Open Global Scientific Journal 5 (1): 41-53 2026

Contents lists available at openscie.com
E-ISSN: 2961-7952
Open Global Scientific Journal
DOI: 10.70110/ogsj.v5i1.108
Journal homepage: https://openglobalsci.com

Lead (Pb) Accumulation by *Typha angustifolia* and *Cyperus alternifolius* in a Constructed Wetland System

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ARTICLE INFO

Article History:
Received 27 April 2026
Revised 3 June 2026
Accepted 5 June 2026
Published 7 June 2026

Keywords:
Bioconcentration factor,
Constructed wetland,
Cyperus alternifolius,
Translocation factor,
Typha angustifolia.

ABSTRACT

Background: Lead (Pb) is one of the most common heavy metal contaminants in aquatic environments due to its extensive use in industrial activities. In developing countries such as Indonesia, wastewater treatment facilities often have limited capacity to effectively process industrial effluents, leading to the release of Pb-contaminated wastewater into the environment.
Aims: This study aimed to evaluate the Pb accumulation potential and phytoremediation performance of *Typha angustifolia* and *Cyperus alternifolius* in a laboratory-scale constructed wetland system operated under a static batch method for the remediation of Pb-contaminated water.
Methods: The experiment consisted of a control treatment without plants and two plant species exposed to three Pb concentrations (10, 20, and 30 mg L^{-1}). Water temperature, water pH, soil pH, and Pb concentrations in water, soil, and plant tissues were measured. Temperature and pH were recorded at 1 and 14 days after planting, while Pb concentrations were analyzed at the end of the 14-day experimental period. The phytoremediation potential of both plant species was evaluated using the Bioconcentration Factor (BCF) and Translocation Factor (TF).
Results: The results showed that the constructed wetland system effectively reduced Pb concentrations in water, with removal efficiencies ranging from 85% to 96%. However, the soil have big contribution in removal Pb in water. *T. angustifolia* demonstrated BCF and TF values greater than 1 across all Pb concentrations, indicating strong accumulation and translocation abilities. In contrast, *C. alternifolius* exhibited BCF values below 1 but TF values greater than 1, suggesting limited accumulation capacity with effective Pb translocation from roots to shoots.
Conclusion: Both species have potential for application in constructed wetland systems for Pb remediation, with *T. angustifolia* showing superior phytoremediation performance.

To cite this article: Kinanti, N., Hadi, I. P. (2026). Lead (Pb) accumulation by *Typha angustifolia* and *Cyperus alternifolius* in a constructed wetland system. *Open Global Scientific Journal*, 4(2), 41–53.

1. Introduction

Heavy metal pollution is one of the environmental problems that receives a lot of attention due to its persistent nature, difficulty to degrade, and ability to accumulate in various environmental compartments such as water, soil, and sediments. One of the most commonly found heavy metals in the environment is lead (Pb). Lead is a non-essential metal that has no biological function for organisms but can be toxic when accumulated at certain concentrations. The presence of Pb in the environment generally originates from anthropogenic activities such as industrial activities, the use of leaded fuel, agricultural activities, and the disposal of poorly managed waste (Sharifi *et al.,* 2023). The widespread use of Pb in various sectors has led to increased distribution and accumulation of this metal in the environment over time (Erfandi & Juarsah, 2015).

The accumulation of Pb in the environment has become a serious concern because this metal can enter the food chain through contaminated soil and water media. In addition, the limited capacity for waste treatment in some industrial sectors has resulted in the continued occurrence of waste disposal that does not meet environmental quality standards (Kumar & Choudhary, 2021). Intensive agricultural activities are also reported to contribute to the increase in heavy metal accumulation through the use of fertilizers and pesticides, accounting for about 69.7–86.7% of heavy metal input into the environment (Wang *et al.,* 2024). Rahayu *et al.* (2020) reported that soil in agricultural land in Poncokusumo District, Malang Regency contained Pb at 7.86–10.20 $mg.kg^{-1}$, while cultivated vegetable plants showed Pb content of 26.51–31.72 $mg.kg^{-1}$, exceeding the maximum limit according to the Indonesian National Standard, which is 0.5 $mg.kg^{-1}$. This condition indicates the need for effective technology to reduce Pb concentration. These conditions indicate the need for effective technology to reduce Pb concentration in the environment.

