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Lead Accumulation in Tidal Swamps: Case Study at Transmigration Area of South Sumatra Indonesia after 40 Years Cultivation

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Abstract: Lead (Pb) is a heavy metal that poses a major hazard to animals and humans when consumed. The content of this metal is significantly high in paddy soil due to the residual effect of phosphate fertilizer. Therefore, this study aims to determine the Pb content in the tidal swamp that has been used for agriculture for 40 years. It was carried out from October 2021 to January 2022 on tidal soils representing land typology of A, B, C, and D distributed in the Transmigration area of Mulia Sari, Tanjung Lago District, Banyuasin Regency of South Sumatra, Indonesia. A detailed survey was used and soil samples were taken from up to 12 soil sampling points. The variables observed were soil Pb, pH, CEC (Cation Exchange Capacity), pyrite, and C-organic. The results showed that the Pb content in tidal soils obtained was varied, namely 22.52 mg/kg, 14.84 mg/kg, 16.84 mg/kg, and 16.68 mg/kg for A, B, C, and D type of land typologies, respectively. Based on these values, the Pb accumulation has exceeded the threshold, which is 12.75 mg/kg.

Key words: Lead (Pb), tidal soil, swamp area, soil typology, transmigration area.

1. Introduction

A tidal swamp is an area, where the water level is influenced by the movement of the moon, which affects the overflowing tides periodically [1], and receives the effect of tidal water [2]. Indonesia has 20.1 million ha of tidal swamp consisting of 2.1 million ha of potential land, 6.7 million ha acid sulfate, 10.9 million ha peat, and 0.4 million ha saline [3]. Tidal lands are grouped based on typology, namely A, B, C, and D. Land with A typology is flooded by both high and low tide, B overflows only during high tide, C is not flooded with high tide and groundwater depth is less than 50 cm from the soil surface, while D is not flooded but groundwater depth is more than 50 cm from the soil surface [4].

The limiting factor of the tidal swamp for agricultural purposes is closely related to land typology, where C and D are areas that do not receive water supply leading to lower productivity compared to A and B [5]. The main problems in typologies of C and D include excessive water loss, deep subsidence, and a critical limit beyond the acid sulfate layer [6], which make the soils acidic and highly dependent on water input, especially from rainfall [7, 8]. Food crops planted in the tidal swamp are faced with several limiting factors such as the presence of pyrites, flooding, drought, and nutrient retention [6, 9]. Although the use of chemical fertilizers can increase soil fertility, excessive application will damage the soil environment. A previous study has discovered that a heavy rate of phosphate fertilizers used in soils continuously supply Pb in soil [10, 11].

Heavy metal pollution is a very critical problem to deal with due to its impact on the environment and

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ecosystem, which is toxic and harmful to living things. The impact of heavy metal pollution in the soil can reduce agricultural productivity and the quality of agricultural products [12]. The accumulation of Pb in excess can cause up to a 42% reduction in the growth of the roots [13]. High concentrations of Pb cause a 14%-30% reduction in the germination of rice seeds and decrease the development of seedlings by more than 13%-45%. This accelerates germination and has adverse effects on the length of radicals and hypocotyls [14]. This metal is dangerous when it enters the metabolic system of living things in amounts exceeding the threshold. When inorganic fertilizers are used continuously with high doses and intensity, they can increase Pb in the soil and uptake by plants [11]. Furthermore, its high content in the soil causes changes in pH, depressed photosynthesis, increased respiration, disturbed water balance, and decreased fertility for a long time. Pb is mostly accumulated by plants in stems, leaves, and roots. The process of circulating Pb from soil to plants is highly dependent on the composition of the metal and soil pH [15]. According to the standard, the critical limit for Pb in the soil is 12.75 mg/kg [16]. This metal is obtained from a natural source, while the anthropogenic process that accumulates is in soils and plants [17]. However, Pb has no biological function and can cause morphological, physiological, and biochemical dysfunctions in plants [18, 19].

According to Rasman and Hasmayani [20], the high soil Pb is caused by the use of high doses of P fertilizers such as SP-36, TSP, and NPK Phonska fertilizers, whose Pb content is around 2.1 mg/kg. This is because the longer the soil cultivation is exposed to fertilizers, the higher the Pb residues in the soil. Based on the P fertilization suggested by Masganti and Nurmili [21] a 60 kg/ha of P_2O_5 is recommended. Due to the long-term cultivation of tidal swamps in the transmigration area, it is necessary to assess the status of Pb contained in tidal rice fields in the Mulia Sari to get safe food for people and determine the soil Pb management strategies.

