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Exploring Ecological Dynamics: A Case Study of Post-Unconventional Tin Mining in Batu Belubang Waters, Bangka Island

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Abstract

The benthic biological resources in Batu Belubang Waters exhibit significant diversity, and as one of Bangka Island's unconventional tin mining as well as post-tin-mining areas, understanding its impact on aquatic life is very important. Therefore, this study aimed to determine the potential risk of heavy metals in post-tin-mining sediments using an Ecological Risk Index (ERI) analysis approach. Purposive sampling was conducted in the post-tin mining areas of Batu Belubang waters. Heavy metal measurement was carried out using Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES). The results showed that the contamination factor (CF) of heavy metals for Cd, Pb, Co, and Ni in sediments were within the criteria of low pollution level (CF < 1), and the value of Pollution Load Index (PLI) was below 1, showing an unpolluted classification. Furthermore, ERI analysis of Cd, Pb, Co, and Ni, in sediments also showed low ecological risk criteria (ERI < 150). The texture of the substrate in the post-tin mining area is dominated by sand, with the base layer exhibiting relative weakness, leading to a slight resuspension, and distribution of heavy metals in the sediment. There is low metal accumulation in tissues, which does not interfere with the metabolism and growth of benthos. The results showed a low ecological risk, suggesting the resilience of the ecosystem to post unconventional tin mining.

Keywords: Sediment; Heavy metals; Water Pollution; Comtamination, Benthic; Mining resilience

1. Introduction

Batu Belubang Waters is an area located on Bangka Island which exemplifies a former unconventional tin mining site. While community tin mining activities have been stopped in 2018, significant quantities of tailings are carried out in the area. This poses a concern due to Batu Belubang rich benthic biological resources. Several studies have shown that tin mining waste contains heavy metals (Umroh *et al.,* 2022). The current velocity facilitates the dispersion of heavy metals in the water column and prompts sediment resuspension. This condition may reduce the heavy metal content in the sediment, and increase the concentration in the water column.

Studies on heavy metal concentrations, including Cd, Pb, Co, Ni in estuarial and marine sediments has been widely conducted (Liu *et al.,* 2016; Effendi *et al.,* 2016; Pamungkas, 2018; Pugung *et al.,* 2018; Yona *et al.,* 2018; Fahimah *et al.,* 2020; Umroh *et al.,* 2022; Umroh *et al.,* 2023). However, these studies primarily focus on the influence of surface currents. There is limited investigation on heavy metal concentrations in both water column and sediments, considering current velocities in the bottom layer of water. The concentration of heavy metals resulting from *the suspension* is affected by the current speed of the base layer. Therefore, it is important to supplement these findings with heavy metal concentrations in the sediment to accurately assess heavy metal levels. This summation can be used as a reference basis for heavy metal concentrations in post-tin mining sediments in Batu Belubang Waters and their ecological impact in the event of changes in current speed at the bottom layer of water (Purba *et al.,* 2022).

Based on the phenomena mentioned above, this study aimed to determine the potential risk of heavy metals such as Cd, Pb, Co and Ni, in the post-tin mining area to ecology in Batu Belubang Waters. The potential risk of heavy metals in post-tin mining areas is carried out using a Potential Ecological Risk (PER) approach, considering the current speed of the bottom layer of water. The results are expected to provide valuable information to the public regarding the presence or absence of post-tin mining impacts on the life of benthos organisms in the coastal area and Waters of Batu Belubang.

2. Methodology

2.1 Sediment sampling and measurement

This study was conducted in March 2023 in Batu Belubang Waters, Central Bangka Regency. The area is characterized by the presence of sand piles (tailing) resulting from previous tin mining operations, alongside abundant benthos biological resources of economic importance during certain seasons. Therefore, a comprehensive examination of the criteria for post-tin mining effects on the surrounding ecology was needed. Data collection on heavy metals in sediment, water, and current velocity was carried out at 12 points (Figure 1), strategically selected based on the representation of the location of former mining activities that have been carried out by the community. Analysis of sediment texture and heavy metals was performed at PT Global Quality Analytical (GQA) Laboratory, Bogor.

