STUDY OF HEAVY METAL LEAD (PB) CONTENT IN THE CORAL REEF ENVIRONMENT OF PANJANG ISLAND, BANTEN

STUDI KANDUNGAN LOGAM BERAT TIMBAL (PB) PADA LINGKUNGAN TERUMBU KARANG DI PERAIRAN PULAU PANJANG, BANTEN

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ABSTRACT: Rapid industrial expansion in Banten has triggered a surge in pollution, impacting areas like Panjang Island in Banten Bay. Pollution on Panjang Island stems primarily from industrial operations and shipping activities. This study investigates the distribution of lead (Pb) metal concentrations in Panjang Island's coral reef environment, focusing on sediment and surface water. It also examines how seasonal variations, influenced by ocean currents, affect Pb concentration distribution. Data were gathered using purposive sampling, collecting sediment samples, surface water samples, and oceanographic data. Pb levels in both sediments and surface water underwent analysis at the National Research and Innovation Agency (BRIN) laboratory, employing atomic absorption spectrophotometry (AAS). Our findings indicate that during the transitional II season, Pb concentrations in sediment ranged from 4.2 to 17 mg/kg, while the westerly season showed Pb concentrations spanning 3.8 to 23.4 mg/kg. Surface water during these seasons exhibited Pb concentrations varying from 0 to 0.03 mg/l. Notably, at several monitoring stations, surface water Pb concentrations exceeded the threshold set by Regulation No. 22 of 2021, suggesting potential harm to the coral reef ecosystem surrounding Panjang Island. Elevated Pb concentrations were observed during the transitional II season in the island's western part and the westerly season in the eastern part. These disparities appear to be influenced by the direction of ocean currents, highlighting their role in shaping Pb distribution in Panjang Island's waters.

Keywords: Lead (Pb), sediment, surface water, transitional II season, westerly season, Panjang Island

***ABSTRAK**: Perkembangan industri yang cepat di Banten telah menyebabkan peningkatan polusi yang signifikan. Pulau Panjang yang terletak di Teluk Banten merupakan salah satu pulau yang terkena dampaknya. Aktivitas industri dan lalu lintas kapal secara signifikan berkontribusi pada polusi di Pulau Panjang. Tujuan dari penelitian ini adalah untuk menentukan distribusi konsentrasi logam timbal (Pb) dalam sedimen dan air permukaan di lingkungan terumbu karang Pulau Panjang, serta untuk menilai pengaruh musim (arus laut) terhadap distribusi konsentrasi Pb. Pengumpulan data dilakukan menggunakan metode pengambilan sampel yang melibatkan sampel sedimen, sampel air permukaan, dan parameter arus laut. Pb dalam sedimen dan air permukaan dianalisis di laboratorium Badan Riset dan Inovasi Nasional (BRIN) menggunakan metode Spektrofotometri Serapan Atom (SSA). Berdasarkan hasil penelitian menunjukkan bahwa selama musim transisi II, kandungan logam Pb dalam sedimen berkisar antara 4,2 - 17 mg/kg, sementara musim barat menunjukkan kandungan Pb berkisar antara 3,8 hingga 23,4 mg/kg. Di air permukaan, konsentrasi Pb selama musim transisi II dan musim barat berkisar antara 0 - 0,03* *mg/l. Beberapa stasiun menunjukkan konsentrasi Pb di air permukaan melebihi ambang batas yang ditetapkan oleh PP. No. 22 tahun 2021, dengan potensi merugikan terhadap kondisi terumbu karang di perairan Pulau Panjang. Konsentrasi Pb yang lebih tinggi di perairan Pulau Panjang selama musim transisi II di bagian barat dan selama musim barat di bagian timur. Perbedaan ini tampak dipengaruhi oleh arah pergerakan arus laut yang berperan dalam membentuk sebaran Pb di perairan Pulau Panjang.*

Kata Kunci: *Timbal, sedimen, permukaan air, musim peralihan II, musim barat, Pulau Panjang*

INTRODUCTION

Heavy metals, characterized by their density exceeding 5 g/cm³ (Holleman and Wiberg, 1985), encompass around 40 elements, including lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), and silver (Ag), among others. These metals can originate from natural processes like rock weathering and atmospheric deposition, but human activities such as industrialization and urbanization contribute significantly to heavy metal contamination. They are most prevalent in soils and aquatic ecosystems (Sharma and Agrawal, 2005), often entering marine waters via rivers or atmospheric deposition. The movement of heavy metals is influenced by various factors such as pH, sediment, organic matter, temperature, and other metal concentrations (Falah *et al*., 2020). While trace amounts of heavy metals are essential for metabolic processes, excess amounts can be toxic (Philips, 1980), especially the highly toxic mercury (Hg), Cd, and Pb (Waldhicuk, 1974).

Banten has witnessed rapid industrial growth, resulting in increased waste production, including solid, gas, and liquid waste. Industrial waste has the potential to contribute to the contamination of Banten Bay's waters with heavy metals (Afiyatillah *et al*., 2022). Moreover, activities at the port and industries, particularly ship-related operations, have the potential to release heavy metal waste, including lead (Pb) (Rizkiana *et al*., 2017). Panjang Island, located near industrial areas and ship traffic routes, is a key site with pollution primarily linked to industrial activities and shipping (Falah *et al*., 2020). Notably, lead (Pb) is present in ship paints and fuels, further contributing to its presence in the waters (Rizkiana *et al*., 2017).

Lithology of Panjang is primarily characterized by limestone coral reefs, formed through the accumulation of coral colonies, shell fragments, and mollusks (Rusmana and Suwitodirjo, 2005). The coral reef ecosystem is highly sensitive to environmental changes, encompassing both physical and chemical alterations in the surrounding environment (Guzman and Jimenez, 1992; Al-Rousan et al., 2007). Notably, anthropogenic pollution poses a significant threat to the health of the coral reefs. A recent investigation revealed a notable presence of persistent organic pollutants originating from the burning of plastic waste on the beaches of Panjang Island which can give negative impact for coral reefs health in the island (Utami *et al*., 2023).

Furthermore, given its proximity to industrial areas, there is a growing concern that Panjang Island may be affected by heavy metal pollution resulting from industrial activities. Heavy metals can become integrated into the coral framework through various processes, subsequently impacting coral health and overall ecosystem stability (David, 2003; Al-Rousan et al., 2007). Of particular concern is the elevated presence of Pb, which has been associated with detrimental effects on coral ecosystems. Elevated levels of Pb can induce physiological stress, reduce reproductive success, alter population dynamics, and contribute to coral bleaching (Harland and Brown, 1989; Falkowski *et al*., 1990; Mitchelmore et al., 2007; Sabdono, 2009). The multifaceted impact of heavy metal contamination underscores the need for comprehensive assessments and mitigation strategies to safeguard the ecological integrity of Panjang Island's coral reefs.

Studies on nearby Tunda Island found heavy metal Pb contamination in coral reefs, raising concerns about Panjang Island's coral reef ecosystem. Elevated dissolved heavy metal concentrations in seawater or sediments disrupt aquatic ecosystems, including coral reefs (Razi *et al*., 2023). Given these concerns, it is essential to study heavy metal Pb concentrations in Panjang Island's coral reef environment, considering oceanographic factors such as ocean currents, to assess its current state and potential impact to the coral reef environment. This research aims to determine heavy metal Pb concentrations in sediment and surface water samples, clarifying distribution patterns influenced by oceanographic phenomena around Panjang Island, Banten.

