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Vertical Distribution of Nickel (Ni) in Mangrove Sediments

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Abstract— Mangrove forests act as natural shields, safeguarding coastlines from erosion, storms, and large waves, while also capturing sediment to support the stability of coastal ecosystems. These sediments in mangrove regions are recognized as the main repository for various pollutants, including heavy metals. Nickel (Ni) is one such metal pollutant of concern, as it is a heavy metal that can be harmful in large quantities and may originate from both industrial activities and natural geochemical processes. A significant buildup of nickel in mangrove sediments can initiate bioaccumulation and biomagnification within the food chain, potentially endangering the health of marine life and humans who consume seafood from the contaminated area. By investigating the vertical distribution of mangrove sediments, the research seeks to uncover how contaminants are deposited and move into deeper sediment layers, as well as to assess the contamination status. The result demonstrate collectively indicate that the study area falls into the low contamination or uncontaminated category when compared to the global geochemical background value (20 ppm). All calculated CF values are well below the threshold of one (CF < 1), indicating that the measured nickel concentrations are generally within the range influenced by natural geogenic sources in each deep layer.

Keywords—Mangrove, Sediment, Nickel, Contamination, Coastal

I. INTRODUCTION

The mangrove forest ecosystem is a coastal zone with extremely high ecological and economic functions. Mangrove forests also serve as natural buffers that protect shorelines from erosion, storms, and high waves, while trapping sediment to help maintain the stability of coastal environments [1,2,3]. Sediments in mangrove areas are known to be the primary sink for various pollutants, including heavy metals [4]. The accumulation of these pollutants occurs due to the unique characteristics of mangrove sediments, which can bind and retain pollutant particles from the surrounding environment, whether originating from anthropogenic or natural activities [5,6]. This function is crucial in reducing the spread of pollutants to open waters and other, more vulnerable ecosystems, thus helping to preserve coastal environmental quality. However, the accumulation of heavy metals in sediments also poses a risk of contamination that can negatively impact organisms living in and around the mangroves, and may potentially threaten human health through the food chain.

One of the contaminants of concern is nickel (Ni), a heavy metal that can be toxic in excessive amounts and may originate from industrial activities as well as natural geochemical processes. High accumulation of Ni in mangrove sediments can trigger bioaccumulation and biomagnification processes through the food chain, which ultimately may threaten the health of marine biota and humans who consume seafood from the area [7,8]. The Rembang region, Central Java, Indonesia, serves as a comprehensive study location because it faces pressures from anthropogenic activities such as industry, ports, and residential settlements. Additionally, Rembang possesses a mangrove ecosystem that is still in relatively good condition [9], compared to other areas along the northern coast of Java Island. The role of mangroves as environmental buffers becomes crucial and important in coastal regions.

Additionally, geochemical profiling combined with sedimentological parameters is employed to thoroughly characterize Nickel's behavior in sediments. This approach not only deepens the understanding of metal cycling within mangrove ecosystems but also sheds light on the broader implications for sediment quality and the health of associated biota. By examining the vertical distribution, the research aims to reveal how contaminants are deposited and migrate into deeper sediment layers and also knowing the contamination status. Given the dynamic and sensitive nature of the Rembang ecosystem, understanding Nickel's behavior in this region is crucial. The results from this research are anticipated to provide essential scientific data necessary for monitoring environmental quality and ensuring the sustainable management of mangrove ecosystems in Rembang, Central Java.

II. RESEARCH METHODS

A. *Site Location*

This research was conducted in August 2025 at Pasar Banggi Village, Rembang Regency. This area is frequently used as a research site for various topics, including: economic valuation studies of mangrove forests, which assess the value of biological resources, aquaculture (milkfish and salt), and studies on the potential for ecotourism development as an effort to conserve mangroves. Land suitability analysis for ecotourism, with results indicating a suitable category for sustainable tourism activities, as well as research related to abrasion risk reduction, in which the mangrove area has proven effective in mitigating coastline erosion while actively involving the community [10,11]. Thus, this area is an ideal location for ecological, conservation, and coastal studies.

