Evaluation the potentiality of Rhizophora mucronata for pollutants remediation on the Red Sea Coast, Egypt

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Abstract

Rhizophora mucronata was assessed as a biological tool for remediation and reduction of heavy metals mobility in sediments in Safaga and Hamata, the Red Sea Coast. It is an important region for tourism and nature reserves; however, this area suffers from various anthropogenic contaminants. Investigation of metal behavior in mangrove plants and sediments is important for clarifying the ability of mangroves to reduce sediments contamination through bioaccumulation, phytostabilization or phytoextraction. Sediments of Safaga site showed higher significant concentrations of all studied heavy metals. Heavy metal contents in sediments were significantly lower in case of elder plants than younger ones as well as in rhizosphere samples than non-rhizosphere ones. The order of remediation efficiency was Mo > Ni > Mn ≥ Co > Al > Cu > Zn ≥ Cr > Fe > V, where the highest % were 99.25, 58.97, 42.64, 42.48, 41.91, 39.47, 37.93, 37.01, 36.89, and 29.44, respectively. *R. mucronata* parts were more significantly contaminated in Safaga site with Co, Cr, Cu, Mo and Zn, meanwhile they were more significantly contaminated in Hamata site with Al, Fe, Mn, Ni and V. The elder plants accumulated higher concentrations than younger ones and contents of heavy metals in plant samples followed the order of root > aerial roots > shoot. Bioconcentration factor (BCF) values representing the accumulation efficiency of *R. mucronata* was Ni > Mo > Zn > Cu > Cr > Co > Mn ≥ Al > V > Fe, where their highest values were 17.74, 7.89, 3.95, 3.84, 2.66, 1.91, 1.67, 1.66, 1.6, 1.18, respectively. BCF values exceeded one for all metals and values of translocation factor (TF) were less than unity in all cases, thus *Rhizophora mucronata* can be considered as a good phytostabilizer of ten studied heavy metals able to reduce their mobility through accumulation by roots, thereby reducing off-site contamination.

Introduction

Pollution represents a serious dilemma in Egypt as a developing country. The Environmental Performance Index (EPI) ranking of Egypt was 66 out of 180 countries in 2018, whereas heavy metals pollution rank was 171 **(Environmental Performance Index, 2018)**. Most of coastal areas in Egypt are characterized by the unique diversity of environmental ecosystems and natural habitats in both the Red Sea coasts represented in coral reefs, mangrove trees etc… and the Mediterranean coasts represented in wetlands, marshes and sand dunes, etc... (**Egypt State of Environment, 2010**). Mangroves are highly productive ecosystems that cover about 60-75% of the world's tropical coastlines. They are distributed over more than 112 countries with a total area near 181,000 km^2 productivity **(Shakilabanu *et al.*, 2012)**. *Rhizophora mucronata* is commonly known as mangrove grows in the tropical and subtropical region coastlines, that helps to maintain marine life and balances the ecosystem **(Sreedhar & Christy, 2015)**. Its natural habitat is estuaries, tidal creeks and flat coastal areas subject to daily tidal flooding. *Rhizophora mucronata* is a small to medium size evergreen tree growing to a height of about 10 or 15 meters on the fringes of the sea. The tree has numerous aerial stilt roots buttressing the trunk **(Batool *et al.*, 2014)**. In Egypt, mangroves reach their northernmost distribution at Hurghada, Red Sea coast, being mainly composed of *Avicennia marina*. However, *Rhizophora mucronata* predominates or dominates with *Avicennia marina* in the most southern part from Mersa El-Madfa (Lat. 23°N) till Mersa Halaib, on the Sudano-Egyptian border. Domination of *Rhizophora mucronata* and *Avicennia marina* extends southwards to cover the whole Red Sea coast of the Sudan **(Ahmed & Abdel-Hamid, 2007)**. Because of the uniqueness of mangrove ecosystems and the protection they provide against erosion, they are often the object of conservation programs, including national biodiversity action plans **(Sreedhar & Christy, 2015)**.

Studies conducted by field testing and remote sensing proved that total area of mangrove trees increased to 700 hectare by the end of 2009, compared with 525 hectare in 2002. This is due to protection of mangroves, stopping encroachment and implementing transplantation program for mangrove trees in many areas along past years **(Egypt State of Environment, 2010)**. *Rhizophora mucronata* is as a desirable species in planting programs and for silvicultural practices because of its noteworthy qualities such as viviparous seeds that are easy to plant and fast growing rate **(Pahalawattaarachchi *et al,.* 2009)**. More than 50 thousand seedlings of its both types (*Avicennia marina* and *Rhizophora mucronata*) were cultivated in more than 50 feddan. The nurseries were established in Nabq, Safaga, Wadi El-Gemal and Shalatin. Mangrove habitats are characterized by high biodiversity, including crustacean (82 species), insects (40 species), algae (36 species), echinoderms (17 species) and fish (22 species) with economic importance, mangrove trees are considered as a habitat for providing protection and food for small fish **(Egypt State of Environment, 2010)**.