METHODS AND MATERIALS

The study area in this research is Panjang Island, Banten, situated between 6°25'18" to 6°28'12" S and 106°22'9" to 106°25'36" E in the Java Sea (Figure 1). The research focuses on four specific regions: west, north, east, and south, along with measurements conducted on the mainland at Grenyang Port and Gope Beach. Grenyang Port, serving as a transit hub to Panjang Island, represents a potential pollution source from the Bojonegara industrial district west of Panjang Island. Gope Beach, at a river mouth in Banten Bay, indicates potential pollution from river discharge into Banten Bay.

The research employs two main types of data: primary and secondary. Primary data, collected in September 2022 (transitional II season) and February 2023 (westerly season), comprises field data from sediment samples, surface water samples, and oceanographic parameters. These samples were processed at the Geological Engineering Laboratory of the National Research and Innovation Agency (BRIN) and the Chemistry Laboratory of BRIN. Secondary data supports the primary data and includes ocean currents, sourced from Marine Copernicus, and validated with field data collected using drifters (data collected on September 28-29, 2022, and February 8, 2023).

The sample collection process comprised two main categories: sediment and surface water sampling. Sediment sampling involved traversing transects across Panjang Island, including the near coast, reef flat, and reef front in the eastern, southern, western, and northern regions. A total of 12 locations were sampled in both seasons using grab samplers. The sediment samples were collected using an Eckman grab sampler and stored in polyethylene bags. Similarly, surface water sampling followed a transect approach to understand the spatial distribution of Pb metal in the coral reef environment. During the transitional II season, surface water samples were taken from areas near the coast of Panjang Island and the reef front. Additional samples were collected at Grenyang Port and Gope Beach to identify potential sources of pollution in Banten. In the westerly season, surface water sampling expanded to include the reef flat, resulting in a total of 10 and 14 samples, respectively. The water sample then collected using 500 ml polyethylene water sample bottles. The samples were preserved with concentrated HNO_3 with a pH of <2

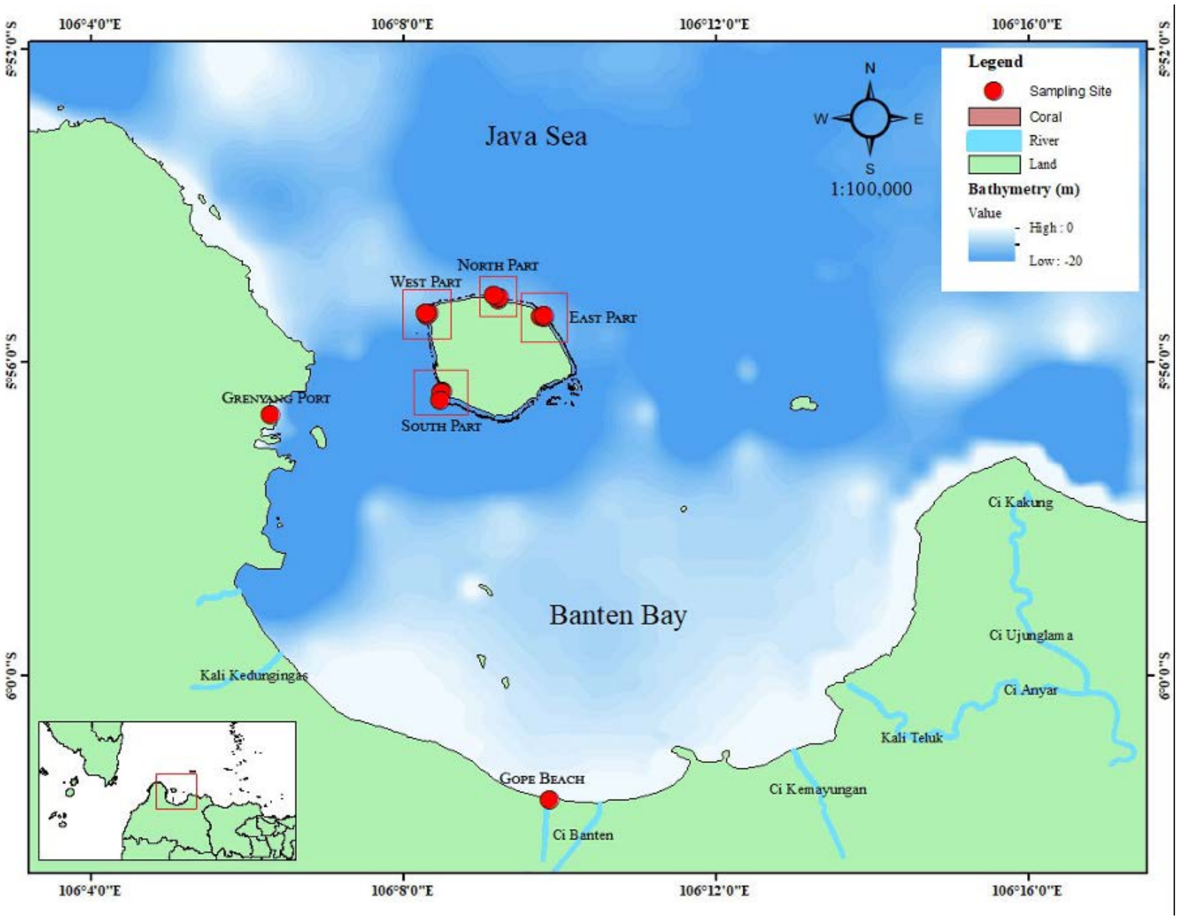

Figure 1. Sampling site location

before being stored in a cool place protected from sunlight.

In the laboratory, sediment samples underwent drying, sieving, sub-sampling, and destruction to enable elemental analysis using atomic absorption spectrophotometry (AAS). Surface water samples were processed similarly, with the addition of dilution and filtration steps. The instrument to measure Pb content in the sediment and water samples were using Shimadzu AA-7000 series Atomic Absorption Spectrophotometers featuring dual atomizer. During laboratory analysis, each sediment sample was divided into three sub-samples to ensure triplicate measurements for quality control. The sub-samples for AAS analysis typically weighed around 0.5000 to 0.5010 grams. Subsequently, the sample destruction process was carried out, transforming the sediment sample into a form that could be measured, enabling the analysis of its elemental content (Asmorowati *et al.*, 2020). The sample destruction process commenced by mixing the sediment sample with a solution containing 10 ml of HF, 1 ml of HNO_3, and 1 ml of H_2SO_4. Prior to heating, the sediment sample and the solution were thoroughly mixed to achieve homogeneity. After the heating process, the sample was cooled until all vapors had dissipated. The subsequent step involved mixing the dried and cooled sample with 25 ml of concentrated HCL until homogenous. The mixture was then heated using a hot plate at a temperature of 360°C for 5 minutes and subsequently cooled until no vapor was present. The following step consisted of diluting the sediment sample with distilled water (aquabidest) and filter paper of Whatman Grade 41. During this process, the sample was filtered to remove any impurities. The dilution process was considered complete when the solution reached a volume of 100 mL within a measuring flask. For surface water samples, the preparation involved taking 50 ml of surface water and adding 1 ml of HNO_3. The mixture was then heated until the water sample was reduced to 20 ml. The shrunken sample was transferred into a 50 ml measuring flask using filter paper, and aquabidest was added to reach the flask's capacity. The sample was then shaken within the measuring flask. After that process, sample analysis with AAS can be carried out. In this study the analysis AAS using AA-7000 machine, this type followed the calibration curve quantification method using Pb standard solutions of varying concentrations, namely 0.08, 0.06, 0.04, 0.02, 0.1, and 0.5 ppm.