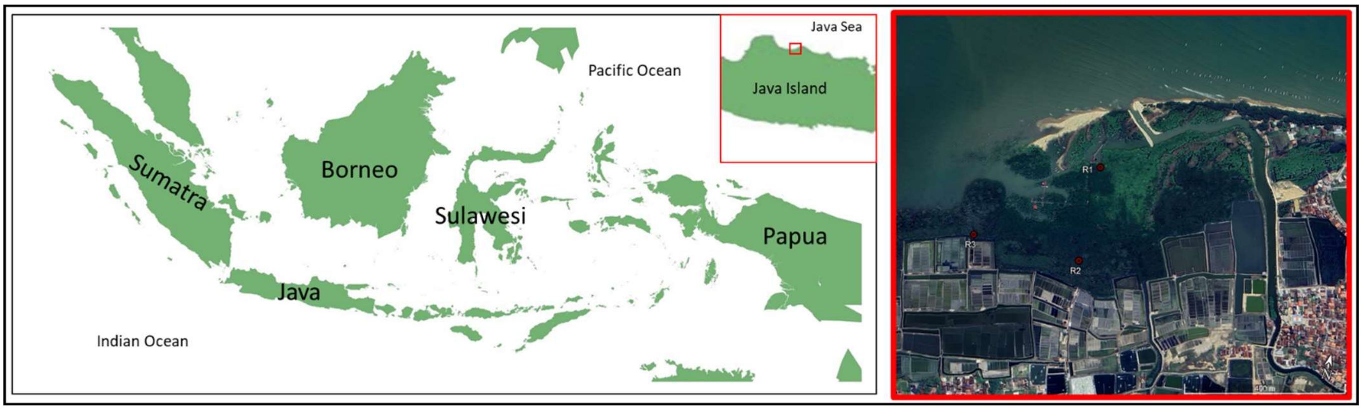

Figure 1. Sampling plot location inside mangrove area in Rembang, Central Java, Indonesia.

B. *Field Sampling and collection sample*

Site location was determined using purposive sampling methods and divided into 3 stations (R1, R2, R3) at the mangrove area (Fig.1). Sediment samples were collected using core sampler in the base of the mangrove ecosystem which has a sandy mud substrate (Fig. 2). This procedure begins in the field using a core sampler (a 30 cm long PVC pipe), which is inserted vertically into the muddy substrate until it reaches a depth of 30 cm [12]. Once intact sediment samples are obtained, the samples are replaced from the corer, labeled specifically based on location and depth (0-10 cm and 20-30 cm), and transported to the laboratory under controlled conditions (kept cool) to minimize changes in chemical content prior to laboratory analysis [13].

C. *Laboratory Analysis*

The process in the laboratory continues with a crucial preparation stage before the analysis of Ni content can be carried out. All the preparation steps include drying the sediment sample (in an oven at 60–80°C) until a constant weight is achieved, followed by grinding and sieving to ensure the sample is homogeneous [14]. The homogeneous dry sample then undergoes wet digestion, where a certain mass of sediment is dissolved in a mixture of strong acids (method followed by Analuddin et al [15]. to release the total

Nickel content from the sediment matrix into the solution. The resulting destruction solution is then measured for its metal concentration using high-precision instruments such as Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), with the final results presented in units of part per million (ppm).

D. Contamination Factor

Contamination Factor (CF) is a quantitative index developed by Hakanson [16] to assess the level of trace element pollution at a sediment site. The main objective of CF is to provide a quick and easily interpretable metric regarding how much the concentration of a specific metal (for example, Nickel) has increased compared to the natural or pre-industrial background concentration [17]. CF is calculated by the equation 1 [18]. The use of CF is very important in environmental research because it only requires target metal concentration data and reference background values (for example, the global average value of the earth's crust or the value from uncontaminated deeper sediment layers) without the need for normalization element data, making it an efficient early-stage contamination screening method [19]. The choice of background value $C_{background}$ is crucial; it usually involves using the average continental crust value (for example, 20 ppm for Ni from Turekian and Wedepohl) [20.21], or values from deeper sediment layers at the study site that are considered unaffected by pollution..

