Index of environmental pollution and adaptation of *Avicennia marina* around the ex-bauxite mining area in Bintan Island

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Abstract. Bintan Island has high bauxite resource potential. However, its utilization is not balanced with efforts to restore ex-mining land. Physical damage includes erosion and sedimentation of red mud along the coast and the surrounding mangrove forest. This study aims to determine environmental pollution based on the accumulation of lead (Pb) and chromium (Cr) in red mud found in mangrove forests around the bauxite ex-mining area and the adaptation of *Avicennia marina* to heavy metals. This research was conducted from April to December 2020. Research survey and laboratory analysis using Atomic Absorbance Spectrophotometry. The results showed that Pb in the sediments and organs of *A. marina* was higher than Cr. The results showed that the mangrove forest around the bauxite ex-mining area of Bintan Island was contaminated with low levels of Pb and Cr metals (CF<1, PL<1) and the environment is lightly polluted (0<Igeo<1). Adaptation of *A. marina* showed that the metal uptake mechanism was rhizofiltration (BCF<1, TF<1, BCF<TF) and the physical condition was slightly damaged. There was no significant effect between Pb and Cr metals in the sediments and organs of *A. marina* on the stem diameter and tree height (Sig.>0.05).

Keywords: *A. marina*; bauxite ex-mining area; Bintan Island; environmental index

1. Introduction
Land clearing in Bintan Island, Riau Islands Province has increased from year to year. There is a former bauxite mine area at PT. Aneka Tambang (ANTAM) in Bintan Regency and Tanjungpinang City has become an office area, densely populated settlement activities [1]. However, most of the ex-bauxite mining areas in Bintan Island have not been adequately restored, causing erosion and sedimentation of red-mud accumulated around the mangrove forest. In contrast the mangrove ecosystem relies heavily on its root system to preserve itself. In addition, the mud containing humus in the substrate contains organic and inorganic elements such as phosphorus (P), nitrogen (N) and potassium (K) which are needed by mangroves [2]. Meanwhile, the physico-chemical properties of the soil derived from the former bauxite mine on Bintan Island showed low content N, P and K content values due to soil leaching [3]. Concentration of pollutants produced from bauxite could disrupt the environmental structure of the soil layer, so that heavy metal content from mining activities can accumulate and cause the concentration of heavy metal levels to increase [4]. The increase in pollutants accumulated in the sediments harms effect on the ecosystem and the quality of the surrounding environment.

*Avicennia marina* is one of the many types of mangroves found on the coast of Bintan Island. According to several research results, *A. marina* can absorb heavy metal elements through its root
However, there has been no study on the ability of *A. marina* located around the former bauxite mining area of Bintan Island to accumulate heavy metals. Therefore, this research is expected to be a source of information in the phytoremediation of heavy metals by *A. marina* around the former bauxite mining area.

2. Materials and methods

This research was conducted from April to August 2020 in Senggarang and Carang River Villages, Tanjungpinang City, Wacopek, and Tembeling at Bintan Regency. Laboratory analysis at the Bioprocess Laboratory, Faculty of Engineering, Riau University, Pekanbaru. The research method was conducted by a survey. Determination of the station was determined by purposive sampling based on consideration of conditions that were indeed exposed to red-mud sediment from the former bauxite mining area and the condition of the area of *A. marina* was found. Determination of the sampling location for *A. marina* stands was determined by purposive sampling referring to the cluster plot technique according to Mangold [7] and USDA-FS [8] (figure 1). Trees were taken only in the plot and had trunk circumferences from 35-50 cm. Sampling used a line transect divided into three plots with 10m² on stands of *A. marina* trees with trunk diameters > 10 cm, only one tree from each plot. The main tools used were a core sampler for sediment sampling, a knife for slicing *A. marina* organs, utilizing a roll meter, plastic samples, label paper, markers, laboratory equipment for destruction and Atomic Absorbance Spectroscopy (AAS) with the Spectra AA plus. The main chemical solutions used are concentrated HNO₃, HCl, and aquadest.

