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Seasonal Variations in Environmental Parameters of Kao Bay, North Halmahera, North Maluku Province, Indonesia

(Variasi Musiman Parameter Lingkungan di Teluk Kao, Halmahera Utara, Provinsi Maluku Utara, Indonesia)

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ABSTRACT

Seasonal changes can alter the physical and chemical properties of seawater. This study aimed to investigate the seasonal variations in water temperature, salinity, water pH, sediment pH, dissolved oxygen, redox potential, total organic matter (TOM), and sediment texture during two contrasting seasons, namely the west monsoon (rainy season) and the east monsoon (dry season), in order to assess the level of metal contamination in the waters of Kao Bay, North Maluku Province, Indonesia. The study was conducted by collecting water quality and sediment samples from Kao Bay, particularly in the waters surrounding the NHM gold mining area. Water temperature, salinity, water pH, sediment pH, dissolved oxygen, and redox potential were measured in situ, while total organic matter was analyzed following the APHA, AWWA, and WEF (2005) standard methods (Part 5000: Aggregate Organic Constituents). Sediment texture was determined using the pipette method and expressed as percentage composition according to the Wentworth scale. The results showed significant seasonal variations in water temperature, salinity, water pH, sediment pH, total organic matter, redox potential (Eh), and sediment texture, which in turn influenced the distribution and concentration of metals in the study area.

Keywords: environmental parameters, North Maluku, sediment, seasonal variation

ABSTRAK

Perubahan musim dapat mengubah sifat fisik dan kimia massa air laut. Penelitian ini bertujuan untuk mengkaji variasi musiman suhu air, salinitas, pH air, pH sedimen, oksigen terlarut, potensial redoks, total bahan organik (BOT), dan tekstur sedimen selama dua musim yang berbeda, yaitu musim barat (musim hujan) dan musim timur (musim kemarau), guna menilai tingkat kontaminasi logam di perairan Teluk Kao, Provinsi Maluku Utara, Indonesia. Penelitian dilakukan dengan mengumpulkan sampel air dan sedimen di Teluk Kao, khususnya pada perairan di sekitar kawasan pertambangan emas NHM. Pengukuran suhu air, salinitas, pH air, pH sedimen, oksigen terlarut, dan potensial redoks dilakukan secara in situ, sedangkan analisis total bahan organik dilakukan berdasarkan metode standar APHA, AWWA, dan WEF (2005) (Bagian 5000: Aggregate Organic Constituents). Tekstur sedimen dianalisis menggunakan metode pipet dan dinyatakan sebagai komposisi persentase berdasarkan skala Wentworth. Hasil penelitian menunjukkan bahwa suhu air, salinitas, pH air, pH sedimen, total bahan organik, potensial redoks (Eh), dan tekstur sedimen mengalami variasi musiman yang nyata, yang selanjutnya memengaruhi distribusi dan konsentrasi logam di wilayah penelitian.

Kata kunci: *parameter lingkungan, Maluku Utara, sedimen, variasi musiman*

INTRODUCTION

Seasonality is a dominant factor in oceanographic studies in Indonesian waters because it significantly influences the distribution and dynamics of various environmental parameters. Seasonal changes can alter both the physical and chemical properties of seawater masses. These changes are primarily driven by increased inputs of organic matter into marine environments, particularly during the rainy season, while the subsequent decomposition of organic matter can lead to a decline in water quality (Patty *et al.*, 2021).

Atmospheric pressure generally tends to be lower during summer and higher during winter, thereby contributing to variations in aquatic environmental conditions. The dynamics and variability of environmental parameters directly influence the reaction rates (kinetics) and behavior of chemical substances, including pollutants, in aquatic ecosystems (Najamuddin, 2017). Among the key environmental parameters influencing these processes are water temperature, salinity, water pH, sediment pH, dissolved oxygen, redox potential, total organic matter (TOM), and sediment texture.

The dynamics and variability of physicochemical parameters in aquatic environments strongly influence the transport, transformation, and fate of pollutants. Estuaries, in particular, function as natural filters for metal contaminants transported from rivers, thereby regulating the amount of pollutants reaching adjacent coastal waters. When estuaries effectively retain metal contaminants through adsorption processes, most metals transported by rivers are adsorbed onto suspended particles and subsequently deposited within estuarine sediments, allowing only a small fraction to reach coastal waters. Conversely, if adsorption processes are ineffective, the estuary's capacity to function as a natural filter is greatly reduced, enabling most or all river-borne metal contaminants to enter marine environments. This process may threaten aquatic organisms and contribute to the deterioration of coastal and marine water quality.