The resulting CF values have clear environmental implications, classified into four levels. A CF value of < 1 indicates a low concentration or even depletion (lower than background). Values of 1 < CF < 3 indicate moderate contamination. Values of 3 < CF < 6 are classified as considerable pollution, showing significant input from pollutants. Meanwhile, values of > 6 indicate a very high level of pollution [22,23]

$$CF = \frac{C_{sample}}{C_{background}} \quad \textbf{(1)}$$

Where :

EF : Contamination Factor

C_{sample} : metal concentration in sample

$C_{background}$: reference concentration in background

III. RESULT AND DISCUSSION

3.1 Heavy metal concentration

The concentrations of nickel show significant variation between stations (Table 1). Station R3 has the highest Ni concentration in the surface layer (2.417 ppm), nearly twice that of R2 (1.274 ppm) and much higher than R1 (0.301 ppm). This indicates that Station R3 is likely the most vulnerable point to Nickel input (for example, from nearby pollution sources). The pattern of Ni variation by depth differs at each station; station R3 shows a very sharp decrease in concentration from the surface (2.417 ppm) to the bottom layer (0.864 ppm). This pattern is characteristic of the accumulation of new or contemporary pollutants, which tend to bind and accumulate in the upper sediment layer (0-10 cm) that is rich in organic material.[24.25]. Station R1 shows an increase in concentration from the upper layer (0.301 ppm) to the lower layer (0.490 ppm). This pattern may indicate older inputs or the process of redistribution and reburial of already contaminated sediments [26]. Station R2 shows a slight decrease from the upper layer (1,274 ppm) to the lower layer (1,002 ppm). The pattern of decreasing Nickel concentration from the upper layer (0-10 cm) to the lower layer (20-30 cm) at Station R2 (1,274 ppm - 1,002 ppm) indicates that there has been layer factors which determine metal concetration from higher concentration (suface layer) into lower concentration (deep layer) [27].

Figure 2. Mangrove sediment (left) and mangrove stands (right).

Table 1. Concentration of Nickel in each sampling points.

Station	Ni (ppm)
R1 (0-10 cm)	0,301
R1 (20-30 cm)	0,490
R2(0-10 cm)	1,274
R2 (20-30 cm)	1,002
R3 (0-10 cm)	2,417
R3 (20-30 cm)	0,864
Reference[a]	20

[a] Reference : Turekian and Wedepohl (1961).

Table 2. Contamination factor (CF) in the sediment sample.

Station	CF_Ni
R1 (0-10 cm)	0.015
R1 (20-30 cm)	0.025
R2(0-10 cm)	0.064
R2 (20-30 cm)	0.050
R3 (0-10 cm)	0.121
R3 (20-30 cm)	0.043

3.1.2 Contamination Factor

The calculation of the contamination factor (CF) for Nickel (Ni) data in the sediment shows that all samples taken from Stations R1, R2, and R3, both at depths of 0-10 cm and 20-30 cm, have a very low level of contamination relative to the global geochemical background value (20 ppm) as referenced from earth's crust [20,21] (Table 2). All CF values are far below the threshold of one (CF < 1), ranging from 0.015 to 0.121. These extremely low values indicate that the sediments in the study area as a whole have not experienced significant contamination of Nickel compared to the average Nickel concentration in the Earth's crust. In other words, the primary source of Nickel input at this location is most likely still dominated by geogenic processes or natural weathering, rather than by massive anthropogenic activities [16,28].

Nevertheless, station-level analysis shows enrichment patterns that warrant attention. The highest CF value was found in the surface layer sample (0–10 cm) at Station R3, with a value of 0.121, which is four times higher than the lowest CF value in the surface layer at R1, namely 0.015. The Ni concentration at R3 also decreased drastically in the bottom layer (20–30 cm) to 0.043, indicating a much stronger accumulation trend in the newer sediment layer (surface) at Station R3 compared to the other stations. This pattern suggests that Station R3 may be located closest to the source of the most recent nickel input (although still in the low category), making it an area that should be prioritized for environmental monitoring. To confirm this finding and rule out natural geological variation, further analysis should use a complete Enrichment Factor (EF) with normalized data from local reference elements such as iron (Fe) or aluminum (Al).

IV. CONCLUSION

Analysis of nickel (Ni) concentration data in sediments at stations R1, R2, and R3, revealed by contamination factor (CF) calculations, collectively indicate that the study area falls into the low contamination or uncontaminated category when compared to the global geochemical background value (20 ppm). All calculated CF values are well below the threshold of one (CF < 1), indicating that the measured Ni concentrations are generally within the range influenced by natural geogenic sources in each deep layer. Nevertheless, the observed vertical pattern, especially at Station R3, where the surface layer (0-10 cm) has the highest Ni concentration and drops sharply in the deeper layer (20-30 cm), suggests a more recent input of Ni into the aquatic system. This pattern is consistent with the accumulation of pollutants in younger sediment layers, strongly bound to organic matter or iron/manganese oxides in the surface aerobic oxidation zone, before being buried or mobilized.

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