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Research Article

Phytoremediation: A Sustainable and Green Approach for the Removal of Heavy Metals from Environment by Mangrove (*Avicenna. marina*)

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Abstract

Introduction: Toxic metal pollution is a universal problem. One of the most rapidly growing ecologically beneficial and lucrative technologies is to use metal-accumulating plants to clean contaminated ecosystems. Nature-based remediation of pollutants is one of the most promising eco-friendly approaches for sustainable ecosystem management.

Objective: In the present research work, samples of soil sediment, root, stem, leaves of mangrove species *Avicenna marina* was collected from Ras Al Khaimah and Umm Al Quwain with the aim of evaluating heavy metal concentrations, Extraction Coefficient (EF) bioaccumulation factors (BAFshoots and BAFroots) and Translocation Factor (TF) to ensure soil contamination and phytoremediation potentiality.

Results and Discussion: Overall, the heavy metals concentration in soil sediment of Ras al Khaimah are Al:3104-3282mg/kg; Zn:104mg/kg; Fe:2782-2929mg/kg; Mn:68.80-70.36mg/kg; Sr:4472-5174mg/kg, Ca:182500-210000mg/kg, K:2238-2540mg/kg, Na:26740-29160mg/kg. The mean concentration of each metal in the plant tissue (root) was found following Al:17.99mg/kg; Zn: 16.53mg/kg; Fe:460.2mg/kg; Mn:3.46mg/kg; Sr:49.62mg/kg, Ca:1857mg/kg, K:2801mg/kg, Na:3437mg/kg. whereas, in the leaf part, the mean concentration (mg/kg) of each metal found as Al:15.93mg/kg; Zn:15.16mg/kg; Fe:23.51mg/kg; Mn:15.27mg/kg; Sr:51.44mg/kg, Ca:1660mg/kg, K:4452mg/kg, Na:6467mg/kg. Phytoremediation potentiality of the species was assessed by Bioaccumulation Factor (BAF), Extraction Coefficient (EF) and Translocation Factor (TF). BAF values in Ras Al Khaimah showed less accumulation for most of the heavy metals (<1) except K which was highly accumulated in all mangrove plants. However, BAF values in Umm al Quwain showed less accumulation for most of the heavy metals (<1) except K and Na which was highly accumulated in all mangrove plants. The Translocation Factor (TF) values depicted that most of the heavy metals were strongly translocated in plant (>1). However, the BAF value depicts that K was highly bioconcentrated in *Avicenna marina*.

Conclusion: All the examined plants can be used as phytoextractors as they have bioaccumulation factors<1 and translocation factors>1. However, A. marina is clearly more suitable for metal extraction in terms of hyper-metabolizing capabilities. Moreover. A. marina has good phytoremediation capability.

Keywords: Heavy metals, Bioaccumulation factors, Translocation factors, *Avicenna marina*, Phytoremediation

Abbreviations: PSD: Standard deviation; TF: Translocation factor; EC: Extraction coefficient; BAF: Bioaccumulation factor; RAK: Ras Al Khaimah; UAQ: Umm Al Quwain

Introduction

Currently the world is facing many challenges, and heavy metal pollution is one of them. Many heavy metals play essential role for plant growth as micronutrients are not toxic (e.g., Co, Cu, Fe, Mn, Mo, Ni, Al, Rb, Ti, and Zn) until they go beyond a certain limit [1,2]. There are non-essential heavy metals which are toxic to plant growth (e.g., Cd, Pb, U, Cr, Ag, Hg, and Zr), while Arsenic and Selenium are metalloids are also toxic [3,4]. Heavy metals are toxic, bio-accumulative, not naturally biodegradable, persistent and can enter the food chain [5,6]. To degrade organic contaminants from environment, chemical treatments are relatively successful, but they are quite expensive and non-ecofriendly. This technique cannot be use for removing toxic heavy metals from the soil [6]. Therefore, there is a demand for the development or use of effective, affordable, and ecofriendly technology to rectify the problem. Sustainable idea of using green plants to eradicate or reduce the metal contaminants, known as phytoremediation, has been successful as a promising environmentally sustainable technology [7]. Plants are remarkably beneficial for bioremediation to prevent leaching and erosion that can spread the toxic substances to surrounding areas (USEPA, 2004). Plants generally control the pollutants without affecting topsoil, thus conserving its utility and fertility with inputs of organic matter [8].

