

## Potential of Mangrove Plants (*Rhizophora apiculata*) as Accumulators of Pb (II) Metal Ions in the Mangrove Ecosystem of Nania Village, Ambon City

Abraham Mariwy\*, Julita. B Manuhutu, Secondina Arbol

Chemistry Education Study Program, Faculty of Teaching and Education, Universitas Pattimura, Jl. Ir. M. Putuhena No.1, Ambon, Indonesia, 97233

\*Corresponding Author: [abraham.mariwy@lecturer.unpatti.ac.id](mailto:abraham.mariwy@lecturer.unpatti.ac.id)

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### Abstract

Mangrove plants play an important role in maintaining the quality of coastal environments because they are capable of absorbing and accumulating heavy metals from water sediments. Therefore, this study aims to determine the potential of mangrove plants (*Rhizophora apiculata*) as accumulators of Pb (II) metal ions in the mangrove ecosystem of Nania Village, Ambon City. The results of this study show that the highest levels of Pb (II) metal ions were found in leaf samples at three sampling locations, followed by sediment and root samples. Characterization results using XRF to identify the types and composition of elements in sediment samples showed that Fe, K, Ca, and Ti were the elements with the highest composition, followed by Ba, Zr, Mn, Zr, Zn, Sn, and Pb. The results of sediment particle type measurements using a sieve shaker at three sampling locations showed that the dominant sediment particle type is coarse gravelly sand, which has a low capacity to absorb and accumulate heavy metals. Meanwhile, the calculation results of the BCF and TF values of mangrove plants (*Rhizophora apiculata*) were  $> 1$ , indicating their ability as accumulators to accumulate Pb (II) metal ions in the mangrove ecosystem in Nania Village, Ambon City.

*Keywords: Bioaccumulation, Accumulator, Lead, Rhizophora apiculata, Sediment*

### INTRODUCTION

Marine water areas are aquatic environments that are directly connected to various human activities, including the industrial, agricultural, and transportation sectors. The waters of the inner Ambon Bay, particularly Nania Village, are one of the coastal areas close to local residential settlements. As an area dense with human activities such as household waste, vehicle emissions, garbage, and other sources, it has a direct impact on the water environment conditions of Nania Village (Male et al., 2017). The decline in the quality of a water body can be caused by pollutants, both organic and inorganic components; the inorganic part contains various dissolved minerals, with heavy metals as one of the components that are toxic. The environment, often contaminated by several types of heavy metals, both essential (Cr, Ni, Cu, and Zn) and non-essential (As, Cd, Pb, and Hg), can become toxic when present at high concentrations in the environment (Khairunnisa, 2017). Lead metal or Pb (Plumbum) is one of the chemical elements classified as a heavy metal and can potentially become a contaminant (Qomariyah, Nuryono, & Kunarti, 2021). Lead that enters water bodies can persist in the water body before

being adsorbed by particulates and deposited in the sediments present in that water.

Sediment plays an important role in the control the concentration of accumulated heavy metals on plants waters tissue. According to Maslukah (2019), sediments with fine particle sizes are easier to accumulate in organic and inorganic matter, one of which is heavy metals that accumulate in sediment and can increase due to human activities around these waters. Heavy metal levels are higher in sediments in aquatic areas because heavy metals are absorbed by particles and then accumulate in sediment (Mariwy, Male, & Manuhutu, 2019).

Nania Village, which is the object of this study, has a mangrove ecosystem with an area of about 2.40 hectares, which has been used by the community as a place to look for fish, shrimp, crabs, and shellfish (Salakory, Harahab, & Yanuwiadi, 2017). Therefore, this mangrove ecosystem must be maintained and preserved because mangrove plants also function as metal accumulators that can naturally accumulate heavy metals around their roots, which is referred to as biosorption (Mariwy, Dulanlebit, & Ode, 2024). The process of metal biosorption in mangrove plants not

only occurs in the roots but can also occur in leaves, stems, and other tissues. However, the roots are the main part most active in the absorb accumulating heavy metals due to direct contact with contaminated sediments and water (Yap & Al-Mutairi, 2023).