Kao Bay, located in North Halmahera Regency, North Maluku Province, is a coastal ecosystem that is subjected to various anthropogenic pressures, particularly from gold mining and port activities, both of which generate liquid and solid wastes. One of the major environmental concerns associated with these activities is metal contamination. Metals are considered hazardous environmental pollutants because of their high toxicity, environmental persistence, and tendency to bioaccumulate in aquatic organisms (Riba *et al.*, 2004).

This study aimed to investigate the seasonal variations in water temperature, salinity, water pH, sediment pH, dissolved oxygen, redox potential, total organic matter, and sediment texture during two contrasting seasons, namely the west monsoon (rainy season) and the east monsoon (dry season). Furthermore, the study sought to evaluate how these seasonal variations may influence the level of metal contamination in the waters of Kao Bay, North Maluku Province.

METHODS

Study Period and Location

his study was conducted from December 2022 to August 2023 in Kao Bay, North Halmahera Regency, North Maluku Province, Indonesia, particularly in the waters surrounding the NHM gold mining area. Three sampling stations were established: (1) the confluence of the Taolas and Tabobo estuaries, (2) the Taolas Estuary, and (3) the Tabobo Estuary. The geographic coordinates of the sampling stations are presented in Table 1, while the study area is shown in Figure 1.

Table 1. Geographic coordinates of the sampling stations

Location	North	Earth
The confluence of the Taolas and Tabobo estuaries	01°03′ 32. 2″	127°44′ 09. 4″
Taolas estuary	01°03′ 27. 1″	127°44′ 49. 9″
Tabobo estuary	01°03′ 45. 7″	127°72′ 8. 92″

