STUDY OF HEAVY METAL LEAD (PB) IN THE NORTHERN WATERS OF BELITUNG REGENCY

STUDI KANDUNGAN LOGAM BERAT TIMBAL (PB) DI PERAIRAN UTARA KABUPATEN BELITUNG

Salsabila Fathona[1*], Rima Rachmayani[1], Ayu Utami Nurhidayati[2], Dwi Amanda Utami[2]

[1] Oceanography Study Program, Institut Teknologi Bandung
[2] Research Center for Climate and Atmosphere, Paleoclimate and Paleoenvironment Research Group, National Research and Innovation Agency Republic of Indonesia

*Corresponding author: salsabilaafath@students.itb.ac.id

(Received 11 November 2023; in revised from 1 December 2023 accepted 14 April 2025)

DOI : 10.32693/bomg.40.1.2025.860

ABSTRACT: Belitung Regency has significant tin potential, spread across the land, rivers, and beaches which have been mined for hundreds of years. However, tin mining activities are indicated to be a source of pollution in the northern region of Belitung Regency. This study aims to determine the distribution of the lead (Pb) concentrations in sediments and water columns in the northern waters of Belitung Regency and to evaluate the seasonal effect, particularly ocean currents, on the distribution patterns. In situ data were collected during the westerly season, including sediment samples, water column samples, and oceanographic parameters such as seawater quality and current measurements. During the easterly season, only sediment samples were obtained. Pb concentrations in sediments and water samples were analyzed at the National Research and Innovation Agency (BRIN) laboratory using the Atomic Absorption Spectrophotometry (AAS) method. The results showed that Pb concentrations in sediment samples ranged from 10.08 to 50.08 mg/kg during the easterly season, and from 10.96 to 60.72 mg/kg during the westerly season. In the water column, Pb concentrations ranged from 0 to 0.05 mg/L during the westerly season. The distribution pattern of Pb in sediments in the easterly season tended to spread offshore, while in the westerly season it is accumulated in the river. These patterns are influenced by seasonal flow variations, geographical location, and sediment grain size. Pb concentrations in sediments are higher in the westerly season compared to the easterly season. This is likely due to increased erosion and surface runoff during the rainy season, which leads to greater deposition of heavy metals in marine sediments.

Keywords: AAS, Belitung Regency, Lead (Pb), ocean currents, sediment, water column

***ABSTRAK**: Wilayah Kabupaten Belitung memiliki potensi timah cukup besar yang tersebar di darat, sungai dan pantai yang telah ditambang sejak ratusan tahun lalu. Namun aktivitas pertambangan timah tersebut diindikasikan menjadi sumber pencemar wilayah utara Kabupaten Belitung. Tujuan dari penelitian ini yaitu mengetahui sebaran konsentrasi logam timbal (Pb) dalam sedimen dan kolom air di perairan utara Kabupaten Belitung, serta mengetahui pengaruh musim, terutama arus laut terhadap sebaran konsentrasi Pb. Pengambilan data dilakukan secara insitu, data yang ambil berupa sampel sedimen, sampel kolom air, dan parameter oseanografi seperti kualitas air dan arus laut, pada musim barat dan sampel sedimen pada musim timur. Konsentrasi Pb dalam sedimen dan kolom air dianalisis di laboratorium Badan Riset dan Inovasi Nasional (BRIN) menggunakan metode Atomic Absorption Spectrophotometry (AAS). Hasil penelitian menunjukkan konsentrasi Pb di sampel sedimen pada musim timur sebesar 10,08 – 50,08 mg/kg sedangkan pada musim barat sebesar 10,96 – 60,72 mg/kg. Pola sebaran kandungan*

Pb dalam sedimen pada musim timur cenderung menyebar ke arah lepas pantai, sedangkan pada musim barat terakumulasi di sungai. Hal ini dipengaruhi oleh pola aliran musiman yang berbeda, letak geografis, dan ukuran butir sedimen (jenis sedimen). Pada musim barat, konsentrasi Pb dalam sedimen lebih tinggi dibandingkan dengan musim timur. Hal ini disebabkan karena pada musim hujan banyak terjadi erosi dan masuknya limpasan air ke badan air, sehingga lebih banyak logam berat yang terendapkan dalam sedimen.

Kata Kunci: *AAS**,** Kabupaten Belitung, Timbal (Pb), arus laut, sedimen, kolom air*

INTRODUCTION

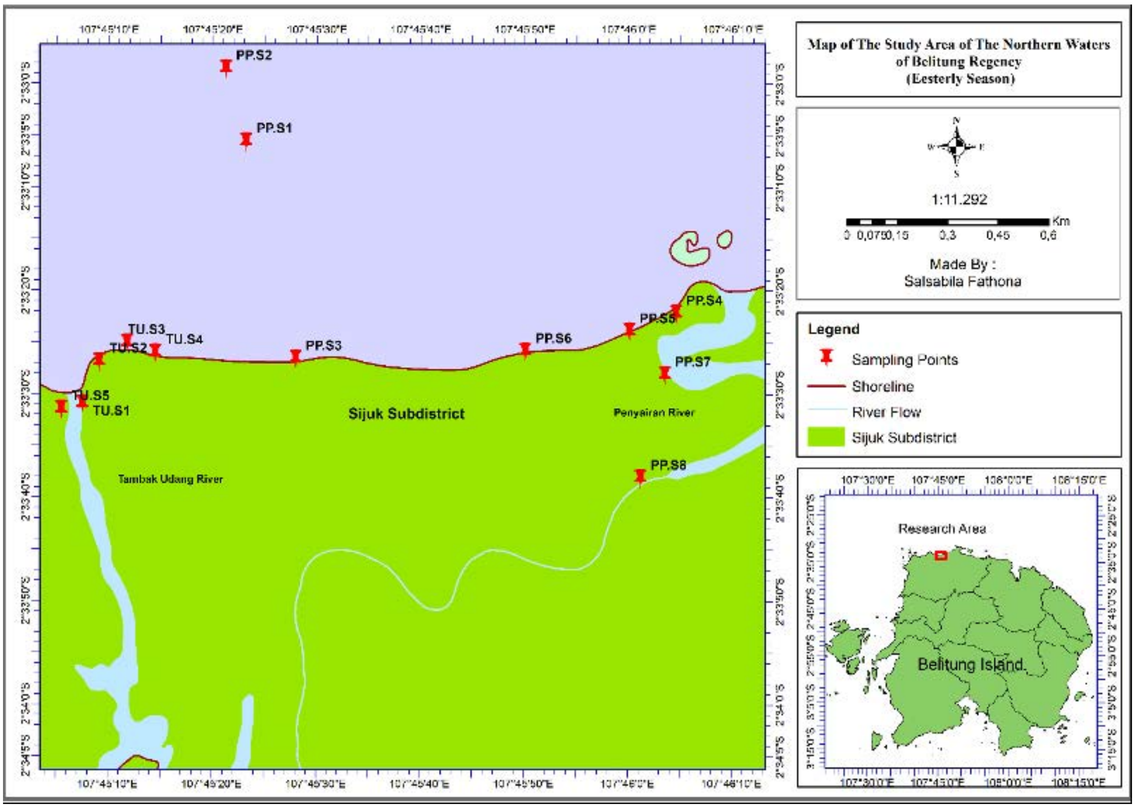
Heavy metals are classified as inorganic metal chemicals with a specific gravity of more than 5 gr/cm³. They exhibit toxic properties when introduced into water bodies in amounts exceeding certain thresholds. The presence of heavy metals poses significant environmental and health risks due to their toxicity, which can adversely affect humans, animals, and plants (Tchounwou et al., 2012). Heavy metals in nature exhibit several distinct properties or characteristics, such as persistence, difficulty to degrade, accumulation in ecosystems, and long half-lives. Among these, mercury (Hg), lead (Pb), and bismuth (Bi) are particularly notable for having the highest levels of these characteristics. These metals are highly persistent, resistant to degradation, prone to bioaccumulation, and possess exceptionally long half-lives compared to other heavy metals (Duffus, 2002). These properties make them particularly hazardous to both environmental and human health, as they can remain in ecosystems for extended periods and accumulate in living organisms, leading to toxic effects over time. Heavy metals in nature can come from two main sources, which are natural and anthropogenic sources. Heavy metals that come from natural sources come from rock weathering, the deposition of particles in the atmosphere, and the lava emitted by volcanoes during an eruption. Meanwhile, anthropogenic sources come from human activity waste such as residential and industrial waste, as well as mining, agricultural, and other waste activities (Demirak et al., 2006; Ghrefat and Yusuf, 2006; Khaled et al., 2006; Singh et al., 2006).