Ecological restoration and plantation of mangrove are part of Egypt's plan to improve environmental conditions, biodiversity preservation and reduce pollution on the Red Sea Coast. The aim of this work was evaluation of *Rhizophora mucronata* plantation as phytoremediator on the Red Sea Coast through comparison of heavy metals contents in recently implanted trees against elder ones.

Methods

***Rhizophora mucronata* plantation:**

The following fertilization treatments were carried out in Hamata and Safaga greenhouses; NPK mineral fertilizer at a rate of 25 g /5 liters of water, biofertilization at a rate of 5 liters/150 liters of water, and bacterial fertilization at a rate of one liter/10 liters of water, then adding 50 ml to each seedling. *R. mucronata* seedlings were planted in two sites, Site (1) is located in 17 km south of Safaga and Site (2) is located in Hamata, 120 km south Marsa Alam, **(Figures 1 and 2)**.

Sampling and analyses:

Samples of water, sediments (rhizosphere and non-rhizosphere) and plant parts (shoots, roots & aerial roots) were collected in April 2018 from recently implanted *R. mucronata* habitat (one year old) as well as elder ones was estimated by eight years old.

Water samples were collected from vicinity of collected plants. Light-proof plastic containers were prewashed with distilled water and used to preserve the samples. In field, a part of water sample was preserved using few drops of H_2SO_4 for COD analysis, another part was preserved using few drops of HNO_3 for heavy metals analysis and a third part was kept as it is for salinity and pH measurements. Water samples were filtered prior to analysis. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) were analyzed according to **ASTM (2002)**.

Sediments were collected from the rhizosphere and non-rhizosphere regions at depth (0-30 cm). They were air-dried, crushed gently and passed through a 2 mm sieve to eliminate gravels and debris. Water extracts of sediment (1: 2.5 ratio) were prepared according to the methods described by **Richards (1954)** and **Jackson (1963)** and used to determine pH and EC. Another part of sample was digested as outlined by **Shumo *et al.* (2014)** using HNO_3 and H_2O_2 mixture prior to analysis of total heavy metals contents.

Plant samples were washed thoroughly with distilled water, air dried at 60ºC and ground to fine particles prior to digestion according to **Shumo *et al.* (2014)**.

Heavy metals analysis:

Ten heavy metals, namely Al, Co, Cr, Cu, Fe, Mn, Mo, Ni ,V and Zn, were analyzed in water and extracts of both plant and sediment samples using Inductively Coupled Argon Plasma, iCAP 6500 Duo, Thermo Scientific, England. Multi-element certified standard solution, Merck, Germany was used as stock solution for instrument standardization.

Statistical analysis:

Three replicates of the results were analyzed using randomized complete block design (RCBD) via MSTAT-C **(Freed, 1991)**. Duncan new multiple test was used to compare mean values as described by **Waller and Duncan (1969)**. Means having the same alphabetical letter in the same column are not significant at significance probability value (P) = 0.05 level.

Calculations:

Data were tabulated using Windows Excel version 2010 and calculated according to **Pahalawattaarachchi *et al.* (2009), Uddin Nizam *et al.* (2016), Kaewtubtim *et al.*, (2016)** and **Mahmudi *et al.* (2021).**

Heavy metal remediation % in sediments = [(concentration in non-rhizosphere - concentration in rhizosphere)/ concentration in non-rhizosphere] X 100

Bioconcentration factor (BCF) = Concentration of metal in plant part / concentration of metal in sediments.

Translocation factor (TF) = Concentration of metal in plant part / concentration of metal in root.

Results

1. Water analyses:

Significantly higher concentrations of parameters were distributed among both sites **(Table 1)**. There was no significant difference in pH between both sites; meanwhile salinity level (i.e. electrical conductance and total dissolved solids) was significantly higher in Safaga site. Hamata site recorded the higher significant BOD and COD values that were 46.49 and 5.2 mg/l against 23.24 and 3.5 mg/l in Safaga site, respectively. Also, Mn and Zn higher significant values were recorded in Hamata site, meanwhile Safaga site showed significantly higher values of Al and Fe. Concentrations of recorded heavy metals followed the descending order of Al (0.101-1.438 mg/l) > Fe (0.068 -0.318 mg/l) > Mn (0.029 - 0.051 mg/l) > Zn (0.026 -0.035 mg/l).

Table (1): Physicochemical parameters and heavy metals contents of Red Sea surface coastal water samples in *Rhizophora mucronata* habitat.

Site	pH	EC, µS/cm	TDS, mg/l	BOD, mg/l	COD, mg/l	Al, mg/l	Fe, mg/l	Mn, mg/l	Zn, mg/l
Safaga	7.9 ^{a}	60600 ^{a}	42271 ^{a}	23.24 ^{b}	3.5 ^{b}	1.438 ^{a}	0.318 ^{a}	0.029 ^{b}	0.026 ^{b}
Hamata	8.0 ^{a}	59700 ^{b}	42201 ^{b}	46.49 ^{a}	5.2 ^{a}	0.101 ^{b}	0.068 ^{b}	0.051 ^{a}	0.035 ^{a}

(Remarks: values with different letters in a column are significantly different at the 0.05 level, n=3, concentrations of Co, Cr, Cu, V, Mo, Ni were not detected in both samples).

