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Heavy metal distribution in water, sediments, and aquatic plants from the middle Songkhla Lagoon: Environmental risk and phytoremediation assessment

Chanok, J.[1,2], Keereerak, K.[1,2], Noppradit, P.[1,2] and Pradit, S.[1,2*]

[1]Marine and Coastal Resources Institute, Faculty of Environmental Management, Prince of Songkla University, Songkhla 90110, Thailand; [2]Coastal Oceanography and Climate Change Research Center, Prince of Songkla University, Hat Yai, Songkhla 90110, Thailand.

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Abstract This study investigated the distribution of aluminum (Al), arsenic (As), and lead (Pb) in water, sediments, and two dominant aquatic plants—morning glory (*Ipomoea aquatica*) and water mimosa (*Neptunia oleracea*)—from the middle part of Songkhla Lagoon. Heavy metal concentrations in water and sediments were below national and international standards, indicating low contamination risk. Both concentrations of As and Pb in sediment had severe enrichment (EF > 15) at all stations, suggesting anthropogenic inputs. In contrast, geo-accumulation index (I_{geo}) values were negative, indicating unpolluted sediments and showing two-index differential sensitivity. In aquatic plants, heavy metals were mainly accumulated in roots, with significantly lower concentrations found in stems and leaves, especially for As and Pb. Morning glory showed greater root uptake of As and Pb than water mimosa, making it a better candidate for bioindication. Despite root accumulation, translocation factors (TF) and bioaccumulation factors (BAF) were closed to zero for all stations and metals, confirming that metals did not effectively move into edible aerial tissues. This pathway from sediment to root, but not to leaf or stem, suggested that the edible parts of these plants remain relatively safe for consumption under current conditions. Low contamination levels in water and sediment limited metal transfer to upward plant parts, and environmental parameters (e.g., sediment pH, organic carbon, and particle size) supporting these species, particularly morning glory for rhizo-filtration and safe, sustainable use in brackish aquatic environments.

Keywords: Water mimosa, Morning glory, Climate Change, Arsenic, Lead

Introduction

The Middle Songkhla Lagoon belongs to the broader Songkhla Lagoon system and stretches across the provinces of Songkhla and Phatthalung in southern Thailand. Its waters are brackish, influenced by the mixing of freshwater from rivers and seawater from the Gulf of Thailand. Over time, this

* **Corresponding Author:** Pradit, S.; **Email:** siriporn.pra@psu.ac.th

mix has shaped a complex landscape filled with small islands and rich natural habitats. The lagoon supports a high level of biodiversity, providing a home for many species of fish, aquatic plants, and migratory birds. One particularly important area within this system is Khu Khut Waterfowl Park, which lies inside the Songkhla Lagoon Non-Hunting Area, a protected zone known for its ecological value and role in conservation. The study area lies within this important ecological zone. The choice of this site was based on its ecological richness as well as the presence of aquatic plants that are commonly collected and consumed by local communities. Two of the most widespread and recognizable aquatic plant species in the lagoon are water mimosa (*Neptunia oleracea*) and morning glory (*Ipomoea aquatica*), both of which have nutritional and economic value and are closely tied to the local food culture. These species are commonly available in Thai markets and are part of everyday meals. Because they are often eaten raw or only lightly cooked, there is concern that they may expose consumers to environmental pollutants, particularly heavy metals. Metals such as aluminum (Al), arsenic (As), and lead (Pb) exist naturally in the environment. Nonetheless, heavy metal concentrations in aquatic habitats can increase beyond the natural background values due to human activities such as agriculture, aquaculture, wastewater discharge, and urban runoff (Aljumaily and Al-Hamndi, 2022; Pradit *et al*., 2024). According to Chapman (1992), once these metals are discharged into water systems, they frequently remain and progressively accumulate in sediments and aquatic animals. Aquatic plants and animals may absorb these contaminants, allowing metals to move through the food chain and potentially threaten ecosystem health and human safety (Shirani *et al*., 2020). In brackish ecosystems like Songkhla Lagoon, factors such as salinity, sediment composition, and land-based pollution influence where and how metals are distributed (Pradit *et al.,* 2019). Although sediments can act as sinks for heavy metals, certain conditions—like low pH or depleted oxygen—can cause these metals to become mobile again and re-enter the water column (Basti *et al*., 2024; Wei *et al*., 2023). Although some environmental monitoring has been conducted in parts of the Songkhla Lagoon, site-specific data from the Middle Songkhla Lagoon—particularly within protected zones like the Khu Khut Waterfowl Park—are still lacking. The presence of heavy metals in aquatic plants commonly consumed by local communities raises concerns about environmental safety and human health. Although *Neptunia oleracea* and *Ipomoea aquatica* are often praised for their phytoremediation potential (Rachmadiarti and Sholikah, 2020), it remains unclear how much of these metals accumulate in edible plant parts, particularly leaves and stems compared to roots. Plants can take in heavy metals even in places with only low to moderate pollution, often without showing any visible signs of stress. This makes it important to study where metals accumulate in plant tissues, especially in edible parts like leaves and stems.