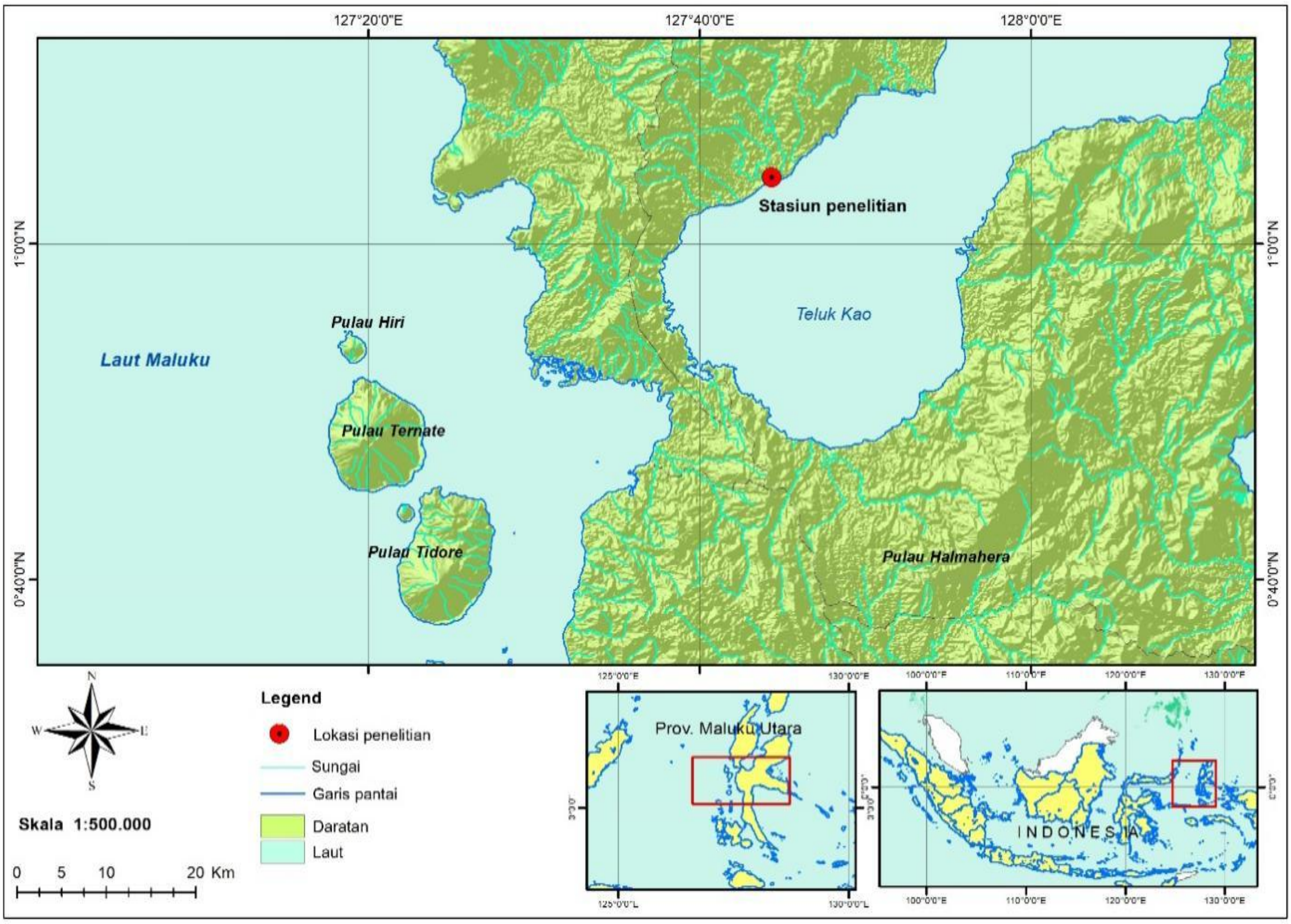

Figure 1. Research location

Equipment and Materials

Water and sediment samples collected from Kao Bay, North Halmahera Regency, North Maluku Province, Indonesia, served as the primary research materials. Field measurements were carried out using a Garmin GPS to determine the coordinates of the sampling stations, a mercury thermometer to measure water temperature, an Atago Master-20M hand refractometer to determine water salinity, a Lutron pH-208 digital pH meter to measure water pH, a Lutron DO-5510 dissolved oxygen (DO) meter to determine dissolved oxygen concentrations, and a Hanna Instruments HI 8314 redox meter to measure sediment redox potential (Eh). Surface sediment samples were collected using PVC corers and stored in plastic bags prior to laboratory analysis.

Laboratory analyses were conducted using a mechanical sieve shaker (SS-8 Inc., 220 V, 200 W), an oven, a digital analytical balance (HZY-B3000R series), 500-mL beakers, dropper pipettes, a non-vacuum desiccator (210 mm), a muffle furnace (PG-SX4-7-12), porcelain crucibles (50 mL), and a soil texture triangle for sediment texture classification. Additional materials used in this study included aluminum foil for weighing sediment samples and distilled water for sample preparation and dilution.

Research Methods

Sample Collection

Water quality and sediment samples were collected during two contrasting seasons, namely the west monsoon (December–February) and the east monsoon (June–August). Sampling stations were selected based on the intensity of anthropogenic activities in the waters surrounding the NHM gold mining area in Kao Bay. Surface sediment samples were collected from the oxic layer at a depth of approximately 1–3 cm using a PVC corer (Werorilangi, 2019).

Measurement of Environmental Parameters

Measurement of aquatic environmental parameters, including:

a. Water parameters, including water temperature, salinity, water pH, and dissolved oxygen (DO), were measured in situ.
b. Sediment parameters, including sediment pH and redox potential (Eh), were measured in situ, whereas total organic matter (TOM) and sediment texture were analyzed in the Chemical Oceanography Laboratory, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar.

RESULTS AND DISCUSSION

Water Parameters

Water Temperature

The results of water temperature measurements during the west monsoon and east monsoon seasons are presented in Figure 2.

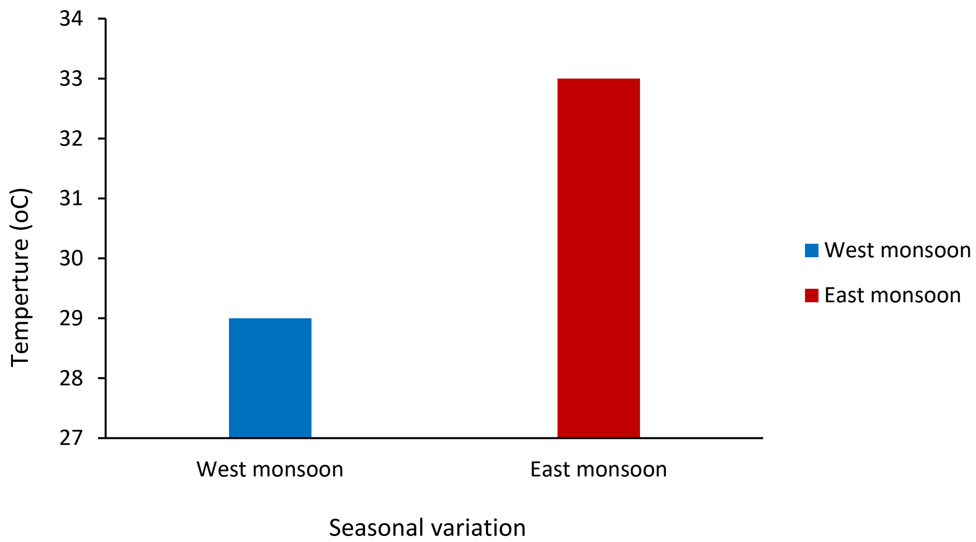

Figure 2. Differences in water temperature (°C) during the west monsoon and east monsoon seasons