2. Sediment analyses:

pH was significantly higher in Safaga site, where it ranged from 7.9 to 8.2 in Safaga site and from 7.8 to 8.1 in Hamata site **(Table 2)**. pH was significantly higher in younger plants than elder ones and also in non-rhizosphere sediments than rhizosphere ones. On the same approach as water samples, EC and TDS were significantly higher in Safaga site than Hamata. EC ranged from 9720- 11170 µS/cm and from 6340- 7980 µS/cm in Safaga and Hamata sites, respectively. TDS values ranged from 5890-6662 mg/l and from 3695-5081 mg/l in Safaga and Hamata sites, respectively. In general, rhizosphere samples were significantly more saline than non-rhizosphere ones. Also, the sediments of elder plants were significantly more saline than younger plants ones.

Table (2): pH and salinity of sediment samples in *Rhizophora mucronata* habitat (water extract 1:2.5).

Site	Plant	Localization	pH	EC µS/cm	TDS mg/l
Safaga	**Younger**	**Rhizosphere**	8.1^{b}	10330^{c}	5957^{c}
		Non-Rhizosphere	8.2^{a}	9720^{d}	5890^{d}
	Elder	**Rhizosphere**	7.9^{c}	11170^{a}	6662^{a}
		Non-Rhizosphere	8.1^{b}	10870^{b}	6369^{b}
Hamata	**Younger**	**Rhizosphere**	7.8^{d}	7190^{g}	4336^{g}
		Non-Rhizosphere	8.1^{b}	6340^{h}	3695^{h}
	Elder	**Rhizosphere**	7.8^{d}	7980^{e}	5081^{e}
		Non-Rhizosphere	7.9^{c}	7440^{f}	4578^{f}

((Remarks: values with different letters in a column are significantly different at the 0.05 level, n=3)

On the same approach as salinity, Safaga site showed higher significant concentrations of all studied heavy metals **(Table 3)**. In Safaga site, ranges of heavy metals concentrations were 2777.5-4873.0 mg/Kg (Al), 2.03-3.365 mg/Kg (Co), 11.655-19.725 mg/Kg (Cr), 1.995-4.75 mg/Kg (Cu), 2997.8-4375.3 mg/Kg (Fe), 70.85-93.65 mg/Kg (Mn), 1.01-1.89 mg/Kg (Mo), 2.31-4.23 mg/Kg (Ni), 22.06-25.15 mg/Kg (V) and 4.10-9.86 mg/Kg (Zn). Meanwhile in Hamata site, the ranges were 841.09-4289.09 mg/Kg (Al), 0.44-2.425 mg/Kg (Co), 2.425-7.03 mg/Kg (Cr), 0.83-1.17 mg/Kg (Cu), 1131.8-3375.3 mg/Kg (Fe), 15.37-77.70 mg/Kg (Mn), 0.48-1.69 mg/Kg (Ni), 5.32-13.21 mg/Kg (V) and 0.72-1.45 mg/Kg (Zn). It was clear that total heavy metal contents in the elder plants sediments were significantly lower than younger ones. Also, total heavy metal contents in rhizosphere samples were significantly lower than non-rhizosphere ones.

Table (3): Total contents of heavy metals in sediment samples in *Rhizophora mucronata* habitat (mg/Kg).

Site	Plant	Localization	Al	Co	Cr	Cu	Fe	Mn	Mo	Ni	V	Zn
Safaga	Younger	Rhizosphere	4817.5^{b}	3.095^{b}	17.42^{b}	2.875^{b}	4285.8^{b}	80.60^{b}	1.695^{b}	3.08^{b}	24.27^{b}	6.18^{b}
		Non-Rhizosphere	4873.0^{a}	3.365^{a}	19.725^{a}	4.75^{a}	4375.3^{a}	93.65^{a}	1.89^{a}	4.23^{a}	25.15^{a}	9.86^{a}
	Elder	Rhizosphere	2777.5^{e}	2.03^{e}	11.655^{d}	1.995^{d}	2997.8^{e}	70.85^{d}	1.01^{d}	2.31^{d}	22.06^{d}	4.10^{d}
		Non-Rhizosphere	3756.5^{d}	2.61^{c}	12.895^{c}	2.445^{c}	3946.3^{c}	77.70^{c}	1.33^{c}	2.51^{c}	22.17^{c}	5.95^{c}
Hamata	Younger	Rhizosphere	2491.5^{f}	1.450^{f}	5.24^{f}	1.135^{f}	2469.8^{f}	44.57^{e}	N.D	1.2^{f}	10.01^{f}	0.90^{f}
		Non-Rhizosphere	4289.09^{c}	2.425^{d}	7.03^{e}	1.17^{e}	3375.3^{d}	77.70^{c}	N.D	1.69^{e}	13.21^{e}	1.45^{e}
	Elder	Rhizosphere	841.09^{h}	0.440^{h}	2.425^{h}	0.83^{h}	1131.8^{g}	15.37^{g}	N.D	0.48^{g}	5.32^{h}	0.72^{h}
		Non-Rhizosphere	1313.5^{g}	0.765^{g}	3.85^{g}	0.905^{g}	1793.3^{g}	25.15^{f}	N.D	1.17^{f}	7.54^{g}	0.85^{g}

(Remarks: values with different letters in a column are significantly different at the 0.05 level, n=3).