Preparation of total heavy metals (Cd, Pb, Co, Ni) in sediments was carried out based on the method of Suteja *et al.* (2020); Umroh *et al.* (2022); Umroh *et al.* (2023), and measurement of heavy metal concentrations was performed using Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES).

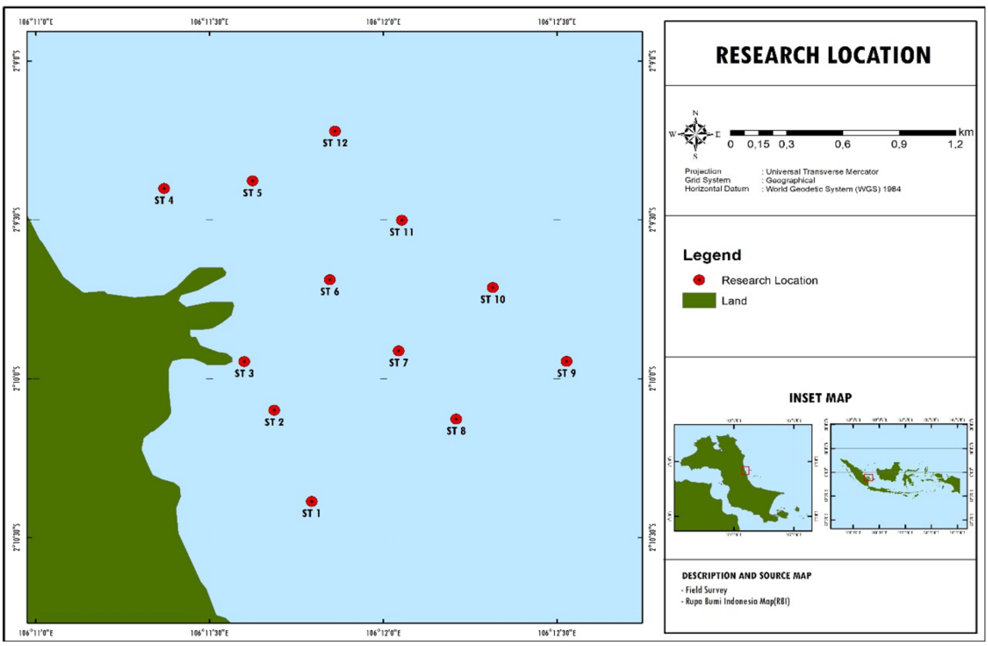


Figure 1. Sediment, water and current speed sampling stations in Batu Belubang Waters

2.2 Current speed measurement using valeport 106 current meter

Current speed measurement is carried out on 3 layers of water, namely surface, mid point and bottom of water (Figure 2). Current measurement using Valeport 106 Current meter (Zikra *et al.,* 2021) is an instrument for measuring current at several depths according to needs. The Valeport 106 Current meter displays speed and direction parameters as standard, with temperature and depth options. The working principle of valeport 106 current meter uses sensors that detect the speed of water currents in the water column. The sensor consists of a coil that rotates when exposed to water currents, or a propeller that can rotate when exposed to water currents. When the water current hits the coil or propeller, there is a change in the magnetic field around the coil or propeller. Changes in the magnetic field will produce electrical signals that can be measured by the measuring unit connected to the sensor, and the Control Display Unit (CDU). The CDU functions to display, organize, retrieve data, and edit sensor recorded data (Valeport Ltd, 2019).