The Pb concentrations were then compared to quality standards, namely the Sediment Quality Guidelines (SQG) and seawater quality standards as per Regulation No. 22 of 2021 (Indonesian State Gazette). Subsequently, the relationship between Pb concentrations and oceanographic parameters (ocean currents) was qualitatively assessed. The pollution index method is a technique for determining the condition of a water body based on the calculation of quality indices, namely the average index (I_R), which indicates the average pollution level of all parameters in one observation period, and the individual index (I_m), which identifies the dominant parameter responsible for the decrease in water quality during one observation period (Desmawati, 2014). The water quality index using the pollution index method is calculated using the following equation.

$$IP_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_m^2 + \left(\frac{C_i}{L_{ij}}\right)_R^2}{2}} \quad \text{.......................} \quad (1)$$

Where:

IP_j : Pollution Index for parameter j

C_i : Concentration of the field test results for parameter.

L_{ij} : Concentration of the parameter according to the water quality standards for parameter j

$\left(\frac{C_i}{Li_{ij}}\right)_m^2$: Maximum of C_i/L_{ij} Value

$\left(\frac{C_i}{Li_{ij}}\right)_R^2$: Average of C_i/L_{ij} value

The evaluation of the IP values is as follows:

$0 \leq IP_j \leq 1$: Goods condition.

$1 < IP_j \leq 5$: Slightly polluted.

$5 < IP_j \leq 10$: Moderately polluted.

$IP_j > 10$: Heavily polluted.

RESULTS

Condition of the ocean current

Drifter measurements were conducted across the western, northern, eastern, and southern regions of Panjang Island during both the transitional II season in September and the westerly season in February. The transitional II season typically spans from September to November and is characterized by the persistence of the easterly monsoon, marked by eastward-blowing winds. This meteorological pattern is reflected in the prevailing westward to north-westward ocean currents observed during the drifter measurements. These current measurements were timed to coincide with the transition from high tide to low tide, particularly during the full moon phase, as shown in Figure 2 (left).

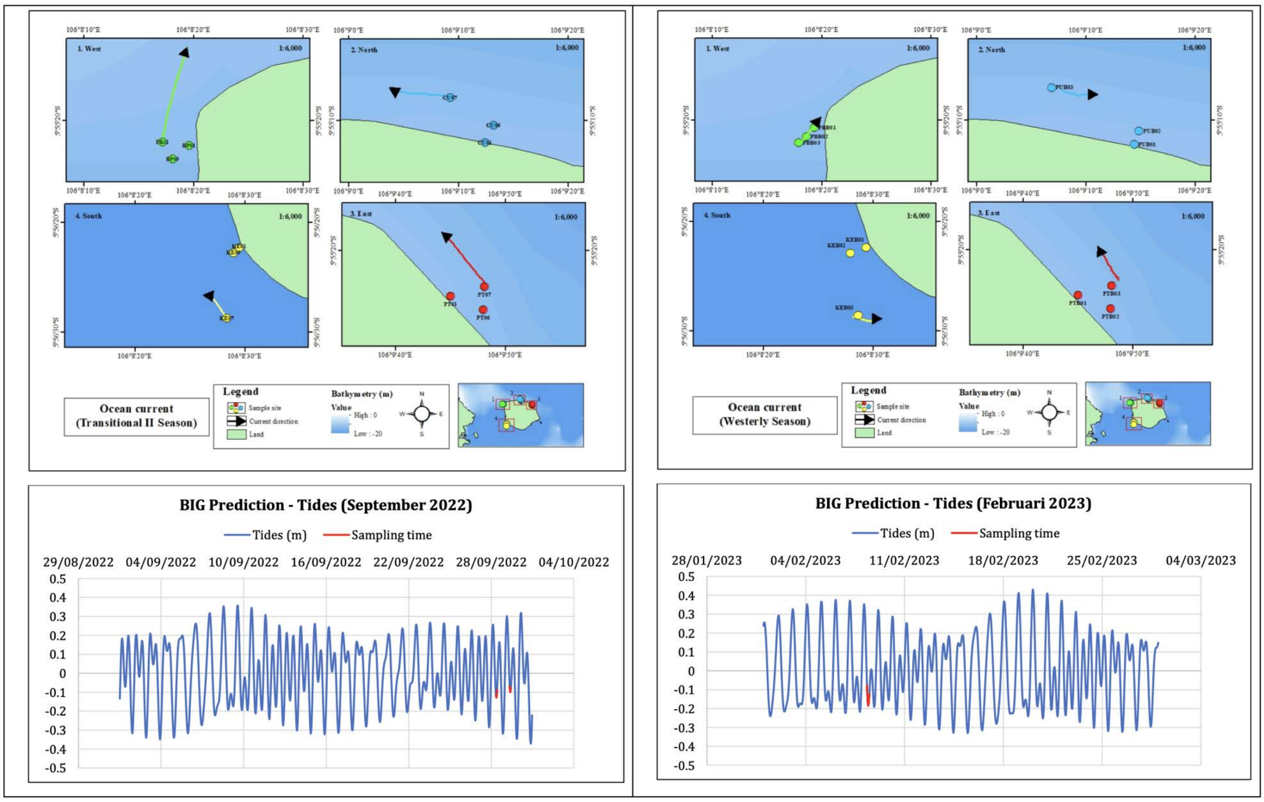

Figure 2. Top: Ocean current during transitional II season (left) and westerly season (right) at Panjang Island (field measurement); 1. West part; 2. North part; 3. East part; 4. South part.
Bottom: Tides from BIG Prediction in September 2022 (left) and February 2023 (right)

The current rose diagrams derived from the drifter data collected during transitional II season as shown in Figure 3 (left), including the four distinct areas—west, north, east, and south—revealed specific current patterns in each location. In the western waters surrounding Panjang Island, the dominant ocean current flows northward, with speeds ranging from 0.2 to 0.5 m/s. In the northern region, the predominant current flows westward, with speeds ranging from 0.1 to 0.2 m/s. In the eastern waters, the dominant current flows north-westward, with speeds ranging from 0.1 to 0.5 m/s. In the southern waters, the dominant current flows north-westward, with speeds ranging from 0.1 to 0.2 m/s.

Figure 3 (right) displays the current rose diagrams in westerly season for the same four areas—west, north, east, and south—revealed the following: in the western waters of Panjang Island, the dominant seaward current moves north-eastward, with current speeds ranging from 0.1 to 0.4 m/s. In the northern waters, the dominant seaward current moves eastward, with speeds ranging from 0.2 to 0.5 m/s. In the eastern waters, the dominant seaward current moves north-westward, with speeds ranging from 0.1 to 0.3 m/s. In the southern waters, the dominant seaward current moves south-eastward, with speeds ranging from 0.2 to 0.5 m/s.

Moreover, by relying on secondary data from Marine Copernicus, we established that the dominant currents in the waters surrounding Panjang Island consistently flow westward throughout the year, from March 2022 to February 2023 (Figure 4). A high level of congruence is evident when comparing this secondary data with the field measurements, as presented in Table 1. This alignment holds true for both the transitional II and westerly seasons, where minor discrepancies exist in seawater current velocity and direction. During the transitional II season in September, the current velocity exhibits a variance of 0.118 m/s, while the westerly season shows a difference of 0.083 m/s. Additionally, the current direction closely matches the field measurements and Marine Copernicus data in both seasons.