The Bangka Belitung Islands Province (Babel) is known as the only tin-producing region in Indonesia. Tin mining activities inevitably generate waste in the form of tailings containing high concentrations of lead (Pb) (Herman, 2006). These tailings are often not managed properly, allowing them to disperse into aquatic environments through surface runoff, infiltration into the soil, or transport by river flows to the sea. Mining activities can also expose heavy metal content previously trapped in geological formations, thereby increasing the release of Pb into aquatic ecosystems, including rivers surrounding tin mining sites. Additionally, dredging and washing of tin ore can accelerate the mobility of Pb in water and sediments, increasing the risk of bioaccumulation in aquatic organisms and the entry of this heavy metal into the food chain (Shazili et al., 2006). Rivers contaminated with Pb will flow into the sea, continuing the hydrological cycle by carrying dissolved chemical elements that can accumulate in aquatic environments (Soegianto, 2019). This accumulation can lead to coastal pollution, potentially damaging marine ecosystems and causing toxic effects on marine biota. In the long term, Pb contamination not only impacts the health of aquatic organisms but also poses a threat to human health through the consumption of contaminated seafood (Guo et al., 2020).

The main problems associated with heavy metals are toxicity, bioaccumulation, and biomagnification, which cause significant effects on ecosystems, human health, and other living organisms. Therefore, it is very important to know the distribution of heavy metal contamination to interpret the mechanisms of accumulation and transportation of heavy metals into the aquatic environment influenced by oceanographic factors and obtain the necessary information for monitoring, maintenance, and utilization of coastal management areas (DeForest et al., 2007; Demirak et al., 2006; Naser, 2013; Ozkan and Buyukisik, 2012; Wang and Rainbow, 2008). This research aims to determine the concentration of heavy metal lead (Pb) in sediment and water samples so that the distribution pattern can be known, which is influenced by oceanographic phenomena in the northern waters of Belitung Regency.

METHODS

The research area is located in the northern waters of Belitung Regency, Bangka Belitung Province, with three areas as the focus of research: the coastal area, estuary, and offshore (Figure 1). Sediment sampling was conducted at 13 stations



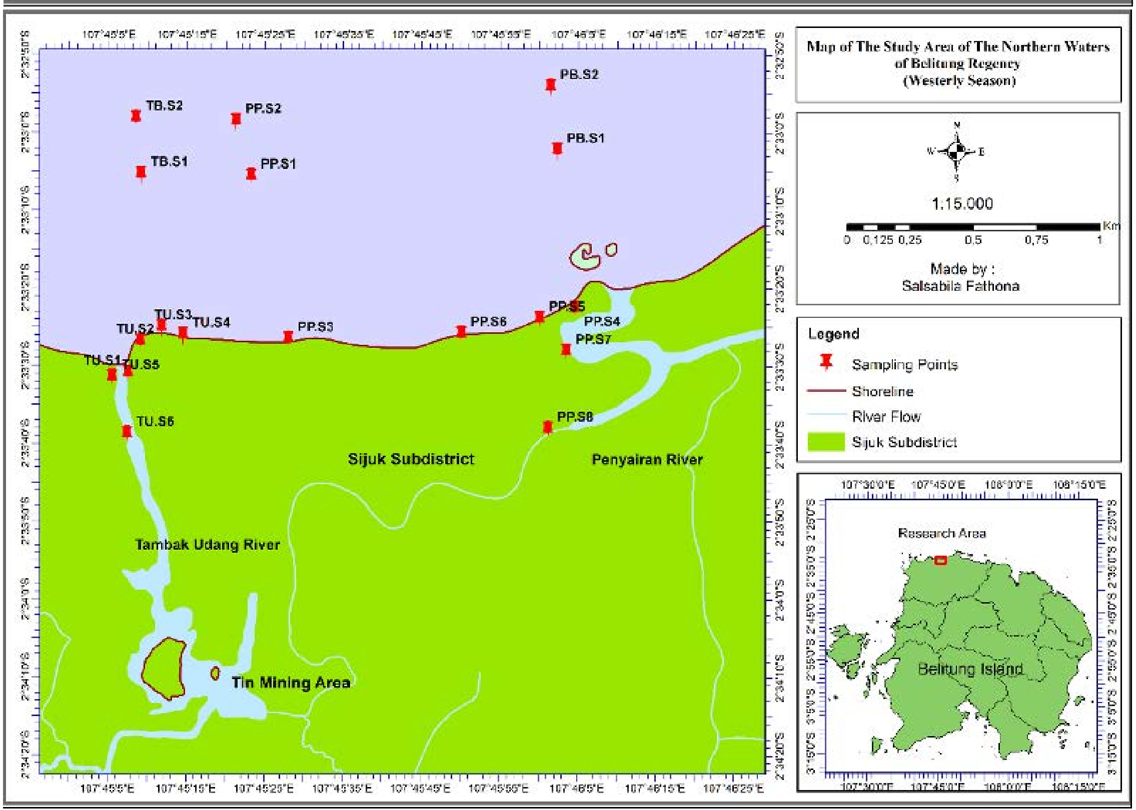


Figure 1. Sampling site location during easterly season (a) and during westerly season (b)

Table 1. Sample site during easterly season

No.	Sample Site	Description of Sample Site
1.	TU.S1	Tambak Udang estuary
2.	TU.S2	Tambak Udang estuary
3.	TU.S3	Penyairan beach close to Tambak Udang estuary
4.	TU.S4	Penyairan beach close to Tambak Udang estuary
5.	TU.S5	Tambak Udang estuary
6.	PP.S1	Offshore, north of Penyarian Beach
7.	PP.S2	Offshore, north of Penyarian Beach
8.	PP.S3	Penyairan beach
9.	PP.S4	Penyairan beach close to Penyairan estuary
10.	PP.S5	Penyairan beach close to Penyairan estuary
11.	PP.S6	Penyairan beach
12.	PP.S7	Penyairan estuary
13.	PP.S8	Penyairan estuary

Table 2. Sample site during westerly season

No.	Sample Site	Description of Sample Site
1.	TU.S1	Tambak Udang Estuary
2.	TU.S2	Tambak Udang Estuary
3.	TU.S3	Penyarian beach (near to the Tambak Udang estuary)
4.	TU.S4	Penyarian beach (near to the Tambak Udang estuary)
5.	TU.S5	Tambak Udang Estuary
6.	TU.S6	Tambak Udang Estuary
7.	PP.S1	Offshore, north of Penyarian Beach
8.	PP.S2	Offshore, north of Penyarian Beach
9.	PP.S3	Penyairan beach
10.	PP.S4	Penyarian beach (near to the Penyairan estuary)
11.	PP.S5	Penyarian beach (near to the Penyairan estuary)
12.	PP.S6	Penyairan beach
13.	PP.S7	Penyairan estuary
14.	PP.S8	Penyairan estuary
15.	PB.S1	Offshore, north of Penyarian Beach
16.	PB.S2	Offshore, north of Penyarian Beach
17.	TB.S1	Offshore, north of Penyarian Beach
18.	TB.S2	Offshore, north of Penyarian Beach

(Table 1) in the easterly season (August 2022), and sediment and water sampling was conducted at 18 stations (Table 2) in the westerly season (December 2022).