Najamuddin (2017) stated that seasonal variations in water temperature are primarily caused by differences in regional characteristics. Estuarine and bay waters generally exhibit relatively uniform water mass characteristics from the surface to the bottom because they are located within the mixed layer depth. Consequently, temperature variations in these environments are strongly influenced by atmospheric conditions and terrestrial inputs. During the west monsoon, high rainfall increases the input of relatively cold freshwater from rivers as well as direct atmospheric precipitation, resulting in a decrease in sea surface temperature. In contrast, during the east monsoon, reduced rainfall and increased evaporation contribute to relatively higher sea surface temperatures. In offshore waters, temperature variation is influenced not only by atmospheric conditions but also by vertical water mass circulation and regional circulation, with little influence from river discharge. This pattern was also observed at the study site, where the water temperature was 29°C during the west monsoon and increased to 33°C during the east monsoon.

Variations in water temperature influence the reactivity of chemical elements in aquatic environments, including metals. At lower water temperatures, dissolved metals tend to be adsorbed onto suspended particles. Consequently, the concentration of dissolved metals in the water column decreases, whereas the concentration of particulate-bound metals increases. Conversely, increasing water temperature enhances metal solubility, thereby promoting the desorption of metals from particles into the water column and increasing the concentration of dissolved metals. The increase in the desorption rate at higher temperatures occurs because elevated temperatures enhance molecular mobility, causing chemical bonds between particles and metal ions to weaken and eventually break (Najamuddin, 2017).

Salinity

The results of water salinity measurements during the west monsoon and east monsoon seasons are presented in Figure 3.

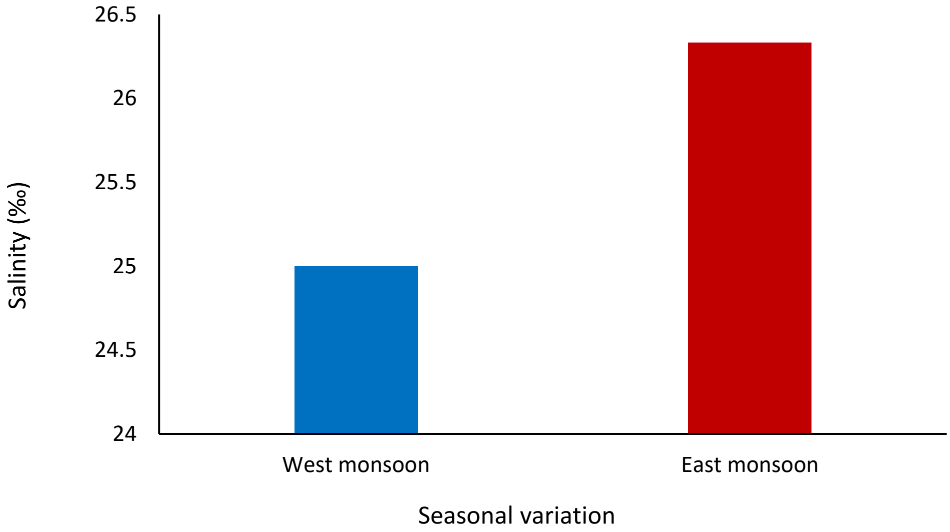

Figure 3. Differences in water salinity during the west monsoon and east monsoon seasons

Salinity during the west monsoon was lower than that during the east monsoon due to the greater input of freshwater from river discharge associated with high rainfall, as well as direct atmospheric precipitation entering the estuarine and coastal waters (Najamuddin, 2017).

According to Patty (2020), seasonal differences in salinity are mainly influenced by weather conditions and wind patterns. The relatively low salinity values observed at the study site are attributable to its location in Kao Bay, where the sampling stations were situated near the mouths of the Tabobo and Taolas Rivers.

The greatest salinity fluctuations were observed in the estuarine waters during both the west and east monsoons. Higher salinity during the east monsoon was primarily associated with increased evaporation and lower precipitation, whereas lower salinity during the west monsoon resulted from higher precipitation and reduced evaporation.