2. Materials and Methods

The field research was carried out from October 2021 to January 2022 and located in tidal swamps of A, B, C, and D land typologies distributed in the transmigration area of Mulia Sari, Tanjung Lago District, Banyuasin Regency of South Sumatra, Indonesia. Soil analysis was conducted at the Laboratory of Chemistry, Biology and Soil Fertility, Faculty of Agriculture and Laboratory of Analytical Chemistry, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Sriwijaya University, Indralaya.

The detailed survey method was adopted using a 1:25,000 scale map as shown in Fig. 1. The area investigation covered 660 ha and the soil sampling from arable layers used a composite system. Each sampling point represents 6 ha and 3 soil samples per typology were taken, where one soil sample is derived from 5 augering. The variables observed were soil lead, pH, CEC (Cation Exchange Capacity), pyrites, and C-organic, using AAS (Atomic Absorption Spectrophotometry), electrometric, NH_4OAC 1 N, 4 N HCl Method, and Walkley-Black approach, respectively.

2.1 Data Analysis

The data obtained were tested using statistical analysis of multiple linear regression between Pb versus pH, CEC, pyrite, and C-organic.

3. Results and Discussion

3.1 General Condition of Sampling Site

The survey was conducted in Mulia Sari located in the transmigration area of Tanjung Lago, Banyuasin of South Sumatra. This area was opened in the 1980s, where the majority of people come from Java Island, while the research area covered 660 hectares. The first

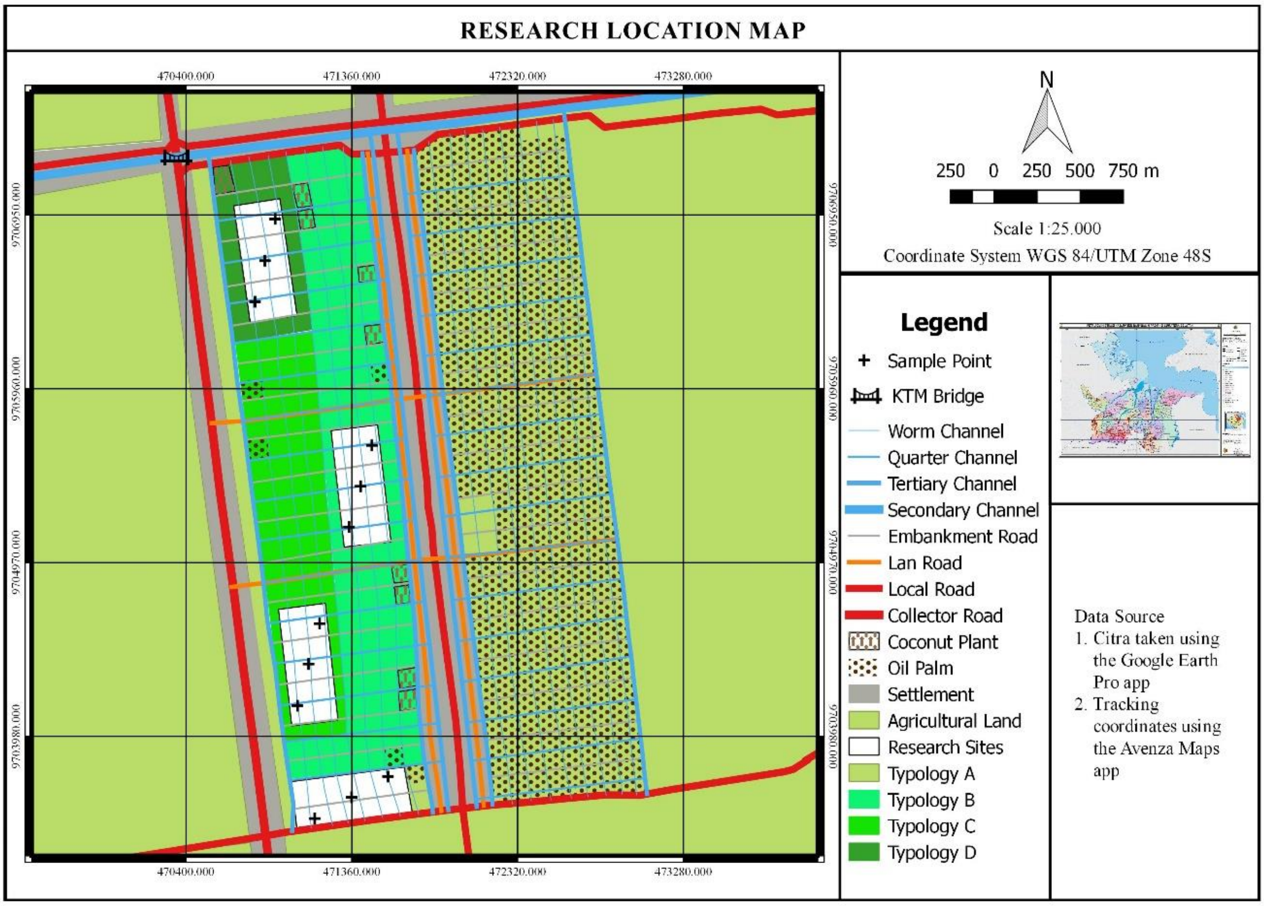

Fig. 1 Map of soil sampling locations (typologies of A, B, C and D).

crop planted was rice with the Bugis variety and the second pattern was Metro corn. Due to infertile soils, farmers used dolomite at a dose of 1 ton/ha for 2-3 growing seasons/year, which has accumulated 40 tons/ha for 40 years.