The research employs two main types of data which is primary and secondary data. Primary data, collected in August 2022 (easterly season) and December 2022 (westerly season), comprises field data from sediment samples, water samples, and oceanographic parameters. The data from the easterly season was collected by the research team from the National Research and Innovation Agency (BRIN) in August 2022. Primary data in the easterly season is sediment data which collected in-situ, and secondary data in the easterly season is current data. The data, including coastal sediments, offshore sediments, and estuary from two rivers, the Penyairan River and Tambak Udang River, were then processed and analyzed *ex-situ* at the Engineering Geology and Chemistry Laboratory at (BRIN).

The data from the westerly season were collected on December 20 and 21, 2022. The data collected from the westerly season is in-situ, such as sediment samples and water column samples, water chemistry-physical parameter data, and current data. Furthermore, the sediment sample and water column samples were processed and analyzed ex-situ at the Engineering Geology and Chemistry Laboratory at (BRIN). Data on the chemical and physical parameters of the waters were taken using the Horiba U-50 Multiparameter Water Quality Checker. The secondary data used in this study is current data that was downloaded from the website https://www.hycom.org/.

Sediment samples on the coast were collected from the bottom layer by using equipment. The boat was occupied to take the samples from Tambak Udang River, Penyairan River, and offshore by a grab sampler. Water sampling was collected by following the methods from (APHA, 2017) and Sutrisyani (2016). Water sampling was carried out using a polyethylene sample bottle with a volume of 500 mL, which had previously been cleaned with tap water and rinsed with ambient seawater. Water samples obtained were then preserved with concentrated HNO_3 with a pH < 2.

In the laboratory, sediment samples were dried, sieved, sub-sampled, and destructed to enable elemental analysis using atomic absorption spectrophotometry (AAS). Surface water samples were processed similarly, with the addition of dilution and filtration steps. 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 (Habibi, 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. AAS analysis followed the calibration curve quantification method using Certipur® lead (Pb) standard solutions of varying concentrations, such as 0.08, 0.06, 0.04, 0.02, 0.1, and 0.5 ppm. After obtaining the value of Pb concentration in sediment samples from the calibration curve, calculations were then carried out to obtain the concentration of Pb in dry samples. The calculation of Pb in dry samples used the following equation.

$$Concentration\ of\ Pb\ \left(\frac{mg}{kg}\right) = \frac{X\left(\frac{mg}{l}\right) \times V(l)}{M(kg)}$$

Where:
X : Pb concentration in sample solution (*mg/l*)
V : Volume of sample solution (*l*)
M : Sample weight (*kg*)

The concentration of lead (Pb) and data on the physical and chemical parameters of the waters were analyzed descriptively. Data obtained from the measurement of physical and chemical parameters of seawater and lead metal concentration data obtained from water column samples were compared with the quality standards of seawater and river water based on the Government Regulation of the Republic of Indonesia as (Indonesian State Gazette, 2021) Data on the concentration of lead (Pb) refers to the Sediment Quality Guideline (ANZECC & ARMCANZ). Furthermore, the lead (Pb) concentration data obtained from sediment and water column samples is compared between the two, as well as the easterly and westerly season sample data, which will be compared to determine which one has more concentration. The results of this comparison are then used to draw conclusions about the qualitative conditions in the northern waters of Belitung Regency.

RESULTS

Condition of the ocean current

The seawater current data in this study were sourced from the Hybrid Coordinate Ocean Model (HYCOM) for August and December 2022, representing the easterly and westerly seasons, respectively. Seasonal patterns strongly influence the seawater currents in the northwestern waters of Belitung Regency. The Quiver plot and current rose diagram (Figure 2) illustrate that during the easterly season (August), surface currents predominantly flow westward and northwestward at speeds ranging from 0.07 to 0.2 m/s. The westerly season, occurring from December to February, is characterized by winds blowing from the west, as depicted in the Quiver plot and the current rose diagram (Figure 3). During this period (December), currents primarily move eastward to southeastward with varying speeds. The daily variability of seawater current speeds ranges from 0.08 to 0.45 m/s.

The concentration of lead (Pb) in sediment and water

This study assessed Pb concentrations in sediment and water samples (Table 3). Laboratory analysis revealed that during both the easterly and westerly seasons, Pb concentrations in sediments generally remained below the threshold established by the ANZECC and ARMCANZ-based Sediment Quality Guidelines (SQG) (Table 4). During the Easterly season, the highest recorded Pb concentration in sediments was 50.09 mg/kg dry weight, with an average of 17.75 mg/kg dry weight. In the westerly season, concentrations peaked at 60.74 mg/kg dry weight, with an average of 27.32 mg/kg dry weight. In contrast, Pb concentrations in water samples from various stations during the westerly season exceeded the water quality standard set by the Minister of Environment and Forestry Regulation No. 22 of 2021. As shown in Table 5, Pb concentrations in river water reached a maximum of 0.057 mg/L, averaging 0.026 mg/L, while seawater concentrations peaked at 0.048 mg/L, with an average of 0.027 mg/L.

During the easterly season (Figure 4), Pb concentrations in the open sea reached 19.02 mg/kg dry weight, exceeding those in coastal areas, which ranged from 10.08 mg/kg to 50.09 mg/kg dry weight. In river areas, Pb concentrations varied between 10.75 mg/kg and 20.49 mg/kg dry weight. In contrast, during the westerly season (Figure 5), Pb concentrations in river sediments near the mainland were significantly higher, with levels reaching 60.74 mg/kg dry weight in the Tambak Udang River and 56.21 mg/kg dry weight in the Penyairan River. Coastal and offshore areas exhibited lower concentrations, ranging from 10.96 mg/kg to 34.15 mg/kg dry weight. Overall, Pb concentrations in sediments were consistently higher during the westerly season compared to the easterly season (Figure 6).

Laboratory test results revealed that Pb concentrations in the water column during the westerly season were detected at nearly all stations (16 out of 18), except for TU.S1 (Tambak Udang River) and TU.S3 (coastal), where Pb was undetectable. According to PP No. 22 of 2021, the threshold for Pb in seawater supporting marine biota is 0.008 mg/L, while for river water across all classes, it is 0.03 mg/L. Pb concentrations in seawater exceeded regulatory limits at 10 out of 11 stations (Figure 7). Spatial variations were observed, with one out of 11 stations showing no Pb detection. Similarly, in river water, one station exhibited undetectable Pb levels. Overall, Pb concentrations in sediment were consistently higher than those in the water column (Figure 8).

