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Ecotoxicological impact assessment of some heavy metals and their distribution in some fractions of mangrove sediments from Red Sea, Egypt

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Abstract The total and fraction concentrations of heavy metals (Mn, Cu, Ni, Pb, Co, and Cd) were analyzed in some sediment fractions (Φ2, Φ3, Φ4, Φ5) of selected mangrove ecosystems collected from the Egyptian Red Sea shoreline. The results revealed that manganese had the highest mean value (133±97 mg/kg) followed by copper (49.9±46.0 mg/kg), nickel (28.1±11.8 mg/kg), lead (19±13 mg/kg), cobalt (6.7±4.0 mg/kg), and cadmium (3.327±1.280 mg/kg). The concentrations of heavy metals in the different sediment fractions showed that there was a preferential accumulation of Cu, Co, Mn, and to a lesser degree Cd in the silt and clay fractions rather than in the sand-sized. The sediment quality was performed by using some sediment quality guidelines. Additionally, the contamination and the risk assessment of these heavy metals were achieved by different methods including, potential ecological risk index, contamination factor, pollution load index, and geoaccumulation index. According to the Sediment Quality Guidelines comparisons, the concentrations of Mn and Pb were low and showed no possibility of detrimental effects on the local environment. The levels of Cu and Ni were high, however, could not be considered to present serious threat to the mangrove ecosystem. The data showed that the mangrove ecosystems were affected by the Cd risk.

Keywords Heavy metals · Mangrove sediment factions · Ecotoxicological assessment · Red Sea · Egypt

Introduction

Mangroves are salt-tolerant plants (Shriadah 1999). They have long been recognized as important habitats for fishes, supporting a high diversity of juvenile estuarine and coral reef fish (Dorenborsch et al. 2004; Mumby et al. 2004). The beds of mangroves are important habitats due to the structural complexity, food, shelter, and the protection from predators that they provide (Nagelkerkan et al. 2000). Generally, the communities of mangrove are widely acknowledged to be important elements in coastal ecosystems in the tropics. Moreover, they stabilize mobile sediments and act as a buffer against coastal erosion (Tam and Wong 1996). In order to protect and conserve these fragile mangroves ecosystems, a complete understanding of their environment and the human impacts upon them is essential. However, sediment quality has been recognized as an important indicator of water pollution, since they act as sink of contaminants (Santos Bermejo et al. 2003). This fact converts the sediments in a permanent record of anthropogenic pollutants inputs (Chen et al. 2010). The examination and study of

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sediment quality can reveal the pollutant variations, degradations and cycles, and their chronic effects on water pollution. In addition, the accumulation of heavy metals in sediments can produce harmful effects on the biota living in them (Harikumar and Nasir 2010; Joksimovic et al. 2011). Since, heavy metals are among the most serious pollutants within the natural environment due to their toxicity, persistence, and bioaccumulation problems (MacFarlane and Burchett 2000); a number of studies were carried out all over the world to assess the levels of different heavy elements in mangrove sediments (Mackey et al. 1992; Rivail et al. 1996; Perdomo et al. 1998; Shriadah 1999; Tam and Wong 2000; Mremi and Machiwa 2003; Defew et al. 2005; Otero et al. 2009; Marchand et al. 2011). Despite the environment significance of mangroves, the scientific efforts on their ecosystems are scarce in Egypt (Okbah et al. 2005; Dar and El-Saharty 2006). The effect of grain size on the adsorption of heavy metals in sediments was studied (Greaney 2005). Bioavailable sediment-bound metals depend, to a significant extent, on the particle size fraction with which a metal is associated (Greaney 2005). Since the metals in this fine-grained fraction are more likely to be biologically available than those in bulk sediments (Bryan and Langston 1992).

The present paper attempts to provide information concerning the levels of some heavy metals (Cd, Co, Cu, Pb, Mn, and Ni) in different sediment fractions (Φ2, Φ3, Φ4, and Φ5) of selected mangrove ecosystems along the Egyptian Red Sea shoreline. Also, the ecological pollution risk assessment of these heavy metals can be predicted.