2.3 Analysis of concentration of heavy metals (Cd, Pb, Co, Ni) in sediment

Sediment samples that have been cleaned, then dried for 24 hours (oven with a temperature of 60 °C), then homogenized (Suteja *et al.,* 2020; Umroh *et al.,* 2022). Sediment sample of 0.5 g was put into a tube, then added 5 mL of nitric acid (HNO_3) and 1 mL of concentrated hydrogen peroxide (H_2O_2), and allowed to stand for 20 - 30 minutes. Next, the sediment sample was put in the microwave for 1 hour (temperature 190 °C). The sample is removed from the microwave, poured into a volumetric flask of 50 mL, and dissolved with aquades water to a limit of 50 mL. If there is still a precipitate, it must be filtered using 42 micron filter paper. Heavy metal concentration analysis was performed using Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES): Thermo Scientific iCAP 7000.

The accuracy of heavy metal measurement methods is checked by certified standard analysis, and supplemented by recovery rates of heavy metals (Cd, Pb, Co, Ni) in the standard reference material were between 24.2 and 58.6%.

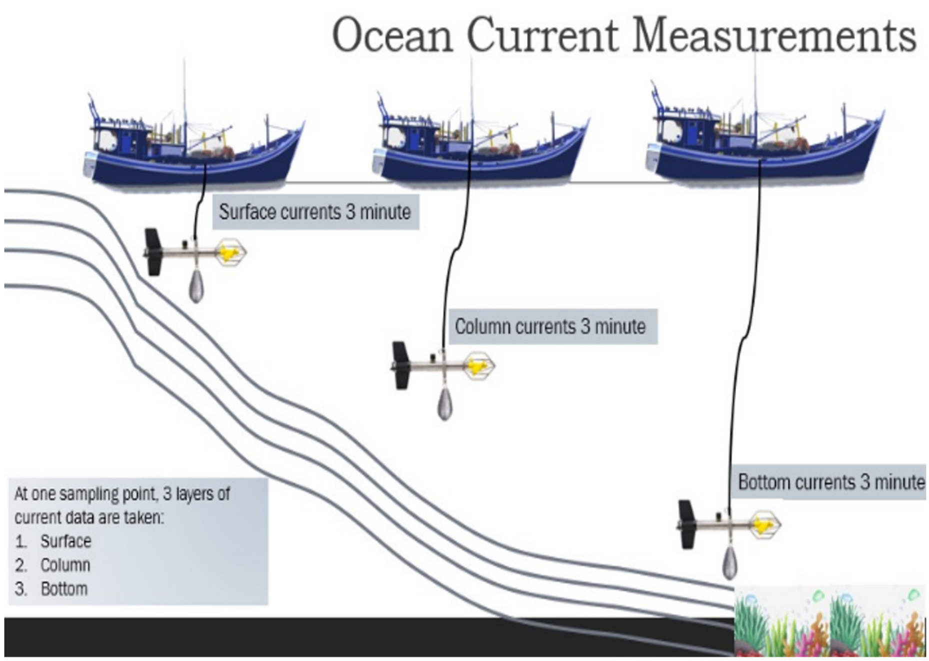


Figure 2. Measurement of surface currents, columns and layers of the bottom of the water with Current Meter 106

2.4 Data analysis

2.4.1 Potential Ecological Risk (PER)

The assessment of the influence of heavy metals from post-mining on the ecology of Batu Belubang Waters was analyzed with Potential Ecological Risk (PER). The PER assessment is the process of evaluating the likelihood that adverse ecological effects may or may not occur as a result of exposure to one or more stressors (Ahmed *et al.,* 2018). The Ecological Risk Index (ERI) is calculated using the equation (Malvandi, 2017; Alahabadi & Malvandi, 2018; Elias *et al.,* 2018; Chakraborty *et al.,* 2022) follows:

$$\text{ERI} = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \cdot C_f^i$$

Where:
E_r^i = the enrichment of a particular metal
C_f^i = concentration value of the metal i divided by the Background value of the metal. Background value in this study refers to the natural average value of the earth's crust layer, for Cd = 0.3 ppm; Pb = 20 ppm; Co = 19 ppm; Ni = 68 ppm (Turekian & Wedepohl, 1961)
T_r^i = "toxic response factor" of metal i reflecting the toxic level and sensitivity of the bioorganism to heavy metals; T_r^i = Toxic response factor Cd; Pb; Co; Ni = 30; 5; 2; 3 (Suresh *et al.,* 2012)

The calculation of ERI values can be divided into four classes: Low ecological risk (ERI < 150); Moderate ecological risk (150 ≤ ERI < 300); The ecological risk is quite large (300 ≤ ERI < 600), and the ecological risk is very high (ERI ≥ 600).