Hatje *et al.* (2003) reported that salinity is one of the key factors controlling the adsorption–desorption processes of metals. In seawater, the rate and extent of metal adsorption are generally lower than those in freshwater. This difference may result from competition between major seawater ions, particularly calcium (Ca) and magnesium (Mg), and trace metals for adsorption sites on particles, as well as from chlorocomplexation.

A decrease in salinity increases the toxicity of metals and enhances their accumulation in aquatic organisms (Eshmat *et al.*, 2014). This pattern was also observed in the present study, where the west monsoon exhibited higher total metal concentrations than the east monsoon, corresponding to the lower salinity values recorded during the west monsoon.

Water pH

The results of water pH measurements during the west monsoon and east monsoon seasons are presented in Figure 4.

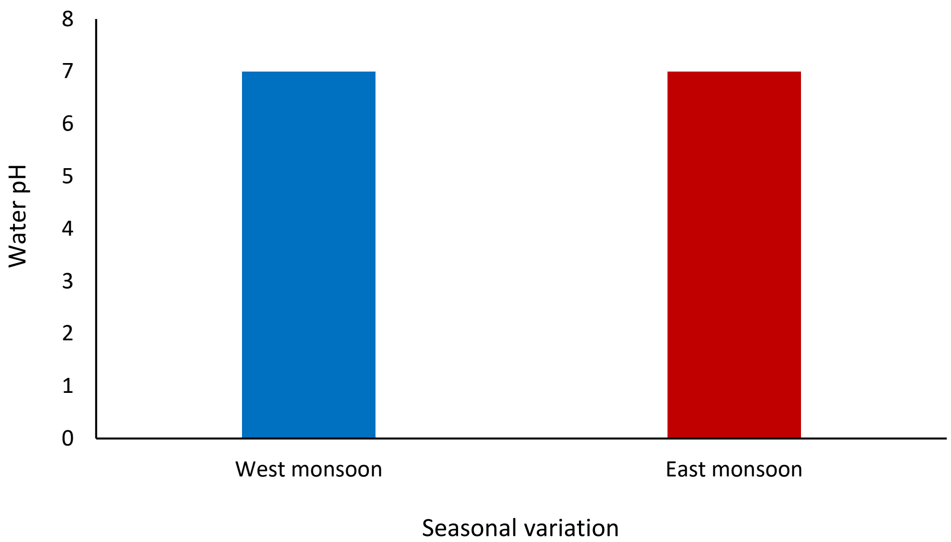

Figure 4. Differences in water pH during the west monsoon and east monsoon seasons

The water pH at the study site, located within the estuarine area, ranged from 6.56 to 6.62 during the west monsoon and from 7.16 to 7.32 during the east monsoon. This pH range is considered favorable for the adsorption of heavy metals. Bibby and Webster-Brown (2006) reported that metal adsorption generally occurs within a pH range of 3.5–7.0, whereas Hatje *et al.* (2003) stated that the optimum pH for metal adsorption ranges from 6.5 to 7.5.

Hatje *et al.* (2003) also reported that pH strongly influences the adsorption of trace metals. Variations in pH affect adsorption through ion exchange mechanisms, which subsequently control interactions between dissolved metals and particle surfaces. At low pH (acidic conditions), the adsorption rate is relatively low, whereas at higher pH (alkaline conditions), metal adsorption becomes more effective.

Dissolved Oxygen

The results of dissolved oxygen (DO) measurements during the west monsoon and east monsoon seasons are presented in Figure 5. According to Fardiaz (1992), low dissolved oxygen concentrations in aquatic environments may result from the input of large amounts of organic matter, as decomposer microorganisms require substantial amounts of oxygen to degrade organic materials. This is consistent with the results obtained at Station 4 in Kao Bay, where the dissolved oxygen concentration was <5 mg L^{-1}. These findings are also consistent with those of Simanjuntak (2007), who reported that one of the primary causes of declining dissolved oxygen concentrations in Klabat Bay was the deterioration of water quality resulting from the input of organic carbon-rich wastes.

The development of anoxic conditions (oxygen deficiency) due to excessive organic matter inputs generally reduces the solubility of trace metals, thereby promoting their precipitation in aquatic environments (Moore and Ramamoorthy, 1984).