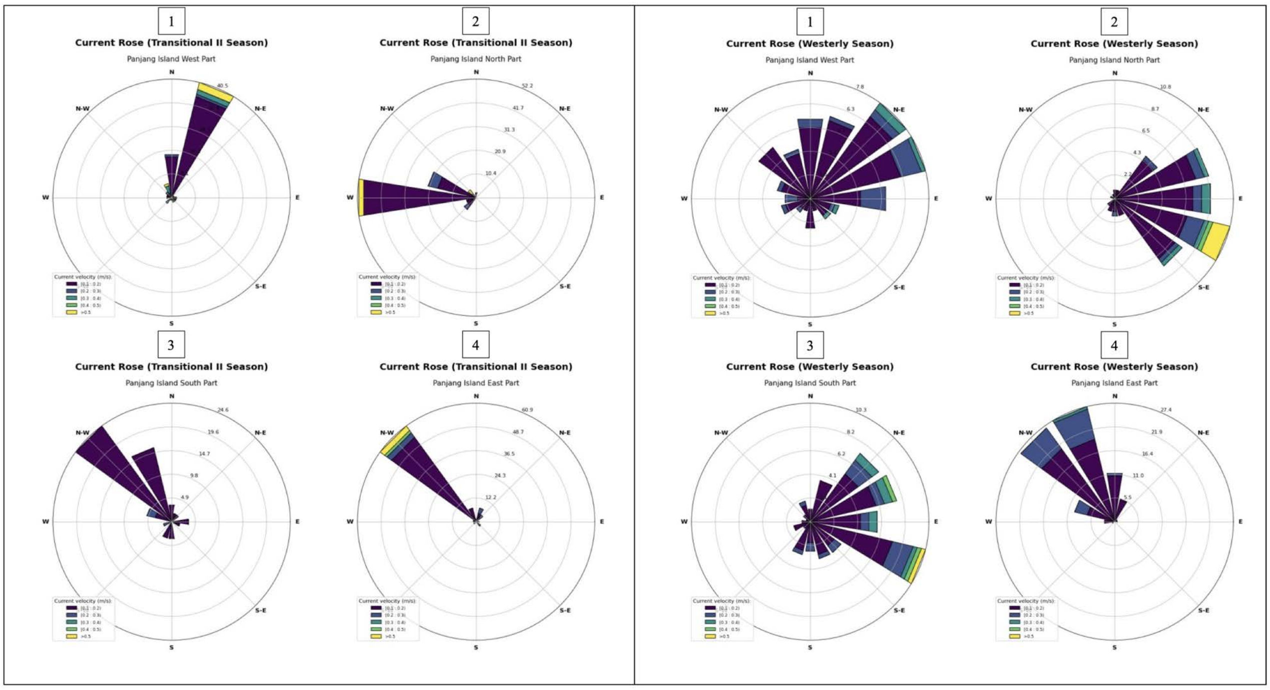

Figure 3. Current rose during transitional II season (left) and westerly season (right) at Panjang Island (field measurement); 1. West part. 2. North part. 3. East part. 4. South part

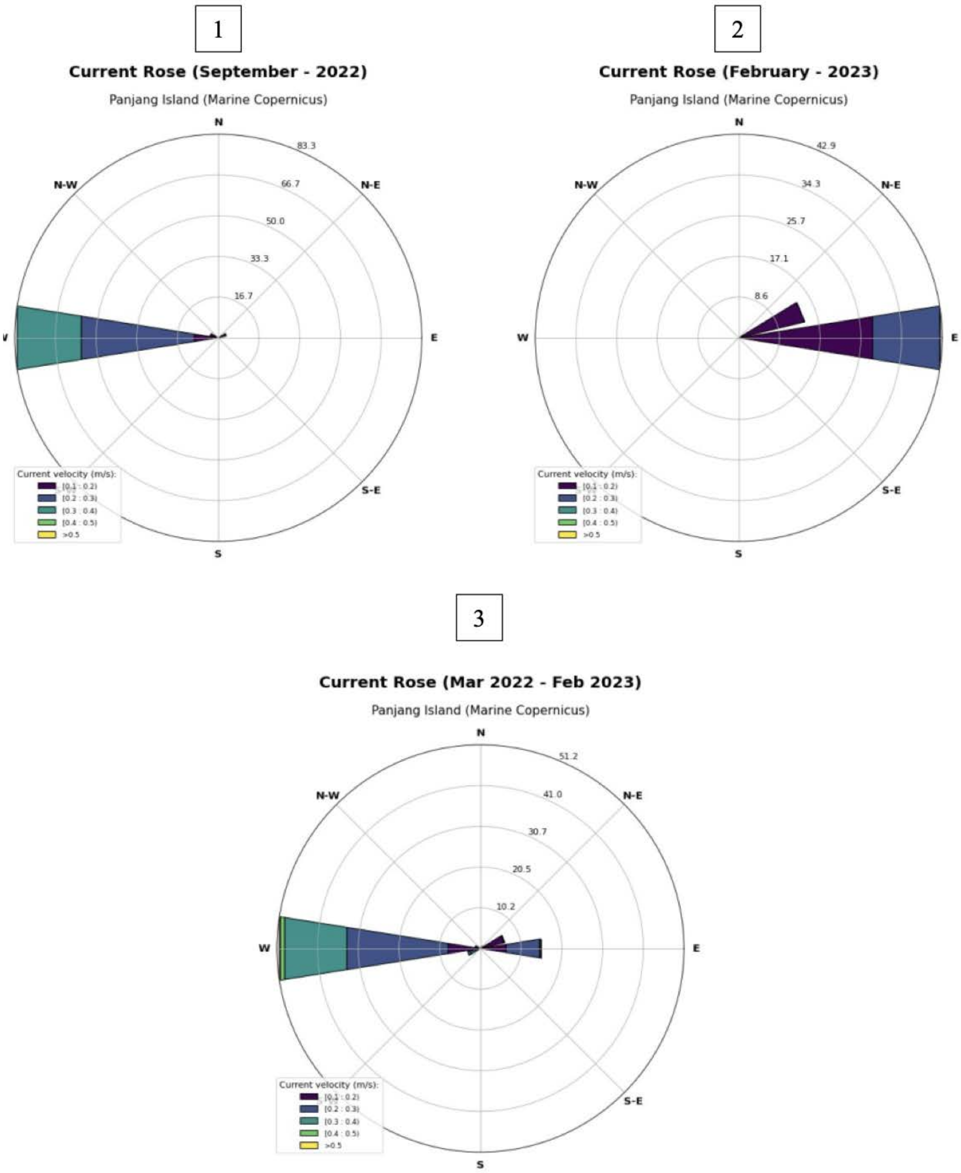

Figure 4. Current rose at Panjang Island (Marine Copernicus). 1: September 2022. 2: February 2023.

Table 1. The comparison of ocean current data between field measurements and Marine Copernicus

Time (DD-MM-YYYY)	Current velocity (m/s)		Current direction (^{o})		Difference	
	Drifter (North part)	Marine Copernicus	Drifter (North part)	Marine Copernicus	Current velocity (m/s)	Current direction (^{o})
29-09-2022	0.187	0.305	262.7 (West)	263.8 (West)	0.118	1.1
08-02-2023	0.113	0.197	115.2 (East)	73.9 (East)	0.083	41.3

Concentration of Pb in sediment and water surface

In this study, the concentrations of Pb metal were assessed in sediment and surface water samples (Table 2). The laboratory results indicated that during both the transitional II and westerly seasons, the concentrations of Pb in sediment generally remained below the thresholds defined by the Sediment Quality Guidelines (SQG) (Table 3). Specifically, during the transitional II season, the maximum Pb concentration recorded was 16.9 mg/kg, with an average of 10.3 mg/kg. In the westerly season, the maximum concentration was 23.4 mg/kg, with an average of 11.4 mg/kg. In contrast, the concentrations of Pb in surface water at various stations during both seasons exceeded the water quality standards set by Regulation No. 22 of 2021 ((Indonesian State Gazette, 2021). As shown in Table 4, during the transitional II season, Pb concentration reached a peak of 0.029 mg/l, with an average of 0.016 mg/l. Similarly, during the westerly season, it reached a

Table 2. The concentration of Pb in sediment and water surface on transitional II season and westerly season.