2.4.2 Contamination factors (CF)

Contamination factors (CF) are also analyzed to assess the degree of anthropogenic heavy metal contamination. The contamination factor is calculated by measuring the ratio of the concentration of each element in the sediment to the *Background value* (Ahmed *et al.,* 2018; Alahabadi & Malvandi, 2018).

$$\text{CF} = \frac{Cn}{C\ Background}$$

Where:
Cn = Concentration of element "n" in the sediment sample
$C_{\text{Background(Bn)}}$ = Concentration of element "n" in nature.

2.4.3 Pollution Load Index (PLI)

The Pollution Load Index (PLI) provides a simple way to assess contamination levels for various elements and is calculated by the following formula (Ahmed *et al.,* 2018; Alahabadi & Malvandi, 2018) :

$$\text{PLI} = [CF_1\ x\ CF_2\ x\ CF_3\ x\ CF_4]^{1/4}$$

Where:
CF = Contamination factor of each metal
n = Number of metals, with PLI value criteria above 1 indicating metal contamination, and PLI below 1 no contamination / contamination (Ferati *et al.,* 2015; Malvandi, 2017)

The relationship of metal concentrations, Cd; Pb; Co; Ni, in sediment resuspensions with the current velocity of the base layer was analyzed using Pearson's correlation analysis. The use of correlation analysis aims to determine the level of closeness of the relationship between the two variables (Xiang *et al.,* 2021).

3. Results and Discussion

The analysis conducted at 12 points showed that in general four heavy metals (Cd, Pb, Co, Ni) in the sediments of Batu Belubang Waters had low concentrations. Cd concentrations ranged from 0.022 – 0.055 mg/kg; Pb ranged from 0.001 to 0.003 mg/kg; Co ranged from 0.020 to 0.054 mg/kg and Ni ranged from 0.032 to 0.066 mg/kg (Figure 3). These concentrations were found to be below the sediment quality standard outlined by (ANZECC & ARMCANZ, 2000). Based on ANZECC/ ARMCANZ Guidelines (2000), the quality standard values for Pb ranged from 50 mg/kg (low) to 220 mg/kg (high); Cd ranged from 1.5 mg/kg (low) to 10 mg/kg (high); Co ranged from 65 mg/kg (low) to 270 mg/kg (high) and Ni ranged from 21 mg/kg(low) to 52 mg/kg (high).

The order of concentration for these metals in sediments was found to be Ni > Cd > Co > Pb. The elevated Ni concentration can be attributed to post-tin mining activities in Batu Belubang Waters which contributes to adding Ni metal in sediments. This study is in line with the investigation by Alimah *et al.,* (2014), which reported the highest concentration of Ni in areas where there is tin and bauxite mining on Singkep Island, Riau Islands. Ni metal sources are dominant from mining (Effendi *et al.,* 2016), and rock as well as subsoil scouring (Wali *et al.,* 2020).

