

Spatial Variations of Sediment Quality in Coastal Waters of Kudat, Sabah, Malaysia

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Abstract

Coastal ecosystem is complex as it is controlled by unique physical, chemical, biological, as well as geological processes. Coastal areas of Kudat, Sabah are dominated by a community of artisanal fishers. The increasing trend of human populations and development leads to a substantial amount of nutrients as well as anthropogenic wastes which ultimately settle as sediments. The present study was undertaken to determine the physicochemical characteristics of sediment in the coastal area of Kudat. Surface sediment samples were collected from five selected locations for a period of 12 (twelve) months to identify the particle sizes and to determine total organic matter (%), total phosphorus (%), and total nitrogen (%). Sediment texture of the sampling stations in coastal areas of Kudat was mostly sand (2 mm to 125 μ m) with 79.69% and silt clay (63 μ m to <63 μ m) with 19.83%. The values of pH in sediment, total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) at different locations were in the range of 7.83 to 8.1, 0.89 to 0.915%, 0.01% to 0.22%, and 0.005% to 0.0068%, respectively. There were no significant ($p > 0.05$) differences among those parameters except for the concentration of total nitrogen (TN) in Kudat's coastal water. Significant differences were observed in the values of total nitrogen among the locations, indicating the human-induced activities in the areas. Sediment characteristics from different locations are the consequences of a diversified ecosystem in the Kudat areas. Drainage of waste and other anthropogenic activities need to be monitored regularly for a healthy ecosystem in Kudat areas.

Keywords

Sediment, Particle Sizes, Organic Carbon, Nitrogen, Phosphorus

1. Introduction

Monitoring the chemical and physical composition of sediments provides insight

into how the environment is changing, as well as the natural and human factors that may be contributing to it. Sediment quality in aquatic ecosystems is the result of discharges of industrial waste, sewage runoff, and agricultural discharges (Zhuang & Gao, 2014). Depositional sediment across large parts of embayment's in urbanized and industrialized zones is contaminated by a wide range of toxicants, according to numerous studies of coastal waterways (McCready et al., 2004). Short and long-term physiochemical environmental assessments of water and sediment can be used to monitor the contamination status of marine ecosystems (Sheela et al., 2012). The source of organic matter in marine sediment, whether marine or terrestrial, is usually determined by determining the range of C:N ratios (Zaaboub et al., 2014). On the other hand, evaluating the heavy metal concentrations in surface sediment can be used to identify the temporal variations of heavy metal pollution levels in the marine environment (Inengite et al., 2010). Sediment quality in the sea is generally declining, especially in places with stagnant water or a weak tidal current (Yanagi, 2015). Contaminated sediment adversely affects the growth of vegetation and bacteria, and because these organisms are at the base of the food chain, these chemicals have an impact on other aquatic life (MacDonald et al., 1996). Sediment is important for the protection and shelter of juveniles, as well as for the spawning of numerous species during breeding (MacDonald et al., 1996). In general, natural processes and anthropogenic sources both contribute to heavy metal deposition as well as nutrients in marine ecosystems, which are ultimately deposited on surface sediment. To compensate for the natural variability of sediment composition, normalisation processes are often applied, allowing the identification and assessment of any anthropogenic inputs to the system (Siddique et al., 2009). The goal of this study was to provide information on sediment qualities as well as due to anthropogenic activities to improve the understanding of the diversity in distribution patterns in this field of research. The scientific data from this study that was provided would enable proper management of the marine environment in coastal areas of the study.

2. Materials and Methods





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

Study area

Five sampling stations were selected based on the sources of inputs in the district of Kudat, in the northern part of Sabah, Malaysia. Samples were collected every month from the selected stations. All the stations (**Figure 1**) were marked by GPS. Details of the five sampling stations' coordinates (**Table 1**) and other features were described (**Romin et al., 2021**).

Table 1. Coordinates of the five selected stations set with GPS

Station	Coordinates (N/E)
ST 1	06°53'29.4"/116°51'26.7"
ST 2	06°52'44.3"/116°50'48.3"
ST 3	06°52'47.4"/116°51'26.7"
ST 4	06°52'10.4"/116°51'32.9"
ST 5	06°51'45.7"/116°49'39.1"

Source: **Romin et al., 2021**.