Sediment samples were taken at low tide, as much as ± 500 grams using a core sampler on the substrate under the canopy of the *A. marina* tree sample. *A. marina* organ samples taken consisted of roots, stems and leaves. Leaf samples were selected from the bottom of the canopy, dark green as much as 500 grams (about 20-30 old leaves). The tree trunk was measured 1.3 meters from the base of the roots in the tree, then sliced with a size of 10 m² and ± 2 cm thick. Root samples were taken from the largest part of the root compared to other roots, as much as ± 500 grams (about 5-10 roots). The destruction of each sample referred to the ash method (English et al., 1994). Sediment samples and each organ sample were heated in an oven at 105°C for 12 hours. After the sample was dry, 5 grams was taken and then dissolved using concentrated HNO₃ and HClO₄, aquadest was added until the volume was 50 ml. The sample solution was heated until the volume was reduced by 30 ml. The sample was deposited briefly, then filtered. The solution obtained was analyzed using AAS. The heavy metal concentrations tested were Pb and Cr. The status and level of environmental pollution of the ex-bauxite mining area contaminated with heavy metals were determined using the Contamination Factor (CF), Pollution Load Index (PLI), and Geo-accumulation Index (Igeo) [9, 10, 11] with the formula:

\[
\text{Contamination Factor (CF)} = \frac{C_x}{C_{background \ (Bn)}} 
\]

\[ C_x = \text{concentration of metal x at sample} \]
\[ C_{Bn} = \text{concentration of metal x normal in nature} \]

\[ 1 < CF < 3 = \text{middle contamination} \]
\[ 3 < CF < 6 = \text{enough contamination} \]
\[ CF > 6 = \text{hyper contamination.} \]

\[
\text{Pollution Load Index (PLI)} = [\text{CF}_1 \times \text{CF}_2 \times \text{CF}_n]^{1/n} 
\]

\[ n = \text{metal quantity} \]
\[ \text{CF} = \text{Contamination Factor} \]
\[ \text{PLI} < 1 = \text{Environment is not polluted} \]
\[ \text{PLI 1-2} = \text{Lightly polluted environment} \]
\[ \text{PLI 2-4} = \text{Medium polluted environment} \]
\[ \text{PLI 4-6} = \text{Severely polluted environment} \]
\[ \text{PLI 6-8} = \text{Very heavily polluted environment} \]
\[ \text{PLI 8-10} = \text{Extremely polluted environment.} \]
The results of the measurement of metal content in the sediment were then analyzed for the value of the translocation factor (TF) while the metal values in A. marina were analyzed for the value of the bio-concentration factor (BCF) based on the following equation [12].

\[ TF_{leafs or stems} = \frac{\text{metals in stems or leaf}}{\text{metals in roots}} \]  

\[ BCF = \frac{\text{average metal concentration in plants}}{\text{metals in sediment}} \]  

**Table 1.** Category of TF and BCF value [12].

| Category           | Value Range |
|--------------------|-------------|
| High accumulator   | >1.0        |
| Middle accumulator | > 0.1 – 1.0 |
| Low accumulator    | 0.01 – 0.1  |
| Non accumulator    | <0.01       |

**Table 2.** Results of Pb and Cr metals in seawater and sediment at sampling sites.

| No | Parameter | Unit | Sei Carang | Wacopek | Senggarang | Tembeling |
|----|-----------|------|------------|---------|------------|-----------|
| 1. | Metal in water | ppm | 0.0136 | 0.0139 | 0.0120 | 0.0013 |
|    | Pb        | ppm | 0.0080 | 0.0059 | 0.0037 | 0.0001 |
| 2. | Metal in sediment | ppm | 0.2323 | 0.2375 | 0.2387 | 0.0596 |
|    | Pb        | ppm | 0.0393 | 0.0460 | 0.0406 | 0.0121 |
|    | Cr        | ppm |        |        |        |          |

The results of the measurement of metal content in the sediment were then analyzed for the value of the translocation factor (TF), while the metal values in A. marina were analyzed for the value of the bio-concentration factor (BCF) based on the following equation [12]. TF and BCF value categories are presented in table 1.

