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Phytoremediation Potential of Shallots (Allium ascalonicum L.) in Iron-Contaminated Mudflow Sites: A Case Study from Lapindo, Indonesia

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Phytoremediation Potential of Shallots (Allium ascalonicum L.) in Iron-Contaminated Mudflow Sites: A Case Study from Lapindo, Indonesia

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Abstract. This research investigates the potential of shallots (Allium ascalonicum L.) for phytoremediation in land areas contaminated with high levels of iron (Fe) metal due to the 2006 Lapindo mudflow in Indonesia. The study was conducted in the Jetis Village, Sidoarjo District, from December 2021 to February 2022, employing the Randomized Complete Block Design (RAK) method. The methodology involved the addition of different concentrations of Lapindo mud (0% as control, 10%, 20%, and 30%) to the planting medium. Our findings reveal a significant relationship between the concentration of Lapindo mud and several plant metrics, such as plant height, leaf count, and wet and dry weight, all of which were assessed using regression and correlation analysis. Additionally, we observed that a 30% concentration of the mud led to physical stunting in the shallot plants, implying that excessive absorption of heavy metals can inhibit growth. Notably, in the 30% mud concentration scenario, the Fe content was reduced from an initial 11.82% to 4.52% post-planting. The study thus confirms the capacity of shallots to perform phytoremediation, specifically by decreasing Fe content, thereby offering a potential sustainable solution to manage metal-contaminated sites resulting from geological disasters.
Keywords: Lapindo mud, phytoremediation, shallots

1 Introduction

The lapindo mudflow incident in the PT. Lapindo Brantas in Renokenongo City, Porong Sidoarjo, on May 29, 2006, which is definitely known as Lapindo mud, is one of the mudflows that contains a lot of volcanic material and contains gas. Based on the results of the examination, lapindo sludge content components contain metal molecules such as Si, Ti, Cr, Mn, Fe, Ni, Cu, Zn. Metal components that pollute the climate in high quantities can harm plants, so that a dirty climate cannot be utilized [1]. With the aim that Lapindo mud can be used, it is necessary to carry out a phytoremediation cycle. Phytoremediation is defined as the washing of pollutants mediated by plants, including trees, grasses, and aquatic plants. Phytoremediation technology is expected to improve the physical, chemical, and biological condition of lapindo mud so that it is suitable for use as a planting medium [2].

Shallots *(Allium ascalonicum* L. *)* is a plant that has high financial value. Because it has a high financial value, the development of onion cultivation has become a plant known throughout Indonesia. According to the synthesis, of the 100 grams of onion bulbs studied, about 80% of the substance is water [3]. Plants that have sufficient water content are believed to be able to assimilate polluted metal components.

2 Research Methods

This research was carried out on the land of Jetis Village, Sidoarjo District, Sidoarjo Regency, which began in December 2021-Februai 2022 and further observations were carried out in the Laboratory.

The tools used in this study include hoes, chips, rulers, drills, stationery, analytical scales, cameras, knives, label paper, markers, sacks, hammers, sieves, polybags 25x25 cm, and plastic 1/4 gr. The materials used are, onion seeds varieties philip, water, soil, mud lapindo Sidoarjo taken from Siring-Porong Village.

Research Design

This study uses the RAK method, using lapindo mud planting media and soil consisting of 4 kinds of treatments, namely:

LP0 = Control (100% Manure)
LP1 =10% Lapindo Sludge + 90% Soil
LP2 =20% Lapindo Sludge + 80% Soil
LP3 =30% Lapindo Sludge + 70% Soil

Each treatment was repeated 4 times, so that overall this study had 16 experimental units.

Research Implementation

The first stage that must be done is the preparation of planting media, before planting lapindo mud that has been taken from Porong Village is dried first so that the texture of the mud hardens then mashed until smoothed and sifted (filtered) using ram wire with a hole of 2 cm, after that lapindo mud that is ready to be used as planting media is weighed and mixed with the ground and put into polybags measuring 25x25 cm with various predetermined dosages.