By gaining an understanding of this distribution, we will be better able to assess the potential dangers that these plants pose to ecosystems and public health, particularly in populations that draw their food supply from these plants. The purpose of this study was to investigate the ways in which heavy metals interact with aquatic plants in the central region of Songkhla Lagoon. The research project was aimed to measure concentrations of aluminum (Al), arsenic (As), and lead (Pb) in water, sediment, and aquatic plants, to compare metal levels across sampling sites, to examine how metals are distributed across different plant parts, including leaves, stems, and roots, to explore how metal concentrations relate to environmental factors such as sediment pH, organic matter, and particle size, to assess sediment contamination using two indicators, the Enrichment Factor (EF) and the Geo-accumulation Index (I_{geo}) and to evaluate the potential of two common aquatic plants to absorb and store metals, using indicators like the Bioaccumulation Factor (BAF) and Translocation Factor (TF).

Materials and methods

Study area

The study area was in the middle of Songkhla Lagoon (360 km², ~2 m depth), a brackish environment impacted by freshwater, ocean, and islands in Songkhla and Phatthalung provinces. Samples were taken at Khokhude Waterfowl Park. These biodiverse areas support oil palm, rubber, sugar palm, poultry, pig farming, and fishing. Based on land use and geography, five stations (ST01–ST05) were selected (Figure 1) and each included three replicates of water, sediment, and aquatic plants to ensure consistency.

Sample collection and preparation

The researchers collected aquatic plants and surface water samples and used a sediment grab sampler to collect sediment. Water samples were filtered and stored at room temperature for heavy metal analysis. After drying in a 60°C oven, the samples were weighed and crushed. Water mimosa and morning glory samples were collected by hand. After washing with deionized water, samples were separated into leaves, stalks, and roots. Heavy metal analysis required small samples to be cut, dried at 60°C, and bagged.

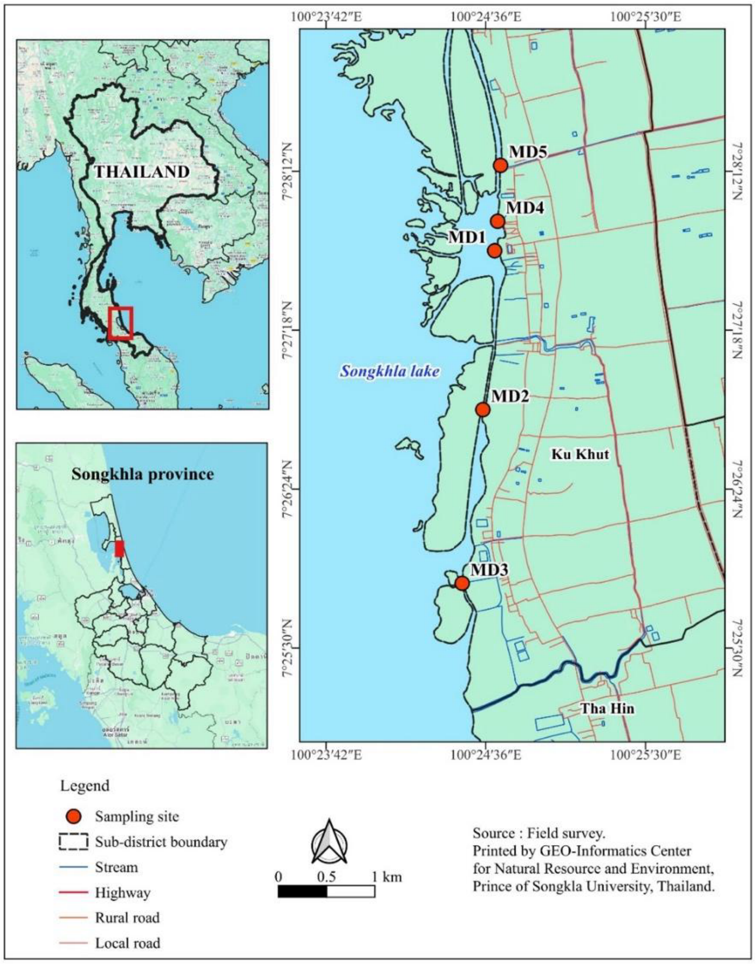

Figure 1. Map of the study area and locations of the sampling stations

Heavy metals analysis

1 gram of sediment or aquatic plant sample was combined with 10 mL water, 2 mL concentrated nitric acid, and heated in a water bath until clear. The solution was diluted with ultrapure water and tested using ICP-OES according to the AOAC Official Method to evaluate heavy metal concentrations (AOAC, 2005).