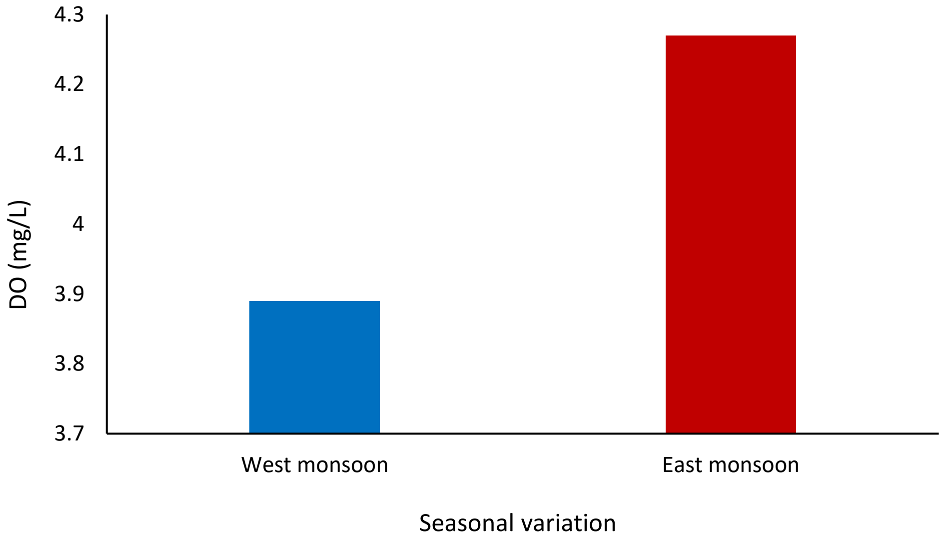

Figure 5. Differences in dissolved oxygen (DO) concentrations during the west monsoon and east monsoon seasons

Sediment Parameters

Sediment pH

The results of sediment pH measurements during the west monsoon and east monsoon seasons are presented in Figure 6.

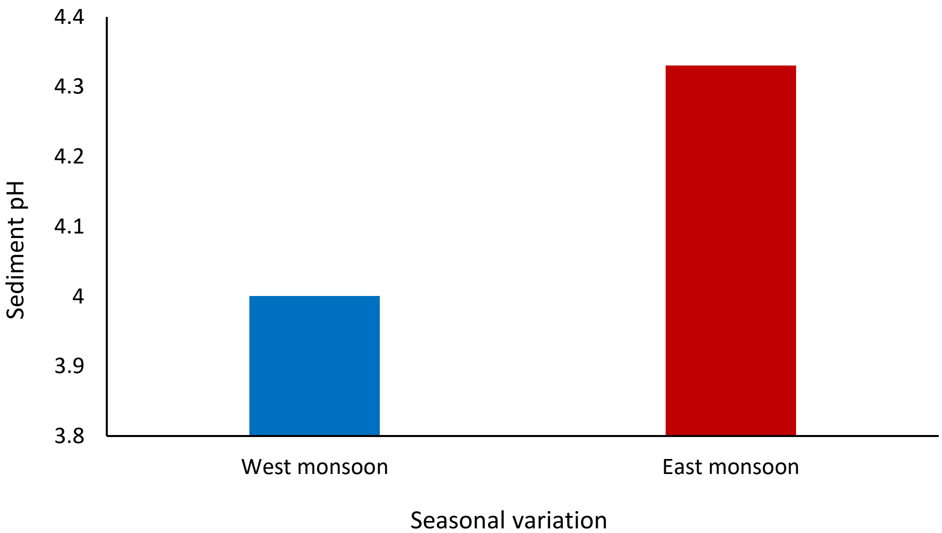

Figure 6. Differences in sediment pH during the west monsoon and east monsoon seasons

According to Rowe (2020), the decomposition of organic matter can influence sediment pH through several mechanisms: (1) Production of Organic Acids: During the decomposition process, some microorganisms produce organic acids as metabolic by-products. These organic acids reduce sediment pH because of their acidic properties; (2) Oxygen Consumption: The decomposition of organic matter is accompanied by oxygen consumption by microorganisms. When oxygen is depleted, anaerobic conditions may develop, leading to the production of acidic compounds that further decrease sediment pH; (3) Release of Sulfate Compounds: Certain microorganisms involved in organic matter decomposition may release sulfate, which can subsequently react with water to form sulfuric acid, thereby lowering sediment pH.

Hatje *et al.* (2003) reported that pH is one of the key factors controlling the adsorption of trace metals. Variations in pH influence adsorption through ion exchange mechanisms, which subsequently regulate interactions between dissolved metals and sediment particles. Under acidic conditions (low pH), metal adsorption is relatively limited, whereas under alkaline conditions (high pH), the adsorption rate generally increases.

Total Organic Matter (TOM)

The results of total organic matter (TOM) measurements in the sediment are presented in Figure 7.