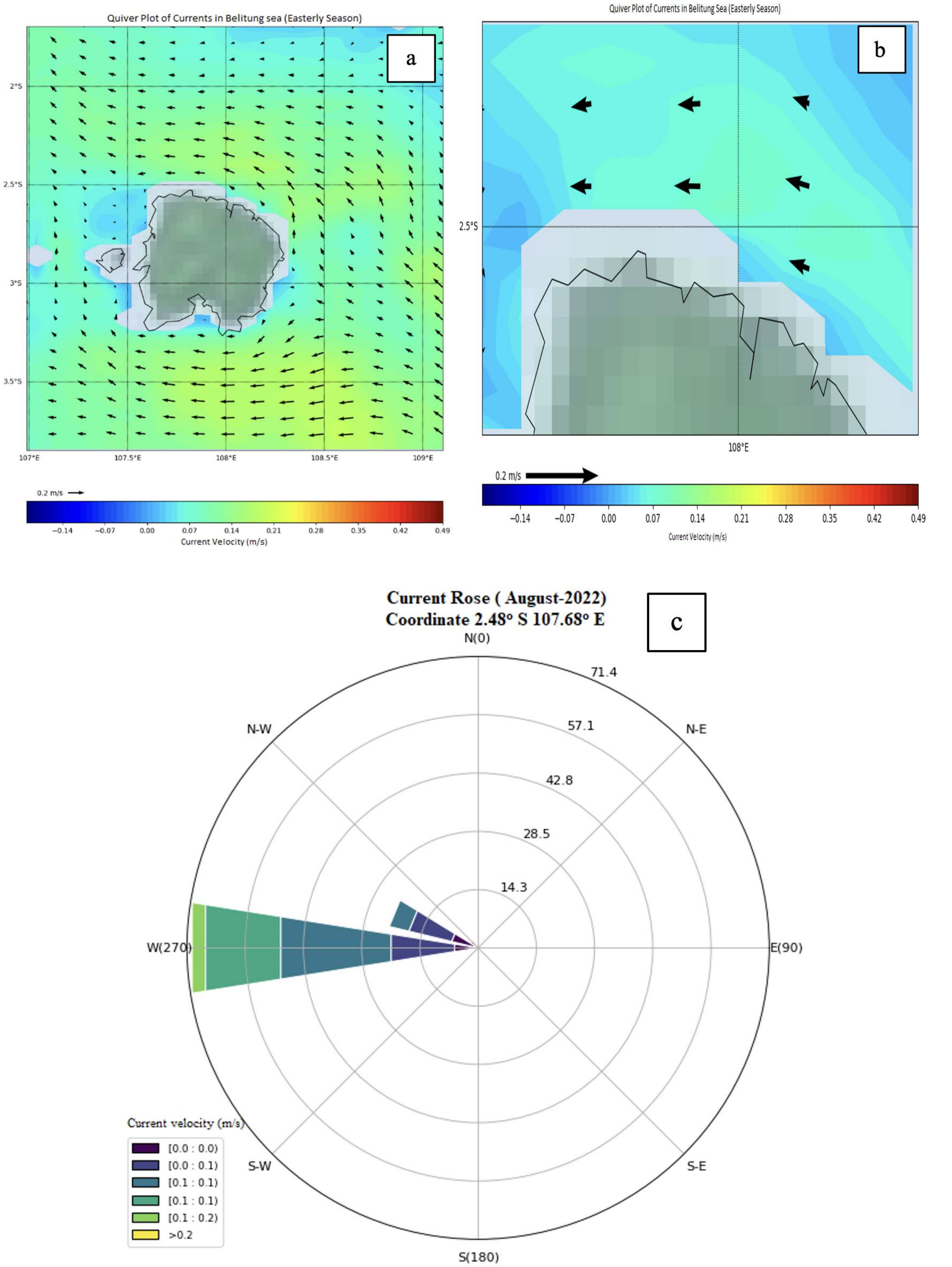


Figure 2. Ocean current at Belitung Island (easterly season) (a), ocean current in Northern of Belitung Regency (easterly season) (b), taken from HYCOM and ocean current rose at Belitung Island (August 2022) (c)

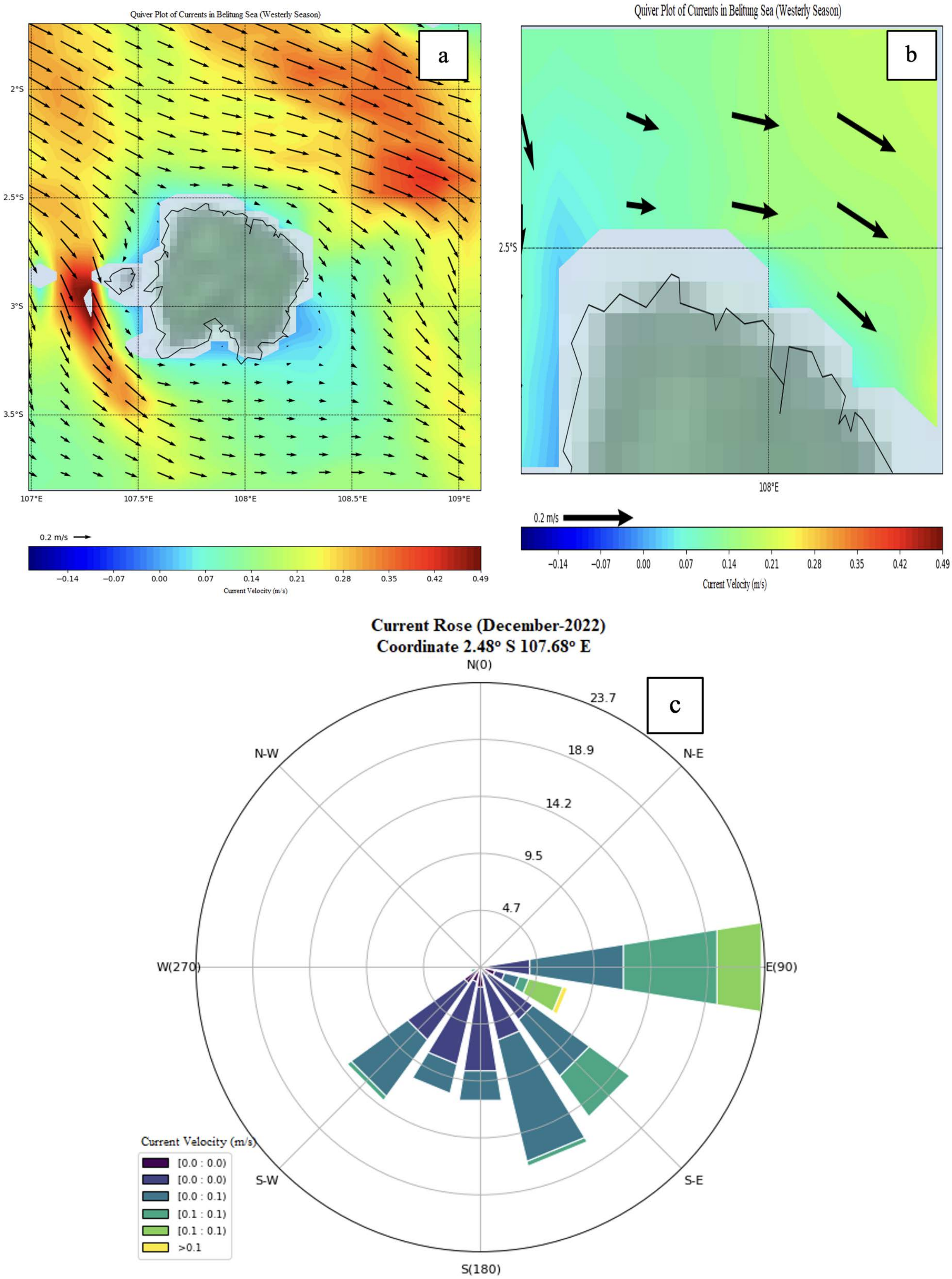


Figure 3. Ocean current at Belitung Island (westerly season) (a), ocean current in Northern of Belitung Regency (westerly season) (b), taken from HYCOM and ocean current rose at Belitung Island (August 2022) (c)

Table 3. The concentration of lead (Pb) in sediment and water during the easterly and westerly seasons.

Sample Site	**Easterly Season** Concentration of lead (sediment) (mg/kg)	**Westerly Season** Concentration of lead (sediment) (mg/kg)	Concentration of lead (river water) (mg/L)	Concentration of lead (seawater) (mg/L)
TU.S1	14.31	16.05	Nd	-
TU.S2	11.06	10.96	0.005	-
TU.S3	18.86	24.53	-	Nd
TU.S4	10.73	20.57	-	0.028
TU.S5	14.31	13.78	0.04	-
TU.S6	-	60.74	0.025	-
PP.S1	20.82	30.18	-	0.037
PP.S2	50.09	18.31	-	0.025
PP.S3	10.08	23.4	-	0.019
PP.S4	10.73	28.49	0.03	-
PP.S5	19.02	21.13	-	0.025
PP.S6	14.31	29.62	-	0.028
PP.S7	15.93	37.54	0.057	-
PP.S8	20.49	56.21	0.025	-
PB.S1	-	34.15	-	0.045
PB.S2	-	21.14	-	0.028
TB.S1	-	10.96	-	0.022
TB.S2	-	34.15	-	0.048