Sample Site	Transitional II Season		Westerly Season	
	Concentration of Lead (Sediment) (mg/kg)	Concentration of Lead (Surface Water) (mg/l)	Concentration of Lead (Sediment) (mg/kg)	Concentration of Lead (Surface Water) (mg/l)
PEL.G	-	0.029	-	0.010
PGP	-	0.016	-	Nd
CU01/PUB01	15.3	0.016	9.5	Nd
CU06/PUB02	7.2	-	5.7	Nd
CU07/PUB03	15.3	0.009	23.4	Nd
PT01/PTB01	7.5	Nd	3.8	0.029
PT06/PTB02	4.2	-	6.2	Nd
PT07/PTB03	8.5	Nd	20.5	0.005
KE01/KEB01	12.4	0.002	11.4	Nd
KE05/KEB02	8.1	-	12.4	Nd
KE07/KEB03	8.8	0.023	11.4	Nd
BP01/PBB01	11.2	0.016	10.0	Nd
BP05/PBB02	7.8	-	9.5	Nd
PB31/PBB03	16.9	0.016	13.3	Nd

Nd : not detected

Table 3. Statistic descriptive of concentration of Pb in sediment during transitional II season and westerly season

	Transitional II Season	Westerly Season
Sample Size (n)		12
Maximum	16.9	23.4
Minimum	4.2	3.8
Average	10.3	11.4
Sediment Quality Guideline		
ANZECC/ARMCANZ Guidelines		50
CCME		30.2

maximum of 0.029 mg/l, with an average of 0.014 mg/l.

When analyzing the spatial distribution of Pb metal concentrations in sediments, we observed that during the transitional II season, the reef flat area exhibited lower Pb metal concentrations (ranging from 4.2 mg/kg to 8.1 mg/kg) compared to the areas near the coast (ranging from 7.5 mg/kg to 15.3 mg/kg) and the reef front (ranging from 8.5 mg/kg to 16.9 mg/kg). However, the concentration values fluctuated when comparing the coastal areas with the reef front. In the western and southern coastal areas, the concentrations were higher than those in the reef front, while in the northern and eastern parts, the reef front had higher concentrations than the coastal areas (Figure 5). Conversely, during the westerly season, Pb metal concentrations in the reef flat area were lower (ranging from 5.7 mg/kg to 12.4 mg/kg) compared to the areas near the coastal area (ranging from 3.8 mg/kg to 11.4 mg/kg) and the reef front (ranging from 11.4 mg/kg to 23.4 mg/kg). In the southern part, the Pb metal content in the reef flat area was higher than both the reef front and the coastal areas. However, when comparing the coastal areas with the reef front, the concentrations were higher in the reef front compared to the coastal areas, except in the southern part, where they were equal in both the reef front and coastal areas (Figure 6).

Additionally, when examining the spatial distribution of Pb metal concentrations in water during the transitional II season, we observed fluctuations. There were areas with higher Pb metal concentrations near the coastal areas in the northern part (0.016 mg/l), while in the southern part, the reef front had higher Pb metal concentrations (0.023 mg/l). In the western part of the water, the Pb metal concentrations remained relatively stable (Figure 7). In contrast, during the westerly season, the concentrations of heavy metals were higher in the coastal areas (0.029 mg/l) compared to the reef front (0.005 mg/l). During the westerly season, measurements were also taken in the reef flat area, and no Pb metal was detected at any of the stations (Figure 8).

Table 4. Statistic descriptive of concentration of Pb in sediment on transitional II season and westerly season

	Transitional II Season	Westerly Season
Sample Size (n)	10	14
Maximum	0.029	0.029
Minimum	Nd	Nd
Average	0.016	0.014
PP No. 22 of 2021		0.008

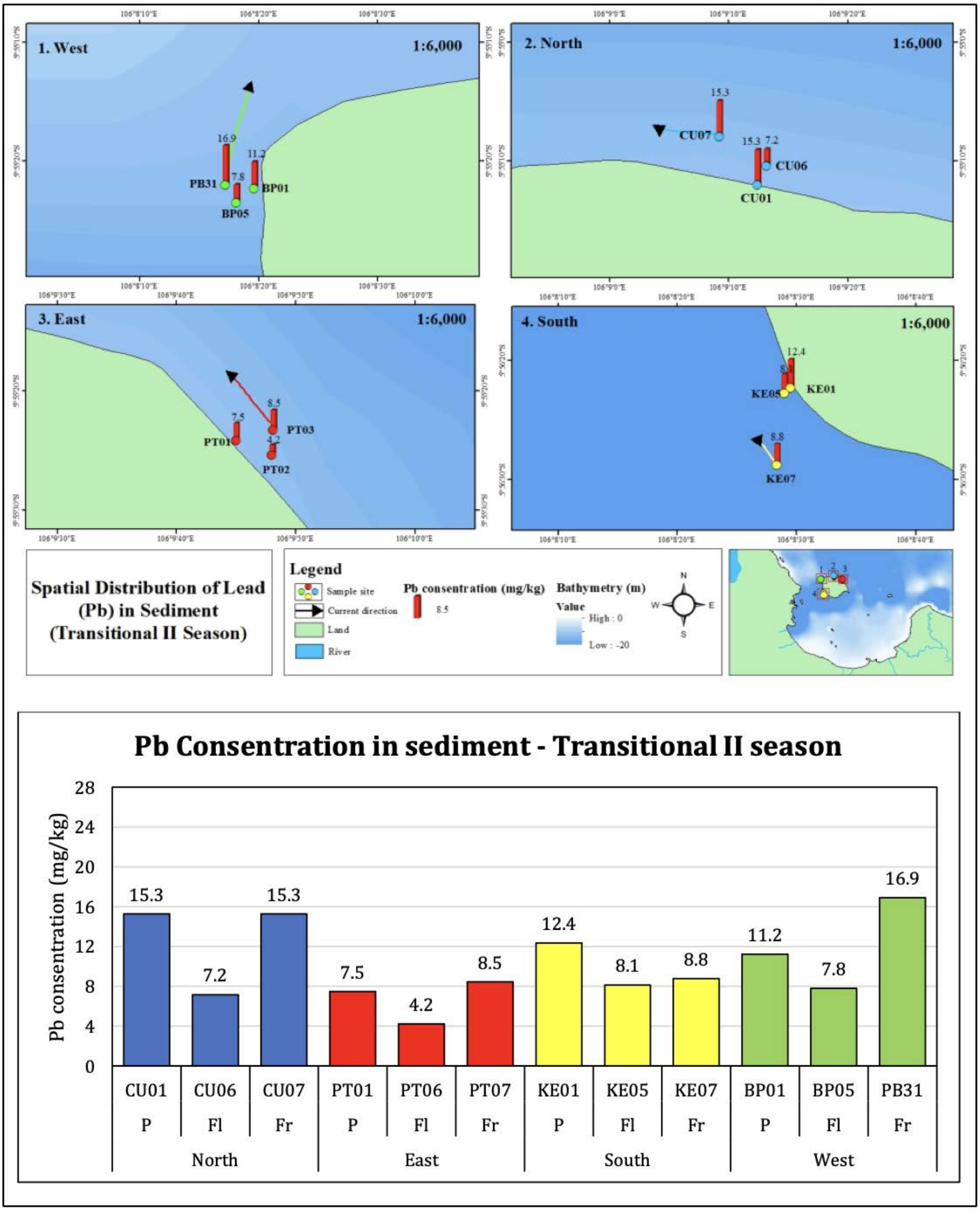

Figure 5. Top: Spatial distribution of Pb in sediment during transitional II season. Bottom: Pb consentration in sediment during transitional II season in all sampling site. P: Near of coastal areas. Fl: Reef flat. Fr: Reef front