Mangrove sediments are thought to sequester toxic metals as several studies have demonstrated that reforestation has improved reduction of metals from water and surrounding environments [9,10]. For industrialization and urbanization, huge amount of metal waste is discharged into the coastal ecosystems [9,10]. Heavy metals expelled into coastal ecosystems because of human activities are frequently associated with particulate matter, which settles and becomes deposited in sediments [11]. A high concentration of Heavy metals in sediment are absorbed by organisms and retained in their tissues, affecting biological responses and hindering growth and development mechanisms [12]. As a result, coastline sediments are interpreted to be important markers for determining the health of ecosystems [13]. Therefore, understanding the distribution of heavy metals including the toxic one, and monitoring their potential bioavailability to mangrove plants have become increasingly important [14]. Recent studies have recognized the incidence and severity of sediment contamination by heavy metals in mangrove ecosystems [15,16]. Pollutants are released through industrial activities and eventually enter aquatic ecosystems [16]. The foremost contaminant metals are Cu, Mn, Ni, Zn, Pb, Cd, and As, which have been revealed in significant concentrations in coastal and inshore waters [17,18] (Figure 1).

(a) (b)

Figure 1: Mangrove plant (a) Google image (b) Ras Al Khaimah Tower links Golf course.

Mangroves are one of the most beneficial biomes on the planet, providing a wide range of services such as animal feeding and habitat, erosion mitigation and coastal landform stabilization [19]. These plants or salt marshes grow in coastal sediments, and providing a medium of biological absorption and can modify the rate of heavy metal adsorption for phytoremediation purposes [20,21]. Mangroves are also characterized as "green barriers" because of their exceptional capacity to reduce metal transmission to nearby environments [18]. In addition, metal concentrations in leaves reflect those in the soil and the environment, justifying its use as bio-indicators [22,23]. However, the translocation of metals from the soil to mangrove leaves, may result in the remobilization of heavy metals stored in the soil during detritus senescence. Although this will lead to a reduction of heavy metals in soils. Despite pollution in mangroves have been widely studied [24-27] and previous studies showed that mangroves have the capacity to reabsorb nutrients before shedding the leaves [28-30] (Figure 2).

The present investigation is to assess the phytoremediation potential of mangrove plants growing on metal enriched sediments. Different parts of the mangrove plant were assessed for heavy metal uptake, accumulation and remediation. The aims of this study are: (i) To determine the concentration of heavy metals in mangrove sediment and plants; (ii) to estimate the accumulation and translocation ability of heavy metals in A. marina mangrove plants. The hypothesis is mangrove plants are highly potential to remove or accumulate heavy metals. This study will help to recognize the A. marina species for phytoremediation.

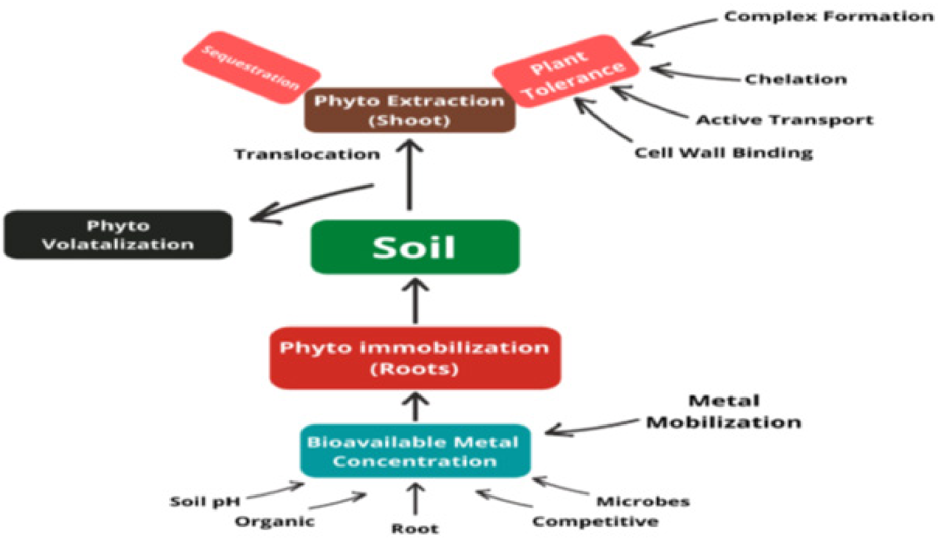

Figure 2: Mechanisms involved in phytoremediation of heavy metals/metalloids in soils [49].

