial Distribution of Dissolved Inorganic Nutrients and Phytoplankton around Kota Kinabalu Wetland, Sabah, Malaysia. *Advances in Biological Chemistry, 10,* 113-126. https://doi.org/10.4236/abc.2020.104009

Azad, S. A., Shaleh, S. R. M., & Soon, T. K. (2016). Temporal and Spatial Distribution of Nutrients and HABs at Coastal Water of Kota Belud, Sabah. *Advances in Bioscience and Biotechnology, 7,* 233-242. https://doi.org/10.4236/abb.2016.75022

Behrenfeld, M. J., O' Malley, R. T., Siegel, D. A., McClain, C. R., Sarmiento, J. L., Feldman, G. C., & Milligan, A. J. (2006). Climate-Driven Trends in Contemporary Ocean Productivity. *Nature, 444,* 752-755. https://doi.org/10.1038/nature05317

Cloern, J. E. (2001). Our Evolving Conceptual Modle of the Coastal Eutrophication 350 Problem. *Marine Ecology Progress Series, 210,* 223-253. https://doi.org/10.3354/meps210223

Coelho, S., Gamito, S., & Perez-Ruzafa, A. (2007). Trophic State of Foz de Almargem Coastal Lagoon (Algarve, South Portugal) Based on the Water Quality and the Phytoplankton Community. *Estuarine, Coastal and Shelf Science, 71,* 218-231. https://doi.org/10.1016/j.ecss.2006.07.017

Dan-kishiya, A. S., Olatunde, A. A., & Balogun, J. K. (2013). Variation in the Concentration of Dissolved Oxygen (DO) and Hydrogen Ion (pH) at the Surface of a Tropical Reservoir: A Case Study of Lower Usuma Reservoir in Bwari Abuja, Nigeria. *American Journal of Research Communication, 1,* 204-214

Department of Environment (DOE) (2008). *Malaysia Environmental Quality Report 2008* (86 p). Department of Environment, Ministry of Natural Resources and Environment Malaysia.

Diehl, S., Berger, S., Ptacnik, R., & Wild, A. (2002). *Phytoplankton, Light, and Nutrients in a Dinoflagellates*. Academic Press.

Eliku, T., & Leta, S. (2018). Spatial and Seasonal Variation in Physicochemical Parameters and Heavy Metals in Awash River, Ethiopia. *Applied Water Science, 8,* Article No. 177. https://doi.org/10.1007/s13201-018-0803-x

Fatema, K., Wan Maznah, W. O., & Isa, M. I. (2014). Spatial and Temporal Variation of Physico-Chemical Parameters in the Merbok Estuary, Kedah, Malaysia. *Tropical Life Sciences Research, 25,* 1-19.

Fonge, A. B., Chuyong, B. G., Tening, A. S., Fobid, A. C., & Numbisi, N. F. (2013). Seasonal Occurrence, Distribution and Diversity of Phytoplankton in Douala Estuary, Cameroon. *African Journal of Aquatic Science, 38,* 123-133. https://doi.org/10.2989/16085914.2013.769086

Gao, X., & Song, J. (2005). Phytoplankton Distributions and Their Relationship with the Environment in the Changjiang Estuary, China. *Marine Pollution Bulletin, 50,* 327-335. https://doi.org/10.1016/j.marpolbul.2004.11.004

Hastuti, A. W., Pancawati, Y., & Surana, I. N. (2018). The Abundance and Spatial Distribution of Plankton Communities in Perancak Estuary, Bali. *IOP Conference Series: Earth and Environmental Science, 176,* Article ID: 012042. https://doi.org/10.1088/1755-1315/176/1/012042

Huang, L. M., Jian, W. J., Song, X. Y., Huang, X. P., Liu, S., Qian, P., Yin, K., & Wu, M. (2004). Species Diversity and Distribution for Phytoplankton of the Pearl River Estuary during Rainy and Dry Seasons. *Marine Pollution Bulletin, 49,* 588-596. https://doi.org/10.1016/j.marpolbul.2004.03.015

Jafari, N. G., & Gunale, V. R. (2006). Hydrobiological Study of Algae of an Urban Freshwater River. *Application Science Environment Manage, 10,* 153-158. https://doi.org/10.4314/jasem.v10i2.43697

Kumar, J. I. N., George, B., Kumar, R. N., Sajish, P. R., & Viyol, S. (2009). Assessment of Spatial and Temporal Fluctuations in Water Quality of a Tropical Permanent Estuarine System—Tapi, West Coast India. *Applied Ecology and Environmental Research, 7,* 267-276. https://doi.org/10.15666/aeer/0703_267276