After preparing the planting medium, the next stage is the preparation of onion seeds. by cutting 1/4 of the top bulb of the onion to accelerate growth, after that put the selected onion seeds for each need per polybag with a depth of 2 cm. Then the maintenance process includes, watering, fertilizing, weeding, and pest control. Watering shallots twice a day, namely in the morning and evening regularly, because shallots cannot live in drought and also cannot live in flooded places, then do enough watering only and depending on the weather climate that occurs.

3 Results and Discussion

Plant Height (cm)

The results of the average observation of plant height with a lapindo sludge concentration of 30% resulted in the lowest average on all observations, while 0% (without lapindo mud) produced the highest crop on all observations.

Table 1. The average height of onion plants on each observation

TREATMENT	DAP							
	7	14	21	28	35	42	49	56
LP0	9.15	13.93	22.50	23.29	25.18	26.80	32.20	33.70
LP1	6.5	13.45	20.49	21.30	21.79	22.84	24.78	25.71
LP2	5.4	11.25	14.59	14.80	16.65	17.19	17.56	19.16
LP3	3.46	7.93	11.21	11.46	12.06	13.26	13.75	14.56

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The results of each observation ranging from 7 to 56 DAP at 0% treatment (control) and the addition of lumpur lapindo concentrations of 10%, 20% and 30%.

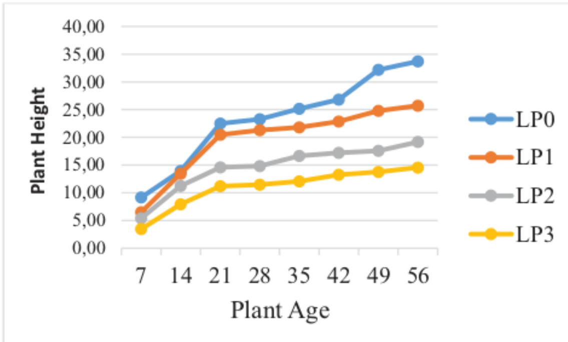

Figure 1. Line graph Plant height development at the age of 7 to 56 DAP

To determine the development in each observation, it was seen through the results of the plant growth graph that the LP0 (control) treatment experienced maximum growth, because judging from the graph, it experienced a very consistent increase in each observation. While in the LP1 LP2 and LP3 treatment on observations 7 to 21 DAP it can be seen that the chart has experienced a normal increase, then at the time of observation 28 to 56 DAP experienced a gentle growth despite the increase but cenderung hanya sedikit angka peningkatannya. Hal ini disebabkan because in the early days of the growth of heavy metals contained in lapindo mud has not absorbed so much into plants so that it experiences growth that is still optimal while at the end of the observation it can be seen that Lapindo mud is very influential on plants.

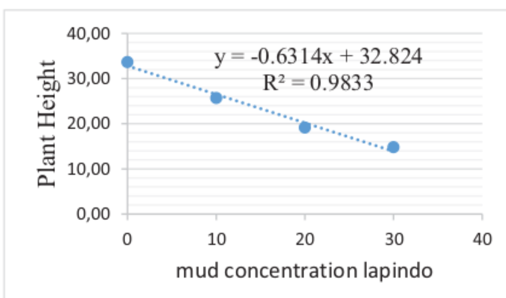

Figure 2. Plant height regression graph on lapindo sludge concentration

From the regression equation obtained (y = - 0.6314 x + 32.824) it shows that an increase in lapindo mud concentration will cause a decrease in plant height with a constant value (-0.6314) from the results of a variety analysis states that a decrease in plant height of 98.33% is influenced by the addition of lapindo sludge concentration, which can be seen by the coefficient of determination (R^2 = 0.9833) . Where X = lapindo sludge concentration (0-30%) , Y = plant height, then it can be seen that the value of the correlation coefficient produced is (r) = -0.99162 it is stated that the degree of relationship between plant height and lapindo sludge concentration is very strong. The addition of sludge concentration (0-30%) will

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lower the high growth rate of onion plants. In the P0 (control) treatment the plant height showed the highest yield compared to the sludge concentration treatment on it (10, 20, and 30%). The presence of heavy metals in lapindo sludge can lead to an excess of the amount of potassium, and iron present in the root tissue, which as a result will slow down the growth and development of plants [4].

Number of Leaves (strands)

The average yield of the number of leaves with a lapindo mud concentration of 30% resulted in the lowest number on all observations , while 0% (without lapindo lump) resulted in the highest number of leaves on all observations.