Environmental factor evaluation

pH: At the sample station, a mobile pH meter measured the pH of the water and sediment. (Trans Instrument Senz pH Pro).

Dissolved oxygen (DO): At the sample station, a multiparameter device (YSI™ Professional Plus Multiparameter Meter) measured dissolved oxygen (DO) in the water.

Organic Carbon content (%OC) analysis: The percentage of organic carbon (OC) was estimated using the LOI method, which involved drying and weighing a preheated crucible (103°C, 1 h). Meanwhile, 5 g of oven-dried, crushed sediment was burned at 550°C for 4 hours. The residue was then weighed again after it had cooled. Weight loss was used to calculate the percentage of OC (Equation 1).

$$\%LOI = \frac{Mb-Ma}{100} \quad \text{..(1)}$$

The organic carbon content (%OC) was estimated using the loss-on-ignition (LOI) method, where Mb is the mass before combustion and Ma is the mass after combustion. The %OC was calculated based on the following conditions:
If %LOI is less than 0.20, the formula used was: %OC = 0.21 + 0.40(%LOI)
If %LOI is greater than 0.20, the formula used was: %OC = 0.33 + 0.43(%LOI)

Particle size analysis with a laser particle size analyzer: Dry sediment samples (10 g) were homogenized in 20 mL of distilled water for 30–60 minutes before particle size analysis. Wet dispersion was used to evaluate the particles with a laser particle size analyzer (ANALYSETTE 22 NanoTec, FRITSCH, Germany). The equipment measures particle sizes from 0.08 to 2000 µm and displays results as cumulative percentage distributions by size class (Straz and Szostek, 2024).

Sediment pollution

Enrichment Factor (EF): Metal contamination was assessed by comparing metal concentrations against a reference element, such as aluminum (Al) or iron (Fe). The EF was calculated using the equation described by Akoto *et al*. (2008) and Pradit *et al*. (2024). The EF equation is shown in Equation (2).

$$\boldsymbol{EF}\ \frac{\left(\frac{M}{Al}\right)s}{\left(\frac{M}{Al}\right)b} \quad \text{..(2)}$$

where $\left(\frac{M}{AL}\right)s$ is the ratio of the metal to Al in sediment samples and $\left(\frac{M}{AL}\right)b$ is the ratio of the metal to Al in background or baseline values.

Geo-accumulation Index (I_{geo}): Metal pollution was assessed by comparing present concentrations to pre-industrial background levels. The geo-accumulation index (I_{geo}) was calculated using the equation described by Akoto *et al*. (2008) and Pradit *et al*. (2024), as shown in Equation (3).

$$I_{geo} = log_2\left(\frac{C_n}{1.5B_n}\right) \text{ ....(3)}$$

where C_n refers to the concentration of the heavy metal in the sediment sample, while B_n represents the background concentration under natural conditions. For aluminum (Al), B_n is 80,000 µg/g, as reported by Turekian and Wedepohl (1961).

Phytoremediation capabilities

Bioaccumulation Factor (BAF): BAF represents a plant's capacity to accumulate heavy metals in its tissues relative to the concentration in the surrounding sediment. In this study, BAF was separately calculated for different plant parts - leaves (BAF_L), stems (BAF_S), and roots (BAF_R) using Equations (4) to (6), as adapted from Hosseini *et al*. (2020) and Rachmadiarti and Sholikah (2020).

Translocation Factor (TF): TF indicates the movement of heavy metals from the roots to the leaves. It was calculated using Equation (7), as adapted from Hosseini *et al*. (2020) and Rachmadiarti and Sholikah (2020).

$$BAF_L = \frac{C_{leaf}}{C_{sediment}} \text{ ....(4)}$$

$$BAF_S = \frac{C_{stem}}{C_{sediment}} \text{ ....(5)}$$

$$BAF_R = \frac{C_{root}}{C_{sediment}} \text{ ....(6)}$$

$$TF = \frac{C_{shoot}}{C_{root}} \text{ ....(7)}$$

where C_{leaf} refers to the metal concentration in leaf, C_{stem} refers to the metal concentration in stem, C_{root} refers to the metal concentration in root, and $C_{sediment}$ refers to the metal concentration in sediment.

Statistical analysis

This study reports heavy metal concentrations (Al, As, and Pb) in water, sediment, and aquatic plants. Mean ± standard deviation was used for water and sediment, while plant values were based on single measurements. One-way ANOVA was applied to compare concentrations across stations in water and sediment, and two-way ANOVA was used to assess differences among plant species and plant parts. Pearson or Spearman correlation was performed to examine relationships between variables.

Results

Study observation

Aquatic plants were recorded during field observations at each sampling station, as summarized in Table 1. Two dominant species, water mimosa (*Neptunia oleracea*) and morning glory (*Ipomoea aquatica*), were commonly found in the surveyed areas (Figure 2).