Based on metals concentrations in the rhizosphere relative to non-rhizosphere sediments, Safaga site showed the highest significant remediation efficiency of two metals under study, where the efficiency reached 39.47% (Cu) and 99.25% (Mo) **(Table 4)**. Meanwhile, Hamata site showed the highest significant remediation efficiency of eight metals under study, where the efficiency reached 41.91% (Al), 42.48% (Co), 37.01% (Cr), 36.89% (Fe), 42.64% (Mn), 58.97% (Ni), 29.44% (V) and 37.93% (Zn). Thus, the order of remediation efficiency as % was Mo > Ni > Mn ≥ Co > Al > Cu > Zn ≥ Cr > Fe > V.

Table (4): Heavy metals remediation efficiency of *Rhizophora mucronata* in Safaga and Hamata sediments.

Site	Plant	Remediation (%)									
		Al	Co	Cr	Cu	Fe	Mn	Mo	Ni	V	Zn
Safaga	Younger	1.140^{d}	8.020^{d}	11.69^{c}	39.47^{a}	2.05^{d}	13.93^{c}	10.32^{b}	27.19^{b}	3.48^{c}	37.32^{b}
	Elder	26.06^{c}	22.22^{c}	9.62^{d}	18.40^{b}	24.04^{c}	8.82^{d}	99.25^{a}	7.97^{c}	0.50^{d}	31.09^{c}
Hamata	Younger	41.91^{a}	40.21^{b}	25.46^{b}	2.99^{d}	26.83^{b}	42.64^{a}	0.00	28.99^{b}	24.22^{b}	37.93^{a}
	Elder	35.97^{b}	42.48 ^{a}	37.01^{a}	8.29^{c}	36.89^{a}	38.89^{b}	0.00	58.97^{a}	29.44^{a}	15.29^{d}

(Remarks: values with different letters in a column are significantly different at the 0.05 level, n=3).

Concerning with plant age, the younger plants achieved the highest significant remediation efficiency of Al, Cu, Mn and Zn that reached 41.91, 39.47, 42.64 and 37.93 %, respectively **(Table 4)**. While the elder plants achieved the highest significant remediation efficiency of Co, Cr, Fe, Mo, Ni, V that reached 42.48, 37.01, 36.89, 99.25, 58.97 and 29.44%, respectively.

3. Plant analyses:

As shown in **Table (5),** the highest significant concentrations of Co, Cr, Cu, Mo and Zn was found in Safaga site, meanwhile the highest significant concentrations of Al, Fe, Mn, Ni and Vwas found in Hamata site. In Safaga site, the heavy metals ranges were 126.04-1197.09 mg/Kg (Al), 0.06-0.865 mg/Kg (Co), 1.655-8.455 mg/Kg (Cr), 0.575-4.765 mg/Kg (Cu), 140.75-1151.3 mg/Kg (Fe), 2.62-24.425 mg/Kg (Mn), 0.89-7.97 mg/Kg (Mo), 1.28-3.925 mg/Kg (Ni), 0.485-7.225 mg/Kg (V) and 1.715-16.175 mg/Kg (Zn). Meanwhile in Hamata site, concentrations ranges were 108.14 -1392.59 mg/Kg (Al), 0.035-0.84 mg/Kg (Co), 1.365-6.445 mg/Kg (Cr), 0.395-3.185 mg/Kg (Cu), 85.35-1336.8 mg/Kg (Fe), 1.595-25.695 mg/Kg (Mn), N.D -0.445 mg/Kg (Mo), 1.085-8.515 mg/Kg (Ni), 0.175 -8.535 mg/Kg (V) and N.D -1.70 mg/Kg (Zn). It was an important finding that the elder plants accumulated higher concentrations than younger ones. Moreover, contents of heavy metals in plant samples followed the order of root > aerial roots > shoot.

Table (5): Contents of heavy metals in *Rhizophora mucronata* samples (mg/Kg dry weight).