One of the technologies developing for waste treatment and heavy metal remediation is Constructed Wetland (CW) or artificial wetlands. Constructed Wetland is an engineered system that mimics natural mechanisms in wetland ecosystems by utilizing the interaction between plants, growing media, and microorganisms in removing pollutants (Ioannidou *et al.,* 2025). This technology is widely used because it is relatively inexpensive, environmentally friendly, easy to operate, and capable of reducing various types of pollutants including heavy metals. In this system, plants play an important role in the phytoremediation process through mechanisms of absorption, accumulation, and translocation of contaminants in plant tissues.

The selection of plant species is an important factor in determining the effectiveness of the phytoremediation process. Plants with rapid growth, high biomass, and tolerance to polluted environments generally show better remediation potential (Malik *et al.,* 2010). *Typha angustifolia* and *Cyperus alternifolius* are wetland plants that are tolerant of waterlogged conditions and have been reported to have the ability to absorb heavy metals. Previous studies have shown that *T. angustifolia* can accumulate Pb at 43.6 $mg.kg^{-1}$ (Birgani *et al.,* 2025), while *C. alternifolius* has a Pb accumulation capacity of around 9 $mg.kg^{-1}$ (Nokande *et al.,* 2022).

Various studies on the utilization of wetland plants for heavy metal remediation have been conducted, but research specifically comparing the Pb accumulation capacity of *T. angustifolia* and *C. alternifolius* in Constructed Wetland systems is still relatively limited. Most previous studies focused more on the effectiveness of pollutant removal in general or the use of a single plant species. Therefore, this study was conducted to evaluate the accumulation capacity of *T. angustifolia* and *C. alternifolius* in absorbing Pb using a Constructed Wetland system and to analyze the phytoremediation potential of both species based on Bioconcentration Factor (BCF) and Translocation Factor (TF) values.

The novelty of this study lies in the comparative assessment of Pb accumulation and translocation by Typha angustifolia *and* Cyperus alternifolius *within a static batch constructed wetland system*. The results of this study are expected to provide information on the potential of both plants as alternative phytoremediators in the treatment of water contaminated with heavy metals.

2. Methods

The study was conducted using a laboratory-scale constructed wetland system operated under a static batch method for the treatment of Pb-contaminated water. In this system, contaminated water was introduced into the treatment reactors and maintained throughout the experimental period without continuous inflow and outflow. The reactor consisted of cylindrical plastic containers with a diameter of 30 cm and a height of 50 cm. Soil media were added into each reactor up to a height of 15 cm according to USEPA (2000), resulting in a soil volume of approximately 10.6 L per reactor. The experimental period was conducted for 14 days, as previous studies have shown that Pb accumulation and physiological responses to heavy metal exposure in aquatic organisms (Li *et al.,* 2018) and macrophytes can be effectively observed within this duration (Bordon *et al.,* 2018). The soil used in this study was collected from Wajak District, Malang Regency, East Java, Indonesia. Initial soil characterization included soil texture analysis using the hydrometer method, soil pH measurement using a pH meter (H_2O), organic carbon analysis using the Walkley and Black method, and cation exchange capacity (CEC) analysis using NH_4OAc extraction at pH 7. The reactor design used in this study is presented in Figure 1.

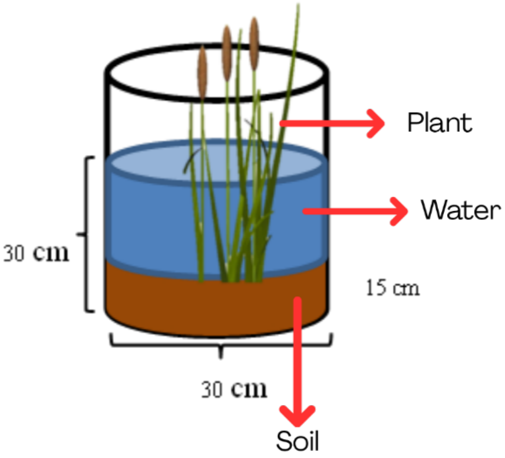

Figure 1. Reactor Tank Design

Water temperature, water pH, soil pH, and Pb concentrations in water, soil, and plant tissues were measured during the experiment. Temperature and pH were recorded at 1 and 14 days after planting, while Pb concentrations in water, soil, and plant samples were analyzed at the end of the 14-day experimental period. Pb concentrations were expressed as mg L^{-1} for water samples and mg kg^{-1} dry weight for soil and plant samples.