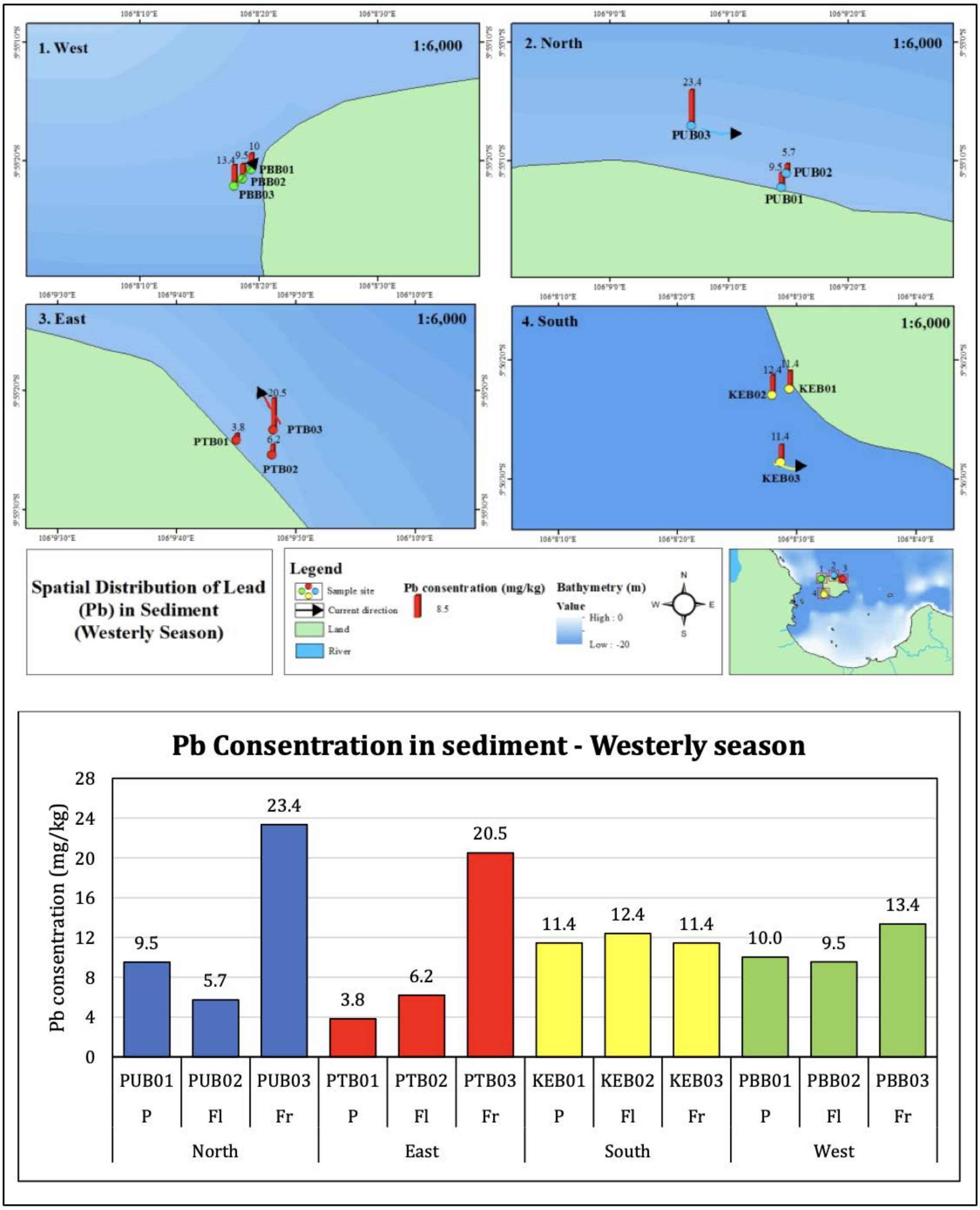

Figure 6. Top: Spatial distribution of Pb in sediment during westerly season. Bottom: Pb consentration in sediment during westerly season in all sampling site. P: Near of coastal areas. Fl: Reef flat. Fr: Reef front

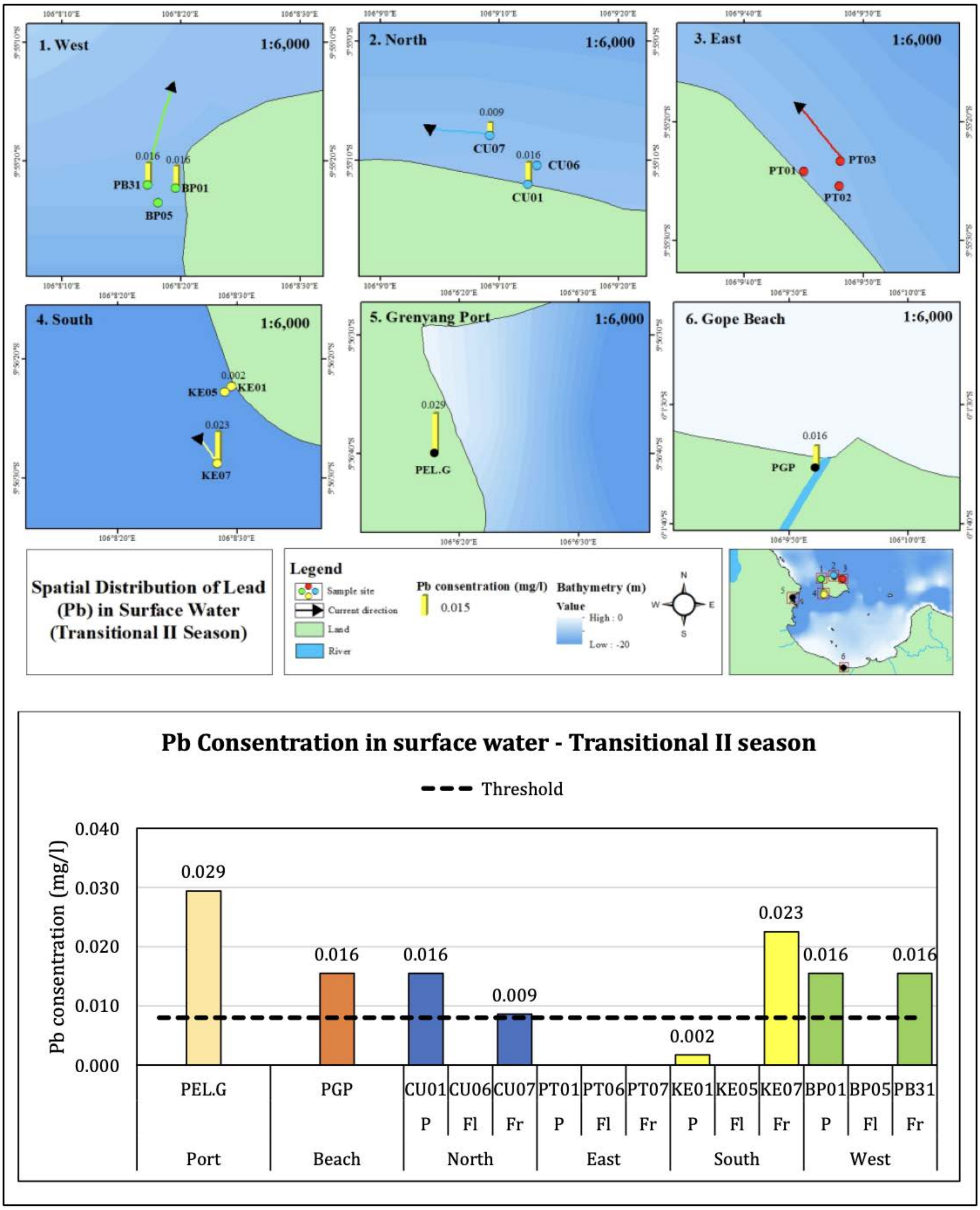

Figure 7. Top: Spatial distribution of Pb in surface water during transitional II season. Bottom: Pb in surface water consentration during transitional II season in all sampling site. P: Near of coastal areas. Fl: Reef flat. Fr: Reef front