Site	Plant	Plant part	Al	Co	Cr	Cu	Fe	Mn	Mo	Ni	V	Zn
Safaga	Younger	Shoot	126.04^{k}	0.06^{j}	1.655^{i}	0.575^{k}	140.75^{j}	2.62^{k}	0.89^{f}	1.28^{k}	0.485^{i}	1.715^{f}
		Root	270.24^{g}	0.135^{g}	4.12^{e}	1.01^{h}	364.95^{f}	8.815^{g}	1.85^{e}	1.74^{h}	1.205^{f}	2.560^{d}
		Aerial roots	188.44^{h}	0.135^{g}	2.68^{h}	0.595^{j}	280.55^{g}	5.24^{i}	1.375^{d}	1.325^{j}	0.785^{g}	2.045^{e}
	Elder	Shoot	307.59^{f}	0.165^{f}	6.40^{c}	1.74^{e}	422.3^{e}	10.64^{e}	2.085^{c}	2.745^{f}	1.305^{e}	3.935^{c}
		Root	1197.09^{b}	0.865^{a}	8.455^{a}	4.765^{a}	1151.3^{b}	24.425^{b}	7.97^{a}	3.925^{c}	7.225^{b}	16.175^{a}
		Aerial roots	712.59^{c}	0.325^{c}	7.685^{b}	2.545^{d}	625.3^{c}	21.405^{c}	2.19^{b}	3.405^{d}	2.605^{c}	8.645^{b}
Hamata	Younger	Shoot	108.14^{l}	0.035^{k}	1.365^{j}	0.395^{l}	85.35^{k}	1.595^{l}	N.D	1.085^{k}	0.175^{l}	N.D
		Root	149.04^{i}	0.11^{h}	3.195^{f}	1.245^{g}	240.4^{i}	5.755^{h}	N.D	2.005^{g}	0.395^{j}	N.D
		Aerial roots	143.69^{j}	0.08^{i}	2.94^{g}	0.785^{i}	216.8^{h}	4.535^{j}	N.D	1.620^{i}	0.36^{k}	N.D
	Elder	Shoot	327.99^{e}	0.19^{e}	5.135^{d}	1.445^{f}	421.6^{e}	9.705^{f}	0.075^{i}	3.125^{e}	0.66^{h}	N.D
		Root	1392.59^{a}	0.84^{b}	6.445^{c}	3.185^{b}	1336.8^{a}	25.69^{a}	0.445^{g}	8.515^{a}	8.535^{a}	1.70^{f}
		Aerial roots	441.14^{d}	0.25^{d}	5.185^{d}	2.845^{c}	446.8^{d}	13.37^{d}	0.135^{h}	6.895^{b}	2.54^{d}	N.D

(Remarks: values with different letters in a column are significantly different at the 0.05 level, n=3).

Values of bioconcentration factor (BCF) also revealed that heavy metals contents in plant samples followed the order of root > aerial roots > shoot **(Table 6)**. In general, BCF values ranged from zero to 17.74. The highest significant values were recorded in case of roots of elder plant in Hamata. BCF values exceeded one mostly in case of elder plants than in younger ones and in case of Hamata site than Safaga one. On the whole, *R. mucronata* has been able to accumulate all metals under study. The order of accumulation according to BCF values was Ni > Mo > Zn > Cu > Cr > Co> Mn ≥ Al > V > Fe, where their highest values were 17.74, 7.89, 3.95, 3.84, 2.66, 1.91, 1.67, 1.66, 1.6, 1.18, respectively.

Table (6): Bioconcentration factor (BCF) values of heavy metals in *Rhizophora mucronata* parts.

Site	Plant	Plant part	Al	Co	Cr	Cu	Fe	Mn	Mo	Ni	V	Zn
Safaga	Younger	Shoot	0.03^{i}	0.02^{h}	0.10^{k}	0.20^{j}	0.03^{i}	0.03^{k}	0.53^{f}	0.42^{l}	0.02^{j}	0.28^{g}
		Root	0.06^{g}	0.04^{g}	0.24^{i}	0.35^{i}	0.09^{g}	0.11^{h}	**1.09^{d}**	0.56^{j}	0.05^{g}	0.41^{e}
		Aerial roots	0.04^{h}	0.04^{g}	0.15^{j}	0.21^{j}	0.07^{h}	0.07^{i}	0.81^{e}	0.43^{k}	0.03^{i}	0.33^{f}
	Elder	Shoot	0.11^{f}	0.08^{e}	0.55^{g}	0.87^{g}	0.14^{e}	0.15^{f}	**2.06^{c}**	**1.19^{h}**	0.06^{f}	0.96^{d}
		Root	0.43^{c}	0.43^{c}	0.73^{d}	**2.39^{c}**	0.38^{c}	0.34^{d}	**7.89^{a}**	**1.70^{d}**	0.33^{d}	**3.95^{a}**
		Aerial roots	0.26^{e}	0.16^{d}	0.66^{e}	**1.28^{e}**	0.21^{d}	0.30^{e}	**2.17^{b}**	**1.47^{f}**	0.12^{e}	**2.11^{c}**
Hamata	Younger	Shoot	0.04^{h}	0.02^{h}	0.26^{h}	0.35^{i}	0.03^{i}	0.04^{j}	0.00	0.90^{i}	0.02^{j}	0.00
		Root	0.06^{g}	0.08^{e}	0.61^{f}	**1.10^{f}**	0.10^{f}	0.13^{g}	0.00	**1.67^{e}**	0.04^{h}	0.00
		Aerial roots	0.06^{g}	0.06^{f}	0.56^{g}	0.69^{h}	0.09^{g}	0.10^{h}	0.00	**1.35^{g}**	0.04^{h}	0.00
	Elder	Shoot	0.39^{d}	0.43^{c}	**2.12^{c}**	**1.74^{d}**	0.37^{c}	0.63^{c}	0.00	**6.51^{c}**	0.12^{c}	0.00
		Root	**1.66^{a}**	**1.91^{a}**	**2.66^{a}**	**3.84^{a}**	**1.18^{a}**	**1.67^{a}**	0.00	**17.74^{a}**	**1.60^{a}**	**2.36^{b}**
		Aerial roots	0.52^{b}	0.57^{b}	**2.14^{b}**	**3.43^{b}**	0.39^{b}	0.87^{b}	0.00	**14.36^{b}**	0.48^{b}	0.00