Plant samples were harvested at the end of the experiment and separated into roots and shoots. The samples were washed with distilled water to remove adhering particles, air-dried for 2–3 days, and ground to obtain a homogeneous material. The powdered samples were further pulverized using a mortar and pestle and passed through a 600-mesh sieve before being oven-dried at 105 °C. Approximately 5 g of each sample was transferred into a beaker glass, mixed with 50 mL distilled water, 5 mL concentrated HNO_3, and 2 mL concentrated HCl, and then digested on a hot plate for 2–3 h until a clear solution was obtained. After cooling, the digest was filtered through filter paper and transferred into a 50 mL volumetric flask. Soil samples were air-dried and sieved prior to analysis. The concentrations of Pb in water, soil, and plant samples were subsequently determined using an Atomic Absorption Spectrophotometer (AAS; Shimadzu AA-7000, Japan).

T. angustifolia and *C. alternifolius* plants were washed with tap water to remove soil particles attached to the roots before transplantation. Plant selection was carried out to obtain uniform plant conditions. T. *angustifolia* plants with a height greater than 50 cm and without flowering structures were selected. Meanwhile, *C. alternifolius* plants were selected based on non-flowering conditions or flowers that had not yet changed to brown color, indicating that the plants had not reached full maturity. Each reactor was planted with 4–7 individuals with a similar fresh weight of approximately ±100 g per treatment (Wang *et al.,* 2019). Initial plant characteristics including plant height, root length, and leaf number were recorded prior to treatment.

Synthetic wastewater was made using Merck brand lead nitrate ($Pb(NO_3)_2$) powder (Merck 107398, Germany). A stock solution (1000 mg/L) was prepared by dissolving 1.598 grams of $Pb(NO_3)_2$ in 1 liter of distilled water. Then, the stock solution was taken and diluted according to the concentration to be used (Githuku *et al.,* 2018). This study used a Randomized Block Design (RBD) consisting of nine treatments with three replications. The following are the treatments and research parameters (Figure 2 and Table 1).