The fertilizers used by farmers were liquid organic at a dose of 6 L/ha with an interval of 30-50 days after planting. Inorganic fertilizers (SP-36, Urea, and Phonska) were also applied at a dose of 300 kg/ha for rice plants carried out 3 times, namely 15-20 days after planting with a dose of 100 kg, the second time after seedling with a dose of 100 kg and the third at fertilization for the same dose, therefore, fertilizer is given in a ratio of SP-36:Urea:NPK Phonska (2:2:1). Meanwhile, maize was given twice, namely at the beginning of planting in a ratio of 200 kg SP-36, 200 kg Urea, 100 kg NPK Phonska and at the end of planting in a ratio of 100 kg SP-36, 100 kg Urea, 200 kg NPK Phonska.

Farmers also used pesticides to control pests and weeds for crop growth. These include herbicides with a dose of 2 L/ha for contact and systemic 4 L/ha with 2 intervals of application and insecticides, namely, contact with a dose of 250 mL/ha and systemic 500 mL/ha with 2 intervals of application. After this treatment, the rice yield obtained was 8 tons/ha and the corn was 6 tons/ha.

3.2 Soil Pb Level

From Table 1, the values of Pb content ranged from 14.84-22.52 mg/kg and exceeded the threshold with a value of 12.75 mg/kg. Highest Pb was obtained in A land typology with a value of 22.52 $\pm$ 2.31 mg/kg. This is because the land is closer to the river and

Table 1 Average of Pb in tidal soils.

Land typology	Pb level (mg/kg)	Threshold (mg/kg)*
A	22.52 ± 2.31	12.75
B	14.84 ± 3.61	
C	16.84 ± 3.30	
D	16.68 ± 1.93	

* Criteria based on research by Soil Research Institute [16].

farmers often grow rice on the land. They also applied P fertilizer, which contained Pb of approximately 4.12 mg/kg to increase the P nutrient. To control this Pb, farmers have to apply organic matter to bind Pb availability before planting. Meanwhile, the accumulation of Pb in plants causes adverse effects on the photosynthetic rate by causing biochemical changes in fruits and flowers due to chlorosis [13].

3.3 Some Soil Chemical Properties of the Sampling Sites

3.3.1 Soil pH

Soil acidity is an indicator of soil fertility because it can reflect the availability of nutrients. Furthermore, soil reaction shows the nature of the acidity or alkalinity, which is expressed by the pH value [22]. The pH analysis used a soil/solution ratio of 1:1, based on the Soil Research Institute in tidal lowland rice fields with various types of overflows A, B, C, and D, the results obtained are shown in Table 2.

Based on the results, 3 samples had an acidic pH and 9 samples had a very acidic pH. This condition was caused by soil management and the use of inorganic fertilizers as additional nutrients in agricultural land. The use of these fertilizers lowers the pH of the soil [23]. Primadani [24] also reported that pH is important to determine plant nutrients as a medium for growth. Meanwhile, some of the nutrients required for their presence depend on pH.

One of the efforts that can be carried out to increase soil pH is by adding ameliorative material. The administration of dolomite on tidal land will improve the chemical and physical properties of the soil. Several studies have shown that ameliorant increases soil pH value [25], suppresses Al toxicity [26], Fe [27], increases nutrient availability, and improves nutrient content, water, and soil permeability.

3.3.2 CEC

The CEC is the ability of soil colloids to absorb and exchange cations. Soil CEC can be influenced by texture and organic matter content [28]. The CEC analysis of paddy fields in tidal land, Tanjung Lago District, Banyuasin Regency is presented in Table 3.

From the Table 3, the CEC of paddy fields in tidal land can be determined. Based on the results, 2 samples have medium and high CEC criteria, 2 samples with medium and 10 have high criteria. The highest CEC value is 40 cmol/kg, while the lowest value is 28.33 cmol/kg. According to Bakri et al. [29], the high value of CEC on paddy soil in tidal land is caused by the decomposition of organic matter, which can produce humus and increase CEC. Soil with a high

Table 2 Soil pH after 40 years of cultivation.

Land typology	pH (H_2O)	Criteria*
A	4.27 ± 0.21	Very acidic
B	4.71 ± 0.38	Acidic
C	3.4 ± 0.29	Very acidic
D	4.49 ± 0.15	Acidic

* Criteria based on Soil Research Institute [16].