Table 1. Aquatic plants observed and environmental descriptions across sampling stations

Station	Aquatic plant		Explanation
	Morning glory	Water mimosa	
MD01	/	/	Located in Moo 5, near a community and a temple. There has been little dredging.
MD02	/	-	Located in Moo 6, where most residents were fishing, using nets, trawls, and fish traps.
MD03	-	/	Located in Moo 7 and 8, near a community and a temple. Residents mostly fish and farm.
MD04	/	/	In Moo 4, nearby a crowded neighborhood. The water smells bad.
MD05	/	-	Located in Moo 3, in a small population community.

In Table 1, “/” indicates plant presence and “–” indicates absence.

Figure 2. Two dominant aquatic plant species were observed in the study area: water mimosa (white arrow) and morning glory (red arrow)

Heavy metals levels

Water: Aluminum (Al) concentrations ranged from 0.1520 mg/L (MD02) to 0.3770 mg/L (MD04). Arsenic (As) was highest at MD02 (0.0040 mg/L), while it was not detected at MD05. Lead (Pb) was not detected at any station as shown in Table 2. All detected quantities were below Thailand's Pollution Control Department (2010) surface water quality limits of 0.01 mg/L As and 0.05 mg/L Pb. Al has no standard, but recorded values are comparable to freshwater natural ranges.

Sediment: Aluminum (Al) concentrations in sediments ranged from 3353.3536 mg/kg at MD03 to 4051.9656 mg/kg at MD01 as shown in Table 2. Arsenic (As) ranged from 0.9589 mg/kg (MD05) to 2.3253 mg/kg (MD01), and lead (Pb) from 12.0987 mg/kg (MD05) to 16.0686 mg/kg (MD01). All concentrations were below Thailand's Pollution Control Department (2010) sediment quality standards of 52 mg/kg Pb and 7 mg/kg As. The results were also below the USEPA sediment standards of 37 mg/kg for Pb and 11 mg/kg for As (USEPA, 1996).

Aquatic plants: Aluminum (Al) contents in aquatic plants varied by part and station. Morning glory leaves had the highest Al content at MD04 (15.1203 mg/kg) and the lowest at MD02 (5.4146 mg/kg as shown in Table 3). Similar trends were observed in stems, with MD04 having the highest concentration (10.9980 mg/kg) and MD02 the lowest (6.7939). Roots exhibited considerably higher Al levels (46.7126 mg/kg (MD02) versus 348.5075 mg/kg (MD01). As and Pb were generally undetectable in upper parts but found in roots, peaking at MD01 (16.7915 mg/kg for As and 3.5472 mg/kg for Pb). In water mimosa leaves, Al content was highest at MD04 (24.5362 mg/kg) and lowest at MD03 (7.5240 mg/kg). MD04 leaves had 0.1197 mg/kg Pb. Less Al was found in stems

(3.0237–10.5947 mg/kg), while As and Pb were undetectable. Al was again highest in roots (301.7190–348.5075 mg/kg) and As and Pb were highest at MD01 (2.3653 and 1.2892 mg/kg) and lowest at MD03 (2.2056 and 2.1064 mg/kg), although their values remained low.

Table 2. Mean ± standard deviation of heavy metal concentrations (mg/L or mg/kg) in water samples

Station	Sample	Heavy Metals		
		Al	As	Pb
MD01	Water[1]	0.2527 ± 0.0529^{ab}	0.0027 ± 0.0046	n.d.
MD02		0.1520 ± 0.0079^{b}	0.0040 ± 0.0026	n.d.
MD03		0.2037 ± 0.0803^{b}	0.0017 ± 0.0015	n.d.
MD04		0.3770 ± 0.0689^{a}	0.0007 ± 0.0012	n.d.
MD05		0.2170 ± 0.0536^{ab}	n.d.	n.d.
MD01	Sediment[2]	4051.9656 ± 116.0972	2.3253 ± 0.8579^{a}	16.0686 ± 0.3439^{a}
MD02		3610.0818 ± 891.6019	2.2048 ± 0.1068^{a}	12.3131 ± 1.3784^{b}
MD03		3353.3536 ± 92.3086	1.3146 ± 0.1585^{a}	13.4599 ± 0.1461^{b}
MD04		3572.8479 ± 499.0494	2.6956 ± 0.4144^{a}	12.2472 ± 0.7735^{b}
MD05		3403.9066 ± 309.4987	0.9589 ± 0.1661^{b}	12.0987 ± 1.0269^{b}

[1]/ Heavy metal concentrations in water (mg/L), [2]/Heavy metals concentrations in sediment (mg/kg)
"-" indicates no sample was available at that station.
"n.d." indicates the heavy metal was not detected.
Different superscript letters indicate significant differences among stations (Tukey's HSD, $p < 0.05$)

Environmental factors

All stations had slightly neutral to weakly basic water pH between 7.25 to 8.50 (Figure 3). Meanwhile, sediment pH ranged from 5.32 to 8.03, suggesting acidic and basic conditions. Some stations have lower pH and dissolved oxygen (DO), indicating water quality degradation. This results in stable compounds reduced mobility under specific pH levels, improving sediment heavy metal accumulation. Particle size distribution was mostly similar across stations, except at MD02, where a different trend was observed. Overall, sediment pH, organic carbon, and particle characteristics are key environmental factors influencing the distribution and retention of heavy metals in aquatic systems.