Collection of Sediment Samples for Sediment Analysis

Triplicate sediment samples were collected at monthly intervals from each of the stations for one year by using an Ekman grab sampler. The collected sediments were mixed properly and placed directly in airtight plastic bags with proper labeling (with date and station number). Finally, samples were taken to the IPMB laboratory for further analysis. The analytical parameters include:

1. pH of the sediment using a pH-electrode.
2. Texture: Based on particle size. Estimation of sand, silt, and clay fractions with the aim to identify sandy loam, clay loam, and silt loam and percentage ratios with the help of the LISST-Portable (SEQUOIA) particle size analyser.
3. Total Organic Carbon: The organic carbon matter in sediments was determined by drying five (5 g) subsamples (wet sample) in an oven at 105°C until a constant weight was obtained. Then, heating in a muffle furnace (550°C for

6 h) and estimated according to the equation below Parsons et al. (1984).

$$\text{Organic carbon} = [(DW - DW_{550})/DW] \times 100$$

where:

DW = Dry weight after being oven-dried at 105°C.

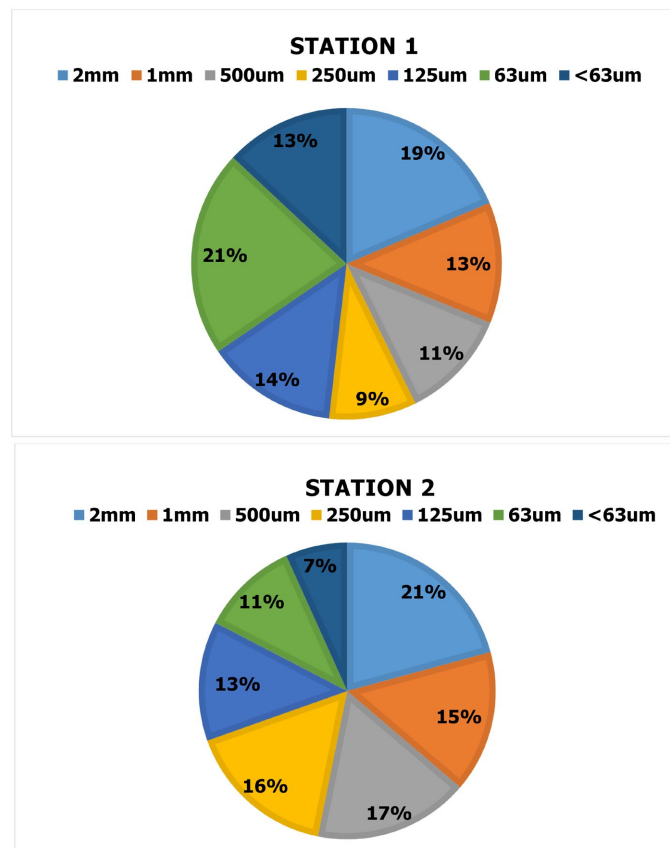
DW₅₅₀ = Dry weight after combustion at 550°C for 6 h.

4. Total Kjeldahl Nitrogen: Organic nitrogen (%) determined using the Micro-Kjeldahl technique with the Kjeltach System.
5. Total Phosphorus: Organic and inorganic components using the standard colorimetric method described by Parsons et al. (1984).

3. Results

Spatial Variations of Sediment Physical Properties

Sediment texture of sediment in the sampling station in the coastal water of Kudat was mostly sand (2 mm to 125 µm) with 79.69% and silt and clay (63 µm to <63 µm) with 19.83% (Figure 2). The surface sediment in the coastal water of Kudat in stations 1, 2, 3, 4, and 5 was found to consist of 21.17% fine silt, 20.70% very coarse sand, 41.79% very fine sand, 36.09% very fine sand, and 33.55% fine coarse sand, respectively. In general, the study area was mostly dominated by very fine sand (125 µm) followed by fine sand (250 µm), medium sand (500 µm), coarse silt (63 µm), very coarse sand (2 mm), coarse sand (1 mm), and silt and mud (<63 µm).