Material and Methods

Site Description

Samples were collected from two different Emirates of United Arab Emirates. The research sample collection area from Emirate of Ras Al Khaimah was Tower links Golf course, Qurm and Khuzam Road and sample's location of Emirate of Umm Al Quwain was from beach (border of Umm Al Quwain and Ras Al Khaimah).

Sample Collection, Preparation and Analysis

Sediment and plants samples were collected from February to April 2024. A total of six surface sediment samples (two samples from each location) were taken from top 0-10cm (recently deposited sediment), which covers an area of $1m^2$. Moreover, *Avicenna marina* species of mangrove trees was selected for collecting samples, because of their dominancy in the study area and have not studied yet in Ras Al Khaimah, United Arab Emirates for their phytoremediation potentiality. Without posing any detrimental effect to the plant, 6 plant samples (shoot and roots) were obtained [21]. Leaves and roots were cut off with a sharp sterilised knife, thoroughly rinsed to remove any clinging dirt and placed in a zip lock plastic bag before being transported to the laboratory.

After collection, the soil sediment samples were sieved in the laboratory to remove debris. After that, each sample placed in oven at temperature (~45°C) [31] until completely dried, as high temperature may influence to the alteration of volatile and even non-volatile organics of the sample [32], until soil sample get fully dried. Samples were sieved through 63µm mesh. Then, individually transferred to vessel tube with conc. 2% HNO_3 for microwave digestion. Leaf, stem and root tissue was oven-dried at 80°C for 2-3 days [33]. Tissue was subsequently ground to a fine powder and sieved through a 2-mm mesh nylon sieve. One gram of plant tissue was placed in each vessel tube with conc. 2% HNO_3 for microwave digestion (CEM MARS Shimadzu.). The digested samples of soil, shoot and root were tested for concentration of heavy metals by ICPOES (Analytik Jena PQ9000).

Assessment of Phytoremediation Potentiality

The ability of plants to withstand and accumulate heavy metals could be used for phytoextraction and bioremediation of the metal-contaminated area. In contrast, BAF and TF can be used to estimate a plant's phytoremediation capacity [34]. Pollutants accumulate in the plant because the increased contaminants it absorbs are not processed fast [35]. The potential of native plants to undertake phytoremediation can be determined by comparing their Bioaccumulation Factor (BAF) and Translocation Factor (TF). BAF was calculated using the following two equations to determine the phytoextraction capabilities of the plants investigated [36].

Three internationally recognized hyperaccumulator indicators were used to evaluate the hyperaccumulator species listed as follows:

Bioaccumulation Factor (BAF): The bioaccumulation factor is the capability of a plant to accumulate metal from soils. It is defined as the ratio of metal concentration in the shoot to the metal concentration in the rhizosphere soil [37]. This value reflects the progressive accumulation of metal in the plant [38]. The bioconcentration factor for metals was calculated as follows:

$$BAF\ leaf = C\ leaf / C\ sediment$$

$$BAF\ bark = C\ bark / C\ sediment$$

$$BAF\ root = C\ root / C\ sediment$$

where Cleaf, Cbark and Croot are the trace metal concentrations in the leaf, bark and root, respectively, and Csediment is the extractable concentration of trace metal in the sediment. It is used for quantitative analysis of accumulation.

Translocation Factor (TF): The TF is the capacity of a plant to transfer metal from its roots to shoots. The Translocation Factor (TF) for each plant was calculated by dividing metal concentration in the shoot by metal concentration in the root. A TF value>1 indicates the plant's capability to translocate metal effectively from root to shoot [37]. The equation was as follows:

TF leaf=Cleaf/Croot

where Cleaf and Croot are the trace metal concentrations in the leaf and root, respectively [39,40]. A translocation factor greater than 1 indicates preferential partitioning of metals to the shoots [32].

Extraction Coefficient (EF): It evaluates the ability of the plant to accumulate heavy metals in shoot biomass [36] and extraction coefficient more than 1 is one of the criteria for identifying hyper-accumulator plants [41]. The equation was as follows:

EF=Cshoot/Csediment

Statistical Analysis

Experiments performed in triplicate. Data are expressed as mean. Experimental error was determined for triplicate and expressed as Standard Deviation (SD).

Results and Discussion

According to the research results, this is possibly the first report to study about phytoremediation potential of A. marina in Ras Al Khaimah, United Arab Emirates. In the present research work, ICPOES was used for heavy metal analysis.