Table 3. Heavy metal concentrations (mg/kg) in aquatic plant samples

Station	Sample	Heavy Metals		
		Al	As	Pb
MD01	Morning glory' s leaves[2]	10.1969	n.d.	0.0100
MD02		5.4146	n.d.	n.d.
MD03		-	-	-
MD04		15.1203	n.d.	n.d.
MD05		10.7168	n.d.	n.d.
MD01	Morning glory' s stems[2]	10.7089	n.d.	0.0700
MD02		6.7939	n.d.	n.d.
MD03		-	-	-
MD04		10.9980	n.d.	0.0399
MD05		9.8433	n.d.	n.d.
MD01	Morning glory' s roots[2]	348.5075	16.7915	3.7936
MD02		46.7126	3.5472	0.8393
MD03		-	-	-
MD04		176.6234	5.9041	1.9580
MD05		346.7266	6.8866	2.4288
MD01	Water mimosa' s leaves[2]	17.1680	n.d.	n.d.
MD02		-	-	-
MD03		7.5240	n.d.	n.d.
MD04		24.5362	n.d.	0.1197
MD05		-	-	-
MD01	Water mimosa' s stems[2]	10.5947	n.d.	n.d.
MD02		-	-	-
MD03		3.0237	n.d.	n.d.
MD04		5.8184	n.d.	n.d.
MD05		-	-	-
MD01	Water mimosa' s roots[2]	333.0339	2.3653	2.2056
MD02		-	-	-
MD03		301.7190	1.2892	1.6490
MD04		356.1945	1.3178	2.1064
MD05		-	-	-

[2]/Heavy metals concentrations in the part of plant tissue (mg/kg)
"-" indicates no sample was available at that station.
"n.d." indicates the heavy metal was not detected.

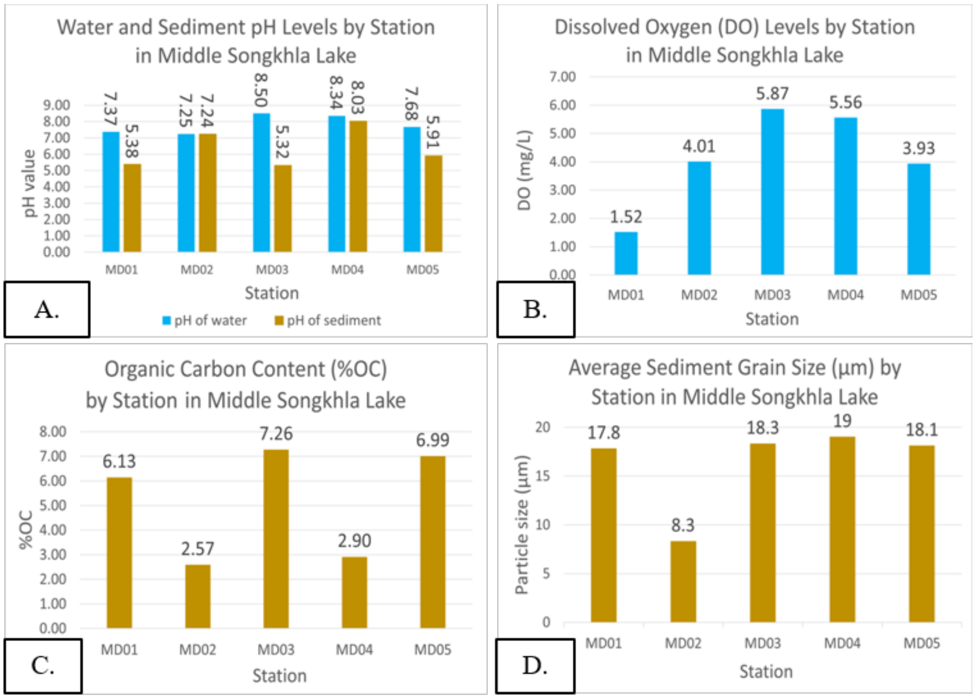

Figure 3. Environmental parameters in Middle Songkhla Lagoon: (A) pH of water and sediment, (B) dissolved oxygen (DO) levels, (C) organic carbon content (%OC), and (D) sediment particle size at each station

Sediment pollution

Enrichment Factor (EF): This study measured sediment pollution using arsenic (As) and lead (Pb) Enrichment Factors (EF) (Figure 4-A). All stations had severe enrichment (EF > 15) for both metals, indicating human impact. The EF values for arsenic ranged from 15.0242 at MD05 to 40.24 at MD04, indicating different contamination levels. Lead had significantly higher enrichment, with the highest EF value at MD03 (214.07), showing severe Pb pollution from land use and human activities.