Area of study

Red Sea is a semi-enclosed narrow water body with no river inputs. It extends for approximately 1,936 km, has a surface area of about 43,970 km^2 and attains a depth of nearly 1,800 m. It lies in a very arid zone, where the climate is hot and the rainfall is scarce. The water of the sea is exceptionally clear and the eutrophic zone extends to a depth of about 80–90 m (Shriadah et al. 2004). Red Sea is apparently subjected to the rapid and increasing levels of human activities due to the recreational (swimming and diving), industrial, and fishing activities (Shriadah et al. 2008). Along the Egyptian Red Sea coast, a number of mangrove forests are present. Avicenna marina is the lonely known mangrove species, observed from the western coast of Aqaba Gulf to Hamata, about 400 km southern of Hurghada (Dar and El-Saharty 2006). The present sampling sites (Fig. 1) represent the sediments of six mangrove forests from the tidal zone and the study area extends from the western coast of Aqaba Gulf to Hamata. The northern stations (1 and 2) which lie near the entrance of the Gulf of Aqaba (Fig. 1), receive sediments by outflowing currents coming from the gulf. The source of the sediments along the area from Safaga (station 3) to Hamata (station 6) is largely autochthonous, mainly biogenic or chemical precipitation of different mud facies (Okbah et al. 2005).

Materials and methods

Sampling

Triplicate sediment samples from the upper 5 cm of sediment were collected from six mangrove sites along the Egyptian coast of the Red Sea during 2003. Sampling was carried out using a clean, acid-washed plastic scoop. The three replicate samples were composed and placed in self-sealed acid pre-cleaned plastic bags. All samples were immediately

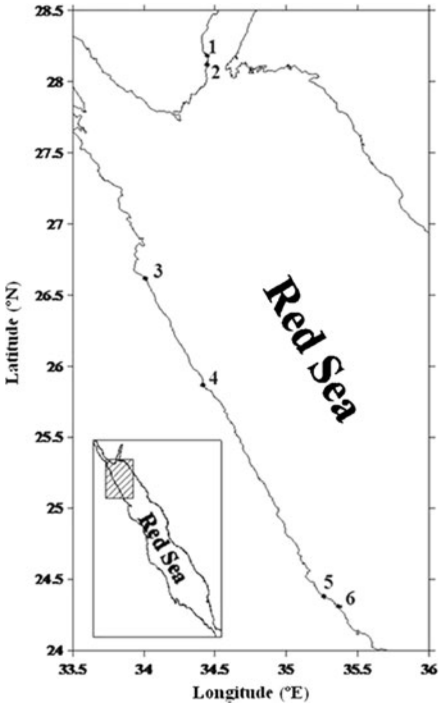

Fig. 1 Sampling sites of mangrove forests along the Red Sea

stored in an ice-cooled box and transferred to the laboratory. In the laboratory, the samples were air dried. The dried samples were sieved in the beginning through a 2 mm plastic sieve to remove mangrove leaves and roots, gravel or large particles, visible shells, shell fragments, and pebbles.

Grain size analysis

Grain size analysis was carried out by dry sieving for sand and by pipette technique for silt and clay fractions (Krumbein and Pettijohn 1938) and the data were treated following Folk 1980. For all sediment samples, the separated powdered fractions of similar grain size (Φ2, Φ3, Φ4, Φ5) were oven dried at 70°C to a constant weight and stored in dry acid-washed plastic bags for metal analysis. These fractions were selected according to their almost existence in all studied samples.

Sediment heavy metals analysis

Of dried and fine-ground sediment fraction, 0.25–0.50 g was put into a closed Teflon vessel with 3 ml HNO_3, 2 ml $HClO_4$, and 1 ml hydrofluoric acid (HF) acids for total digestion of heavy metals. To obtain high pressure, the vessels were placed inside a well-closed stainless steel block and heated on a thermostatically controlled hot plate at 70°C for about 12 h (Oregioni and Aston 1984). To eliminate HF, the digestion mixture was nearly evaporated with 2 ml H_2SO_4. The residue was redissolved in 10 ml diluted HNO_3 and preserved in acid-clean polyvinyl chloride bottles for analysis. For each digestion program, a blank was prepared using the same procedure. All reagents were of analytical grade and contained very low concentrations of trace metals. All the glassware and the Teflon vessels were previously soaked overnight with 20% HNO_3 and then rinsed with metal-free distilled water. Sample solutions and reagent blanks were analyzed for the heavy metals using a Perkin Elmer 2830 flame atomic absorption spectrophotometer. Working standards of studied metals were prepared by diluting concentrated stock solutions (Merck, Germany) of 1,000 mg/l in metal-free distilled water. Each metal concentration was estimated quantitatively according to the standard conditions described in the instrument manual. Duplicate measurements were made for each sample, by direct aspiration into air acetylene flame of the instrument.