This study was conducted to assess the ability of the mangrove plant *Rhizophora apiculata* to accumulate Pb (II) metal ions found in sediments in the mangrove ecosystem of Nania Village, Ambon City. This village was chosen because it has a much smaller mangrove forest area than other coastal villages in Ambon Bay, so the results of this study can be a reference for the government and community for conserving mangrove forests in Nania Village.

The sampling location is determined by GPS. Sediment samples are collected using PVC pipes, while the temperature is measured by a thermometer. The pH measurement of seawater uses a pH meter, and the salinity is determined by a salinometer, with Pb(II) metal ion concentration in the sample using spectrophotometer Analysis SSA, while the analysis of the type and composition of metals in sediment samples uses XRF.

## METHODOLOGY

### Materials and Instrumentals

The materials used in this research include mangrove root and leaf samples, sediment samples,  $\text{Pb}(\text{NO}_3)_2$  1000 ppm raw solution, concentrated  $\text{HNO}_3$  solution, concentrated  $\text{HClO}_4$  solution, aquades, filter paper, and aluminum foil.

The equipment used in this research includes SSA (SHIMADZU, 7000), XRF (HITACHI X-MET 8000), Sieve shaker (Sieving Machine AS 200 basic), (Garmin), thermometer (Omron Digital Thermometer MC - 341a), refractometer (ATC), hotplate, oven (Menmert), neraca analitik (Cyberscan WITH 1110), pH meter (ATC), PVC pipe, chemical glassware (pyrex), 200 mesh sieve.

### Methods

#### *Initial Treatment of Mangrove Sediment, Roots, and Leaves Samples*

Sediment samples are placed in petri dishes, while mangrove roots and leaves are cut into small pieces. The entire sample is then dried in the oven at 100 °C until it reaches a dry state. After that, the sample is ground until smooth and filtered using a 200-mesh sieve. The homogeneous sample was weighed on an analytical balance, placed in a labeled plastic bag, and then prepared for further analysis (Mariwy et al., 2024). Destruction of Mangrove sediment, roots, and leaf samples. A total of 3 grams of the mashed sample was weighed and placed in a 100 mL beaker. The

sample was then added to 15 mL of  $\text{HNO}_3$  and 5 mL of  $\text{HClO}_4$  as a solvent solution. The mixture is left to sit for 24 hours until a clear solution is formed. Next, the sample is heated using a hotplate until it is dissolved and almost dry. The heated solution is added to 10 mL of aquadest, then filtered into a 25 mL measuring flask and re-diluted with aquades until it reaches the limit mark. Samples are ready to be analyzed using the SSA (Mariwy et al., 2024; Mariwy, Manuhutu, & Tuhauruw, 2025).

#### *Manufacture of Pb Standard Solution*

A total of 1 mL of Pb solution from the parent solution with a concentration of 1000 ppm is put into a 100 mL measuring flask, then diluted with aquades until it reaches the limit mark. Standard solution with a concentration of 0.05; 0.5; 1; 1.5; 2; 3; and 4 ppm each made as much as 100 mL by pipetting 0.5; 5; 10; 15; 20; 30; and 40 mL of 10 ppm Pb solution, then diluted using aquades to the boundary mark. Furthermore, the absorbance value of each standard solution was measured using SSA at a wavelength of 217 nm.

#### *Lead level (Pb) Analysis with SSA*

Each sample was analyzed by measuring its absorbance value using a Pb cathode lamp at a wavelength of 217.00 nm. Absorbance value. The obtained was incorporated into the regression equation of the standard curve to determine lead metal (Pb) levels in mangrove sediment, root, and leaf samples (Mariwy et al., 2024).

#### *Elemental Composition Analysis in Sediment Samples with XRF*

The sediment sample is first dried until it reaches a constant weight, then smoothed and sifted to obtain a uniform particle size. After that, the sample is placed on a sample holder and analyzed using the XRF instrument. In the measurement process, the sample is shot with high-energy X-rays so that the atoms in the sample experience excitation and emit fluorescent rays with a typical energy for each element. The energy and intensity of the resulting fluorescence beam are then detected by the device to identify the type of element as well as determine the relative concentration of each metal in the sediment sample. The data from the analysis are then interpreted to determine the composition of the dominant metal and the presence of heavy metals in sediments at the research site.