The concentration of heavy metals (Cd, Pb, Co, Ni) in Batu Belubang sediments showed lower values compared to several locations on Bangka Island. Some studies, such as Komalasari *et al.,* (2019) reported the average concentration of Pb in Teluk Kelabat Dalam ranging from 7.40 mg/kg, while Nugraha *et al.,* (2022) reported a similar result in sediments of Matras Waters. Sungailiat showed an average concentration of heavy metal Cd around 0.04 mg/kg, and Pb around 0.15 mg/kg. The study by Teluk Kelabat Luar showed an average concentration of Cd of about 0.03 mg/kg, Pb of about 9.29 mg/kg (Umroh *et al.,* 2022), and measurements of Pb concentration in north and south Bangka Island ranged from 0.06 – 44.71 mg/kg (Umroh *et al.,* 2023). The relatively low heavy metal content in Batu Belubang sediments can be attributed to the predominant sand substrate texture of the water area (Figure 4). The percentages of sand texture at stations 1 to 12 are 73.7%; 91.4%; 89.5%; 78.0%; 98.0%; 88.7%; 97.7%; 99.6%; 87.1%; 99.4%; 99.9% and 94.9% (Figure 4). The texture of the sand substrate has a low capacity to bind heavy metals, because the coarser the texture, the smaller the bonding ability with metals. This condition causes sediment in Batu Belubang to have a low concentration of metal. The texture of sand that has pores is quite large and causes low

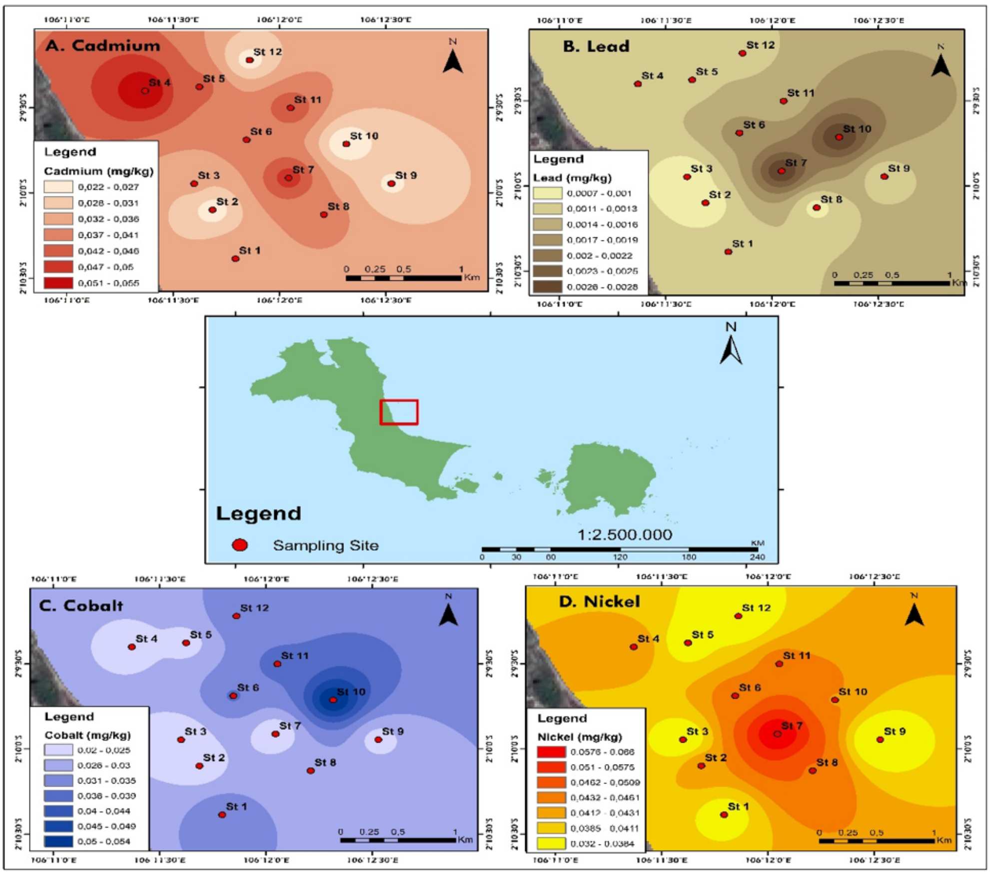
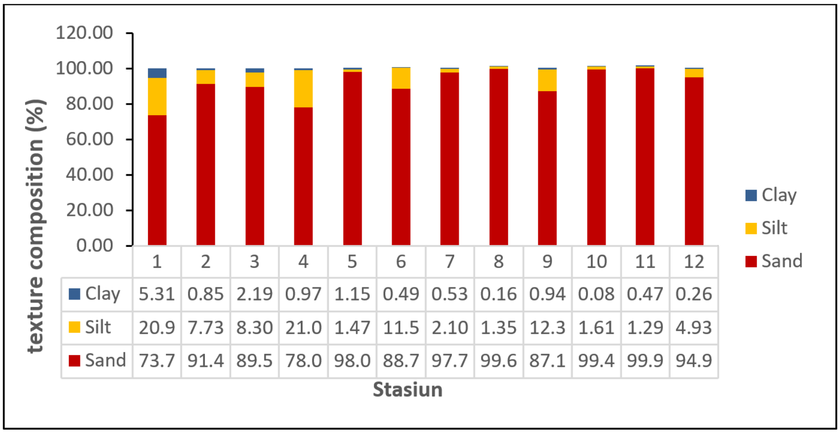