Geo-accumulation Index (I_{geo}): Arsenic (As) and lead (Pb) geo-accumulation index (I_{geo}) values were negative at all stations, indicating unpolluted sediments (Figure 4-B). The lowest As I_{geo} value was MD05 (–4.55), while the lowest Pb was MD02 (–1.31). Based on I_{geo} classification, the findings suggest no contamination.

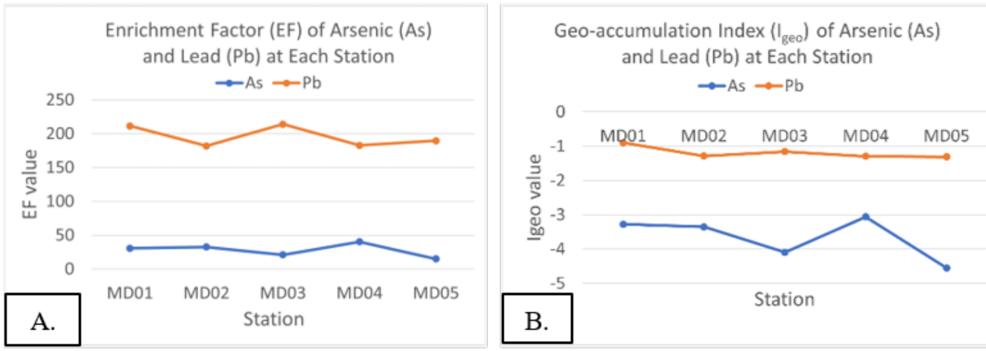

Figure 4. (A) Enrichment Factor (EF) and (B) Geo-accumulation Index (I_{geo}) of As and Pb at each station in Middle Songkhla Lagoon

Phytoremediation capabilities

The bioaccumulation factors (BAF) of morning glory indicate that the concentrations of aluminum (Al), arsenic (As), and lead (Pb) in both leaves and stems were close to zero relative to sediment concentrations (Figure 5). This suggests that these metals did not translocate from sediment into the aerial parts of the plant. In contrast, the BAF for As in roots exceeded 1 at some stations, particularly at MD01, indicating that As was taken up from the sediment and accumulated in the roots. Water mimosa showed a similar trend, with BAF values for Al, As, and Pb in leaves, stems, and even roots all close to zero. This implies that metal uptake from sediment was minimal across all plant parts. However, an exception was observed at MD01, where the BAF for As in roots was greater than 1, suggesting localized As accumulation in the roots at this station. In terms of translocation, translocation factor (TF) values for all metals in both plant species were either zero or close to zero, indicating limited or no movement of metals from roots to shoots.

Relationship between concentration of heavy metals and environmental factors

Water Samples: Post hoc analysis using Tukey's HSD revealed significant differences (Table 1) in aluminum (Al) levels across the sample stations, with markedly elevated values seen at ST04 in comparison to ST02 and ST03 ($p < 0.05$). No significant variations in arsenic (As) and lead (Pb) concentrations were observed across the stations ($p > 0.05$), indicating a generally similar distribution of these elements throughout the research area. The observed variance in Al concentrations may be linked to local sources or environmental variables affecting its distribution, in contrast to As and Pb. Sediment Samples: Aluminum concentrations in sediment were constant among areas, while arsenic (As) and lead (Pb) levels varied significantly (Table 1). Al levels did not significantly differ among the five stations, according to the one-way ANOVA ($F = 0.98$, $p = 0.46$). Arsenic (As) concentrations at ST05 were significantly lower than those at the other stations, which were grouped together according to subsequent Tukey HSD tests. The amounts of Pb at ST01 were much greater than those at the other stations, which were clustered together. These trends show that while Al is unaffected by geographical considerations, As and Pb deposition in sediment are affected by geographical considerations.