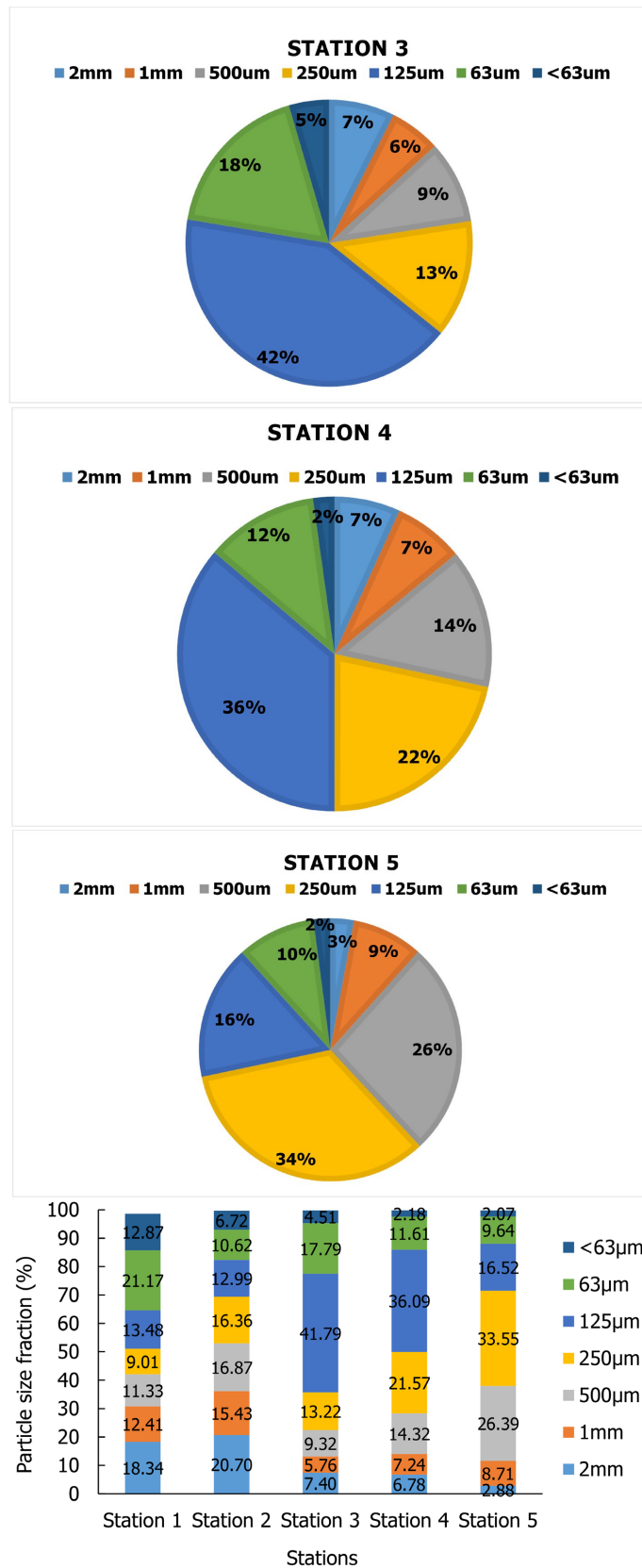


Figure 2. The particle size fraction (%) of sediment at stations located in the coastal area of Kudat.

Spatial Variations of Sediment Chemical Properties

For spatial variations, the mean values of pH, total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) ranged between 7.83 to 8.1, 0.89 to 0.915%, 0.01% to 0.22%, and 0.005% to 0.0068%, respectively. All sediment parameters in the study areas were found to be not spatially significant ($p > 0.05$) at all the stations except for TN, where $p = 0.000$.

The lowest and highest mean values of pH in this study were found in ST3 (7.83 ± 0.4) and ST4 (8.1 ± 0.3), while TOC (%) in sediment was observed to be the highest at (0.92 ± 0.02) in ST5. The highest value of $0.0068\% \pm 0.004$ total phosphorus was determined in ST4, followed by ST1 (0.0066 ± 0.002), ST2 (0.0061 ± 0.003), ST5 (0.0055 ± 0.003), and ST3 (0.0050 ± 0.002). On the other hand, the highest mean value of $0.22\% \pm 0.05$ total nitrogen was recorded in ST2, which was significantly higher ($p < 0.05$) than the mean values obtained in ST4 and ST5 (**Figure 3**).