Leidonald, R., Muhtadi, A., Lesmana, I., Harahap, Z. A., & Rahmadya, A. (2019). Profiles Temperature, Salinity, Dissolved Oxygen and pH in Tidal Lakes. *IOP Conference Series: Earth and Environmental Science, 260,* Article ID: 012075. https://doi.org/10.1088/1755-1315/260/1/012075

Lomoljo, R. M., Ismail, A., & Yap, C. K. (2009). Nitrate, Ammonia and Phosphate Concentrations in the Surface Water of Kuala Gula Bird Sanctuary, West Coast of Peninsular Malaysia. *Pertanika Journal of Tropical Agricultural Science, 32,* 1-5.

Muhammad, A., Abdus, S., Sumayya, I., Tasveer, Z. B., & Kamran, A. Q. (2005). Studies on Monthly Variations in Biological and Physico-Chemical Parameters of Brackish Water Fishpond, Muzaffar Garh, Bahauddin Zakariya University, Multan, Pakistan. *Pakistan Journal of Scientific Research, 16,* 27-38.

Rahaman, S. M.B., Sarder, L., Rahaman, S., Ghosh, A. K., Biswas, S. K., Siraj, S. S., Huq, K. A., Hasanuzzaman, A. F.M and Islam, S. S. (2013). Nutrient Dynamics in the Sundarbans Mangrove Estuarine System of Bangladesh under Different Weather and Tidal Cycles. *Ecological Processes, 2,* Article No. 29. https://doi.org/10.1186/2192-1709-2-29

Reed, M. L, Pinckney, J. L., Keppler, C. J., Brock, L. M., Hogan, S. B., & Greenfield, D. I.

(2016). The Influence of Nitrogen and Phosphorus on Phytoplankton Growth and Assemblage Composition in Four Coastal, Southeastern USA Systems. *Estuarine, Coastal and Shelf Science, 177,* 71-82. https://doi.org/10.1016/j.ecss.2016.05.002

Romin, M., Azad, S. A., & Saleh, E. (2021). Variations in the Physicochemical Water Parameters and Phytoplankton Community in Coastal Water of Kudat, Sabah, Malaysia. *Journal of Geoscience and Environment Protection, 9,* 86-99. https://doi.org/10.4236/gep.2021.97006

Smayda, T. J., & Reynolds, C. S. (2001). Community Assembly in Marine Phytoplankton: Application of Recent Models to Harmful Dinoflagellate Blooms. *Journal of Plankton Research, 23,* 447-461. https://doi.org/10.1093/plankt/23.5.447

Soon, T. K., & Ransangan, J. (2016). Effects of Environmental Conditions and Nutrients on the Occurrence and Distribution of Potentially Harmful Phytoplankton in Mesotrophic Water. *Sains Malaysiana, 45,* 865-877.

Srinivasan, K., & Natesan, U. (2013). Spatio-Temporal Variations in Water Quality of Muttukadu Backwaters, Tamilnadu, India. *Water Environment Research, 85,* 587-595. https://doi.org/10.2175/106143012X13560205144812

Stirling, G., & Wilsey, B. (2001). Empirical Relationships between Species Richness, Evenness, and Proportional Diversity. *The American Naturalist, 158,* 286-299. https://doi.org/10.1086/321317

Stirling, H. P. (1985). *Chemical and Biological Methods of Water Analysis for Aqua Culturists* (119 p). Institute of Aquaculture, University of Stirling Scotland.

Tomas, C. R. (1997). *Identifying Marine Phytoplankton*. Academic Press.

Vajravelu, M., Martin, Y., Ayyappan, S., & Mayakrishnan, M. (2018). Seasonal Influence of Physico-Chemical Parameters on Phytoplankton Diversity, Community Structure and Abundance at Parangipettai Coastal Waters, Bay of Bengal, South East Coast of India. *Oceanologia, 60,* 114-127. https://doi.org/10.1016/j.oceano.2017.08.003

Xia, M., Craig, P. M., Wallen, C. M. Stoddard, A., Mandrup-Poulsen, J., Peng, M., Schaeffer, B., & Liu, Z. (2011). Numerical Simulation of Salinity and Dissolved Oxygen at Perdido Bay and Adjacent Coastal Ocean. *Journal of Coastal Research, 27,* 73-86. https://doi.org/10.2112/JCOASTRES-D-09-00044.1