*Determination of Sediment Particle Detail Type*

Analysis of sediment grain size was carried out using the wet sifting method with the help of a sieve shaker. The sediment sample is first placed in a container and dried in the oven at 70–80 °C for 24 hours. After drying, the sample is weighed using an analytical scale to obtain a total dry weight. The sample is then soaked in aquades for 5 hours to separate the sediment grains. Furthermore, arranged Sieve Based on the order of grain size from the smallest at the bottom to the largest at the top, and the sample was sifted starting from a >4.00 mm sieve. The washing process is carried out by flushing running water while stirring using a brush so that the sediment particles separate well. The material retained in each sieve is transferred to an aluminum tray and dried again in the oven at 70– 80 °C for 2 hours. Each sediment fraction obtained is then weighed and recorded in weight as grain size data. The data were then analyzed using Microsoft Excel to determine the type of sediment (Mariwy et al., 2024).

**Data Analysis***Calculation of the absorbance Value*

The calculation based on the data of the absorbance results of the sample solution that has been tested, the concentration of the Lead metal content (Pb) of the sample solution can be determined by entering the absorbance data into the linear regression line equation of the standard solution. For the standard solution of lead, the linear equation is as follows:

$$y = ax + b \quad (1)$$

Description:

$y = \text{sample's absorbance}$

$a = \text{slope}$

$x = \text{concentration}$

$b = \text{intercept}$

The concentration of the sample is obtained from the standard curve; hence, the calculation of the lead content should be made using the formula:

$$Pb \text{ content} = \frac{\text{concentration} \left(\frac{mg}{L}\right) \times \text{volume (L)}}{\text{sample's mass (kg)}} \quad (2)$$

*The calculation of the Bioconcentration Factor (BCF)*

BCF in the roots is calculated to find out how much metal content in the roots comes from the environment. According to Yoon et al. (2006) and Mariwy (2021), the formula for the BCF calculation is as follows:

$$BCF = \frac{Pb \text{ content in the plants tissue (mg/kg)}}{Pb \text{ content in the sediment (mg/kg)}} \dots\dots (3)$$

According to Baker (1981) in Mariwy et al. (2021), the BCF category is divided into 3, namely:

- 1) Accumulator : BCF > 1
- 2) Indicator : BCF = 1
- 3) Excluder : BCF < 1

*Translocation Factor (TF) Calculation*

The TF value is calculated to determine the transfer of the accumulated metals from the roots to the leaves (Yoon et al., 2006; in Mariwy, 2021). TF can be calculated with the formula:

$$TF = \frac{Pb \text{ Metal value at leaf}}{Pb \text{ Metal value at root}} \quad (4)$$

TF values have 2 categories, namely;

- 1) TF > 1: Phytoextraction mechanism
- 2) TF < 1: Phytostabilization mechanism

**RESULTS AND DISCUSSION****Sample Collection Process**

The research samples were taken on the coast of Nania Village, Baguala District, Ambon City, Maluku Province. Samples in the form of sediment, roots, and mangrove leaves were collected during low tide on October 4, 2025, from 13:55 to 15:10 WIT. Samples were taken at 3 different random locations, considering main factors such as the amount of mangrove vegetation and environmental conditions close to residential areas. The sample collection points are shown in Figure 1.