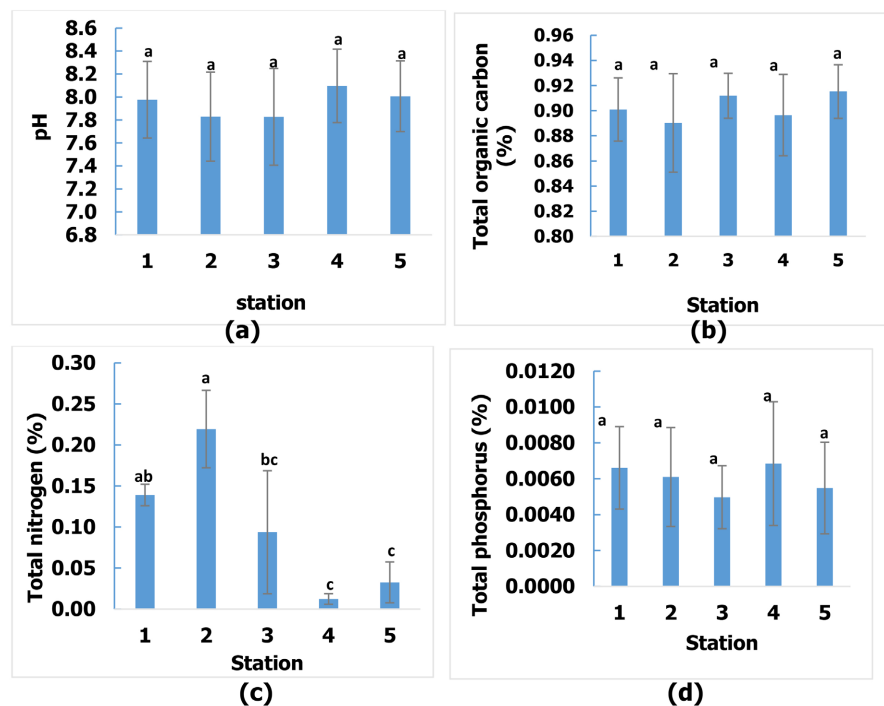


Figure 3. Spatial variations of sediment properties: pH values (a); total organic carbon (b); total nitrogen (c); and total phosphorus (d) in coastal water of Kudat.

4. Discussion

Spatial Variations of Sediment Physical Properties

The stations near the coastal line ST1 are generally dominated by silt particles; this might be due to increasing transport capacity with river opening (Porrello et al., 2005) and the direction of water movement. In contrast, ST2 (20.7%), adjacent to the river mouth, has a coarser particle size than other stations and open water areas; ST4 (6.78%) and ST1 (18.34%). Such observation could be influenced by

fluvial discharges of sediments and a lower level of turbulence due to the lower velocity depositional forces in the locations (Abdul Rahim et al., 2016). The main particle sizes of sediment are in the form of sand (60%), silt (36%), and 4% clay (Azad, 2024). The distribution of particle sizes was influenced by Typically, the coastline will generally be dominated by coarser particles due to increasing transport capacity with river opening (Porrello et al., 2005), while in the present study, the station with the river mouth was observed to be dominated by only 20.7% of very coarse sand. Particle sizes in the river mouth station are not only influenced by the fluvial discharge's sediment but also might be due to the lower level of turbulence. Fine sand and mud result from weak current and higher water depth. Proportions of sand particles generated from shallow lower areas might be due to biogenic and terrigenous origin, but clay and silt particles are observed to be in higher proportions with increasing depth (Matijević et al., 2008). The physical parameters of the environment, like waves, current patterns, and mode of transportation media, are some of the major factors that control the deposition of sediment (Azad, 2024). Larger particles like gravel can easily be deposited on the bottom, where low nutrient content in the sediment as well as in water is generally detected (Azad, 2024). Distribution of the sand and muddy sand zones on the edge of the bay, and sandy mud with mud zone in the centre of the bay along the river mouth, are due to current systems and the discharge of the amount of sediment from the river (Lee et al., 2008).