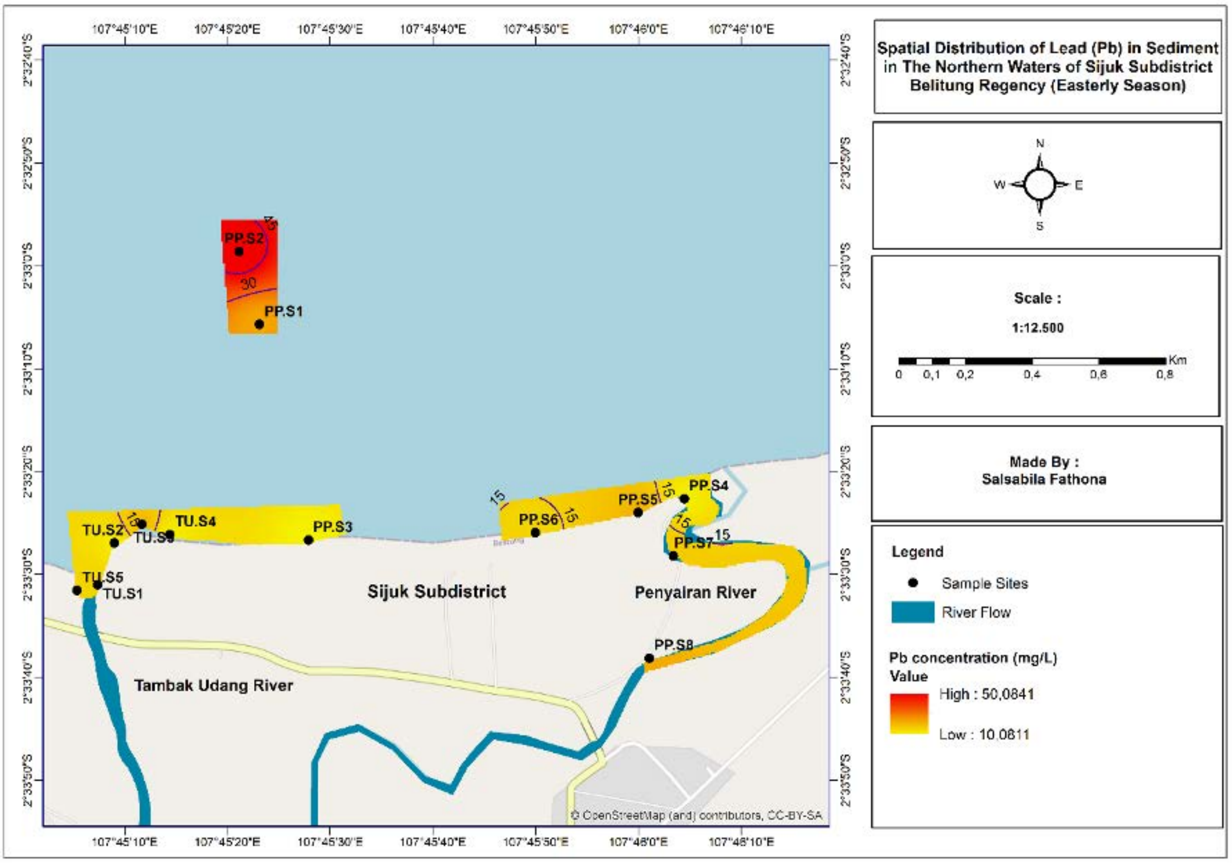
Nd: Not detected.

Table 4. Statistics descriptive of the concentration of lead (Pb) in the sediment during easterly and westerly seasons

	Easterly Season	**Westerly Season**
Maximum	50.09	60.74
Minimum	10.08	10.96
Average	17.75	27.32
Sediment Quality Guideline		
ANZECC/ARMCANZ Guidelines		50

Table 5. Statistics descriptive of Pb the concentration in the sediment on westerly season

	River Water	Seawater
Maximum	0.057	0.048
Minimum	Nd	Nd
Average	0.026	0.027
PP No. 22 of 2021	0.008	0.03



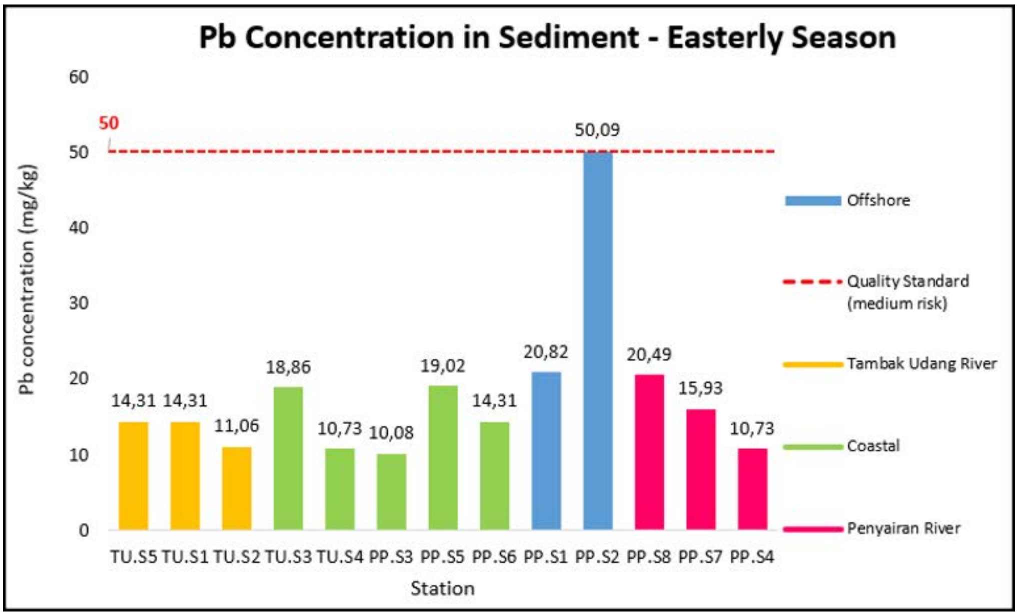


Figure 4. Spatial distribution of lead (Pb) in sediment during the easterly season (a), Lead (Pb) concentration in sediment during the easterly season at all sampling sites (b).