(Remarks: values with different letters in a column are significantly different at the 0.05 level, n=3).

On the other hand, values of translocation factor (TF) were less than one in all cases, ranged from zero to 0.99 **(Table 7)**. The highest significant TF values of Co, Mn, Mo, Ni and Zn were in Safaga site, meanwhile the highest significant TF values of Al, Cr, Cu, Fe and V were in Hamata site. Quantitative translocation of heavy metals was noticed in younger plants than elder ones, as the highest significant TF values of seven metals (Al, Co, Cr, Fe, Mo, V and Zn) out of ten were recorded in younger plants in both sites. TF values were significantly higher in aerial roots than shoot in all cases. There were different translocation rates for each metal from root to shoot and to aerial roots. The order of metals translocation from root to aerial roots was Co > Al > Cr > V > Fe > Cu > Mn > Ni > Zn > Mo where the highest TF values were 0.99, 0.96, 0.92, 0.91, 0.90, 0.89, 0.88, 0.87, 0.80 and 0.74, respectively. The order of metals translocation from root to shoot was Cr > Ni > Al > Zn > Cu > Mo > Co≥ Mn ≥V > Fe where the highest TF values were 0.80, 0.74, 0.73, 0.67, 0.57, 0.48, 0.44, 0.44, 0.44, 0.39, respectively.

Table (7): Translocation factor (TF) values of heavy metals in *Rhizophora mucronata* from root to plant parts.

Site	Plant	Plant part	Al	Co	Cr	Cu	Fe	Mn	Mo	Ni	V	Zn
Safaga	**Younger**	**Shoot**	0.47^{e}	0.44^{c}	0.40^{g}	0.57^{d}	0.39^{c}	0.30^{g}	0.48^{b}	0.74^{d}	0.40^{d}	0.67^{b}
		Aerial roots	0.70^{c}	0.99^{a}	0.65^{e}	0.59^{c}	0.77^{b}	0.59^{c}	0.74^{a}	0.76^{c}	0.65^{b}	0.80^{a}
	Elder	**Shoot**	0.26^{g}	0.19^{h}	0.76^{d}	0.37^{g}	0.37^{d}	0.44^{e}	0.26^{d}	0.70^{e}	0.18^{g}	0.24^{d}
		Aerial roots	0.60^{d}	0.38^{d}	0.91^{b}	0.53^{e}	0.54^{c}	0.88^{a}	0.27^{c}	0.87^{a}	0.36^{e}	0.53^{c}
Hamata	**Younger**	**Shoot**	0.73^{b}	0.32^{e}	0.43^{f}	0.32^{h}	0.36^{d}	0.28^{h}	0.00	0.54^{f}	0.44^{c}	0.00
		Aerial roots	0.96^{a}	0.77^{b}	0.92^{a}	0.63^{b}	0.90^{a}	0.79^{b}	0.00	0.81^{b}	0.91^{a}	0.00
	Elder	**Shoot**	0.24^{h}	0.23^{g}	0.80^{c}	0.45^{f}	0.32^{f}	0.38f	0.00	0.37^{g}	0.08^{h}	0.00
		Aerial roots	0.32^{f}	0.30^{f}	0.80^{c}	0.89^{a}	0.33^{e}	0.52^{d}	0.00	0.81^{b}	0.30^{f}	0.00

(Remarks: values with different letters in a column are significantly different at the 0.05 level, n=3).

Discussion

As a part of environmental restoration and management, mangrove communities may provide effective traps to immobilize water and soil borne metals. Physical properties of soil and water may affect the phytoremediation process, as salinity and pH may represent a sort stress on mangrove plants. In the present study, salinity and pH results of water samples were in agreement with a report has been made along the Red Sea coast by Ministry of State for Environmental Affairs (**Egypt State of Environment, 2010**), where minor changes were recorded in the salinity, ranged between (39400 - 43700 mg/l) and pH values ranged between (8.1 - 8.2). This finding clarifies that physical measurements were at their normal levels and the impact of pollutants discharging or human activities in the Red Sea is still limited.