Spatial Variations of Sediment Chemical Properties

The most important components of sediments are pH, total organic carbon (TOC), total phosphorus, and total nitrogen (TN), which can be used to distinguish between marine and terrestrial sources of organic matter, environmental depositional conditions, pollution indices, and soil quality and productivity indicators.

pH of the sediment

The values of the pH were observed in the range of 7.83 to 8.1, and no significant differences were observed among the stations. The alkaline nature in all stations might be due to the influences of tidal action by the influx of neritic water. In addition, the deposition of calcium-coated marine fauna and their shells, coral fragments, or other biological sources like dead skeletons of marine fauna may contribute. Biogenic origin of calcium carbonate through due process in the long run is deposited and increases the pH of the sediment. The observed value of pH is comparatively higher than the values of 6.9 to 7.78 observed by other researchers (Anitha & Kumar, 2013). The ocean is the highest absorber of atmospheric carbon dioxide. The alkaline nature indicates proper utilization of dissolved carbon dioxide in the photosynthetic process in the water column. However, the impact of CO₂ in sediment goes through complex processes. Sediment interfaces play vital roles and enrich pore water with CO₂. The shifting pH in sediment due to enriched pore CO₂ is the consequence of loss of biodiversity in the microbenthic environment (Taylor et al., 2015). The mobilization of metals from the sediment

with the speciation of elements can also alter the sediment pH (Payan et al., 2012). Thus, sediment pH is closely related to the CO₂ leak and microbial mineralization of carbon within the surface sediment and water layer interface.

Total Organic Carbon

The organic carbon in marine sediment is the vital parameter that governs and controls the ecosystem through the carbon cycle. The sources are from biogenic as well as deposition from human-induced activity, such as the use of fertilizer in cropping patterns, agro-based industrial waste, and chemical contamination from various sectors. Therefore, the storage and renewal capacity of total organic carbon in marine sediment depends on inputs from the terrestrial and processes in the carbon cycle. The observed values of TOC in the current study are in the range of 0.89 to 0.915%, which is comparatively higher than the values of TOC in the range of 0.061% to 0.522% (Anitha & Kumar, 2013). In addition, the observed values from the current study are lower than the values of TOC in the range of 2.1 to 4.0% (Azad, 2024). Enrichment of TOC indicates the surface runoff of organic matter via the river water in the sediment. It also indicates the index of degradation of particulate organic matter and productivity of the ecosystem. Further, enrichment of TOC is due to sewage discharge along with other anthropogenic activities, adsorption of organic matter by the increased finer fractions of the sediment (Martin et al., 2014). Lower values of TOC are associated with heavy flooding of river water, which dilutes the surface runoff of organic matter, and flushing of sediments deposited at the bottom (Anitha & Kumar, 2013). The microbial degradation of organic matter that increases biomass is crucially important and acts as a limiting factor in lowering the TOC in sediment. Thus, processes of oxidation and reduction at the water-sediment interface are vital in the lowering of TOC in marine sediment (Bouwman et al., 2013). Besides these, higher TOC is also observed in fine-sized sediment, and a positive correlation exists between the TOC and fine silt particles (Matijević et al., 2008) but was not covered in the current analysis.

Total Nitrogen

Total nitrogen includes the components of inorganic nitrogen and organic nitrogen in the marine ecosystem. Nitrogen is limiting in the marine ecosystem due to the absence of nitrogen-fixing organisms like blue-green algae in the marine environment. Marine sediment enriched with organic load through microbial activity regenerates inorganic nutrients in the water column and makes them available for utilization in the phytoplankton production process. Human-induced activity and surface runoff from the terrestrial environment accelerate the process of increasing the availability of total nitrogen in marine sediment. The values of total nitrogen in marine sediment are comparatively very low but vary with the locations and surrounding environmental conditions. Total nitrogen values obtained in the range of 0.03 to 0.39% (Helen & Ramalingom Pillai, 2014) were comparatively higher than the values of 0.01 to 0.22% obtained in the current study. Human-induced activity like the use of agricultural fertilizer in nearby locations,