Figure 3. Heavy metal spread in the sediments of Batu Belubang: (a) Cadmium; (b) Lead; (c) Cobalt; (d) Nickel

absorption of metals (Nurhamiddin & Zam, 2013; Putri *et al.,* 2022). Substrate texture plays a significant role in the accumulation and distribution of heavy metals in sediments (Umroh *et al.,* 2022; Umroh *et al.,* 2023). Visually, the sand texture appears mixed with coral fragments and mollusk shells, indicating the presence of damaged coral reef ecosystems. Additionally, mining activities in the waters of Bangka Island cause changes in substrate texture (Septiani *et al.,* 2022). Coal mining activities also cause the texture of the substrate to become a mixture of sand, shells, mollusks, and corals that have been damaged (Nursalam & Salim, 2020).

The concentration of heavy metals in the sediment is influenced by texture, and the distribution is influenced by the speed and direction of the current. Water and sediment sampling were carried out during the transition season I (March 2023), with ocean currents observed flowing from northwest to southeast (Figure 6). During the course of this study, current speeds in the surface layer ranged from 0.098 to 0.183 m/s, and the bottom layer of water ranged from 0.053 to 0.133 m/s (Figure 5). According to Yusuf *et al.* (2022), the current speed at the surface falls within the medium criterion, while at the bottom of the water, it is categorized as low. Subsequently, the low speed of the current has an impact on the weak distribution of heavy metals in Batu Belubang, this causes all stations to have a low concentration of heavy metals. The low distribution was also added by the influence of low rainfall intensity in the Bangka Island area during this study. This is similar to the investigation of Sagala *et al.,* (2014), which showed the significant impact of current speed and rainfall intensity on heavy metal distribution in Natuna Waters (Rezki *et al.,* 2013; Sagala *et al.,* 2014).



	1	2	3	4	5	6	7	8	9	10	11	12
Clay	5.31	0.85	2.19	0.97	1.15	0.49	0.53	0.16	0.94	0.08	0.47	0.26
Silt	20.9	7.73	8.30	21.0	1.47	11.5	2.10	1.35	12.3	1.61	1.29	4.93
Sand	73.7	91.4	89.5	78.0	98.0	88.7	97.7	99.6	87.1	99.4	99.9	94.9

Figure 4. Composition of sediment fractions at 12 research stations, with clay fractions (< 0.002 mm), mud (0.06 - 0.002 mm), and sand (2 - 0.06 mm)