Table 2. Rata-average number of onion plants on each observation

TREATMENT	DAP							
	7	**14**	**21**	**28**	**35**	**42**	**49**	**56**
LP0	12	16	20	21	24	26	28	29
LP1	12	14	18	19	22	23	26	27
LP2	10	12	14	15	16	17	19	20
LP3	8	10	12	12	13	13	14	14

In order tobe increasingly seen the results of each observation ranging from 7 to 56 DAP on the 0% treatment (control) and the addition of the concentration of lapindo 10%, 20% and 30%.

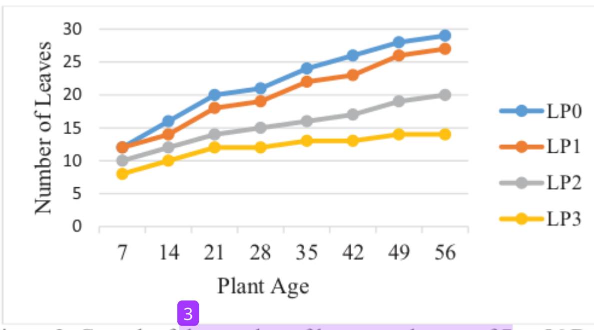

Figure 3. Growth of the number of leaves at the age of 7 to 56 DAP

To determine the development of the number of leaves in each observation, it was seen that the results of the growth chart between LP0 and LP1 experienced consistent growth. Although in the LP1 treatment with the presence of a mixture of Lapindo sludge 10% of the heavy metal Fe contained in the media is not so much, so it still experiences maximum leaf growth. Meanwhile, in the LP2 and LP3 treatments, it was seen at the beginning of observations at the age of 7 to 21 DAP experienced consistent growth while in observations 28 to 56 DAP experienced gentle growth. Although the graph has increased but only a few numbers have increased. This is because at the beginning of the growth of heavy metals in the Lapindo sludge has not absorbed much into plants so that it still experiences maximum growth (Figure 2).

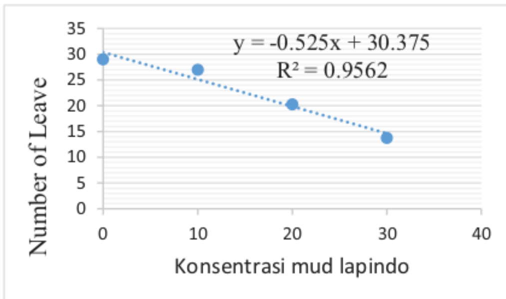

Figure 4. Regression graph of leaf count regression on lapindo sludge concentration

From the regression equation obtained (y = -0.525 x + 30.375) it shows that an increase in the concentration of lapindo sludge will result in a decrease in the number of leaves with a constant value (-0.525) from the results of the variance analysis, it is stated that the decrease in the number of leaves by 95.62% is influenced by the addition of lapindo sludge concentration, which can be seen by the coefficient of determination (R^2 = 0.9562) . Where X = lapindo sludge concentration (0-30%) , Y = number of leaves, then it can be seen that the value of the correlation coefficient produced is (r) = -0.97786 it is stated that the degree of relationship between the number of leaves and the concentration of lapindo mud is very strong. The addition of sludge concentration (0-30%) will reduce the growth rate of the number of leaves. At the P0 (control) the number of leaves showed the highest results compared to the sludge concentration treatment on it (10, 20, and 30%). This is because lapindo mud contains high salt levels and poisoning of several nutrients [1].

Wet weight (gr)

The average wet weight yield with a lapindo mud concentration of 30% resulted in the lowest wet weight on all observations, while 0% (without lapindo lump) resulted in the highest wet weight on all observations.

Table 3. Average wet weight of red onion plants on each treatment

Treatment	Average
LP0	17.207
LP1	10.971
LP2	5.199
LP3	2.660

The results of wet weight observations on onion plants grown on planting media ranging from control to addition of lapindo mud concentrations of 10%, 20% and 30%.