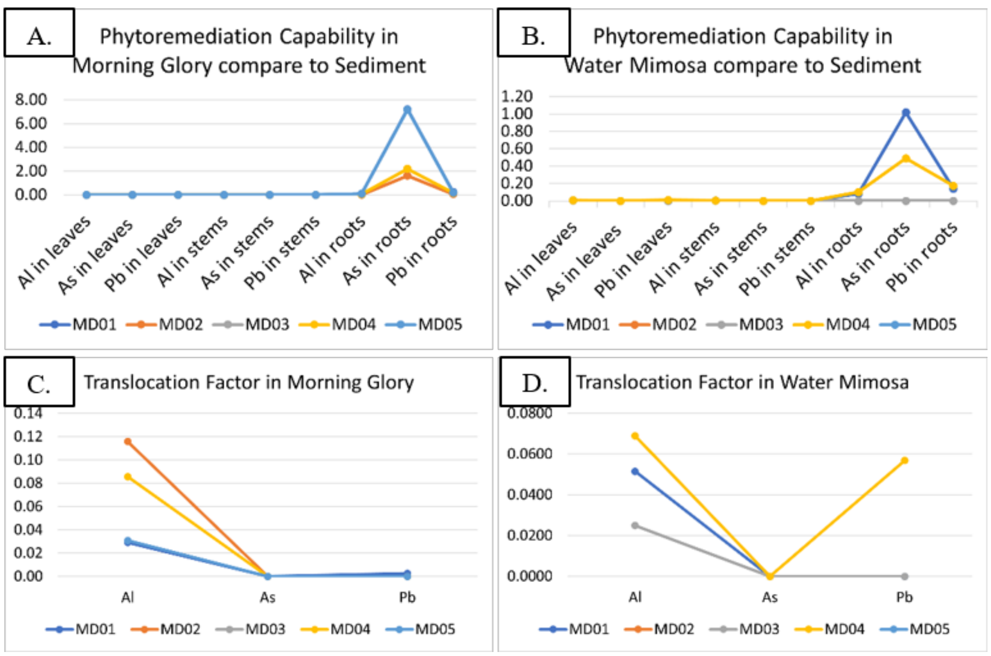

Figure 5. (A–B) Bioaccumulation factor (BAF) of Al, As, and Pb in plant parts of morning glory and water mimosa; (C–D) Translocation factor (TF) showing metal movement from roots to shoots of morning glory and water mimosa

The two-way ANOVA determined that the concentrations of Al, As, and Pb in aquatic plants were significantly influenced by plant part ($p < 0.05$), while plant species and the interaction between species and part had no significant effect ($p > 0.05$). Further analysis showed that metal accumulation was much higher in roots compared to stems and leaves, which had similar concentrations to each other. This trend was consistent for both Water mimosa and Morning glory, highlighting their capacity to sequester metals predominantly in root tissues and underscoring their utility as bioindicators of metal contamination in aquatic ecosystems.

Spearman correlation analysis: Spearman correlation analysis of water samples (Table 4) showed a significant positive correlation between water pH and dissolved oxygen (DO) (r = 0.700, p = 0.004). No significant correlations were found between heavy metal concentrations in water (Al, As) and water quality parameters (pH, DO). Lead (Pb) was excluded from the correlation analysis because its concentrations in water samples were below the detection limit. In sediment samples (Table 5), sediment pH was significantly negatively correlated with organic matter (r = –0.800, p < 0.01) and Pb (r = –0.644, p < 0.01) but positively correlated with As concentrations (r = 0.524, p < 0.05). Organic matter content was also negatively correlated with As (r = –0.720, p < 0.01). A positive correlation was found between Al and Pb concentrations in sediment (r = 0.607, p < 0.05). No significant correlations were observed between particle size and heavy metal concentrations.

Table 4. Spearman's correlation coefficients between water quality parameters and heavy metal concentrations in water samples

Variables	WpH	DO	WAl	WAs
WpH	1.000	.700**	.349	-.267
DO	.700**	1.000	.033	.142
WAl	.349	.033	1.000	-.289
WAs	-.267	.142	-.289	1.000

Note: Correlation coefficients (ρ) are shown. p < 0.01 (**) and p < 0.05 (*). Pb in water was excluded due to concentrations below detection limits.
Abbreviations: WpH = Water pH, DO = Dissolved oxygen, WAl = Aluminum in water, and WAs = Arsenic in water

Table 5. Spearman's correlation coefficients between sediment characteristics and heavy metal concentrations in sediment samples

Variables	SpH	%OC	Particle Size	SAl	SAs	SPb
SpH	1.000	-.800**	.100	.000	.524*	-.644**
%OC	-.800**	1.000	.400	-.306	-.720**	-.316
Particle Size	.100	.400	1.000	-.393	-.065	-.153
SAl	.000	-.306	-.393	1.000	.304	.607*
Sas	.524*	-.720**	-.065	.304	1.000	.079
SPb	-.644**	.316	-.153	.607*	.079	1.000

Note: Correlation coefficients (ρ) are shown. p < 0.01 (**) and p < 0.05 (*). Pb in water was excluded due to concentrations below detection limits.
Abbreviations: SpH = Sediment pH, %OC = Percent organic carbon, SAI = Aluminum in sediment, SAs = Arsenic in sediment, and SPb = Lead in sediment

Discussion

Study observation

This study is confirmed the finding of the Department of Marine and Coastal Resources (2009) that morning glory dominates Songkhla Lagoon, with absence of water mimosa reported. This absence may indicate that water mimosa is a new arrival, either due to natural migration or human introduction, and that ecological studies in the area are lacking.