Quality assurance

To monitor the quality of chemical analysis and examine the accuracy of the data, sediment reference materials (IAEA-433, International Atomic Energy Agency, Austria) were analyzed with the sediment samples during the course of analysis. The analytical results of the selected metals of interest indicated a good agreement between the reference and analytical values of the reference materials. In addition, the recovery rates for the selected metals from the standard reference material were 93.34–105.49% (Table 1).

Sediment quality

The sediment quality was done using some Sediment Quality Guidelines and potential ecological risk index (RI) (Hakanson 1980; Wang et al. 2011), contamination factor (CF) (Turekian and Wedepohl 1961), pollution load index (PLI) (Tomlinson et al. 1980) and geoaccumulation index (I_{geo}) (Muller 1969) methods.

Potential ecological risk index

With the aim of achieving a broader assessment of heavy metal pollution in the mangrove sediments in terms of ecological risks, Hakanson (1980) developed the following quantitative approach. The potential ecological risk factor of a given contaminant (E_i) is defined as:

$$E_i = T_i \times C_i / C_0$$

Table 1 Average (milligram per kilogram) and standard deviation obtained for four replicates of the standard reference material IAEA-433

Metal	Certified	Measured	Recovery%
Cadmium	0.153±0.033	0.161±0.037	105.49
Cobalt	12.9±1.2	12.0±1.5	93.34
Copper	30.8±2.6	29.8±3.0	96.73
Lead	26±2.6	26±2.8	99.30
Manganese	316±16	321±20	101.43
Nickel	39.4±3.1	39.2±3.5	99.56

Table 2 Muller`s classification for the geoaccumulation index; I_{geo} (Muller 1981)

I_{geo} value	I_{geo} class	Sediment quality
≤0	0	Unpolluted
0–1	1	From unpolluted to moderately polluted
1–2	2	Moderately polluted
2–3	3	From moderately to strongly polluted
3–4	4	Strongly polluted
4–5	5	From strongly to extremely polluted
>5	6	Extremely polluted

where, T_i is the toxic response factor for a given substance (i.e., Hg=40, Cd=30, As=10, Pb=Cu=Ni=5, Cr=2, Zn=1), C_i represents the metal content in the sediments, and C_0 is the regional background value of heavy metals in the sediments, based on values from relatively nonpolluted bottom sediments (Adami et al. 2000; Adamo et al. 2005).

The sum of the individual E_i presents the potential ecological RI for a region and can be expressed as:

$$\mathrm{RI} = \sum\nolimits_{i=1}^{n} E_i$$

According to Hakanson (1980), the following E_i and RI values give an indication of ecological risk:

$E_i<40$, RI<150=low potential ecological risk
$40\le E_i<80$, 150≤RI<300=moderate potential ecological risk
$80\le E_i<160$, 300≤RI<600=considerable potential ecological risk
$160\le E_i<320$, RI≥600=very high potential ecological risk
$E_i\ge 320$=dangerous

Contamination factor

The level of contamination of sediment by a metal is often expressed in terms of a contamination factor as follows (Turekian and Wedepohl 1961):

$$\mathrm{CF} = \text{metal content in the sediment/background level of metal}$$

Where CF<1 refers to low contamination, 1≥CF ≥3 means moderate contamination, 3≥CF ≥6 indicates considerable contamination and CF>6 indicates very high contamination.

Pollution load index

The extent of pollution by trace metals has been assessed by employing the method based on PLI developed by Tomlinson et al. (1980) and the relation is shown below:

$$\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \times \mathrm{CF}_4 \ldots. \times \mathrm{CF}_n)^{1/n}$$

where CF=contamination factor and n=number of metals. PLI provides a simple, comparative means for assessing a site or estuarine quality: a value of 0 indicates perfection, a value of 1 indicates only baseline levels of pollutants present and values above 1 would indicate progressive deterioration of the site and estuarine quality.