On contrary, BOD and COD results were extremely higher than reported by **Fahmy *et al.,* (2016)** in their study on Safaga surface coastal water, where BOD and COD values ranged from 1.43 to 1.23 mg/l and 7.54 to 8.32 mg/l, respectively. The noticed relatively high BOD and COD concentrations in Hamata site may be attributed to the widespread tourist activity and its impact on water body, where Wadi El-Gemal and Hamata Mountain Reserve is a major attraction for tourism. The recorded concentrations of Fe, Mn and Zn were slightly higher than reported by **Fahmy *et al.,* (2016)** that were 0.0361, 0.0019 and 0.0129 mg/l, respectively. Meanwhile the non-detected concentrations of Cu, Ni and Cr in the current study were less than those that were 0.0037, 0.0013 and 0.0010 mg/l, respectively.

In sediments, pH was significantly higher in younger plants than elder ones and also in non-rhizosphere sediment than rhizosphere. This may attributed to the extensively fibrous root system which forms thick peat-like mud and subsequently lower the pH after decomposition **(Ahmed & Abdel-Hamid, 2007).** Mangrove plants possess a variety of adaptations to high salt concentration as an extreme environmental stresses. One of them is salt exclusion by root ultra-filtration driven by the pulling force generated by transpiration. In particular, *Rhizophora* sp. lacks salt glands as some other mangroves, but has a more strict salt exclusion mechanism at root level, avoiding salt entering the sap of the tree **(Noor *et al.,* 2015)**. This explains why rhizosphere samples were more saline than non-rhizosphere ones and sediments of the elder plants were more saline than younger ones.

Higher significant concentrations of all studied heavy metals in Safaga sediments can be attributed to the industrial and economic activities in Safaga, as it is not only a tourist city but also a seaport represents a gateway for Duba sea port to travelers or some pilgrims to Saudi Arabia by ferries, meanwhile Hamata is considered as tourist area in the first place.

The significant lower heavy metal contents in the elder plants sediments than younger ones, and the significant lower contents in rhizosphere samples than non-rhizosphere ones reflect the high efficiency of *Rhizophora mucronata* to remediate heavy metals from the contaminated sediments especially on the long run.

Based on the calculated remediation % of sediments, elder plants achieved the highest significant sediments remediation efficiency of six metals (five in Hamata and one in Safaga) against four metals in younger plants (three in Hamata and one in Safaga). This is because of the lower concentrations in Hamata than Safaga, which makes the calculated percentage of removal higher by smaller taken amount.

In solidarity with the results of sediments analyses, plant parts analyses revealed that the elder plants accumulated higher concentrations than younger ones.

In general, the calculated value of bioconcentration factor indicates the ability of plants to remove metal compounds from the soil/substrate. Meanwhile, the value of translocation factor indicates the ability of the compound to be transferred from plant roots to other organs **(Mellem *et al.*, 2012** and **Wang, 2016)**. Bioaccumulator plants should have bioconcentration and translocation factors > 1. Plants have bioconcentration factor values > 2 are considered to be hyperaccumulators. Plants can be used as phytoextractors if they have bioconcentration factors < 1 and translocation factors >1 and as phytostabilizers if they have bioconcentration factors >1 and translocation factors < 1 **(Takarina and Pin, 2017)**.

Phytostabilization involves the establishment of a plant cover on the contaminated sites surfaces aiming to reduce the mobility of contaminants through accumulation by roots, thereby reducing off-site contamination **(Bolan *et al.,* 2011)**. Regarding to the calculated BCF values, *R. mucronata* has been able to accumulate all metals under study following the order of root > aerial roots > shoot. Aerial roots came second after roots, as aerial roots of mangrove plants diffuse oxygen into the substrate such that oxidation occurs within the rhizosphere, leading to metal accumulation in fine roots **(Kaewtubtim *et al.,* 2016)**.

Hereby values of BCF and TF values, *R. mucronata* can be considered as good phytostabilizer of heavy metals under study. The wide range of BCF values in current study that ranged from zero to 17.74 revealed the variation of the phytostabilization capacity of *R. mucronata* in the mangrove ecosystem from metal to another. **Pahalawattaarachchi *et al.* (2009)** concluded that all the metals studied showed mobility in *R. mucronata* at different extents, where Cu, Mn and Fe showed restricted mobility, while Cd, Ni, Cr, Zn and Pb had greater mobility. This conclusion concurred with findings in the current study, where the translocation factor from root to shoot followed the order of Cr > Ni > Al > Zn > Cu > Mo > Co≥ Mn ≥V > Fe.

Recommendations:

Rhizophora mucronata can be used efficiently for stabilization of metals in sediments of mangrove ecosystems. Widening of ecological restoration and plantation of mangroves along the Red Sea Coast is recommended to eliminate the pollution of heavy metals in such important tourist area.

Conclusions

Phytostabilization capacity of *Rhizophora mucronata* varies from metal to metal. The order of metals accumulation in plant tissues was Ni > Mo > Zn > Cu > Cr > Co > Mn ≥ Al > V > Fe. Concentrations of ten studied metals were lower in the rhizosphere sediments than the non-rhizosphere ones. Concentrations of all studied metals were lower in the sediments where the elder plants grown than the younger ones. This coincides with their concentrations in plant tissues where, the elder plants accumulated higher concentrations than younger ones. Heavy metals contents in plant tissues followed the order of root > aerial roots > shoot. *Rhizophora mucronata* is an efficient phytostabilizer of plenty heavy metals from the contaminated sediments especially on the long run.