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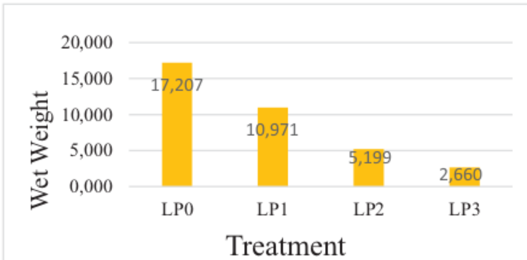

Figure 5. Wet weight average bar chart onion crops

Thus, it can be seen that the results of the bar chart in the LP0 treatment (without lapindo mud) produced a wet weight of 17,207gr, but in the application of lapindo sludge by 10% (LP1) produced a wet weight of 10,971 gr, the difference in wet weight reduction in the LP0 and LP1 treatment was 6,236 gr then in the LP2 treatment produced a wet weight of 5,199 gr. occurrence of a decrease in wet weight between LP0 and LP3 were 14,547 gr, the lowest result was obtained by the LP3 treatment with a value of 2,660 gr. a decrease in the LP1, LP2 and LP3 treatment was caused by the increase in lapindo sludge concentration so that there could be a decrease in wet weight. Meanwhile, the LP0 (control) treatment without a mixture of lapindo mud so as to produce maximum growth.

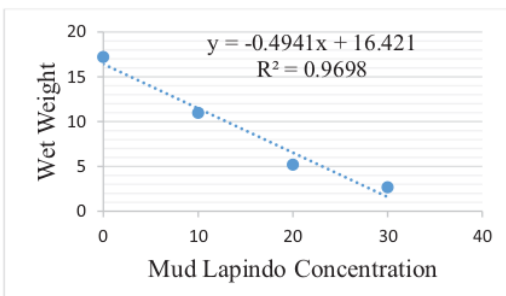

Figure 6. Wet weight regression graph on lapindo sludge concentration

From the regression equation obtained (y= -0.494 x + 16.421) shows that an increase in lapindo mud concentration will cause a decrease in wet weight with a constant value (-0.4941) from the results of a variety analysis states that the reduction of wet weight 96.98% is influenced by the addition of lapindo sludge concentration, which can be seen by the coeffesient of determination (R^2 = 0.9698) . Where X = lapindo sludge concentration (0-30%) , Y = wet weight, then it can be seen that the value of the correlation coefficient produced is (r) = -0.98479 it is stated that the degree of relationship between the number of leaves and the concentration of lapindo mud is very strong. With the addition of the concentration of sludge (0-30%) will decrease the wet weight of onion plants. In the P0 (control) wet weight treatment showed the highest results compared to the sludge concentration treatment on it (10, 20, and 30%). According to [1] planting media that does not use Sidoarjo mud mixture, plant growth is maximum, because nutrients meet the needs of plants.

Dry Weight (gr)

The average dry weight yield with a lapindo mud concentration of 30% resulted in the lowest dry weight on all observations, while 0% (without lapindo mud) resulted in the highest dry weight on all observations.

Table 4. Average dry weight of red onion plants on each treatment

Treatment	Average
LP0	3.652
LP1	2.282
LP2	1.255
LP3	0.571

The results of the observation of dry weight in onion plants in planting media ranging from control to the addition of lapindo mud concentrations of 10%, 20% and 30%.

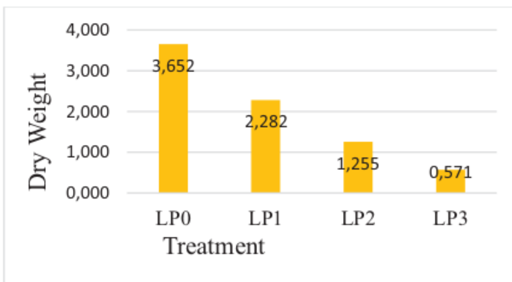

Figure 7. Dry weight bar chart onion crops

Thus, it can be seen that the results of the bar chart in the LP0 treatment (without lapindo mud) produced a dry weight of 3,652 gr, while in the 10% treatment (LP1) with a value of 2,282 gr, the difference in the decrease in dry weight of LP0 and LP1 was 1.37gr, then in the LP2 treatment with a value of 1.255 gr. The lowest yield was obtained by the treatment of LP3 0.571 gr. The difference between LP0 and LP3 treatment was 3,081 gr of dry weight reduction in LP1, LP2 and LP3 treatments due to the addition of Lapindo sludge concentrations, then in LP0 and LP3 treatments the difference in the value of the decrease was very large, because LP0 did not add Lapindo sludge so that LP0 experienced normal growth.