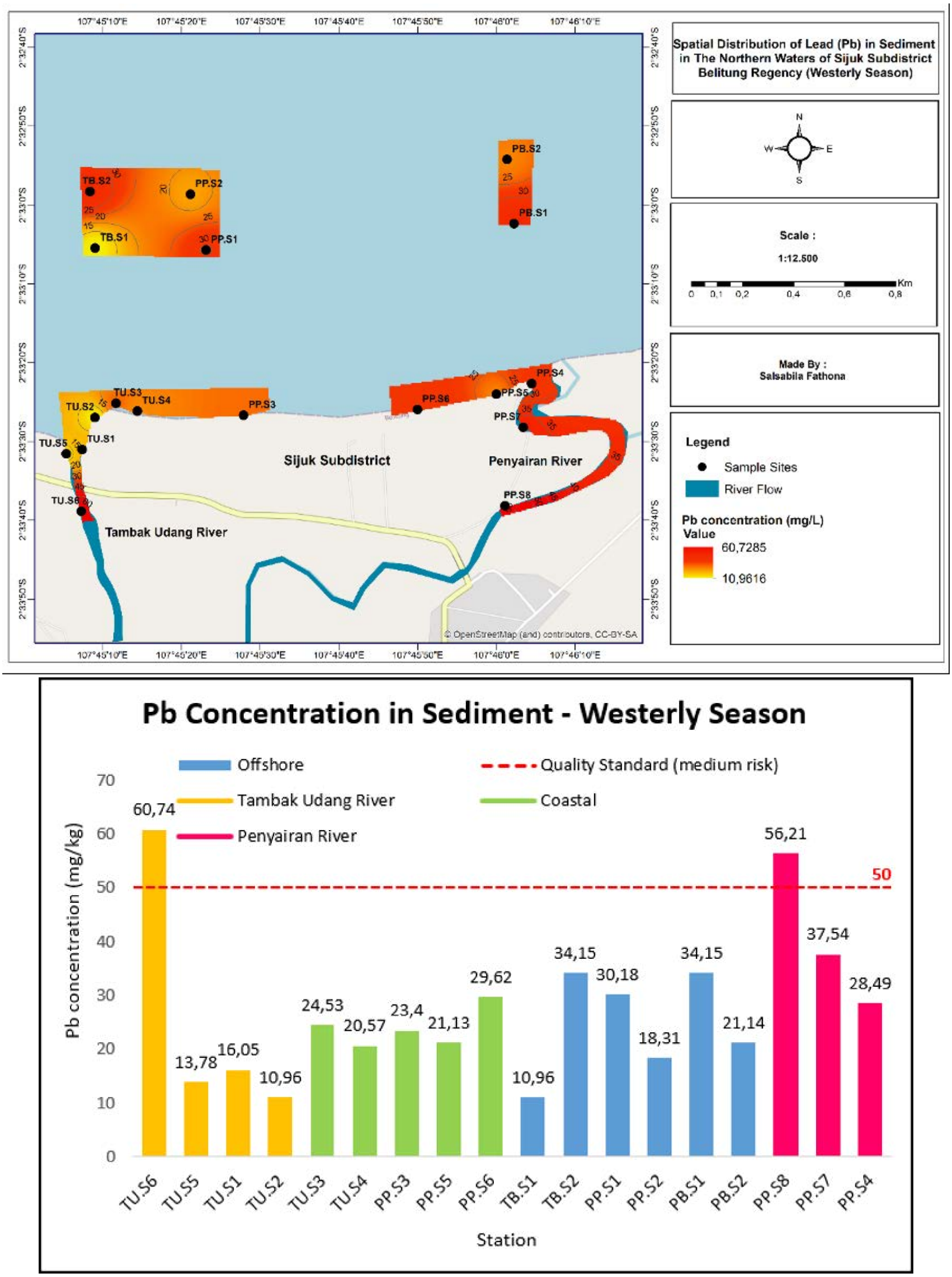


Figure 5. Spatial distribution of lead (Pb) in sediment during the westerly season (a), Lead (Pb) concentration in sediment during the westerly season at all sampling sites (b).

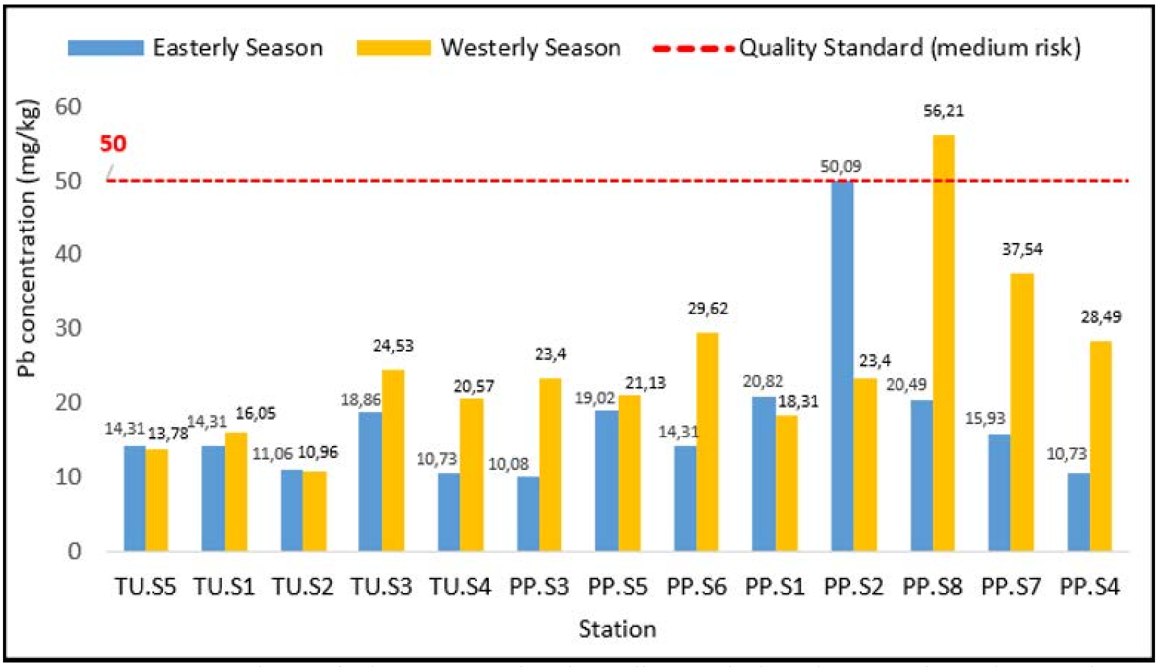


Figure 6. Comparison of Pb concentration in sediment during the easterly and westerly

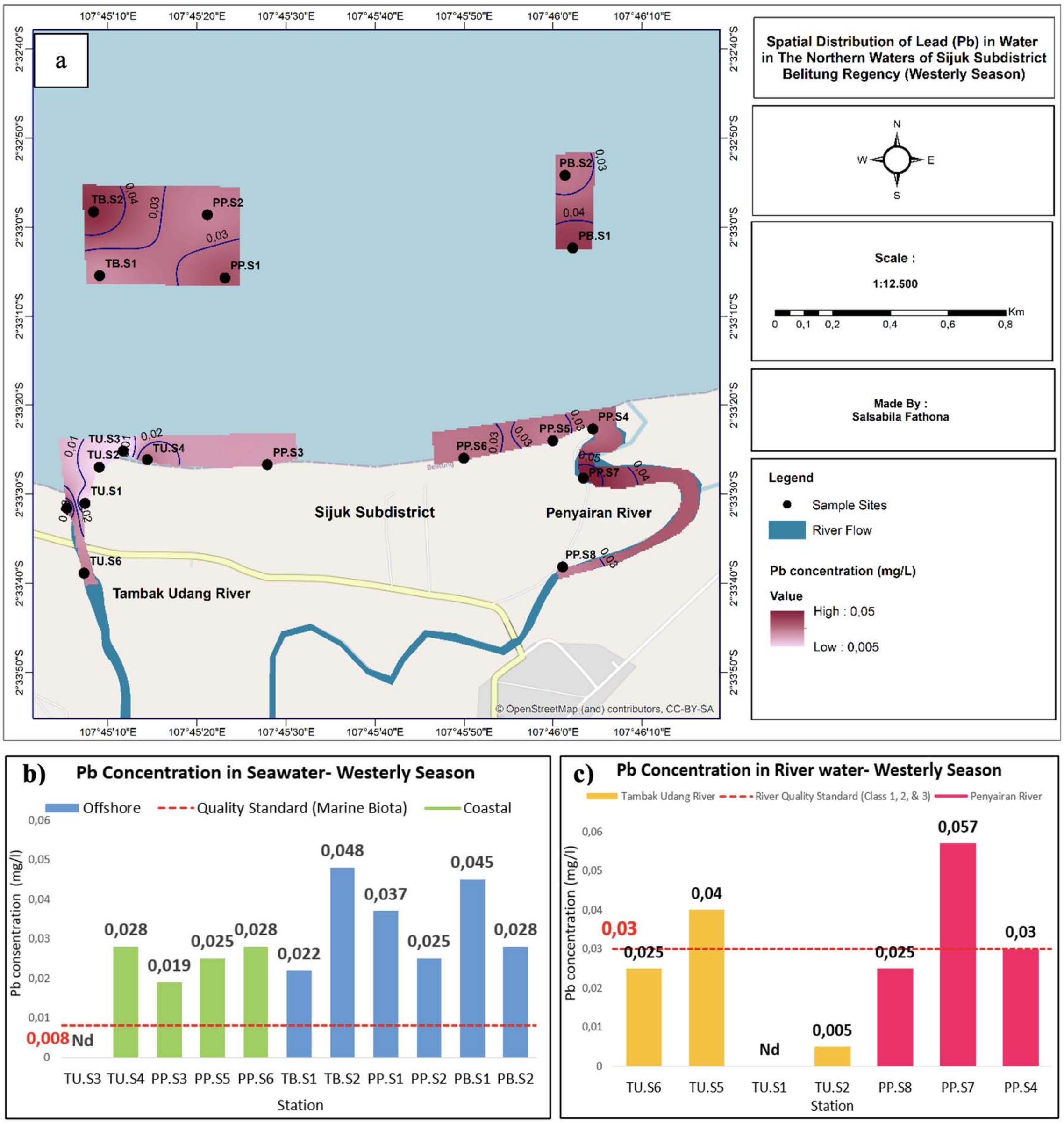


Figure 7. Spatial distribution of lead (Pb) in water during the westerly season (a), lead (Pb) concentration in seawater during the westerly season at all sampling sites (b), lead (Pb) concentration in river water during the westerly season at all sampling sites (c)