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Figures

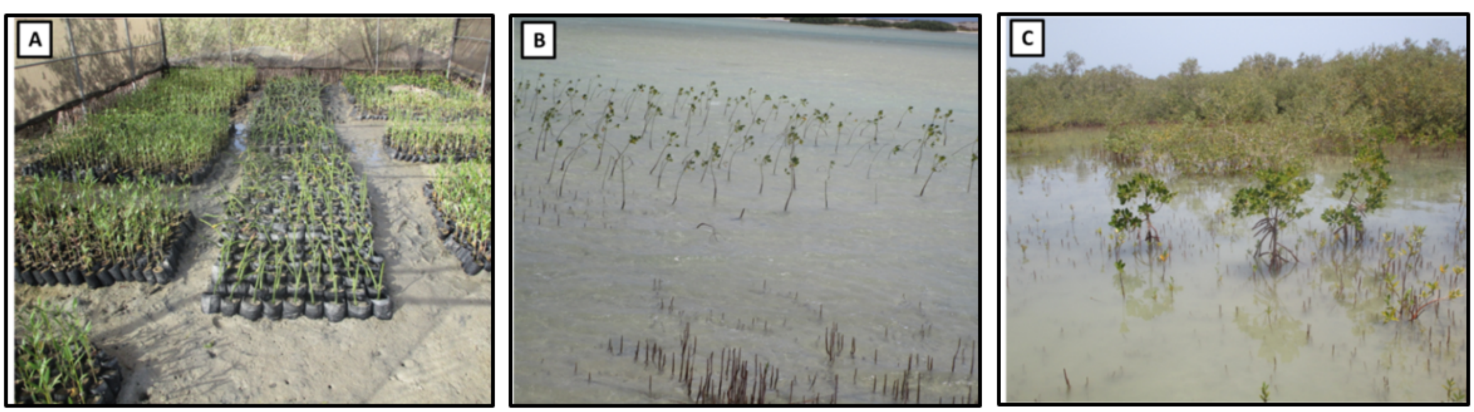

Figure 1

Plantation of *Rhizophora mucronata* on the Red Sea Coast: (A) the seedlings of *R. mucronata* in the greenhouse, (B) the implanted seedlings on the Red Sea Coast (one year old), (C) the growing plant (8 years old).

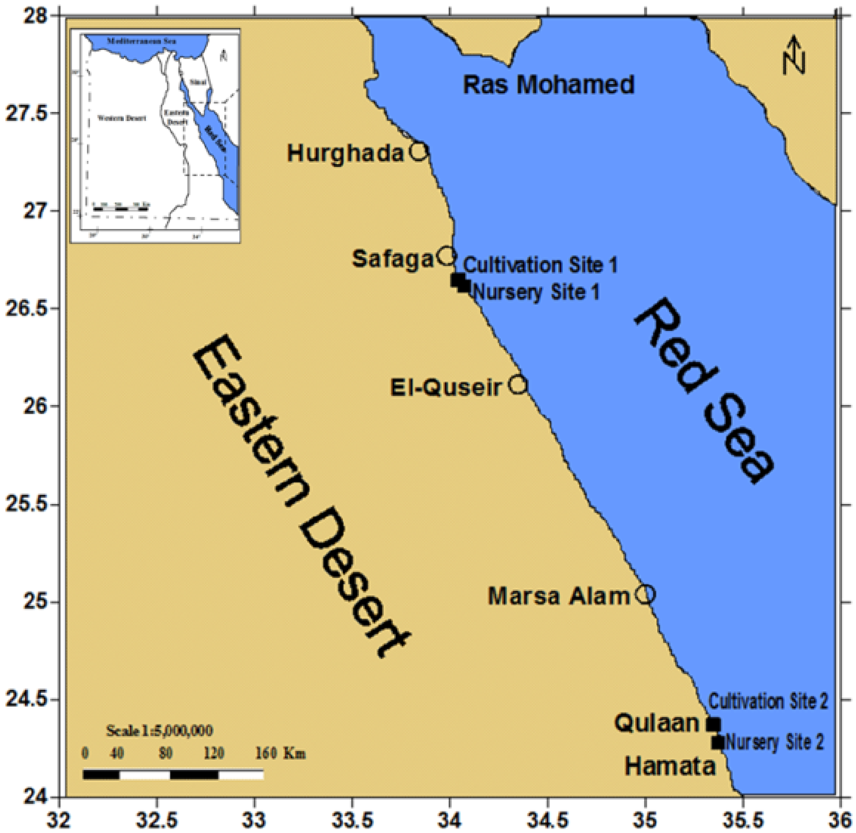

Figure 2

Location map of study area and samples showing nursery and cultivation sites.