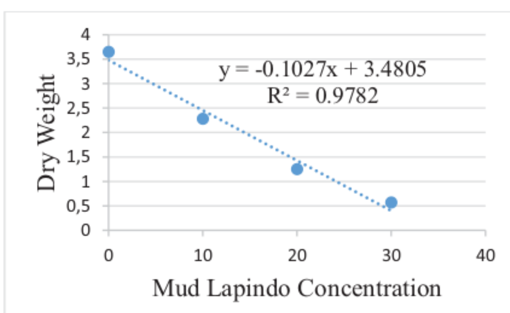

Figure 8. Dry weight regression graph on lapindo sludge concentration

From the regression equation obtained (y= -0.1027 x + 3.4805) it shows that an increase in lapindo sludge concentration will cause a decrease in dry weight with a constant value (-0.1021) from the results of a variety analysis n that the lowering n dry weight of 96.98% is influenced by the addition of lapindo sludge concentration, which can be seen by the coefficient of determination (R^2 = 0.9782) . Where X = lapindo sludge concentration (0-30%) , Y = dry weight, it can then be seen that the value of the correlation coefficient produced is (r) = -0.98903 it is stated that the degree of relationship between dry weight and lapindo mud concentrations very strong. Then it can be stated that the relationship between dry weight and lapindo mud concentration is very strong. With the addition of the sludge concentration (0-30%) will decrease the dry weight of onion crops. In the LP0 (control) treatment the dry weight showed the highest results compared to the sludge concentration treatment on it (10, 20, and 30%).

Fe Content in Media before and After Planting (%)

The following are the results of the analysis of Fe content in the media before and after planting starting from the treatment of LP0 (control) to LP3 (table 5).

Table 5. The results of the analysis of Fe content in the media before and after planting.

No.	Treatment	Fe (%)	
		Before	After
1.	LP0	0,32	0,04
2.	LP1	6,67	3,22
3.	LP2	8,87	4,29
4.	LP3	11,82	4,52

It can be seen that the Fe content in the media before planting the Fe content with the addition of 10%, 20%, and 30% sludge was detected to be very high and after planting there was a decrease in Fe content in each treatment, LP0 obtained the smallest value because the media did not add lapindo mud, then in the LP3 treatment with media before planting obtained a Fe content of 11.82%, in this case, the higher the concentration of lapindo sludge given, the higher the Fe content detected.

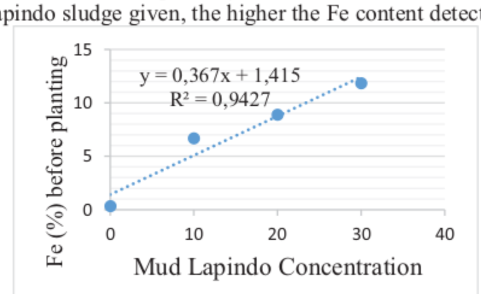

Figure 9. Regression graph of Fe content on pre-media Plant at lapindo mud concentration

From the results of the regression equation obtained (y = 0.367x + 1.415) shows that an increase in lapindo sludge will cause an increase in the Fe content of the media before planting, with a constant value (0.367), from the results of various lysis analyzes states that the increase in Fe content in the media before planting 94.27% is caused by the addition of lapindo sludge concentration, which can be seen by the coefficient of determination (R^2 = 0.9427). Where X = lapindo sludge concentration (0-30%) , Y = Fe content in the medium before planting, then it can be seen that the resulting correlation coe value is (r) =

0.970947 it is stated that the degree of relationship between the Fe content in the medium before planting and the lump concentration of your lapindo is very strong.