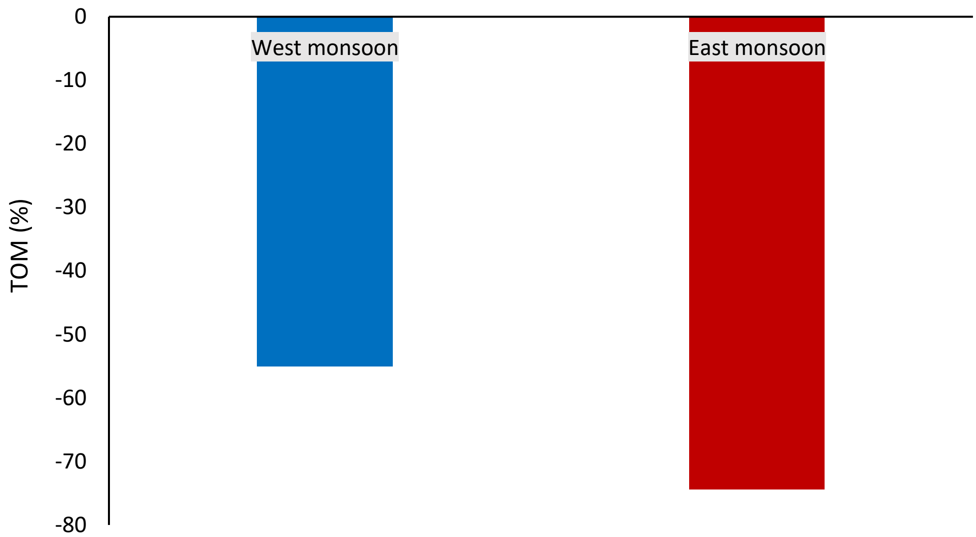

Figure 7. Differences in total organic matter (TOM) content during the west monsoon and east monsoon seasons

The total organic matter (TOM) content at the study site was 6.97% during the west monsoon and 10.37% during the east monsoon. The relatively high TOM content is attributable to the location of the sampling station at the confluence of the Taolas and Tabobo Rivers in Kao Bay. Dahuri et al. (1996) explained that river estuaries are dynamic transition zones where freshwater and seawater meet and remain influenced by marine processes such as salinity, tides, and seawater intrusion. In the upstream area of these estuaries, gold mining activities operated by PT Nusa Halmahera Permai (NHM), together with human settlements and port activities, may contribute organic matter to the estuarine environment. These findings are consistent with those of Najamuddin (2017), who reported that the distribution of organic matter during the west monsoon tends to remain relatively stable in riverine, estuarine, and coastal waters because its primary source is particulate organic carbon derived from terrestrial erosion and transported by rivers.

Sediment Redox Potential (Eh)

The results of sediment redox potential (Eh) measurements during the west monsoon and east monsoon seasons are presented in Figure 8.

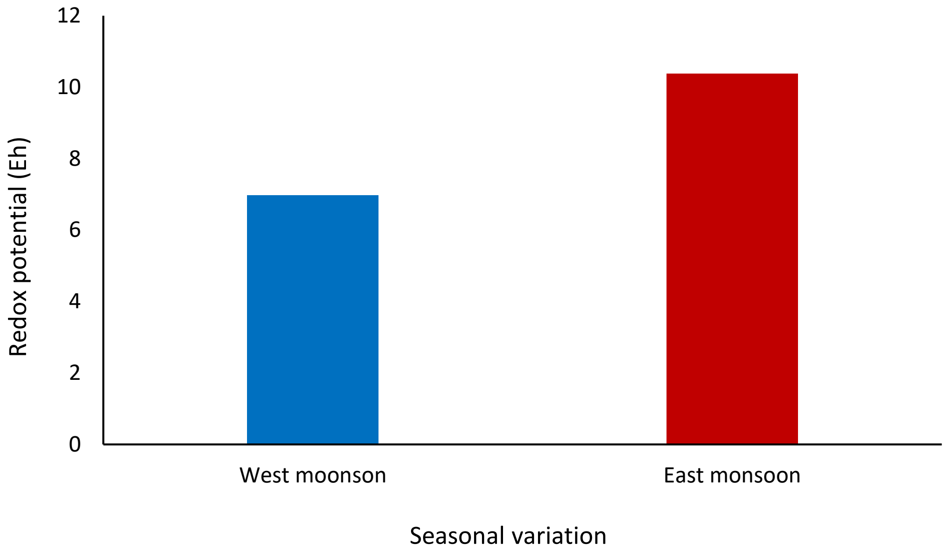

Figure 8. Differences in sediment redox potential (Eh) during the west monsoon and east monsoon seasons

Redox potential (Eh) is an important indicator of sediment geochemical conditions and plays a significant role in the diagenesis of sedimentary materials, including the transformation of organic matter into petroleum. Positive redox potential values generally indicate well-oxygenated sediments, which are typically coarse-grained and contain relatively low organic matter. In contrast, negative redox potential values are characteristic of fine-grained sediments enriched with organic matter.