Metal Concentrations in Sediment

The present study analysed 23 metals from the mangrove sediments. Concentrations of heavy metals in mangrove soil of Ras Al Khaimah ranged as follows; Al:3104-3282mg/kg; Zn:104mg/kg; Fe:2782-2929mg/kg; Mn:68.80-70.36mg/kg; Sr:4472-5174mg/kg, Ca:182500-210000mg/kg, K:2238-2540mg/kg, Na:26740-29160mg/kg, Mg:11920-12190mg/kg (Table 1). Moreover, the concentration of heavy metal in mangrove soil of Umm Al Quwain as follows Al:5300-5508mg/kg; Zn:23.36-24.43mg/kg; Fe:6571-7303mg/kg; Mn:283.5-307.9mg/kg; Sr:1052-1061mg/kg, Ca:221600-227700mg/kg, K:993.5-1072mg/kg, Na:1207-1324mg/kg.

Table 1: Heavy metal concentration in Ras Al Khaimah Mangrove.

Parameters (PPM)	RAK Soil 1	RAK Soil 2	RAK Roots	RAK Stem	RAK Leaves
Silver	-	-	-	-	-
Aluminium	3282	3104	17.99	10.45	15.93
Boron	58.76	67.08	6.582	4.923	8.02
Barium	129.2	145.8	-	-	-
Bismuth	-	-	-	-	-
Cadmium	-	-	-	-	-
Cobalt	-	-	-	-	-
Chromium	-	-	13.69	-	-
Copper	-	-	-	-	-
Iron	2782	2929	460.2	24.7	23.51
Gallium	-	-	-	-	-
Indium	-	-	-	-	-
Manganese	68.8	70.36	3.462	3.698	15.27
Nickel	34.3	34.84	8.859	2.073	-
Lead	-	-	-	-	-
Calcium	182500	210000	1857	1666	1660
Strontium	4472	5174	49.62	65.44	51.44
Potassium	2238	2540	2801	4090	4452
Thallium	-	-	-	-	-
Magnesium	11920	12190	1277	937.3	1412
Lithium	-	-	-	-	-
Sodium	26740	29160	3437	8295	6467
Zinc	104	104	16.53	7.684	15.16

However, Na, Mg and Ca concentrations were found higher in Ras Al Khaimah (Table 1) than the UAQ. Among the studied metals Fe, Ca, Mg and Al concentrations were found higher in UAQ (Table 2).

Magnesium and calcium, occurs naturally in water bodies, are among the most highly available alkali metals in the environment [42]. Magnesium salts are found naturally and in high concentrations in surface and ground water, and the only other elements that occur in greater abundance are sodium and calcium cations. Magnesium and calcium concentrations in ground and surface waters increase as those elements are washed out from bedrock [43].

Table 2: Heavy metal concentration in Umm Al Quwain Mangrove.

Parameters (PPM)	UAQ Soil 1	UAQ Soil 2	UAQ Stem	UAQ Leaves
Silver	-	-		-
Aluminium	5508	5300	112.9	41.1
Boron	-	-	7.89	4.278
Barium	-	-		-
Bismuth	-	-		-
Cadmium	-	-		-
Cobalt	-	-		-
Chromium	107.4	74.83		-
Copper	-	-		-
Iron	7303	6571	135.1	58.9
Gallium	-	-		-
Indium	-	-		-
Manganese	307.9	283.5	3.684	4.099
Nickel	45.74	42.59	2.821	-
Lead	-	-		-
Calcium	227700	221600	1401	1175
Strontium	1052	1061	29.54	17.38
Potassium	1072	993.5	6592	3208
Thallium	-	-		-
Magnesium	11480	11400	905.2	1278
Lithium	-	-		-
Sodium	1324	1207	8246	7634
Zinc	23.36	24.43	7.932	5.032