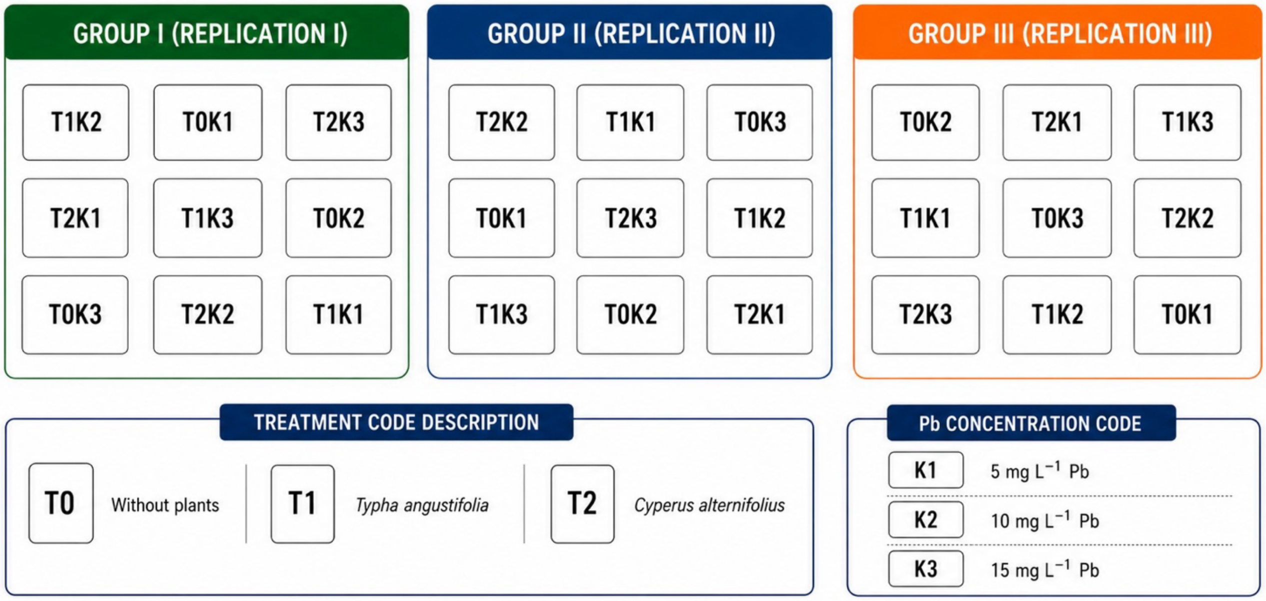

Figure 2. Research Treatment and Layout

Table 1. Research parameters

Parameters	Unit	Observation Time
Water temperature	°C	1 DAP dan 14 DAP
Water pH		1 DAP dan 14 DAP
Soil pH		1 DAP dan 14 DAP
Pb in Water	$mg\ L^{-1}$	14 DAP
Pb in Soil	$mg\ L^{-1}$	14 DAP
Pb in plants	$mg\ L^{-1}$	14 DAP

Note: DAP: Days After Planting

Next, the data were analyzed using one-way analysis of variance (ANOVA) with an F test at a 5% level and further test DMRT (Duncan's Multiple Range Test) using IBM SPSS Statistics 24 and Microsoft Excel software. The potential of plants in accumulating heavy metals in tissues was determined by calculating the Bioconcentration Factor (BCF) and Translocation Factor (TF) values. According to Yoon *et al.* (2006), BCF is the ratio of metal concentration in plant tissues to the metal concentration in the growth medium used to describe the plant's ability to accumulate metals.

$$\mathrm{BCF} = \frac{\text{Heavy metals in plant (mgkg}^{-1})}{\text{Heavy metals in soil (mgkg}^{-1})}$$

Meanwhile, TF is the ratio of metal concentration in the shoot to the root, which is used to indicate the plant's ability to translocate metals from the root to the upper part of the plant.

$$\mathrm{TF} = \frac{\text{Heavy metals in leaves (mgkg}^{-1})}{\text{Heavy metals in roots (mgkg}^{-1})}$$

The removal efficiency (RE) value was calculated using the equation proposed by Ren *et al.* (2016). This calculation aims to determine the percentage decrease in the concentration of the observed parameter after the treatment process. In the equation, Co is the initial concentration of the parameter in the wastewater (mg L^{-1}), while Ct is the concentration of the parameter after treatment (mg L^{-1}). The higher the RE value obtained, the more effective the treatment process is in reducing the concentration of the analyzed pollutant. The equation used to calculate the RE value is as follows: The RE value (%) is calculated using the equation proposed by Ren *et al.* (2016) as follows:

$$\mathrm{RE} = (\mathrm{Co}-\mathrm{Ct})/\mathrm{Co} \times 100\%$$

3. Results and Discussion

3.1 Physiological Response and Biomass

Plants will develop self-defense mechanisms so that physiological processes within them continue to function normally. The response of test plants to heavy metal stress during the study is presented in Figure 2. These physical changes only occurred in the first week, marked by the leaves of the plants starting to yellow and eventually drying out. Chlorosis can occur due to an increase in the production of Reactive Oxygen Species (ROS) triggered by oxidative stress in plants (Batra, 2021). Exposure to lead (Pb) can disrupt the redox balance within plant cells through interference with physiological processes, such as photosynthesis and respiration, thereby causing ROS formation to exceed the capacity of the plant’s antioxidant defense system. Excessive accumulation of ROS triggers oxidative stress that can damage cellular components, such as lipid membranes, proteins, DNA, chlorophyll pigments, and cell organelles such as chloroplasts (Kiran *et al.,* 2019). The damage can reduce chlorophyll content, triggering chlorosis symptoms characterized by the leaves turning yellow.