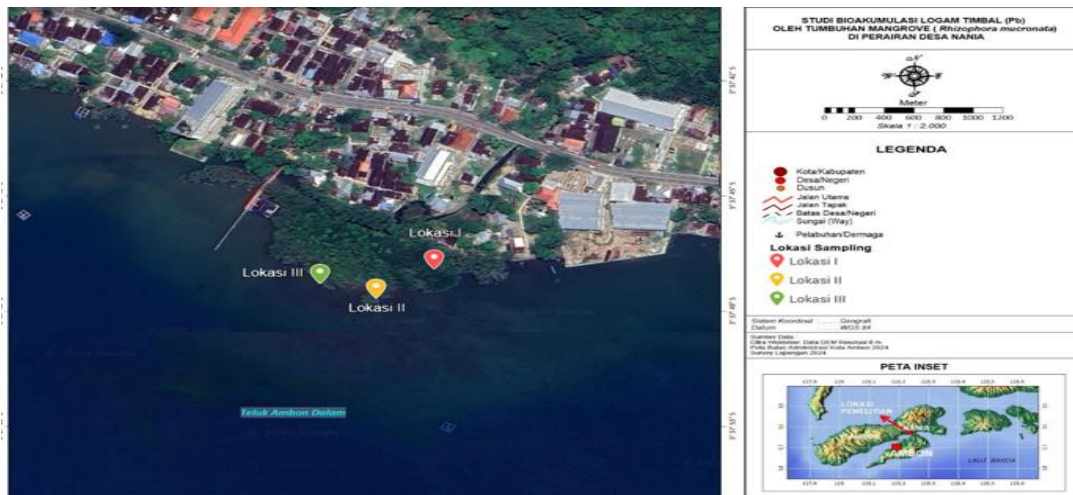


Figure 1. Sampling Location Map

**Physicochemical Parameters of Waters**

The quality of seawater used for marine biota ideally must meet standards, both physically, chemically, and biologically (Umasugi, Ismail, & Irsan, 2021). Observations of conditions and measurements of seawater quality conducted during the study provide an overview of the water conditions at the sampling locations (Kahula et al., 2024). The physicochemical parameters of the water measured in this study were temperature, pH, and salinity. Furthermore, the results of the physical and chemical parameters of Nania waters based on the quality standards set by Government Regulation No. 22 of 2021 are shown in Table 1.

Table 1. Physical and Chemical Parameter Measurement Results

Parameter	Unit	Location			Standard
		1	2	3	
Temperature	°C	28	30	30	28-32
Salinity	‰	20	20	19	33-34
pH	-	5,9	6,3	6,3	7,0-8,5

The water temperature at the sampling locations, as shown in Table 1, indicates an optimal range for the life of aquatic organisms, which is between 28 and 32 °C. Thus, the temperatures measured at the three research sites remain within normal and safe limits according to the seawater quality standards established in Government Regulation No. 22 of 2021. The ability of water to dissolve heavy metal contaminants strongly depends on the temperature in the aquatic environment; the higher the water temperature, the greater the solubility of heavy metals (Mariwy et al.,

2025), and conversely, the lower the water temperature, the higher the toxicity of heavy metal concentrations.

Meanwhile, the results of salinity measurements in the waters of Nania Village at locations 1, 2, and 3 were 20, 20, and 19 ‰, respectively. Based on these measurements, the salinity in Nania Village is still considered low. Referring to the seawater quality standards set in Government Regulation No. 22 of 2021, the optimal salt content for the life of aquatic organisms is in the range of 33-34 ‰, so the measured salinity at the three research locations shows lower numbers compared to the standards set as ideal conditions for the life of marine organisms. The low salt content in the waters of Nania Village is caused by the inflow of freshwater from the land, originating from river flows and river mouths close to the coastal area (Haidar, Handoyo, & Indrayanti, 2021). Changes in salt levels have a significant impact on the concentration of heavy metals in water. When salt levels decrease, the toxicity of heavy metals increases, resulting in a more intense bioaccumulation process of the heavy metal Pb in aquatic organisms.

The measurement of pH serves as an indicator of the acidity or alkalinity level within an aquatic environment, as well as reflecting the concentration or activity of hydrogen ions (H<sup>+</sup>) present in the water. A water body is considered neutral when the pH value equals 7. If the pH value is less than 7, the water is classified as acidic, whereas water with a pH value greater than 7 is considered alkaline. Based on the pH measurements conducted in the waters of Nania Village, the recorded values at Locations 1, 2, and 3 were 5.9, 6.3, and 6.3, respectively. Referring to the marine water quality standards established under Government Regulation No. 22 of 2021, the optimal pH range for the survival of aquatic organisms is

between 7.0 and 8.5. Therefore, the pH levels measured at all three locations can be considered insufficiently safe for aquatic life, as the relatively low pH values indicate acidic water conditions.