Concentration of Metals in Mangroves

Trace metals are absorbed by plants through their roots, branches and leaves and store them in various plant parts. The distribution and accumulation of trace metals are influenced by plant types, metal sources and sediment metal concentrations [44]. In the analysed mangrove species, the mean concentration in Ras Al Khaimah of each metal in the plant tissue (root) was found following Al:17.99mg/kg; Zn:16.53mg/kg; Fe:460.2mg/kg; Mn:3.46mg/kg; Sr:49.62mg/kg, Ca:1857mg/kg, K:2801mg/kg, Na:3437mg/kg. In leaves, the mean concentration (mg/kg) of each metal found as Al:15.93mg/kg; Zn:15.16mg/kg; Fe:23.51mg/kg; Mn:15.27mg/kg; Sr:51.44mg/kg, Ca:1660mg/kg, K:4452mg/kg, Na:6467mg/kg (Table 1). However, the metal concentration in UAQ mangrove plant leaves were found as Al:41.10mg/kg; Zn:5.032mg/kg; Fe:58.90mg/kg; Mn:4.099mg/kg; Sr:17.38mg/kg, Ca:1175mg/kg, K:3208mg/kg, Na:7634mg/kg, Mg:1278mg/kg (Table 2). Particularly, Na and K concentrations were higher in the roots and leaves of A. marina of RAK and UAQ. The concentrations of Zn were almost similar in roots and leaves, but for the Sr the concentrations were higher in leaves than the roots of all plants in RAK (Table 1). *Chowdhury R*, et al., [45] reported that the concentration of Fe in mangrove tissue of all the plants was the highest and Mn showed the second highest concentrations than the other heavy metals of mangroves of India. The variation of specific metal accumulation depends on their individual physiological rhythms and prevailing ecological conditions of the inhabiting environment [46,47]. For example, in acid-sulphate soil, the Fe concentrations are higher and resulted in higher accumulation of this metal in mangrove plants [45].

Phytoremediation Potentiality of Mangroves

Bioaccumulation Factor (BAF): The Bioaccumulation factor (BAF) from sediment to various body parts (root and leaf) of the mangrove species Avicennia marina was used as an indicator of species accumulation ability from nature and is calculated as the proportion of metal concentration in plant tissue and sediment. This study assumed that plants with BAFshoot values>1 are accumulators, while plants with BAFshoot values<1 are excluders [48]. Additionally, plants were classified as potential hyperaccumulators if the BAFshoot values were>10 [49]. The values of BAF for 23 metals from sediment to roots and leaves of the mangrove species were calculated in this study (Table 3). The results showed that all the plant parts (roots and leaves) had BAF values<1 except potassium and sodium. However, the BAF value>1 for K was found in both roots, stem and leaves of mangrove species of Ras Al Khaimah. Overall, the highest BAF value (6.228) was found for Na in the stem of Avicennia marina of UAQ. [50,45] also reported same BCF value for mangrove plants in their studies in India.

Table 3: Bioaccumulation Factor (BAF) Ras Al Khaimah (RAK) and Umm Al Quwain (UAQ).

Parameters (PPM)	BAF Leaf RAK	BAF Stem RAK	BAF Root RAK	BAF Leaf UAQ	BAF Stem UAQ
Silver	-	-	-	-	-
Aluminium	0.0049	0.0032	0.0055	0.0075	0.0205
Boron	0.136	0.083	0.112	-	-
Barium	-	-	-	-	-
Bismuth	-	-	-	-	-
Cadmium	-	-	-	-	-
Cobalt	-	-	-	-	-
Chromium	-	-	-	-	-
Copper	-	-	-	-	-
Iron	0.0085	0.0089	0.165	0.0081	0.0185
Gallium	-	-	-	-	-
Indium	-	-	-	-	-
Manganese	0.2219	0.0538	0.0503	0.0133	0.012
Nickel	-	0.0604	0.2583	-	0.0617
Lead	-	-	-	-	-
Calcium	0.0091	0.0091	0.0102	0.0052	0.0062
Strontium	0.0115	0.0146	0.0111	0.0165	0.0281
Potassium	1.989	1.827	1.251	2.992	6.149
Thallium	-	-	-	-	-
Magnesium	0.1185	0.0786	0.107	0.1113	0.0789
Lithium	-	-	-	-	-
Sodium	0.2418	0.3102	0.1285	5.765	6.228
Zinc	0.145	0.0739	0.158	0.215	0.339

***Note:** BAF leaf =C leaf/C sediment; BAF bark=C bark/C sediment; BAF root=C root/C sediment where Cleaf, Cbark and Croot are the trace metal concentrations in the leaf, bark and root, respectively, and Csediment is the extractable concentration of trace metal concentration in the sediment.

Our results showed that A. marina had BAFshoot values>1, indicating that they had the potential for use as accumulators or hyperaccumulators of K. The success of the phytoextraction process depends on heavy metal removal by the shoots [39]. Therefore, we suggested that the plant species having the higher metal concentrations in their shoots than in their roots can be considered as accumulators or hyperaccumulators for phytoremediation.