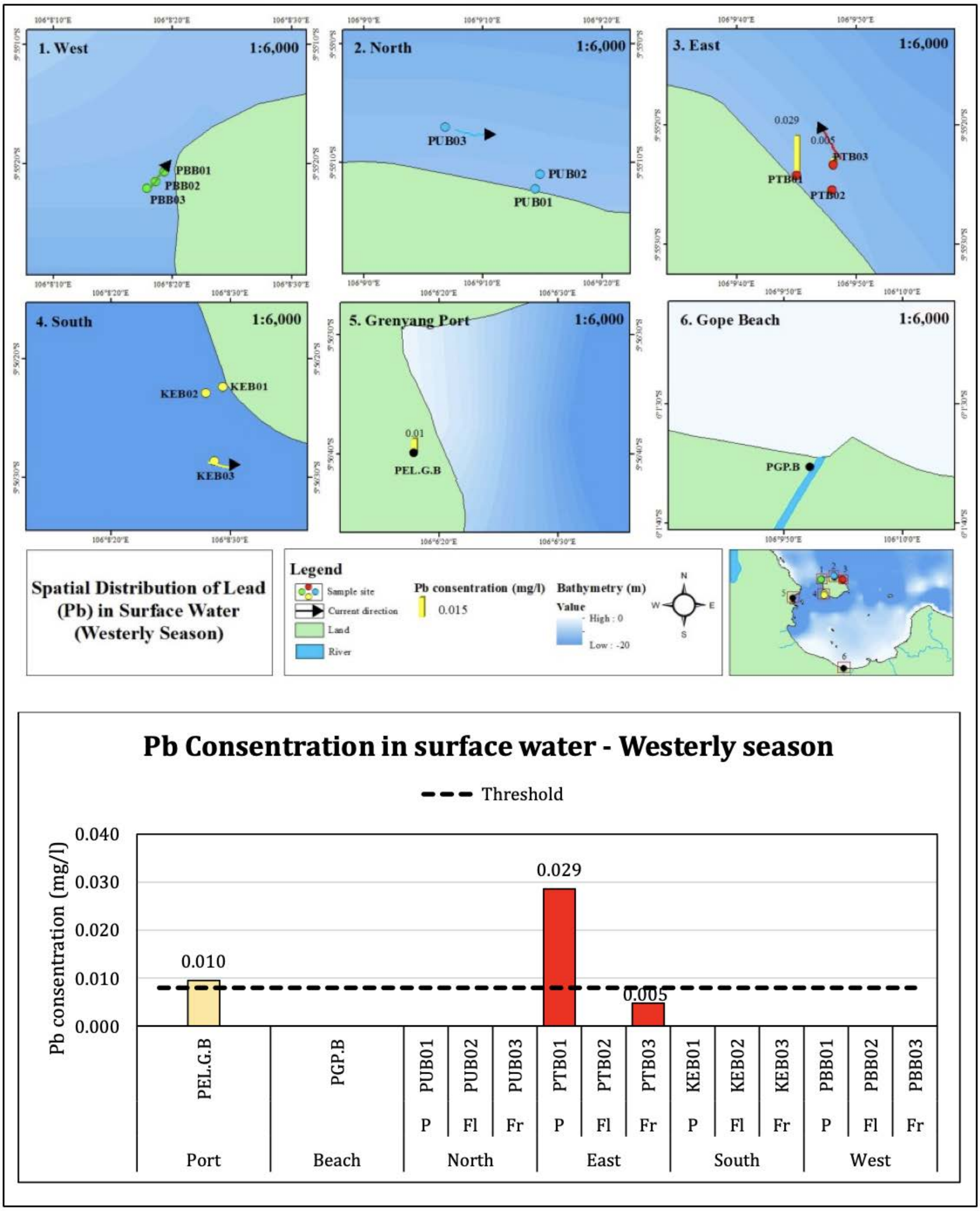

Figure 8. Top: Spatial distribution of Pb in surface water during westerly season. Bottom: Pb in surface water consentration during westerly season in all sampling site. P: Near of coastal areas. Fl: Reef flat. Fr: Reef front

IP Method

Based on the pollution index calculation results for the transitional II season, all measurement stations exhibited a condition of slightly polluted with IP scores ranging around 4 (Table 5). Meanwhile, during the westerly season, Gope Beach experienced a moderately polluted condition with an IP score of 6, while other stations remained in a slightly polluted condition with IP scores ranging from 3 to 4 (Table 5).

Table 5. IP Method on sample siteduring transitional II season and westerly season for water sample

Sample Site	Transitional II Season		Westerly Season	
	IP Score	Condition	IP Score	Condition
PEL.G	4.2	Slightly Polluted	3.6	Slightly Polluted
PGP	4.2	Slightly Polluted	6.2	Moderately Polluted
CU01/PUB01	4.3	Slightly Polluted	4.2	Slightly Polluted
CU06/PUB02			4.2	Slightly Polluted
CU07/PUB03	4.2	Slightly Polluted	4.3	Slightly Polluted
PT01/PTB01	4.4	Slightly Polluted	4.5	Slightly Polluted
PT06/PTB02			4.3	Slightly Polluted
PT07/PTB03	4.2	Slightly Polluted	4.1	Slightly Polluted
KE01/KEB01	4.1	Slightly Polluted	4.5	Slightly Polluted
KE05/KEB02			3.9	Slightly Polluted
KE07/KEB03	4.3	Slightly Polluted	3.8	Slightly Polluted
BP01/PBB01	4.3	Slightly Polluted	4.0	Slightly Polluted
BP05/PBB02			3.9	Slightly Polluted
PB31/PBB03	4.3	Slightly Polluted	4.3	Slightly Polluted

DISCUSSIONS

This study focuses on evaluating the concentration of Pb metal in both sediment and surface water and its implications for the coral reef ecosystem in the vicinity of Panjang Island, Banten. The laboratory results show that, in general, Pb metal concentrations in sediment are higher than those in surface water. This discrepancy can be attributed to the gradual accumulation of metals in sediment over time, possibly due to the binding of metals with hydroxides and organic matter within the sediment (Suryono, 2016). Sediments play a crucial role in aquatic ecosystems as the primary repository and origin of heavy metals (Peng *et al*., 2009). Metals in a dissolved state can find their way into water sources through various pathways and may gather in sediments through processes such as adsorption, precipitation or coprecipitation, and biological interactions. This leads to significantly higher concentrations of heavy metals in sediments, often exceeding those observed in the water above (by order of magnitude). Nevertheless, alterations in the environmental physicochemical conditions, such as changes in pH, redox potential (Eh), dissolved oxygen levels, can trigger the release of heavy metals stored in sediments back into the overlying water (Peng *et al*., 2009).