**3. Results and discussion**

**3.1. Metals in water and sediment**

This study used the analysis of Pb and Cr as heavy metals to be tested for accumulation in mangrove organs which had the highest density and frequency index at the research site. The analysis results showed that the sediments and waters contained heavy metals Pb and Cr at each sampling location. The proportion of Pb and Cr content in sediments tends to be higher than those dissolved in water. The values of Pb and Cr metal content in sediment and seawater from the sampling location in April
Based on Table 2, it is known that the average value of Pb content in 2020 are presented in Table 2.

Figure 1. Sampling location in Bintan Island: (a) Tembeling, (b) Senggarang, (c) Sungai Carang and (d) Wacopek.
sily distributed by currents in the form of suspension, while the larger ones will settle to the bottom. The difference in rainfall each time will also affect the amount of sediments into the waters [17, 18].

This difference in levels is possible due to the variability of metal deposition in sediments caused by currents, adsorption, tides or deposition. Generally, bauxite mine sediments are fine sediments that are small in size and easily distributed by currents in the form of suspension, while the larger ones will settle to the bottom. The difference in rainfall each time will also affect the amount of accumulated sediment because the heavy flow of water from the land will cause erosion and bring suspended sediments into the waters [17, 18].

The content of heavy metals in sediments around coastal areas can be used as an indicator of the level of pollution of an environment [19]. This indication is obtained by using an analytical tool or method. The methods commonly used to assess environmental quality based on heavy metal content in sediments include the Contamination Factor (CF/Contamination Factor), Pollution Load Index (PLI/Pollution Load Index) and Geoaccumulation Index (Igeo/Geoaccumulation Index). The results of CF, Igeo and PLI calculations on mangrove forest sediments around the former bauxite mining area of Bintan Island are presented in table 3.

Based on the table, the value of the contamination factor (CF) of Pb and Cr metals in sediments in mangrove forests shows a low level of contamination (CF value < 1). The pollution load value (PLI) in mangrove forests also shows a PLI value < 1. The mangrove forest environment does not experience Pb and Cr metals pollution around the former bauxite mining area. While the value of the geo-accumulation index (Igeo) of Pb and Cr metals in mangrove forest sediments indicates that the

dissolved in seawater around the mangrove forest that grows in the post-bauxite mining area of Bintan Island ranges from 0.0013-0.0139 ppm. The highest Pb value was in Wacopek, followed by Carang River, Senggarang and the lowest was in Tembeling. The Pb value in the sediment at the exact location ranged from 0.0596 – 0.2387 ppm. However, the highest Pb content in the sediment was Senggarang while the lowest was Tembeling. Based on the quality standard according to Environment Minister's Decision No. 51 of 2004 Appendix III for Marine Biota and Marine Ecotourism [13] value in seawater around the post-bauxite mining area in the Carang, Wacopek and Senggarang Rivers has exceeded the limit maximum quality standard.

The average value of Cr in the sea waters at the study site ranged from 0.0001 to 0.0080 ppm. The highest value was found in Carang River, then Wacopek. Senggarang and the lowest value were found in Tembeling. In sediments, the average Cr content is higher than in dissolved in water. The highest Cr value was found in Wacopek, then, Senggarang, Carang River and the lowest was found in Tembeling. Concentration of Cr is influenced by organic material in the sediment [14]. Chromium in nature is never found as a pure metal. Sources of Cr in nature are very few, namely rock chromite (Fe₃Cr₂O₆) and chromate oxide (Cr₂O₃). Generally, Cr comes from the industrial waste of metals, textiles, paper, leather tanning, wool treatment and others [15].

### 3.2. Index of environmental pollution.

The average Pb and Cr content values in the sediments from our study found are smaller than the research by Putra et al. [16]. According to Putra et al. [16] in Bintan Island the Pb content is higher than Cr. Wacopek area has the highest Pb concentration value of 0.421 ppm while Sei Carang is 0.273 ppm. The value of Cr concentration in sediment in Wacopek is 0.018 ppm lower than Cr. Wacopek area has the highest Pb concentration value of 0.421 ppm while Sei Carang is 0.273 ppm. However, the highest Pb content in the sediment was Senggarang while the lowest was Tembeling. Based on the quality standard according to Environment Minister's Decision No. 51 of 2004 Appendix III for Marine Biota and Marine Ecotourism [13] value in seawater around the post-bauxite mining area in the Carang, Wacopek and Senggarang Rivers has exceeded the limit maximum quality standard.