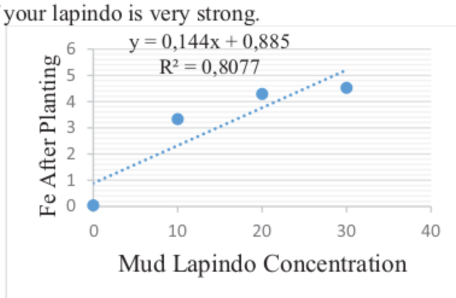

Figure 10. Regression graph of Fe content in media after planting at lapindo mud concentration

From the results of the regression equation obtained (y = 0.144x + 0.885) shows that an increase in lapindo sludge will cause an increase in Fe content in the media after planting, with a constant value (0.144), from the results of variety analysis states that the increase in Fe content in the media after planting 80.77% is influenced by the addition of lapindo mud concentration, which can be seen by the efficiency of determination (R^2 = 0.8077) . Where X = lapindo sludge concentration (0-30%) , Y = Fe content in the media after planting, then it can be seen that the correlation coe value produced is (r) = 0.898706 it is stated that the degree of relationship between the Fe content in the media after planting and the lump concentration of your lapindo is very strong.

Discussion

With the addition of concentrations of 10%, 20% and 30% in the growing onions, there is a decrease in plant height, number of leaves, dry weight and wet weight. Appear in habitation of growth in the LP3 treatment, continued on the per DAP observation that the plant grew as a whole with varying height and number of leaves, especially in the LP1, LP2 and LP3 treatments on the observation of plant height and the number of leaves subjected to normal n observers at the time of 7 to 21 DAP to mud at observations 28 to 56 DAP Experience gentle growth. Continued on the 56th observation of DAP LP3 treatment in the smallest size this was due to the influence of Sidoarjo mud concentration of 30%. Plants with a high iron content (Fe) in the medium cause the plant roots to be unable to absorb the nutrients needed, so that plant activity is disturbed [5]. Most of the iron elements in plants are stored in chloroplasts, so an excess of iron causes the organelles to affect [6]. Some heavy metal elements detected in lapindo sludge include Si (5.10%), Ti (3.30%), Cr (1.20%), Mn (0.32%), Fe (16.20%), Ni (28.4 0%),Cu (2.50%), and Zn (1.10%) [7]. Iron poisoning also results in decreased permeability of the cell membranes of the guard cell yang regulates the opening of the stomata [6]. Fe poisoning of this plant is shown by numerous attacks of brown spots, the presence of small brown stains on the leaves [8].

In some cases it can lead to the death of the plant and reduce the yield to 100%. In this study, with the addition of concentrations with each treatment, it was found that the tops of onion plants had yellowed leaf discoloration, stunted plants, abnormal rooting. Based on the results of the study, it was found that the concentration of Sidoarjo mud affects the treatment of LP1, LP2, and LP3 on onion plants, this is due to the heavy metals contained in lapindo mud that can anchor the growth rate of plants. As supported by several similar studies as in study [1] overall there was an increase in metal absorption in plants due to treatment after the concentration of Sidoarjo sludge where heavy metals are microelements that are easily soluble so that they are actively absorbed by plants in large quantities. Natural research [9] which concluded that the difference in the concentration of lapindo mud in the growing medium had a significant effect on plant height growth, stem diameter, leaf area, root length, as well as wet weight and dry weight of mangrove plants. [7] Suggests that lapindo mud concentrations can cause inhibition of dragon fruit plant growth. At a concentration of 10% lapindo mud, the dragon fruit plant showed a growth response although it was lower when compared to the control treatment, so it can be said that the dragon fruit plant has a tolerance to the lapindo mud concentration of 10%. Whereas at higher concentrations (20% and 30%) showed greater inhibition. In addition, lapindo sludge with a high pH content of 5.8-7.2 also affects the absorption of metal elements by plants [10].

4 Conclusion

This study reveals a substantial association between the concentration of Lapindo mud and several key plant characteristics, including plant height, leaf count, and both wet and dry weight, as demonstrated through rigorous regression and correlation analysis. Notably, in a planting medium with a 30% Lapindo mud concentration, onion plants manifested significant phytoremediation potential by reducing the Fe content from an initial 11.82% to 4.52% post-planting. These findings underscore the potential role of onion plants in mitigating heavy metal contamination, offering a promising, sustainable solution for remediation of geologically compromised sites. However, the observed plant stunting at high mud concentration points to potential adverse effects of heavy metals on plant growth, warranting further research into the trade-off between phytoremediation efficacy and plant health under high contamination scenarios. Future research should also aim to explore the potential of other plant species in the remediation of similarly contaminated environments.

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