Despite the higher concentrations of Pb in the sediment, they remain below the established threshold values outlined in the sediment quality guidelines during both the transitional II and westerly seasons. In contrast, several surface water stations exceeded the water quality standards mandated by Government Regulation No. 22 of 2021 (Indonesian State Gazette, 2021). These findings suggest potential repercussions for the condition of coral reefs around Panjang Island, Banten, a conclusion further supported by this study's outcomes. Utilizing the Pollution Index (IP) method, we determined that the waters surrounding Panjang Island, Banten, experienced lightly polluted conditions during both the transitional II and westerly seasons (Table 5).

The geochemical processes governing the distribution of Pb metal in both sediment and the water column are complex and influenced by various factors. This study also aims to shed light on the possible influence of seawater quality parameters on the variability of Pb metal concentrations. This hypothesis is grounded in existing literature, which suggests that Pb metal concentrations in both sediment and water are generally associated with various seawater quality parameters, including temperature, salinity, pH, and dissolved oxygen (Fauziah *et al*., 2012; Rompas, 2010; Effendi, 2003; Putri *et al*., 2014). However, it's essential to acknowledge that the limited dataset in this study may not provide definitive evidence for the relationships between Pb metal and these seawater quality parameters, as described in existing literature. Some of these relationships are as follows: temperature can affect the solubility of substances in water. In general, as temperature increases, the solubility of most substances, including Pb compounds, tend to increase. This can result in higher concentrations of dissolved Pb in the water. Higher temperatures can increase metal concentrations in the water column, while lower temperatures promote metal accumulation in sediments (Fauziah *et al*., 2012). Changes in salinity can impact the solubility and speciation of Pb. Increasing salinity can reduce the solubility of Pb compounds, leading to decreased concentrations of dissolved Pb in the water column. Reduced salinity levels can lead to higher Pb accumulation in aquatic environments (Rompas, 2010). pH influences the speciation of Pb in water. At lower pH values, lead is more soluble and can remain in the water column. At higher pH, it maybe precipitated or adsorbed onto sediment which result in elevated pH levels that typically correspond to a decreased heavy metal concentrations in water bodies (Effendi, 2003). Dissolved oxygen is a key factor in determining the redox conditions of the water column and sediment. In oxygen-rich (aerobic) conditions, Pb is more likely to form insoluble precipitation, reducing its mobility. Conversely, in oxygen-depleted (anaerobic) conditions, Pb may be more soluble and mobile. Low dissolved oxygen levels can result in increased heavy metal accumulation in sediments (Putri *et al*., 2014).

Furthermore, our study reveals distinctions in the distribution of Pb metal concentrations within sediment and surface water. These variations are prominently evident across different locations, including the coastal areas, reef flats, and reef fronts surrounding Panjang Island's waters in the western, northern, eastern, and southern regions. The observed difference can be explained by the main source of Pb metal, which primarily comes from Banten rather than Panjang Island. As a result, there is a higher accumulation of metals in the reef front, as it serves as the initial point of contact for pollutants originating from Banten. Additionally, there are indications that human activities, particularly shipping operations on Panjang Island, contribute to elevated Pb metal concentrations in the coastal areas.

An intriguing observation from both seasons is that during the transitional II season, Pb in surface water was undetectable in the eastern region, while during the westerly season, only the eastern region exhibited detectable levels of the heavy metal Pb. These findings align with the patterns observed in sediment. During the transitional II season, the predominant ocean current movement is westward, suggesting the likely accumulation of Pb metal in the western waters of Panjang Island, Banten. Conversely, during the westerly season, Pb metal accumulates in the eastern waters of Panjang Island, Banten, due to the dominance of eastward-moving ocean currents. Additionally, the waters around Panjang Island intersect with several river estuaries, such as Cibanten, Cibeureun, Cengkok, and Ciruas (Juniardi *et al*., 2021). These estuaries may contribute to human activities on the mainland that elevate Pb metal concentrations in Panjang Island's waters. Moreover, rainfall patterns can influence Pb metal concentrations in surface water (Rochyatun *et al*., 2006). Rainfall during the night before data collection can lead to undetectable Pb metal concentrations during the westerly season. According to Darmono (1995), the metal content in water varies based on environmental and climatic conditions. During the rainy season, metal content tends to be lower due to dilution processes, while during the dry season, metal content tends to be higher as metals become more concentrated.

Gope Beach was selected to represent potential pollutant sources originating from river inflow into the Banten Bay region, while Grenyang Port was chosen to detect potential sources of pollution arising from shipping activities. The measurement data indicate indications of Pb metal originating from both shipping activities and the mainland during both seasons. Pb metal was detected at Grenyang Port, and during the transitional II season, it was found at Gope Beach. Examination of the conditions at Gope Beach also reveals that Pb metal can originate from human activities on the mainland, corroborating the findings of Juniardi et al. (2021). When comparing Grenyang Port and Gope Beach, it is evident that Pb metal concentrations are higher at Grenyang Port. This is attributed to Grenyang Port's location in the Bojonegara industrial area, where numerous shipping activities occur, resulting in a higher likelihood of elevated Pb metal concentrations (Falah *et al*., 2020). This assertion is further supported by Liyubayina (2018), who reported the existence of 44 types of industrial activities in Bojonegara Regency, some of which are situated in coastal areas. One of the significant waste products generated by port and industrial activities, such as the use of ship lubricants, is heavy metal waste, which has the potential to be an environmental pollutant.

CONCLUSIONS

The study on Pb metal content in the coral reef environment of Panjang Island waters, Banten, has yielded several key findings:

(1) In sediment samples, Pb concentrations during the transitional II season ranged from 4.2 to 16.9 mg/kg, while in the westerly season, they varied from 3.8 to 23.4 mg/kg. For surface water samples, Pb concentrations during the transitional II season ranged from 0 to 0.029 mg/l, and in the westerly season, they also spanned from 0 to 0.029 mg/l. According to the pollution index method, the overall state of Panjang Island waters in Banten can be classified as lightly polluted during both the transitional II and westerly seasons.

(2) The spatial distribution of Pb concentrations exhibited fluctuations during both seasons (transitional II and westerly). Some areas had elevated Pb concentrations near the coast, while others showed higher concentrations at the reef front. Generally, Pb concentrations in the reef flat area were lower in comparison to the reef front and nearshore regions. This pattern is primarily attributed to the main Pb source in Panjang Island waters, which originates from the mainland. This allows Pb to accumulate on the reef front, as it serves as the initial point of contact for Pb arriving from the mainland. When higher concentrations are detected near the coast, it may indicate human activities on Panjang Island are contributing to heightened Pb levels in coastal areas.

(3) Ocean current movements provide valuable insights into the distribution of Pb concentrations in Panjang Island waters, Banten. During the transitional II season, Pb concentrations in sediment and surface water tended to be higher in the western part of Panjang Island waters, suggesting that pollution originates from river inflows in Banten Bay (eastern part of Panjang Island, Banten). Conversely, in the westerly season, Pb concentrations tended to be higher in the eastern part of Panjang Island waters, indicating a pollution source from the Bojonegara industrial area (western part of Panjang Island, Banten).

These findings provide valuable insights into the distribution of Pb metal in the waters surrounding Panjang Island and its potential environmental impact. They serve as a foundational basis for further research and management strategies aimed at preserving the health and sustainability of the coral reef environment around Panjang Island.

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