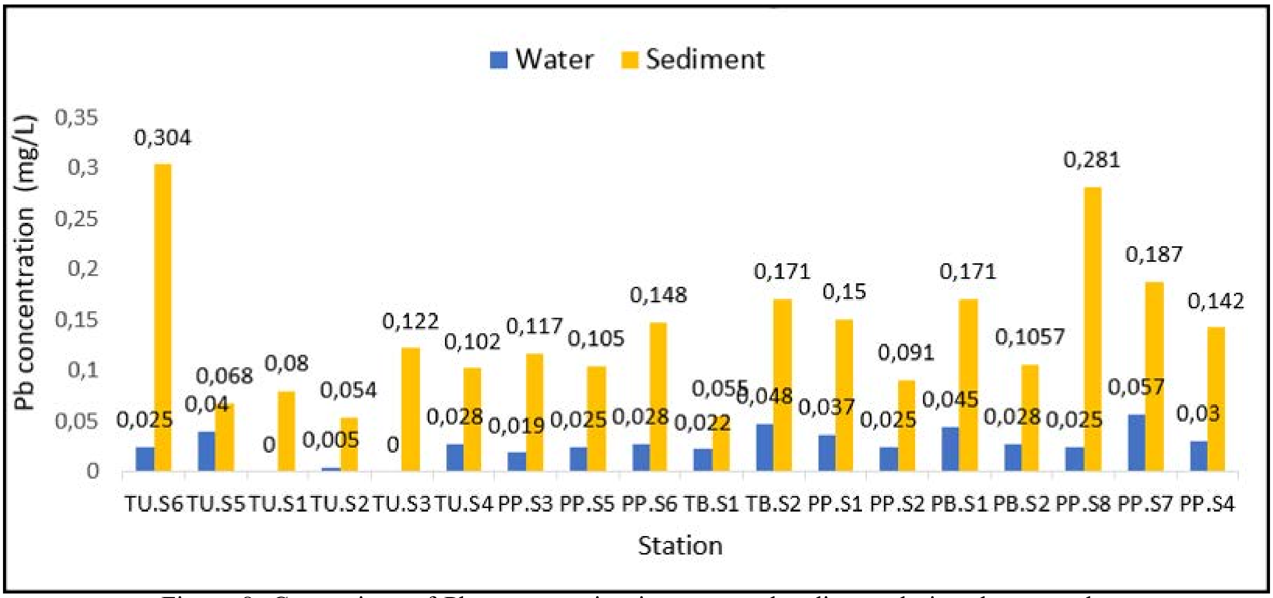


Figure 8. Comparison of Pb concentration in water and sediment during the westerly

DISCUSSIONS

This study assessed Pb concentrations in both sediments and the water column, with sampling conducted in the Penyairan River, Tambak Udang River, coastal areas, and offshore. Sediment samples were collected during both the easterly and westerly seasons, whereas water samples were obtained only during the westerly season. The absence of settlements or port activities in the study area strongly suggests that the primary source of Pb contamination originates from tin mining operations directly connected to the site.

Spatial analysis revealed that during the easterly season, Pb concentrations were higher offshore compared to coastal and river areas. This distribution pattern is likely influenced by seawater currents, which in Sijuk waters move northwestward at low speeds of 0.07 to 0.2 m/s during this season. As a result, Pb-contaminated water masses are transported away from the mainland and deposited offshore.

During the westerly season, Pb concentrations in river sediments near the mainland were higher than those in coastal and offshore areas. This distribution pattern is likely influenced by seawater currents, sediment grain size, geographical location, and tidal dynamics. In this season, currents in Sijuk waters move from east to south at higher speeds (0.08–0.45 m/s) compared to the easterly season. As a result, Pb-contaminated water masses are transported toward the mainland and deposited in river sediments.

They facilitate the movement of particles from one location to another, significantly influencing pollutant distribution. As noted by Lebreton et al. (2017), currents play a crucial role in transporting materials, including various forms of waste, across vast areas. These dynamic forces carry both solid and liquid contaminants, spreading pollution over large distances and affecting ecosystems far beyond the initial source of contamination. Geographical location also plays a crucial role in the distribution of Pb concentrations across the four regions. In Sijuk, Belitung, Pb contamination primarily originates from former tin mining sites on land, which are directly connected to the two rivers flowing into the sea. As a result, Pb accumulates in the sediments of the Tambak Udang and Penyairan Rivers, contributing to elevated concentrations in these areas.

Heavy metal concentrations in sediments are strongly influenced by sediment grain size. Finer sediments, such as clay and silt, exhibit higher heavy metal accumulation due to their larger surface area and greater cation exchange capacity, which enhances metal adsorption and retention. Zhao et al. (2023) demonstrated a significant positive correlation between heavy metal content and fine sand or clay fractions. The highest heavy metal concentrations are typically found in fine-grained sediments, including clay, silty sand, and mud, rather than in pure sand. This phenomenon is driven by electrochemical attraction forces between sediment and mineral particles, which facilitate metal adsorption. Fine-grained sediments provide a more effective binding surface for heavy metal ions compared to coarse sediments like pure sand (Zhang et al., 2014). Additionally, the offshore dispersion of Pb is influenced by tidal patterns. Belitung Waters experience a diurnal tide, characterized by a single tide per day on average. This results in a back-and-forth water movement, which periodically transports heavy metals from coastal areas to offshore regions. The tidal-driven currents play a crucial role in redistributing contaminants, contributing to the accumulation of Pb in offshore sediments.

The seasonal variation in Pb concentration in sediments indicates significantly higher levels during the westerly season compared to the easterly season. Najamuddin (2016) reported that heavy metal concentrations tend to be lower in the dry season (easterly season) and higher in the rainy season (westerly season). This increase is primarily attributed to intensified erosion and surface runoff during the rainy season, which transports greater amounts of heavy metals into water bodies, leading to their accumulation in sediments.

Laboratory results confirm that Pb concentrations in sediments are significantly higher than in the water column. This discrepancy arises because heavy metals, including Pb, predominantly settle in sediments, making them a reliable indicator of heavy metal accumulation in aquatic environments. Upon entering marine systems, heavy metals dissolve in water before binding to organic matter and fine-grained sediments, leading to their long-term accumulation. Amin et al. (2011) noted that heavy metal concentrations in sediments tend to increase over time, depending on environmental conditions. Similarly, Bai et al. (2016) reported that heavy metals readily bind to organic matter and settle at the bottom, where they integrate with sediments. Their strong affinity for fine particles, such as clay and silt, further enhances their accumulation in benthic environments, solidifying sediments as a primary sink for these pollutants.

Moreover, Pb concentrations in both the water column and sediments are influenced by various marine water quality parameters, including temperature, salinity, pH, and dissolved oxygen (Sagala et al., 2015). This study observed variations in these parameters between river and sea stations. However, due to the limited dataset, establishing a strong correlation between Pb concentrations and these water quality parameters remains challenging. A more comprehensive dataset is necessary to substantiate these relationships with greater certainty, as suggested by findings from previous studies.

The relationship between water quality parameters and the behavior of lead (Pb) in marine environments is significantly influenced by temperature. Lower seawater temperatures enhance the adsorption of heavy metals onto particulates, facilitating their deposition onto the seabed. In contrast, higher temperatures reduce adsorption efficiency, increasing the dissolution of heavy metal compounds in the water column. This temperature-dependent mechanism underscores the dynamic mobility of heavy metals in aquatic systems, emphasizing temperature as a critical water quality parameter (Wang et al., 2011). Additionally, heavy metals are more prevalent in low-salinity areas, as lower salinity conditions reduce the ability of metals to precipitate or bind to particulates, keeping them in suspension or solution. In contrast, higher salinity levels promote metal precipitation and adsorption onto sediments, effectively removing them from the water column (Connel & Miller, 1995, as cited in Ali et al., 2010).