Geoaccumulation index

The geoaccumulation index I_{geo} values were calculated for different metals as introduced by Muller (1969) as follows:

$$\mathrm{I_{geo}} = \log_2(\mathrm{C_n}/1.5 * \mathrm{B_n})$$

where, C_n is the measured concentration of element n in the sediment sample and B_n is the geochemical

Table 3 Sand, silt, and clay%, mean and type of the sediment samples of mangrove

Staion number	Sand%	Silt%	Clay%	Mean Φ	Significant	Type of sediment
1	78.00	22.00	0.00	2.11	Fine sand	Silty sand
2	51.50	6.23	42.27	4.06	very fine sand	Clayey sand
3	57.43	40.62	1.96	3.58	very fine sand	Silty Sand
4	56.37	22.15	21.48	3.63	Medium sand	Clayey silty sand
5	53.79	25.32	20.89	3.86	Medium sand	Clayey silty sand
6	79.77	14.77	5.46	2.93	Fine sand	Silty sand

Table 4 The distribution of the heavy metals in the different fractions of studied mangrove sediment stations

Heavy metal concentration (mg/g)	Station number	Φ2	Φ3	Φ4	Φ5
Mn	1	16.1	41.6	17.6	111.7
	2	123.3	192.5	85.2	160.1
	3	51.0	58.1	101.8	65.8
	4	234.5	254.5	223.0	280.5
	5	18.4	114.9	59.4	214.2
	6	101.8	248.5	60.3	367.5
Ni	1	5.5	13.8	15.3	22.0
	2	34.0	30.0	29.0	23.1
	3	11.3	29.8	23.3	17.3
	4	41.2	43.9	50.1	52.4
	5	28.4	29.5	26.8	24.8
	6	27.2	29.7	22.2	43.2
Cu	1	6.8	22.9	11.2	108.0
	2	40.8	17.0	35.7	90.0
	3	28.3	11.8	40.3	90.7
	4	31.1	25.1	47.8	110.9
	5	10.8	42.3	25.4	127.8
	6	21.3	16.4	46.2	190.2
Co	1	5.3	5.7	8.5	14.1
	2	4.5	7.5	8.3	14.4
	3	2.8	1.8	5.4	3.1
	4	8.5	4.9	10.6	3.9
	5	3.3	9.2	5.3	5.2
	6	3.0	11.2	0.2	14.0
Cd	1	0.7	2.2	4.4	1.8
	2	4.7	2.2	4.7	3.4
	3	3.3	2.6	3.3	5.4
	4	3.4	3.7	4.2	4.5
	5	2.6	2.7	5.8	3.8
	6	1.7	4.7	2.3	2.2
Pb	1	21.0	10.0	13.0	25.0
	2	52.5	13.0	10.5	22.1
	3	15.5	8.0	5.0	20.5
	4	55.5	11.0	17.5	12.0
	5	9.6	32.0	23.0	19.6
	6	12.0	14.0	10.5	24.5

background for the element *n* (Adamo et al. 2005). The factor 1.5 is introduced to include possible variation of the background values that are due to lithogenic variations. Muller (1981) proposed seven grades or classes of the geoaccumulation index. Different geoaccumulation index classes along with the associated sediment quality are given (Table 2).

Statistical analysis

Using the Minitab 13.1 software program, a simple correlation and the hierarchical cluster analyses were done to assess the relationships between various parameters.

Results and discussions

Characteristics of sediments

Table 3 shows that all the studied sediments contain high sand fractions (51.50–79.77%). This indicates that the sand is the dominant component in the collected samples. Additionally, the components of clay and silt fluctuate between 0–24.27% and 6.23–40.62%, respectively. Accordingly, it seems that the sediment type varies along the studied stations. However, these sediments contain varieties of sediment types including clayey sand (station 2), silty sand (stations 1, 3 and 6) and clayey silty sand (stations 4 and 5).

Spatial variation of the metals in the mangrove sediments

The levels of heavy metals in different mangrove fractions in the studied area are presented in Table 4 and Fig. 2. The heavy metals concentration fluctuates not only within different stations but also within different fractions. Mn and Ni are the only heavy metals that show relatively similar distribution trend along the different fractions in the different stations. Generally, no particular trend is observed in the distribution of most metals with respect to the sampling locations. So, for each station, the mean of determined metal concentrations within studied fractions (Φ2, Φ3, Φ4, and Φ5) are calculated and hierarchical cluster analysis is applied for grouping of samples according to their similarities. The obtained cluster analysis dendogram for these means (Fig. 3) reveals that the sediment mangrove communities from stations 1, 3, 5, and 2 differ from those in stations 4 and 6. These variations may be attributed to the effects of biological and physical phenomena, such as tidal inundation, salinity