At the study site, sediment redox potential values were within the reduction zone because the sampling stations were located in estuarine waters characterized by high organic matter content. The decomposition of organic matter by microorganisms increases oxygen consumption, resulting in low dissolved oxygen conditions and consequently lower redox potential values.

Sediment Texture

The percentage composition of sediment texture during the west monsoon season is presented in Figure 9. While, the percentage composition of sediment texture during the east monsoon season is presented in Figure 10.

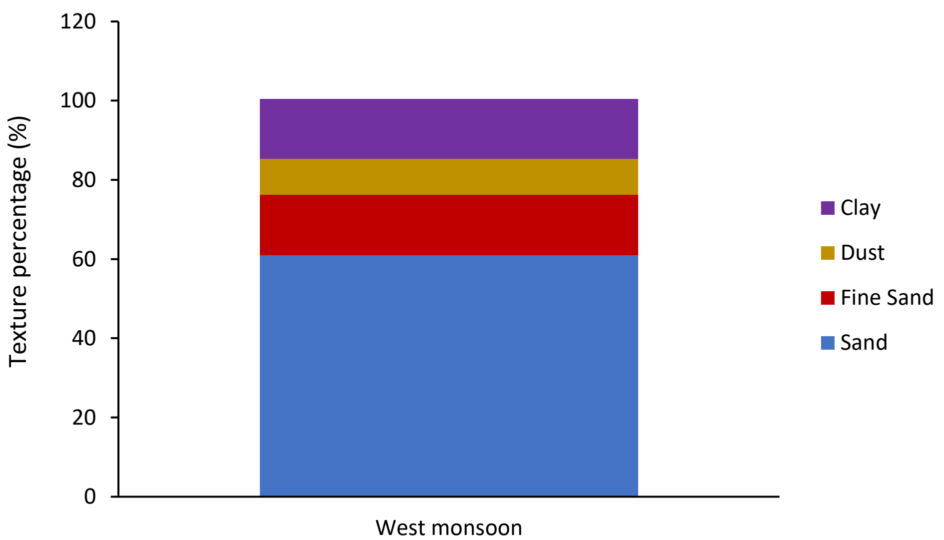

Figure 9. Percentage composition of sediment texture during the west monsoon season

Figure 10. Percentage composition of sediment texture during the east monsoon season

The results showed that the proportion of sand was higher during the west monsoon than during the east monsoon. This pattern is attributed to the stronger water movement during the west monsoon, resulting from higher wind intensity, which promotes the transport and deposition of coarser sediment particles. Conversely, the proportions of finer sediment fractions (silt and clay) increased during the east monsoon because weaker hydrodynamic conditions favored the deposition of fine particles on the seabed.

The relatively high proportion of clay observed at the study site is associated with its location at the estuary of the Tabobo and Taolas Rivers in Kao Bay. The inner part of the bay is characterized by relatively calm waters and weak current velocities, creating favorable conditions for the deposition and accumulation of fine sediment particles. These findings are consistent with those of Pamungkas and Farhaby (2018), who reported that current velocities in the inner part of Kelabat Bay are relatively lower than those in the outer bay.

The distribution of metals in sediments is closely related to sediment grain size. In general, fine-grained sediments with higher organic matter content contain greater concentrations of metals than coarse-grained sediments (Yang *et al.*, 2007). Fine sediments, particularly mud, have a greater capacity to adsorb and retain metals because of their small particle size and large specific surface area. Consequently, sediments with a high mud content generally exhibit higher metal concentrations.

The finest sediment fractions, namely clay and silt, have an even greater capacity to bind metals because their larger surface area provides more adsorption sites. In addition, these fine fractions readily associate with organic matter, promoting the formation of stable metal–organic complexes within the sediment. As reported by Sanusi (2006), metal concentrations are generally higher in clay, mud, sandy mud, and mixed fine sediments than in coarse sandy sediments due to the stronger electrochemical attractive forces associated with fine sediment particles.

CONCLUSION

The environmental parameters measured at the study site exhibited clear seasonal variations, including water temperature, salinity, water pH, sediment pH, total organic matter (TOM), redox potential (Eh), and sediment texture. Water temperature, salinity, sediment pH, total organic matter (TOM), and redox potential (Eh) showed higher values during the east monsoon than during the west monsoon. These seasonal variations may influence the distribution and concentration of metals in the study area.

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