Although there are physical changes in both types of plants, the application of Pb above standard limits does not affect the survival of *T. angustifolia* and *C. alternifolius* used in the study, as indicated by the plants' ability to continue producing shoots or offshoots. Table 2 shows that increasing Pb concentration does not have a significant effect on the dry weight biomass of both plant species. Based on these results, it can be stated that Pb exposure does not have a significant effect on plant biomass during the study period. The study results of Tang *et al.* (2017) also indicate that *T. angustifolia* is a potential adsorbent for removing Cd and Pb from aqueous solutions, where increasing Pb concentration and contact time do not have a significant effect on the decrease in plant biomass. In general, high biomass reflects the ability of plants to maintain growth while reducing the phytotoxic effects of heavy metals.

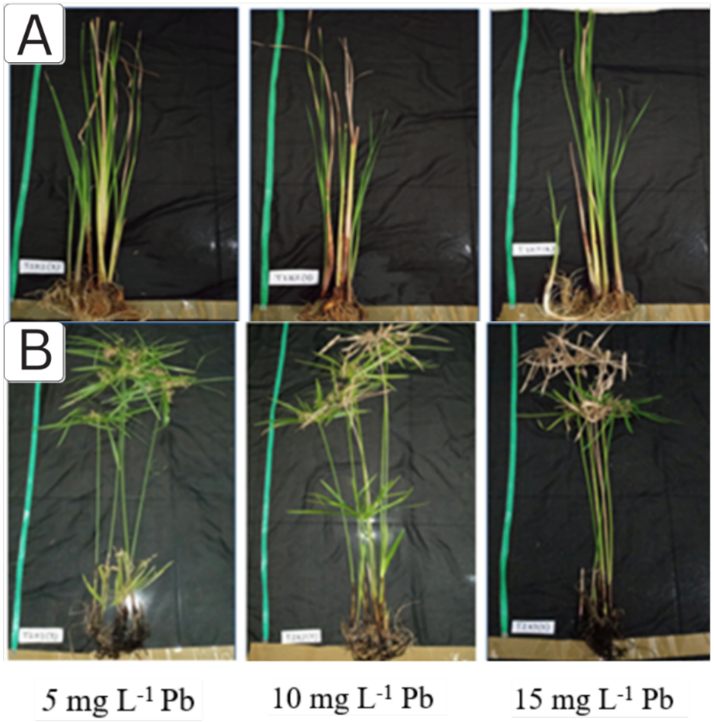

Figure 3. Growth of *T. angustifolia* (A) and *C. alternifolius* (B) under Pb stress

Table 2. Plant biomass at the end of observation

Treatments	Total Pb mg.L^{-1}	Dry Weight Biomass (g)		Total
		Title	Root	
Tanpa Tanaman	10	-	-	-
	20	-	-	-
	30	-	-	-
T. angustifolia	20	10.23	9.47	19.70 ± 5.35^{a}
	30	7.60	12.17	19.77 ± 1.12^{a}
	30	10.17	8.83	19.00 ± 1.32^{a}
C. alternifolius	10	19.73	10.60	30.33 ± 6.53^{b}
	20	25.33	8.67	34.00 ± 2.50^{b}
	30	24.83	11.00	35.83 ± 4.86^{b}

Note: Letters that are the same are not statistically significantly different between treatments according to the DMRT 5% test, total data (mean ± SD, n = 3)

Heavy metals such as Pb, Cd, and Cr can cause oxidative stress through the formation of reactive oxygen species (ROS) that have the potential to damage proteins, lipids, and DNA of plant cells (Alam *et al.,* 2025). To cope with these conditions, plants develop antioxidant defense systems in the form of enzymes such as SOD, POD, CAT, APX, and GPX that play a role in heavy metal detoxification, thereby increasing plant tolerance to Pb stress (Bah *et al.,* 2010). This adaptive response is also observed in *T. angustifolia* treated with 20 mg Pb L^{-1}, where root biomass (12.17 g) is higher than shoot biomass (7.60 g). This condition indicates a change in biomass allocation to the root system as an adaptation mechanism to heavy metal stress. Roots are the first organ to interact with Pb and serve as the main site for metal accumulation and detoxification, so plants tend to maintain root growth to support water and nutrient absorption while limiting Pb translocation to the shoot parts (Li *et al.,* 2016). Although there are changes in biomass distribution between roots and shoots, the total biomass of *T. angustifolia* does not differ significantly among treatments, indicating that the plants are still able to maintain their growth and survival under Pb-exposed conditions.