The solubility of heavy metals in water is strongly influenced by dissolved oxygen (DO) levels. Under low-oxygen or anoxic conditions, the solubility of heavy metals decreases, leading to their precipitation and accumulation in sediments. Metals such as Zinc (Zn), Chromium (Cr), Cadmium (Cd), Lead (Pb), Mercury (Hg), and Silver (Ag) exhibit reduced solubility in anoxic environments, resulting in their deposition rather than remaining in the water column (Wang et al., 2015). Additionally, pH and heavy metal solubility have an inverse relationship. Heavy metals dissolve more readily in low-pH conditions, increasing their concentration in the water column, whereas higher pH levels promote their precipitation and adsorption onto sediments (Sagala et al., 2015).

CONCLUSSIONS

This study on Pb content in the northern waters of Belitung Regency yielded the following key findings. Pb concentrations in sediments ranged from 10.08 to 50.08 mg/kg (dry weight) during the easterly season and from 10.96 to 60.72 mg/kg (dry weight) during the westerly season. In the water column, Pb concentrations during the westerly season were approximately 0–0.05 mg/L. The distribution of Pb in sediments varied by season. In the easterly season, Pb tended to disperse offshore, whereas in the westerly season, it accumulated in river sediments. This pattern was influenced by seasonal flow dynamics, geographical location, and sediment grain size. Pb concentrations in sediments were generally higher in the westerly season than in the easterly season. This increase is attributed to intensified erosion and runoff during the rainy season, leading to greater heavy metal deposition in sediments. These findings provide valuable insights into the distribution, accumulation, and transport of heavy metals in aquatic environments. They also highlight the importance of continuous monitoring and effective coastal management strategies to mitigate heavy metal contamination.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Oceanography Study Program for providing opportunities and platforms in exploring oceanography fieldwork and facilitating research tools. In addition, the authors also want to express their sincere appreciation to the National Research and Innovation Agency (BRIN) for research guidance services and laboratory services.

REFERENCES

Ali, H., Khan, E., and Sajad, M.A., 2010. Phytoremediation of Heavy Metals Concepts and Applications. *Chemosphere,* 91(7): 869–881.

Amin, B.E., Afriyani, M., and Saputra, A., 2011. Distribusi Spasial Logam Pb dan Cu pada Sedimen dan Air Laut Permukaan di Perairan Tanjung Buton Kabupaten Siak Provinsi Riau. *Jurnal Teknobiologi*, 2011(2): 1–8.

APHA (American Public Health Association), 2017. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, DC: APHA, AWWA, WEF.

Bai, Jihong, Xiao, R., Zhang, K., and Gao, H., 2016. Heavy Metal Concentrations in Riverine and Coastal Sediments. *Environmental Science and Pollution Research*, 23(10): 9485-9498.

Duffus, John H., 2002. Heavy Metals A Meaningless Term?. *Pure and Applied Chemistry*, 74(5): 793-807.

DeForest, D., Brix, K., and Adams, W., 2007. Assessing metal bioaccumulation in aquatic environments: The inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. *Aquat Toxicol*, 84:236–246.

Demirak, A., Yilmaz, F., Tuna, A.L., Ozdemir, N., 2006. Heavy Metals in Water, Sediment and Tissues of Leuciscus Cephalus from a Stream in Southwestern Turkey. *Chemosphere*, 63:1451–1458.

Ghrefat H., and Yusuf, N., 2006. Assessing Mn, Fe, Cu, Zn, and Cd Pollution in Bottom Sediments of Wadi Al-Arab Dam Jordan. *Chemosphere*, 65:2114–2121.

Guo, W., He, M., Yang, Z., Lin, C., Quan, X., and Wang, H., 2020. The Role of Sediment-Water Exchange in the Fate of Heavy Metals in Aquatic Systems. *Environmental Pollution*, 266, 115–127.

Habibi, Y., 2020. Validasi Metoda Destruksi Basah dan Destruksi Kering pada Penentuan Logam Timbal (Pb) dan Kadmium (Cd) dalam Tanaman Rumput. *Integrated Lab Journal*, 8(1): 25– 31.

Herman, D. Z., 2006. Tinjauan Terhadap Tailing Mengandung Unsur Pencemar Arsen (As), Merkuri (Hg), Timbal (Pb), dan Kadmium (Cd) dari Sisa Pengolahan Bijih Logam. *Indonesian Journal on Geoscience*, 1(1): 31-36.

Indonesian State Gazette, 2021. Government Regulation no. 22 of 2021 on Environmental Protection, Organisation and Management. Republic of Indonesia.

Khaled, A., Nemr, A.E., Sikaily, A.E., 2006. An Assessment of Heavy Metal Contamination in Surface Sediments of the Suez Gulf Using Geoaccumulation Indexes and Statistical Analysis, *Chem Ecol*, 22:239–252.

Lebreton, Laurent, Zwet, J.V.D., Damsteeg, J.W., Slat, B., Andrady, A., and Reisser, J., 2017. River Plastic Emissions to the World's Oceans. *Nature Communications*, 8(1): 15611.

Najamuddin, T. Prartono, H.S., Sanusi, and Nurjaya, I.W., 2016. Distribusi dan perilaku Pb dan Zn terlarut dan partikulat di perairan estuaria Jeneberang, Makassar, *Jurnal Ilmu dan Teknologi Kelautan Tropis,* 8(1):11-28.

Naser, H. A., 2013, Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review, *Mar Pollut Bull*, 72:6–13.

Ozkan, E. Y., and Buyukisik, B., 2012. Geochemical and Statistical Approach for Assessing Heavy Metal Accumulation in the Southern Black Sea Sediments, *Ekoloji*, 21(83):11–24.

Sagala, S.L., Bramawanto, R., Kuswardani, A.R., and Pranowo, W.S., 2015. Distribution Of Heavy Metals in Natuna Coastal Waters. *Jurnal Ilmu Dan Teknologi Kelautan Tropis,* 6: 297-310.

Shazili, N.A.M., Yunus, K., Ahmad, A., Abdullah, N., and Rashid, M.K.A., 2006. Heavy Metal Pollution Status in the Malaysian Aquatic Environment. *Aquatic Ecosystem Health & Management*, 9(2), 137–145.

Singh, K.P., Mohan, D., Singh, V.K., and Malik, A., 2006. Studies on Distribution and Fractionation of Heavy Metals in Gomti River Sediments-a Tributary of The Ganges. *J Hydrol,* 312:14–27.

Soegianto, A., 2019. Pencemaran Logam Berat di Perairan dan Dampaknya terhadap Biota Laut. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 11(2): 451–462.

Sutrisyani, S., 2016. Metode Pengambilan dan Pengawetan Sampel Air Laut. *Buletin Teknik Litkayasa Akuakultur*, 1(1): 1-8.

Tchounwou, Paul B., Clement G., Yedjou, Anita K., Patlolla, and Dwayne J.S., 2012. Heavy Metals Toxicity and the Environment. *EXS,* 101: 133–164.

Wang, Ning, Chen, X., Sheng, Y., and Liu, G., 2015. Effects of Dissolved Oxygen on the Solubility and Mobility of Heavy Metals in Aquatic System. *Journal of Environmental Sciences*, 34: 1-10.

Wang, W. X., and Rainbow, P.S., 2008. Comparative Approaches to Understand Metal Bioaccumulation in Aquatic Animals, *Comp Biochem Physiol Part C Toxicol Pharmacol,* 148:315–323.

Wang, Shaofeng, Yan, Y., and Pan, X., 2011. Effect of Temperature on the Adsorption and Desorption of Heavy Metals in Aquatic Environments. *Environmental Sciences and Pollution Research*, 18(6): 908-916.

Zhang, Chuanbo, Yang, Z., Li, Z., Wang, Y., and Zeng, L., 2014. Distribution and Enrichment of Heavy Metals in Sediment of Xiangjiang River, China. *Environmental Earth Sciences*, 71(9): 3949-3957.

Zhao, Y., Wang, L., Li, Y., and Zhang, J., 2023. Analysis of Heavy Metals in Sediments with Different Particle Sizes. *Scientific Reports,* 13: Artikel 71502.