retting of coconut husk, and river discharge allows an increase in the concentration of nitrogen in the sediment. On the other hand, the lower values in the range of 0.014% to 0.052% (Anitha & Kumar, 2013) and 0.01 to 0.11% (Azad, 2024) of total nitrogen were obtained due to seasonal variability and locations of the marine ecosystem. The values of TN in marine sediment were observed to be higher during pre-monsoon because of the high rate of oxidation of dead planktonic matter that consequently settled on the top layer of sediment. A lower amount of organic matter during post-monsoon resulted in lower values of total nitrogen in the sediment, as the rainy season carries a higher percentage of sand particles, which are low in nutrients (Anitha & Kumar, 2013). Nearby mangroves and other human-induced activities, together with drainage of waste from anthropogenic origin in the location, contribute to the highest deposition of TN in sediments (Azad, 2024). The scenario of total organic carbon and total nitrogen in present study reflects the origin of organic matter in the study area. The values of C:N ratio in the stations 1,2 (near Jetty) and 3 (near aquaculture farm) were observed less than 10, which indicated the organic matter are generated in the marine ecosystem. On the other hand, ratio of C:N in the stations 4 (near mouth of river) and 5 (high density populated area) were calculated higher than 20 and assumed the terrestrial organic matter (Burdige, 2006).

Total Phosphorus

Phosphorus is essentially important as a vital component in the formation of cellular structures. In marine ecosystems, both inorganic and organic forms of phosphorus, termed total phosphorus (TP), enter the phosphorus cycle and are recycled via physical and chemical processes. Only a single loop of microbial transformation of phosphorus takes place in the immobilization and mineralization processes. Excess phosphorus settles in the marine sediment and, in due course, is released into the water column as soluble reactive phosphorus. Concentrations of TP vary greatly by location, with higher levels often indicating human-induced activities, nutrient runoff, or high organic matter deposition. These levels are influenced by terrestrial and biological inputs, hydrodynamic conditions, and geochemical processes as found in iron-phosphate speciation. Speciation of phosphorus in various forms and bioavailability, together with chemical and physical factors in the marine sediment, are crucially important in the recycling of phosphorus in marine ecosystems. The TP in the sediment of this study was observed in the range of 0.005% to 0.006%; the values were very low compared to the TP obtained by other researchers. Total phosphorus was obtained in the range of 0.03% and 0.09% and was greatly influenced by the runoff of fertilizers from surrounding agricultural lands; the use of detergents and domestic sewage played a great role in contributing to the heavy loading of phosphorus in the sediment (Anitha & Kumar, 2013). The total phosphorus in the sediment was determined in the range of 0.2 to 0.09 (mg/100 g of dry sediment). The availability of TP was due to influences from the mangrove ecosystem as well as human-induced activities; together with drainage of waste from anthropogenic sources in the area, this

attributed to the highest deposition of TP in sediment (Azad, 2024). The percentage of TP was determined in the range of 0.16 to 0.59%, which was comparatively higher than the current study. The higher deposition of TP might be due to agricultural waste discharges from the paddy fields and coconut husk activities (Bragadeeswaran et al., 2007). The amount of P in the sediments is strongly dependent on grain size and is highest in mud (<63 µm) and fine sand (63 - 250 µm) and decreases with increasing grain size (Kozyrev et al., 2023); however, this type of relationship was not covered in the current study. In aquatic systems, P occurs in a number of basic forms, including dissolved inorganic P (IP, readily reactive P, which is immediately bioavailable), dissolved organic P (org-P), particulate organic P (detritus and living biomass), and particulate inorganic P (Kozyrev et al., 2023), which need to be addressed to understand the TP dynamics in study areas.

5. Conclusion

The values of all the parameters obtained in this study were considered lower than the values obtained by other researchers. This indicates low human-induced activities and pressure in the study areas. Physical, chemical, biological, and geological processes cause changes in the circulation and deposition of nitrogen, phosphorus, and total organic material in the sediments. Usually, the important parameters for the complex ecosystem need to be addressed to improve or maintain the healthy marine environment status of the locations. The ecosystem of this area might be changes due the pressure from anthropogenic activity, which is necessary to check regularly.

Conflicts of Interest

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

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