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### Table 3. CF, Igeo and PLI values in mangrove forest sediments.

| Location   | Pb Concentration (ppm) | CF | Igeo | Cr Concentration (ppm) | CF | Igeo | PLI |
|------------|------------------------|----|------|------------------------|----|------|-----|
| Sei Carang | 0.2323                 | 0.0116 | 0.0023 | 0.0393                 | 0.0025 | 0.0005 | 0.0053 |
| Wacopek   | 0.2375                 | 0.0119 | 0.0024 | 0.0460                 | 0.0029 | 0.0006 | 0.0058 |
| Senggarang| 0.2387                 | 0.0119 | 0.0024 | 0.0406                 | 0.0025 | 0.0005 | 0.0055 |
| Tembeling | 0.0596                 | 0.0030 | 0.0006 | 0.0121                 | 0.0008 | 0.0002 | 0.0015 |

Based on the table, the value of the contamination factor (CF) of Pb and Cr metals in sediments in mangrove forests shows a low level of contamination (CF value < 1). The pollution load value (PLI) in mangrove forests also shows a PLI value < 1. The mangrove forest environment does not experience Pb and Cr metals pollution around the former bauxite mining area. While the value of the geo-accumulation index (Igeo) of Pb and Cr metals in mangrove forest sediments indicates that the
environment is classified as lightly polluted because $0 < I_{geo} < 1$. Based on these values, the environmental conditions of mangrove forests in the former bauxite mining area Bintan Island has not experienced heavy metal pollution. Whilst, they have been contaminated by heavy metal elements. However, several types of mangrove vegetation and other aquatic biota in the area, suspected that heavy metal accumulation has occurred in this vegetation and biota. Suppose the accumulation continues for a long time. In that case, it will endanger the ecological system in the mangrove ecosystem, such as the food chain process, which will impact on humans as consumers at the highest trophic level.

3.3. Adaptation of *A. marina* 

Based on the test results, the average value of Pb and Cr metal content in mangrove organs (roots, stems and leaves) showed varying values. The average Pb and Cr content values in *A. marina* mangrove roots are higher than the stems and leaves. Based on table 4, it is known that Tembeling has the lowest accumulation of Pb and Cr metals in its mangrove plant organs. The area with the highest metal accumulation in its mangroves is Senggarang, then Wacopek and Carang River. The variation of metal accumulation in mangrove organs is also related to Pb and Cr metals in seawater and sediments. Based on the study results, Tembeling is an area with the lowest average value of Pb and Cr metal content in seawater, sediments and mangroves. Meanwhile, the Carang, Wacopek and Senggarang rivers have a higher average metal accumulation value in seawater, sediments and mangroves.

From the analysis results, mangrove species of *A. marina* can absorb Pb and Cr metals through their roots and then translocate them to other plant parts such as stems and leaves. The high content of heavy metals in the roots of the two types of mangroves indicates an attempt to localize toxic materials that enter the body that is more immune to the effects of toxic materials. Heavy metal elements in plants tend to be toxic, Pb concentration of 1 ppm has a significant impact on plant processes, including photosynthesis and respiration. The tolerable Pb concentration in plants was around 0.1-10 ppm dry matter [20].

The ability to absorb Pb and Cr in *A. marina* is known from the BCF (Bio-Concentration Factor) and TF (Translocation Factor) values. The BCF and TF values for Pb and Cr metals in the two types of mangroves are presented in the following table 5.