3.2 Measurement Results of Temperature and pH in Artificial Wetlands

The water temperature during the study ranged from 26–31°C, which is still within the optimal range for the phytoremediation process in constructed wetland systems. Chen *et al.* (2009) reported that a temperature of 25–30°C is a good condition to support the removal of heavy metals in artificial wetlands, while Truu *et al.* (2009) stated that a temperature range of 15–30°C is capable of supporting plant and microorganism metabolic activities. In *C. alternifolius*, a temperature range of 20–28°C has been reported to support enzymatic activity and minimize physiological stress, thus potentially increasing phytoremediation efficiency (Jinzhao *et al.*, 2022). In the Typha genus, environmental conditions are also known to affect metal accumulation ability. Kola *et al.* (2026) reported that *Typha capensis* shows higher metal accumulation in the dry-winter and dry-summer seasons compared to the wet-summer season. The findings indicate that environmental factors, including temperature and hydrological conditions, play a role in regulating the processes of metal uptake and accumulation by Typha plants.

The changes in temperature and pH are suspected to be related to processes occurring within the constructed wetland system. The decrease in water temperature is likely influenced by the presence of vegetation, which provides a shading effect on the water surface, thereby reducing solar radiation absorption (Kalny *et al.*, 2017). Additionally, the evapotranspiration process of plants and heat exchange between water and soil media also play a role in maintaining the temperature stability of the system. Meanwhile, the increase in water pH is suspected to occur due to the photosynthetic activity of plants and microorganisms that utilize dissolved CO_2 in the water (Ghermandi *et al.*, 2009). The reduction in CO_2 concentration leads to decreased formation of carbonic acid, causing a decline in H^+ ion concentration and an increase in water pH (Fonseca *et al.*, 2024). These conditions indicate that the interaction between plants, soil media, and microorganisms contributes to creating a more stable environment during the treatment process.

Changes in temperature and pH also affect the behavior of Pb in the system. Temperatures within the optimal range support the biological activity of plants and microorganisms so that the remediation process can proceed effectively. On the other hand, an increase in pH toward neutral can reduce the solubility and mobility of Pb in water, making the metal more easily adsorbed by soil media, precipitated as less soluble compounds, or bound to organic matter. According to Sukoasih *et al.* (2017), temperature and pH are important factors that influence the solubility and bioavailability of heavy metals in aquatic environments. Therefore, the temperature and pH conditions formed during the study are suspected to also support the high Pb removal efficiency in the constructed wetland system, reaching 85.40–95.66%.

Table 3. Water temperature, water pH and soil pH on 1 DAP and 14 DAP

Treatments	**Total Pb mg L^{-1}**	**Water Temperature (°C)**		**pH Water**		**pH Soil**
		1 DAP	**14 DAP**	**1 DAP**	**14 DAP**	**14 DAP**
Kontrol (Without Plants)	10	30	26	6.40	7.63	6.74
	20	30	27	6.58	7.72	6.76
	30	31	26	6.70	7.58	6.82
T. angustifolia	10	31	27	6.75	7.66	6.85
	20	31	26	6.80	7.61	6.91
	30	31	26	6.83	7.60	6.88
C. alternifolius	10	31	26	6.81	7.69	6.88
	20	31	27	6.82	7.72	6.90
	30	31	26	6.77	7.82	6.94
Average		30.77	26.33	6.72	7.65	6.85

3.3 Pb Concentration in Water, Soil, and Plants after Remediation

The presence of the heavy metal Pb in water has become a concern due to its persistent nature and difficulty in undergoing natural degradation. Heavy metals generally tend to bind with suspended particles, settle at the bottom of water bodies, and accumulate in solid phases such as sediments or aquatic organisms (Garvano *et al.,* 2017). Based on Table 4, Pb levels in water decreased from the total Pb concentration added during the study, with Removal Efficiency (RE) values ranging from 85.40–95.66%. The high percentage of removal across all treatments indicates that the constructed wetland system is capable of effectively reducing Pb concentrations. Nevertheless, Pb concentrations in water did not significantly differ among treatments, suggesting that the presence of plants has not yet become the primary mechanism in the Pb removal process during the initial stage of remediation.