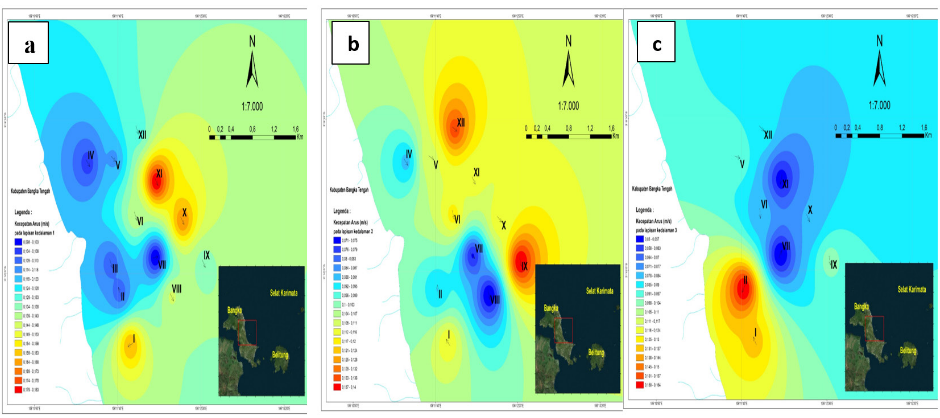


Figure 5. Current speed at the location: (a) surface layer; (b) water column with a depth of 2 m; (c) bottom waters with a depth of 3 m

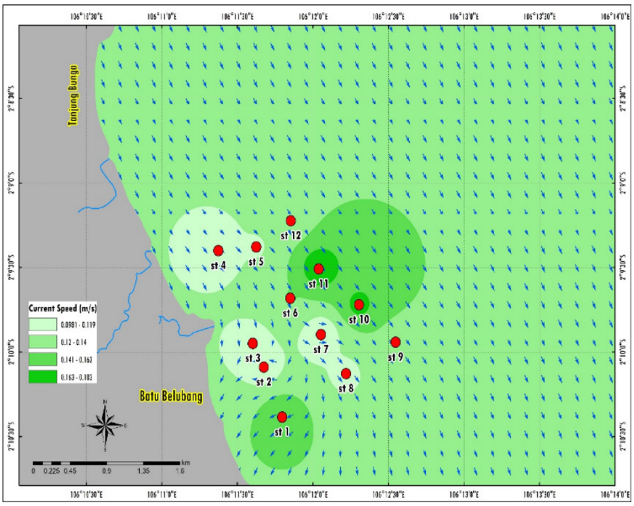


Figure 6. Current direction at the research location: northwest to southeast

Based on the analysis of the movement of seawater, it is known that surface currents and bottom layers have differences in speed, with deeper depths corresponding to lower current strength (Figure 5). The slow/low motion of the base layer current results in minimal resuspension of heavy metals from sedimentary aggregates. The range of heavy metals released from sedimentary aggregates, namely Cd, ranged from 0.0017 - 0.0065 mg/L; Pb < 0.0002 mg/L; Co < 0.001 mg/L; Ni < 0.001 mg/L. This causes the concentration of heavy metals in the sediment not to decrease much. Based on the correlation analysis between the current speed in the base layer and heavy metal resuspension, Cd showed a value of < 0.5 (r = 0.327), and the criteria included a low positive correlation. This finding underscores the positive correlation between the flow speed of the bottom layer of water and the concentration of heavy metals suspended from sediment aggregates.

The results of the summation of heavy metal concentrations in sediments and resuspensions from sediment aggregates were further analyzed using the Ecological Risk Index (ERI) to assess the potential ecological risks in the Batu Belubang water area. Some assessments to support ERI analysis are Contamination Factor (CF), and Pollution Load Index (PLI) (Table 1). Based on the results of the analysis of heavy metal CF values for Cd, Pb, Co, and Ni in sediments, they fell within the criteria of low contamination content (CF < 1). Similarly, Pollution Load Index (PLI) values below 1 were classified as no contamination. Subsequent ERI analysis of heavy metals Cd, Pb, Co, and Ni in sediments also showed low ecological risk criteria (ERI < 150). This condition illustrated that the influence of heavy metals from post-tin mining in Batu Belubang Waters on ecology is still relatively low, and does not pose a significant threat to organism metabolism.