The increased acidity of the waters may be attributed to the direct discharge of domestic waste into the sea, as such waste contributes to elevated levels of organic matter. The decomposition of organic matter by microorganisms produces CO<sub>2</sub> and acidic compounds, which can subsequently lower the pH of the aquatic environment (Harmesa, Wahyudi, Wong, & Ikhsani, 2024). This finding is consistent with the opinion of Mariwy et al. (2019), who stated that when water pH decreases or becomes more acidic, the toxic effects of heavy metals also tend to increase. This phenomenon facilitates the transfer of metals from sediments into the water column and potentially enhances their toxicity (Girones, Oliva, Negrin, Marcovecchio, & Arias, 2021).

### Calibration Curve Preparation

The parameters that need to be made to analyze heavy metal levels are the linearity of the calibration curve. The calibration curve is generated from measurements of the absorption of standard solutions at predetermined concentrations, so from the curve, a regression equation can be obtained. The creation of the calibration curve begins by preparing lead (Pb) standard solutions with concentration variations of 0.05, 0.5, 1, 1.5, 2, 3, and 4 ppm. Next, the absorbance is measured using SSA test parameters. The absorbance measurements from the standard solutions are then plotted to obtain the calibration curve and linear equation shown in Figure 2.

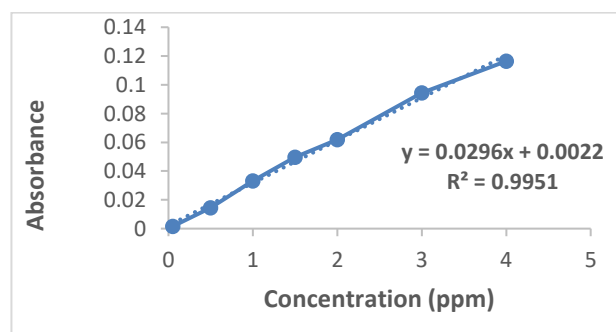


Figure 2. Calibration curve for Pb

The calibration curve equation of the Pb standard solution in Figure 2 shows the linear equation of the Pb standard solution, which is  $y = 0.0296x + 0.0022$  with a correlation coefficient value ( $R^2$ ) = 0.9951. This calibration curve indicates that there is a relationship between the concentration variations and absorbance,

resulting in a slope and intercept. As the concentration increases, the absorbance also increases (Mariwy et al., 2019).

### Pb Metal Levels in Sediment, Leaf, and Root Samples

Subsequently, solutions of each sample to be analyzed were prepared using the wet digestion method, and their absorbance values were measured using Atomic Absorption Spectrophotometry (AAS) at a wavelength of 217.00 nm to determine the Pb concentration in the samples. The results of Pb concentration measurements obtained from sediment, mangrove leaf, and mangrove root samples at the three sampling locations are presented in Figure 3.

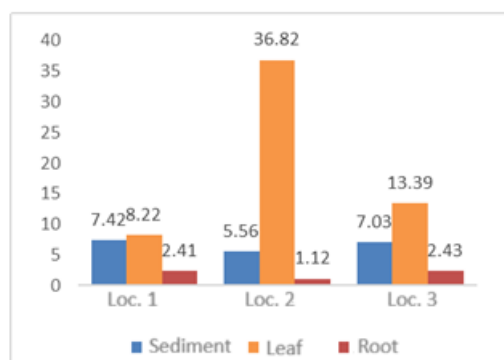


Figure 3. Pb Concentration Diagram of Samples at Locations 1, 2, and 3

The analysis results of Pb metal content in Figure 3 show the presence of Pb metal levels contained in samples at Locations 1, 2, and 3, respectively, which are in sediment at 7.42; 5.56; 7.03 mg/kg, leaves at 8.22; 36.82; 13.39 mg/kg, and roots at 2.41; 1.12; 2.43 mg/kg. In sediment and leaf samples, Pb metal levels are higher compared to Pb metal levels in root samples. According to Mariwy et al. (2024), this is caused by the smooth translocation process, where the Pb metal absorbed by the root tissues can quickly move and accumulate in the leaf parts of the plant, which can lead to high Pb metal levels in leaf samples.