The accumulation of Pb in the soil medium indicates that the process of metal sequestration occurs more through retention mechanisms by the soil rather than direct absorption by plants. Pb concentrations in the soil after remediation in the control treatment ranged from 3.53–4.04 mg kg^{-1}, while in the *T. angustifolia* treatment they ranged from 1.44–2.20 mg kg^{-1}, and in *C. alternifolius* from 0.77–1.54 mg kg^{-1} (Table 5). This condition indicates that most Pb is initially retained in the medium, resulting in a decrease in metal concentration in the solution. This retention can occur through various mechanisms, such as adsorption on soil particle surfaces, cation exchange, complex formation with organic matter, and precipitation, which reduce the mobility and bioavailability of Pb (Liu *et al.,* 2022; Xing *et al.,* 2023). Initial soil analysis showed that the medium has a sandy clay texture, pH 5.9 (slightly acidic), 2.4% organic carbon, and a CEC of 24.59 cmol kg^{-1}, which is considered medium. These characteristics support the ability of the media to retain Pb through interactions with clay fractions and organic matter, although the relatively high sand content still allows for the movement of metals in the soil solution (Nascimento *et al.,* 2014). In addition, pH, organic matter, and CEC play an important role in controlling adsorption and the bioavailability of Pb for plant uptake (Georgin *et al.,* 2026). Therefore, the high efficiency of Pb removal in constructed wetland systems is suspected to be not only caused by plant absorption but also by Pb retention in the soil media.

Table 4. Pb Concentration in water after remediation

Treatments	**Total mg Pb L^{-1}**	**Pb in Water (mg L^{-1})**	**Removal Efficiency (%)**
Soil/ Control (Without plants)	10	1.21 ± 0.03tn	87.89
	20	1.20 ± 0.04tn	94.01
	30	1.30 ± 0.07tn	95.66
T. angustifolia	10	1.28 ± 0.05tn	87.23
	20	1.25 ± 0.02tn	93.73
	30	1.35 ± 0.12tn	95.50
C. alternifolius	10	1.46 ± 0.12tn	85.40
	20	1.43 ± 0.11tn	92.90
	30	1.48 ± 0.28tn	95.07

Description: Letters that are the same are not significantly different between treatments according to the DMRT 5% test, total data (mean ± SD, n = 3), tn (not significantly affected), RE (Removal Efficiency)

Table 5 shows that administering different Pb concentrations to both plant species resulted in Pb absorption in the shoot and root parts that did not differ significantly. The highest Pb accumulation in shoots and roots was found in the *T. angustifolia* treatment at an initial concentration of 10 mg Pb L^{-1}, followed by concentrations of 20 and 30 mg Pb L^{-1}. Pb absorption by *C. alternifolius* in shoot and root tissues showed lower values compared to *T. angustifolia*, with Pb content in shoots ranging from 0.47–0.77 mg kg^{-1} and in roots ranging from 0.31–0.61 mg kg^{-1}. Although Pb removal efficiency reached 85.40–95.66%, Pb accumulation in plant tissues was relatively low and did not show significant differences between treatments. These results are consistent with the high Pb accumulation still found in the soil medium, indicating that most Pb remained bound in the medium before being absorbed by the plants. These results are consistent with the high accumulation of Pb still found in the soil media, indicating that most of the Pb is retained in the media before being absorbed by the plants. The presence of Pb in the roots and shoots shows that both species still play a role in the phytoremediation process. Heavy metals absorbed through the roots can be translocated to the shoots, where the metals are stored or detoxified as a mechanism of plant tolerance to heavy metal stress (Gupta *et al.,* 2024).

In general, Pb is a metal with low mobility, so its accumulation tends to be higher in the roots compared to the upper parts of the plant. However, in this study, the concentration of Pb in the shoots tended to be higher than in the roots, although the difference was not significant. This condition indicates that some of the Pb absorbed by the roots can be translocated to the above-ground tissues through the xylem flow influenced by the transpiration process. This translocation process is suspected to involve metal transporter systems, such as Heavy Metal ATPases (HMA) and the ZIP family proteins, which play a role in the movement of metals from roots to shoots (Gupta *et al.,* 2024). The presence of Pb in shoot tissues shows that both species have the ability to distribute metals to the upper parts of the plant as one of the mechanisms for tolerance and detoxification against heavy metal stress.