The low potential risk of heavy metals in Batu Belubang Waters has minimal effects on the life and growth of organisms in these waters. This is also evidenced by the population of benthos organisms in the intertidal area, specifically darah mussels (*Anadara granosa*) and kepah mussels (*Meretrix meretrix*), found during the transition season. Both shellfish are economically important and are often consumed by local people and migrants. The Benthos life in the intertidal area of Batu Belubang is also supported by the physical-chemical conditions in the waters. Parameters such as dissolved oxygen ranging from 6.7 – 7.3 mg/L, temperature ranging from 28.3 – 30.9 ^{o}C, and salinity ranging from 28 – 31‰, were within the Indonesia Government Regulations (PPRI, 2021), indicating suitability for aquatic biota life. These physical and chemical conditions closely resemble those observed in studies conducted in the waters of South Bangka and North Bangka, known to support the

Table 1. Results of the assessment of the level of contamination (CF), and *Ecological risk index* (ERI) of heavy metals in Batu Belubang sediments, Central Bangka, Bangka Island

Stations	Contamination Factor (CF)				PLI	Contamination level	ERI	Ecological risk
	Cd	Pb	Co	Ni				
1	0.1167	0.0001	0.0018	0.0000	0.0003	Low (CF < 1)	1.1711	RI < 150 (Low)
2	0.0800	0.0000	0.0012	0.0000	0.0000	Low (CF < 1)	0.8032	RI < 150 (Low)
3	0.1067	0.0000	0.0011	0.0005	0.0000	Low (CF < 1)	1.0718	RI < 150 (Low)
4	0.0550	0.0001	0.0012	0.0006	0.0001	Low (CF < 1)	0.5564	RI < 150 (Low)
5	0.0210	0.0001	0.0012	0.0005	0.0000	Low (CF < 1)	0.2156	RI < 150 (Low)
6	0.0127	0.0001	0.0018	0.0006	0.0001	Low (CF < 1)	0.1347	RI < 150 (Low)
7	0.0120	0.0001	0.0011	0.0010	0.0000	Low (CF < 1)	0.1279	RI < 150 (Low)
8	0.0076	0.0000	0.0015	0.0007	0.0000	Low (CF < 1)	0.0832	RI < 150 (Low)
9	0.0043	0.0001	0.0012	0.0005	0.0000	Low (CF < 1)	0.0487	RI < 150 (Low)
10	0.0031	0.0001	0.0028	0.0006	0.0000	Low (CF < 1)	0.0410	RI < 150 (Low)
11	0.0055	0.0001	0.0019	0.0006	0.0000	Low (CF < 1)	0.0631	RI < 150 (Low)
12	0.0028	0.0001	0.0017	0.0005	0.0000	Low (CF < 1)	0.0342	RI < 150 (Low)

benthic life of various species including barking snails (Umroh *et al.,* 2021), darah mussels (*Anadara granosa*) and kepah mussel (*Meretrix meretrix*). Morphologically, these organisms exhibit normal growth patterns. This suggests that the accumulation of heavy metals in their tissues remains in the low category and has not caused damage. High accumulation of heavy metals can disrupt the metabolism and growth of biota, as documented in previous studies. However, in Batu Belubang Waters, the current levels of heavy metals do not pose a significant threat to benthic organisms (Cordova, 2016; Riani *et al.,* 2017; Umroh *et al.,* 2021).

4. Conclusion

The potential risk of heavy metals; Cd, Pb, Co, Ni, in post-tin mining sediments to ecology in Batu Belubang Waters shows a low ecological risk criterion (ERI < 150), and this condition is still relatively safe for living organisms in Batu Belubang. The low influence of tin mining in Batu Belubang is known from several benthos biota that have normal morphology and growth. This is due to the low concentration of heavy metals in the sediments, and has implications for the accumulation of low heavy metals in benthos in the intertidal area of Batu Belubang.

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