Plants utilize chelates to bind and absorb heavy metals from the environment (Irhamni, Pandia, Purba, & Hasan, 2017). Phytochelatin is a form of plant adaptation to high levels of heavy metals in the environment. This compound is formed from proteins composed of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S), and consists of long chains of amino acids. In the process, heavy metals bind to phytochelatin to form heavy metal-phytochelatin complexes, which are then filtered by the plants to absorb heavy metals more effectively (Titahena,

Mariwy, & Sunarti, 2023). The structure of the phytochelatin compound can be seen in Figure 4 below.

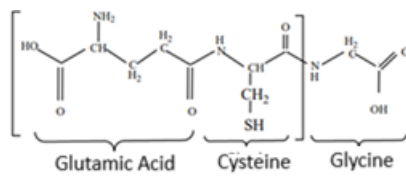


Figure 4. Phytochelatin compound structure

As for the factors causing the high levels of Pb metal in leaf samples at Locations 2 and 3, besides the fact that the places are quite close to residential areas, leading to household waste, it is also because Locations 2 and 3 are near the PT Lumbung Ikan Maluku building, so the factory's operational processes and fish transport ship traffic, including the ship painting process using paint containing lead, also contribute to the increased levels of Pb (II) metal ions in leaf samples at these locations.

Previous research conducted by Mariwy et al., 2024, to study the bioaccumulation capacity of Pb metal in mangrove plants of the same species, namely *Rhizophora apiculata*, in the waters of Poka Village, Ambon Bay, showed opposite data, indicating that the Pb (II) ion content was higher in sediment samples. This suggests that the grain size and type of sediment greatly influence the Pb (II) ion levels, where sediments with a muddy substrate, such as in Poka

Village, are capable of binding heavy metals more effectively because the ion density in muddy substrates is more stable compared to the sediment size and type in Nania Village, where most of the sediment is sandy gravel (Mariwy et al., 2024).

#### Determination of Elemental Composition in Sediments Using XRF

The purpose of determining the elemental composition in sediments using XRF (X-Ray Fluorescence) is to identify and measure the concentration of chemical elements contained in the sediments both qualitatively and quantitatively, so that the geochemical characteristics of the sediments can be known. Elemental composition data from XRF can be used to detect the presence of major, minor, and trace elements, including heavy metals, making it useful in studies of environmental pollution, sediment quality evaluation, and interpretation of potential geochemical interactions occurring in aquatic or terrestrial environments where the sediments are located (Ambrosino et al., 2023). The results of the analysis of the types and composition of elements in the sediment samples indicate that Fe, K, Ca, and Ti are the elements with the highest composition, followed by Ba, Zr, Mn, Zr, Zn, Sn, and Pb. Furthermore, the types and elemental composition in sediments at the three sampling locations can be seen in Table 2 below.

Table 2. Types and Elemental Composition in Sediments by using XRF

Sampling location	Elemental Composition (%)											
	Fe	K	Ca	Ti	Ba	Mn	Zr	Rb	Sr	Zn	Sn	Pb
1	26361	13158	9283	2813	375	297	245	177	93	75	61	32
2	2459	14602	9167	1987	408	314	179	113	87	49	42	37
3	22224	16808	7905	2001	375	349	206	181	87	76	51	37