Table 3 CEC for paddy fields in tidal land.

Sample point	CEC (cmol/kg)	Criteria*
A	36.67 ± 2.89	High
B	36.67 ± 5.77	High
C	28.33 ± 10.10	High
D	40 ± 5	High

* Criteria based on Soil Research Institute [16].

CEC can absorb and provide nutrients better than soil with a low value. This is because the nutrients in the colloid adsorption complex will not be washed away by water [22].

3.3.3 Pyrite

The results of pyrite analysis of rice fields in tidal land, Tanjung Lago District, Banyuasin Regency are shown in Table 4.

From Table 4, the pyrite of paddy fields in tidal land ranged from 0.004% to 0.005%. The uplifted pyrite mineral is oxidized more intensively, causing a very low pH than when the same material is oxidized in the unuplifted layer. Pyrite oxidation occurs very quickly on land still under aerobic conditions due to excessive drainage or extreme dry season conditions, which increases soil acidity. Meanwhile, pyrite oxidation will stop with the increase in groundwater level.

3.3.4 C-Organic

Organic carbon is one of the variables used to determine the content of organic material in the soil. This organic matter content will affect several other soil chemical properties such as pH, nutrient availability, and soil CEC [30]. Data on C-organic are presented in Table 5.

Table 5 shows that the C-organic of paddy fields in tidal land has various values, which vary from medium, high, and very high. Based on the results, 2 samples have C-organic with medium criteria, another 2 samples have high, and 8 samples have very high. The highest C-organic value is 6.17 with a typology sample code of A, while the lowest is 4.05 with a D typology sample code.

The high value of C-organic in paddy soil in tidal land is due to the presence of decaying plant litter. This will affect the high content of organic matter in the paddy soil of the land because carbon material comes from decomposed organic matter. According to Bakri et al. [29], the remains of mature plants will provide the raw material for microbial root reform, which contains 50% carbon. Plant roots that live for a short time and litter will support the amount of humification of organic matter. This affects the low levels of C-organic in paddy fields in tidal lands because the land management system carried out by farmers is not yet intensive. Almost all organic matter is transported at harvest and the crop residues are burned, therefore, plant remains and crop rotation systems are used to maintain soil organic matter [31].

3.4 Relationship between pH, CEC, Pyrite, C-Organic, and Pb in Soil

A multiple linear regression analysis model was used to know the relationship between pH, CEC, pyrite, C- organic, and Pb content in the soil. Based on the SPSS (Statistical Package for Social Sciences)

Table 4 Pyrite in tidal soils.

Land typology	Pyrite (%)
A	0.005 ± 0.001
B	0.004 ± 0.000
C	0.004 ± 0.001
D	0.005 ± 0.000

Table 5 C-Organic soil.

Sample point	C-organic (%)	Criteria*
A	6.17 ± 1.19	Very high
B	5.32 ± 2.58	Very high
C	6.04 ± 0.31	Very high
D	4.05 ± 1.69	High

* Criteria based on Soil Research Institute [16].

output, the correlation coefficient (*R*) is 0.742, which indicates that the degree of relationship (correlation) between the independent and the dependent variables is 74.2%. This implies that the coefficients of C-organic, pH, CEC, and pyrite have a strong relationship with heavy metal Pb.

The adjusted coefficient of determination (adjusted *R* square) is 0.293. This indicates that 29.3% of the dependent variable for heavy metal Pb is explained by the independent variables, namely C-organic, pH, CEC, and pyrite. Meanwhile, the remaining 70.7% (100%-29.3%) is explained by other variables outside the ones used. The results of the multiple linear regression analysis did not show a relationship between C-organic, pH, CEC, and pyrite with the heavy metal content of Pb. The equation shows that Pb content = 0.921 C-organic – 3.276 pH + 0.438 CEC + 0.175 Pyrite (R^2 = 0.293). The *R* square shows that the relationship is not significant. This indicates that C-organic, pH, CEC, and pyrite have no significant effect on Pb.

4. Conclusion

The soil in the tidal fields of Mulia Sari Village, Tanjung Lago District, Banyuasin Regency contains Pb more than the threshold. The heavy metal content of Pb typology A, B, C, and D has an average value of 22.52 mg/kg, 14.84 mg/kg, 16.84 mg/kg, and 16.68 mg/kg, respectively. The level of acidity (pH) had very acidic and CEC ranged from medium to high CEC criteria with values of 22.5 to 40 cmol/kg, while the pyrite content was low. Furthermore, C-organic ranged from medium to very high criteria with a value of 2.13% to 7.68%. The regression equation for the relationship between pH, CEC, pyrite, C-organic, and Pb in the soil does not have a significant effect on heavy metal Pb.

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