Translocation Factor (TF): The Translocation Factor (TF) is required for a detailed explanation of entire scenario of metal accumulation in the plant body [48,51,34,39]. TF is defined as the ratio of the metal concentration in the shoots to that in the roots. Plants with TF values>1 is classified as high-efficiency plants for metal translocation from the roots to shoots [49]. Tables 4 show the TF of A. marina of Ras Al Khaimah which shows highest values are Mn4.4107, Na1.881, K1.589, B1.218, Sr1.0367, Zn0.917, Ca0.8939, based on metal concentration ratios in the leaf and root of mangrove species of Ras Al Khaimah (Table 4). TF values were found>1 for maximum metals except Fe, Ca and Zn in the studied plants which mean these plants can actively take up trace metals from the sediment and are able to accumulate them in their aerial parts, as a result can be good phytostabilisers. This result was very similar with the investigation of [45], for Indian mangroves.

Table 4: Translocation Factor (TF) Ras Al Khaimah.

Parameters (PPM)	TF
Silver	-
Aluminium	0.0885
Boron	1.218
Barium	-
Bismuth	-
Cadmium	-
Cobalt	-

Chromium	-
Copper	-
Iron	0.0511
Gallium	-
Indium	-
Manganese	4.4107
Nickel	0.234
Lead	-
Calcium	0.8939
Strontium	1.0367
Potassium	1.589
Thallium	-
Magnesium	1.1057
Lithium	-
Sodium	1.881
Zinc	0.917

***Note:** TFleaf=Cleaf/Croot, where Cleaf and Croot are the trace metal concentrations in the leaf and root, respectively. A translocation factor greater than 1 indicates preferential partitioning of metals to the shoots (Usman et al., 2009; Usman et al., 2012).

Similar results were found by [52] who observed significant metals mobilization between the plant parts above and below the surface of the sediment with translocation factor (TF)>1. This indicates that the plant translocates elements effectively from root to the shoot. According to [45] translocation factor values shows that S. apetala exhibited high values for Mn (4.48 and 31.99), Zn (9.95, 3.25) and Cu (3.42, 3.47) and Pb (1.84, 18.01) for Jharkhali (S1) and Gangadharpur (S2), respectively.

Extraction Coefficient Factor (EF): It evaluates the ability of the plant to accumulate heavy metals in shoot biomass [36] and extraction coefficient more than 1 is one of the criteria for identifying hyperaccumulator plants [41]. According to our research findings, in case of Ras Al Khaimah mangrove sample, K1.827 showed highest extraction coefficient and Na0.3102 second highest. However, in case of UAQ mangrove plant sample Na6.228 showed the highest extraction coefficient then K6.149 and then Zn0.339 respectively (Table 5).

Table 5: Extraction Coefficient (EF) Ras Al Khaimah and Umm Al Quwain (UAQ).

Parameters (PPM)	EF Ras Al Khaimah	EF Umm Al Quwain
Silver	-	-
Aluminium	0.0032	0.0205
Boron	0.083	-
Barium	-	-
Bismuth	-	-
Cadmium	-	-
Cobalt	-	-
Chromium	-	-
Copper	-	-
Iron	0.0089	0.0185
Gallium	-	-
Indium	-	-
Manganese	0.0538	0.012
Nickel	0.0604	0.0617
Lead	-	-
Calcium	0.0091	0.0062
Strontium	0.0146	0.0281
Potassium	1.827	6.149
Thallium	-	-

Magnesium	0.0786	0.0789
Lithium	-	-
Sodium	0.3102	6.228
Zinc	0.0739	0.339

Conclusion

This study concluded that the A. marina mangrove plant species has phytoremediation capacity. Our results revealed that, plant species of A. marina as a hyperaccumulator, and is appropriate for phytoextraction of heavy metals from contaminated soils. However, in the case of TF, all the plants exhibited values greater than one for most of the metals, indicating that these plants can translocate metals from root to leaf and may operate as a phytoremediator in the study region. Taken together, our these findings indicate that phytoremediation may provide a sustainable option to remediate heavy metal contaminated soils, by A. marina mangrove plant. Future studies are necessary to evaluate the phytoremediation efficacy of identified plant species against various types and concentrations of metals, and to investigate the mechanisms of phytoextraction of heavy metals.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Materials

The relevant data and materials are available in the present study.

Competing Interests

The authors declare that they have no competing interests. All procedures followed were in accordance with the ethical standards (institutional and national).

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Author's Contributions

VB performed all the experiments. VB analysed the data and wrote the manuscript.

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