The data in Table 2 show very high concentrations of Fe, Si, Ca, and Ti in the sediment, indicating the dominance of mineral matrices that play an important role in controlling Pb distribution. The high Fe content indicates the presence of iron oxides as the main adsorbent phase for Pb, while Ca suggests a possible association of Pb with the carbonate fraction. The dominance of Si reflects the silicate matrix of the sediment, while Ti indicates a contribution from geogenic material. This combination of characteristics indicates that the presence of Pb in the sediment is greatly influenced by geochemical interactions with the sediment-forming minerals (Moushmi et al., 2022). The spectrum of XRF measurement results shows a very dominant peak in the range of 6.3–6.5 keV, which is very likely Fe K $\alpha$  (6.40 keV). This is consistent with mangrove sediments that are generally rich in iron oxides and silicate minerals. The presence of Fe in high amounts is very important because iron oxides are known to have a high adsorption capacity for heavy metal ions such as Pb through surface complexation and ion exchange mechanisms (Ambrosino et al., 2024). Furthermore, the spectrum of the measurement results of the elemental composition in sediments at locations 1, 2, and 3 can be seen in the following Figure 5.

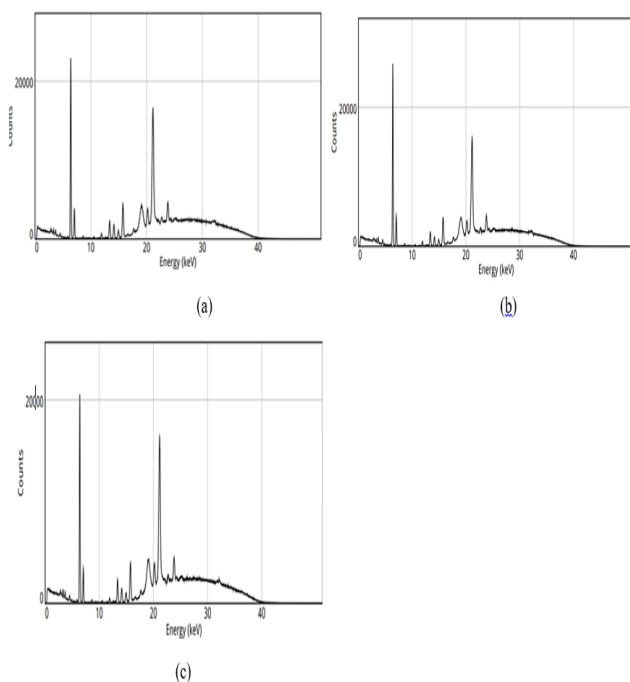


Figure 5. XRF Spectrum of sediment sample in (a) location 1, (b) location 2, and (c) location 3

### Determination of Sediment Particle Types

The presence of heavy metals in sediment layers is not solely determined by the amount of metal entering the environment but is also influenced by the size and distribution of sediment particles. These factors play important roles in the sedimentation process that ultimately forms sediment layers (Ridha, Ernawati, & Cahyadi, 2019). The sediment grain-size classification commonly used by hydraulic experts is the classification proposed by the Subcommittee on Sediment Terminology of the AGU (American Geophysical Union) (Lane, 1947). This classification was also adopted as the basis for sediment particle classification in the present study, namely: fine gravel = 8–4 mm, fine sand = 1/4–1/8 mm, and fine silt = 1/64–1/128 mm (Mregawati, Ikhsan, & Koosdaryani, 2017). The results of sediment particle-size measurements at Locations 1, 2, and 3 in Nania Village, which have been classified accordingly, are presented in Figure 8.

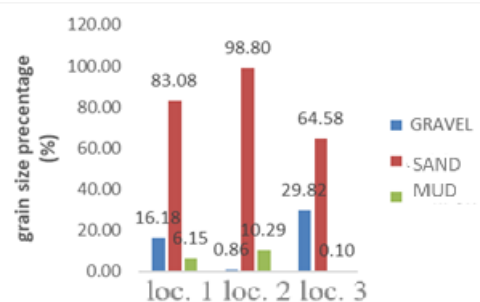


Figure 8. Sediment Grain Size Classification Diagram

The results of sediment grain-size determination at Locations 1, 2, and 3 indicated that sand particles were more dominant than gravel and silt, although the percentage composition of sediment sizes varied among the sites. Therefore, the sediments were classified as gravelly sand substrates. This type of substrate possesses coarser sediment particles compared to other substrate types, thereby reducing the capacity for the adsorption and deposition of heavy metals and organic matter.