Based on Table 5, it is known that the absorption mechanism of Pb and Cr of *A. marina* has a TF value < 1 and BCF > 1. This value indicates that the absorption mechanism carried out by plants is classified as phytostabilization. Mangroves are found to translocate pollutants from the soil to the roots effectively. The results of the calculation of TF for Pb metal in *A. marina* also show a TF value

| Table 4. Metal results in *A. marina* organs. |
|------------------------------------------------|
| Location  | Sample | Metal Results |
|          |        | Pb (ppm) | Cr (ppm) |
| Sei Carang | Roots  | 2.1691   | 0.0446   |
|           | Stems  | 2.0215   | 0.0290   |
|           | Leafs  | 1.7320   | 0.0267   |
| Wacopek   | Roots  | 2.0770   | 0.1043   |
|           | Stems  | 1.7558   | 0.0937   |
|           | Leafs  | 1.7785   | 0.0886   |
| Senggarang | Roots  | 2.1281   | 0.0744   |
|           | Stems  | 2.1516   | 0.0875   |
|           | Leafs  | 2.0097   | 0.0951   |
| Tembeling | Roots  | 0.8056   | 0.0123   |
|           | Stems  | 0.7789   | 0.0085   |
|           | Leafs  | 0.8015   | 0.0170   |
< 1, but for Cr metal there is a TF value > 1, namely in the Senggarang and Tembeling areas. These differences indicate that *A. marina* in the Carang and Wacopek River areas, the heavy metal absorption mechanism is classified as a phytostabilization mechanism. In contrast, in the Senggarang and Tembeling areas, it is a phytoextraction mechanism. The TF value was obtained from the comparison of metal accumulation in the mangrove leaves with the roots. The TF value is calculated to determine the translocation of heavy metal contaminants that enter the plant parts from the soil to the roots or to other parts of the plant. If the TF value > 1 indicates that the plant effectively translocates pollutants from the soil to the roots. Furthermore, the calculation of BCF and TF can be used to determine the status of plants as phytoextraction (TF>1) and phytostabilization (TF<1).

The BCF value is the ratio between the total accumulation of mangrove organs (roots, stems and leaves) and metals in the sediment. The BCF parameter compares the concentration of compounds in the environment and the tissues or bodies of organisms [21]. A plant in accumulating heavy metals could be divided into three, namely BCF > 1 classified as Accumulator, BCF < 1 classified as Excluder while BCF = 1 classified as Indicator [22]. Based on table 5, *A. marina* are classified as plants that are low heavy metal accumulators because the BCF value is < 250.

In general, the absorption mechanism for Pb and Cr metals shows BCF values > 1 and BCF > TF. This value indicates that the species is classified as an accumulator plant that cannot prevent heavy metals Pb and Cr from the sediment to the roots. It is just that the mechanism of absorption of heavy metal elements carried out by the roots is selected by rhizofiltration by the root system, so that it does not poison the body. That mechanism is a form of adaptation of *A. marina* to the accumulation of heavy metals in high sediments. Thus, allow *A. marina* to survive in such conditions, classified as effective plants in translocating metals from the soil to the roots.

**4. Conclusions**

The status of the environmental pollution index in the former bauxite mining area on Bintan Island is classified as unpolluted but has been lightly contaminated by heavy metals. The values of Pb and Cr metals that accumulated in the sediment and dissolved in the waters of the mangrove forest ecosystem were still of low value, and varied. The adaptation of *A. marina* to the accumulation of Pb and Cr was rhizofiltration and phytostabilization. This adaptation shows that *A. marina* can live in former bauxite mining areas that contain heavy metals and accumulate them in their bodies without experiencing physical disturbances.

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**Table 5. BCF and TF calculation results for *A. marina* in Bintan Island post-mining bauxite area**

| No | Metals | Location | TF  | BCF  |
|----|--------|----------|-----|------|
| 1  | Pb     | Sei Carang | 0.80 | 25.50 |
|    |        | Wacopek   | 0.86 | 23.63 |
|    |        | Senggarang | 0.94 | 26.35 |
|    |        | Tembeling  | 0.99 | 40.06 |
| 2  | Cr     | Sei Carang | 0.60 | 2.55  |
|    |        | Wacopek   | 0.85 | 6.23  |
|    |        | Senggarang | 1.28 | 6.32  |
|    |        | Tembeling  | 1.38 | 3.13  |
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