Heavy metals levels

This study found that there was good water quality in the research area, although regular monitoring is advised to detect potential future contamination.

Moreover, lower water heavy metal concentrations were found in the present study than reported in Meesuk and Thosakun (1992), which found lead (Pb) levels of 0 to 0.10 ppm. Pb was not detected in the current samples, like the finding of the Regional Environment Office 16 (Regional Environment Office 16 (Songkhla), 2025) that determined low Pb and As concentrations that were below acceptable limits. This data implies that Songkhla Lagoon has high water quality. For sediment, this study indicates low contamination risk and there is a low ecological concern at all stations. This study also found sediment arsenic and lead values of 0.96–2.70 mg/kg and 12.10–16.07 mg/kg, which are much lower than that previously reported in Pradit *et al*. (2024) which found As levels between 1.20–13.74 mg/kg and Pb levels between 3.26–39.02 mg/kg, while Pradit *et al.* (2018) discovered 10–20 times greater As and 4–5 times higher Pb. This study focused only on the middle of Songkhla Lagoon, while past research collected samples from all parts of the Songkhla lagoon. Water mimosa had higher leaf Al concentrations than morning glory, which had slightly higher stem Al. Metal buildup in the roots was considerable in both species, suggesting little upward translocation. Morning glory roots had higher As and Pb than water mimosa, suggesting a better sediment heavy metal uptake capacity. Morning glory may be a stronger bioindicator for sediment-associated heavy metals, particularly As and Pb, while water mimosa may better represent Al in the water column and sediments due to its higher leaf accumulation.

Environmental factors

This study found a slightly alkaline water and sediment pH (7.25–8.50 and 5.32–8.03, respectively), similar to the Songkhla Lagoon findings in Pradit *et al.* (2024). Particle size distribution was mostly similar across stations. However, variation may influence metal binding behaviour, as finer particles typically have greater surface area for metal adsorption. At some stations, nearby communities and aquaculture activities may lower pH and DO due to organic matter accumulation and decreased dissovled oxygen, which might change metal mobility and chemical forms in sediments. Regional Environment Office 16 (Regional Environment Office 16 (Songkhla), 2025) showed low dissolved oxygen concentrations in Ban Pak Ja of Songkhla Lagoon. This present study of surrounding places showed a similar pattern. The similarity may be due to similar environmental conditions, such as community and aquaculture, which reduces aquatic oxygen availability. The particle size pattern may have influenced heavy metal distribution, as finer particles have more metal-adsorption surface area. Alina Kabata-Pendias (2001) found a substantial association between small particles and higher heavy metal contents in river sediments.

Sediment pollution

Since higher EF results can suggest long-term environmental concerns, continuous monitoring is essential. The findings may guide local pollution control and sediment management. The enrichment factor (EF) results from this study suggest anthropogenic contamination of arsenic (As) and lead (Pb), similar to the findings of Pradit *et al.* (2024) which also reported elevated EF values for As. Although the EF values for Pb in this study were higher, both studies point to human activities as the main source of contamination. The geo-accumulation index (I_{geo}) showed that Pb was unpolluted to moderately contaminated, while As was more contaminated. This study used aluminum (Al), while other researchers used iron (Fe), which could affect EF estimates due to local geochemical circumstances. EF results showed notable enrichment at all stations for both metals (EF > 15), but I_{geo} results showed no contamination. The more sensitive EF can detect important enrichment compared to background levels even at low relative concentrations. Due to its logarithmic formula and correction factor (1.5), I_{geo} may underestimate pollution at low levels of pollution. EF therefore shows human influence while I_{geo} indicates slight contamination levels. Combining both indices improves sediment quality and pollution risk assessment.

Phytoremediation capabilities

The high bioaccumulation factor (BAF) of arsenic (As) in morning glory roots is related to the greatest sediment concentration at station MD01. This contrast is due to differences in the values obtained from the two indices. This supports the idea that more contaminated sediment causes plant roots to more capably absorb metals. In Taihu Lagoon, China, where submerged macrophytes in areas with contaminated sediments held onto more heavy metals (Bai *et al.,* 2018). Nonetheless, it is essential to remember that heavy metals mostly accumulate in the roots of both morning glory and water mimosa, which are not usually consumed by people. These findings suggest that while morning glory shows some potential for root-level arsenic uptake, both species have limited capabilities in translocating or accumulating metals in above-ground tissues and may function more effectively as rhizo-filtrators rather than as full phytoextractors.

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Conflicts of interest

The authors declare no conflict of interest.

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