In comparison, muddy substrates with finer textures have a larger surface area. This characteristic results in a more stable ion density within the muddy substrate, enabling it to bind heavy metals more effectively (Mariwy et al., 2024). The percentage of muddy substrate was relatively higher at Location 2 than at Locations 1 and 3, which may be one of the factors contributing to the elevated concentration of Pb(II) metal ions at Location 2, since muddy substrates possess a greater ability to retain heavy metals within sediments.

### Bioconcentration Factor (BCF) and Translocation Factor (TF) Values

The calculation of the Bioconcentration Factor (BCF) was conducted to evaluate the effectiveness of Pb heavy metal accumulation from sediments into mangrove plants. Meanwhile, the Translocation Factor (TF) was calculated to determine the ability of mangrove plants to translocate and accumulate Pb metal from the roots to the leaves. The results of the BCF and TF calculations are presented in Table 3.

Table 3. BCF and TF Values

Location	BCF root	BCF leaf	Total BCF	TF
1	0,32	1,10	1,42	3,41
2	0,20	6,62	6,82	31,74
3	0,34	1,90	2,24	5,51

Based on the calculation results presented in Table 3, the total BCF values of Pb in the roots and leaves at Locations 1, 2, and 3 were generally greater than 1 (>1). These average values indicate that the mangrove plant *Rhizophora apiculata* can be categorized as an accumulator plant for Pb heavy metal, due to its ability to accumulate heavy metals within its tissues. However, the average BCF values in the roots were less than 1 (<1), indicating excluder characteristics, namely the ability of the roots to limit the absorption of heavy metals from the surrounding environment, including water and sediments (Santana, Gde Sasmita J., & Wijayanti, 2018). Nevertheless, once heavy metals successfully penetrate this defense mechanism and enter the root tissues, they are rapidly translocated to other plant organs, thereby preventing excessive accumulation in the roots. This phenomenon explains the significant difference between Pb BCF values in roots and leaves, leading to the classification of *Rhizophora apiculata* as a Pb accumulator plant.

The results presented in Table 3 also showed that the TF values of Pb from roots to leaves at Locations 1, 2, and 3 were greater than 1 (>1). These findings indicate that *Rhizophora apiculata* can be classified as a phytoextraction plant because its roots effectively absorb heavy metals, which are subsequently translocated and accumulated in other plant organs, particularly the leaves. This mechanism contributes to the high BCF values observed in mangrove leaves (Rachmawati, Yona, & Kasitowati, 2018). Heavy metals detected in plant leaves may originate not only from internal translocation but also from external atmospheric deposition. Heavy metal particles present in the atmosphere can adhere to leaf surfaces and

subsequently enter through the stomata, accumulating within leaf tissues. This process may explain the higher Pb concentrations found in leaves compared to roots (Mariwy et al., 2024).

### CONCLUSION

The results of this study indicate that the concentration of Pb(II) metal ions in mangrove leaf samples at the three sampling locations was higher than that found in sediment and root samples. This condition may be attributed to the relatively high translocation factor, in which Pb(II) metal ions were directly translocated to the leaves. The characterization results obtained using X-ray Fluorescence (XRF) analysis to determine the types and elemental composition of the sediment samples revealed that Fe, K, Ca, and Ti were the dominant elements, followed by Ba, Zr, Mn, Zn, Sn, and Pb.

Meanwhile, the determination of sediment particle types at the study sites using a sieve shaker showed that the sediments in the waters of Nania Village were predominantly composed of gravelly sand substrates with relatively large particle sizes. Such sediment characteristics generally exhibit a lower capacity for the adsorption and accumulation of heavy metals. Furthermore, the calculated Bioconcentration Factor (BCF) and Translocation Factor (TF) values of the mangrove plant *Rhizophora apiculata* were greater than 1, indicating its capability as a metal accumulator and confirming that this species is effective in the phytoremediation process, particularly in phytoextraction.

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