Table 5. Pb uptake by *T. angustifolia* and *C. alternifolius*

Treatments	**Total Pb mg L^{-1} added**	**Pb in Soil (mg kg^{-1})**	**Pb in Plant (mg kg^{-1})**	
			Shoots	**Root**
Soil/ Control (Without plants)	10	4.04 ± 0.11g		
	20	3.75 ± 0.13 f		
	30	3.53 ± 0.19 f		
T. angustifolia	10	2.20 ± 0.09 e	1.45 ± 0.15d	1.35 ± 0.10d
	20	1.69 ± 0.08 d	1.25 ± 0.05cd	1.01 ± 0.06c
	30	1.44 ± 0.12bc	0.93 ± 0.33bc	0.72 ± 0.29bc
C. alternifolius	10	1.54 ± 0.12cd	0.77 ± 0.04ab	0.61 ± 0.05ab
	20	1.26 ± 0.13 b	0.65 ± 0.05ab	0.50 ± 0.04ab
	30	0.77 ± 0.16 a	0.47 ± 0.07a	0.31 ± 0.08a

Note: Letters that are the same are not statistically significantly different between treatments according to the 5% DMRT test, total data (mean ± SD, n = 3)

3.4 Bioconcentration Factor and Translocation Factor Values

The ability of plants to accumulate heavy metals can be seen by looking for the Bioconcentration Factor (BCF) and Translocation Factor (TF) values presented in Table 6. Table 6 shows that *T. angustifolia* treatment at each concentration has BCF > 1 and TF > 1. Meanwhile, *C. alternifolius* has BCF < 1 but TF > 1. According to Sugiyanto *et al.* (2016), there are 3 categories of plant groups related to BCF and TF values, namely BCF > 1 including accumulator plants, BCF < 1 including excluder plants, BCF close to 1 including accumulator indicator plants, TF > 1 for phytoextraction, and TF < 1 for phytostabilization.

Table 6. BCF and TF values

Treatments	Total Pb mg.L^{-1}	BCF	TF
T. angustifolia	10	2.19	1.08
	20	1.81	1.24
	30	1.45	1.28
C. alternifolius	10	0.95	1.25
	20	0.81	1.31
	30	0.52	1.53

Plants with TF > 1 indicate that the plants are part of the phytoextraction mechanism, so the aerial parts of the plant above the ground can be easily harvested. High Pb accumulation can be associated with a good plant detoxification mechanism based on sequestration (storage) of heavy metal ions in vacuoles, by binding them in the form of complex compounds with organic acids, proteins, and peptides (Cui *et al.,* 2007). According to Nascimento *et al.* (2014), the translocation process is generally influenced by mechanisms, root and leaf transpiration, as well as the solubility of metals in the soil, which is restricted due to adsorption to soil mineral fraction particles.

According to Tangahu *et al.* (2013), phytoextraction is the uptake or absorption and translocation of heavy metals by plant roots to the above-ground parts of the plant (shoots) that can be harvested and burned to obtain energy while recycling metals from the ash. Based on the statement of Soda *et al.* (2012), wetland plants with high biomass and high TF allow the above-ground parts of the plant to be easily harvested without requiring much effort. New shoots can also grow from the remaining roots. However, Wang *et al.* (2019) stated that the TF value in wetland systems using emergent plants is not very important as an indicator of plants acting as phytoremediators because the root and shoot parts can be easily harvested.

4. Conclusion

The plants *T. angustifolia* and *C. alternifolius* have been proven capable of reducing lead (Pb) levels using the Free Water Surface Flow Constructed Wetland method in batch type, with Pb reduction over 2 weeks reaching 85-95%. Treatment with *T. angustifolia* at each given Pb concentration had BCF > 1 and TF > 1, whereas for *C. alternifolius*, BCF < 1 and TF > 1. Both plants are considered species of heavy metal hyperaccumulators with potential in practical applications for cleaning environments contaminated with heavy metals and have potential as phytoremediation with TF values > 1.

5. Authors Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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