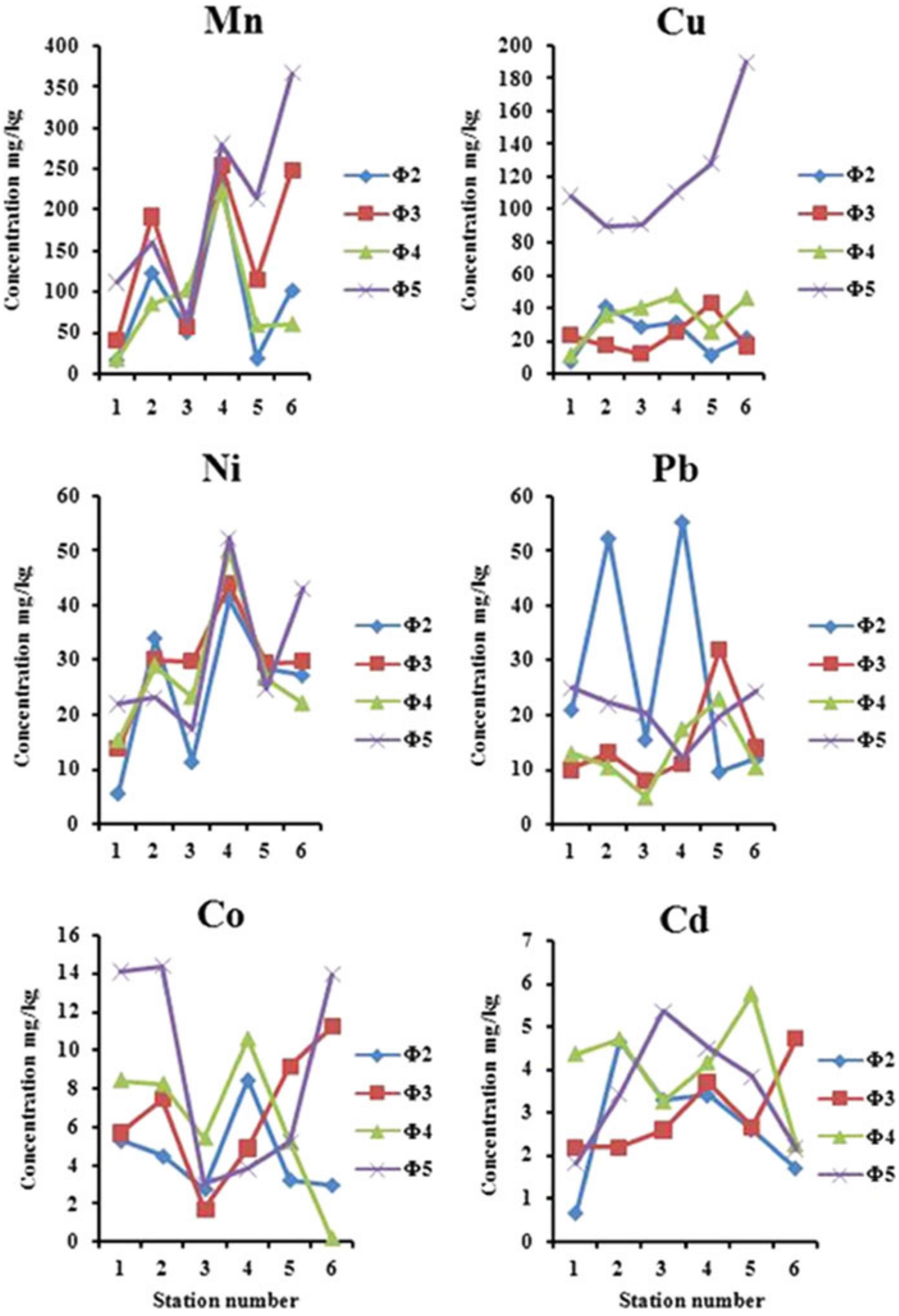

Fig. 2 Levels of heavy metals in different fractions of studied mangrove sediment stations

changes, wind, and waves. These phenomena allow the processes of bioturbation, resuspension, and erosion that are known to affect the metal concentrations in surface sediments (Bellucci et al. 2002). A simple correlation analysis was done to clarify the relationships between various metals. Pearson's correlation coefficient matrix (Table 5) shows that there are significant correlations between the metals of Mn and Ni (r=0.777, with confidence limit=100%), Mn and Cu (r=0.583, with confidence limit=95%), Mn and Co (r=0.465, with confidence limit=95%), and Cu and Co (r=0.412, with confidence limit=95%). This means that these metals probably originate from a common source, and are transported and deposited by common carriers (particles).

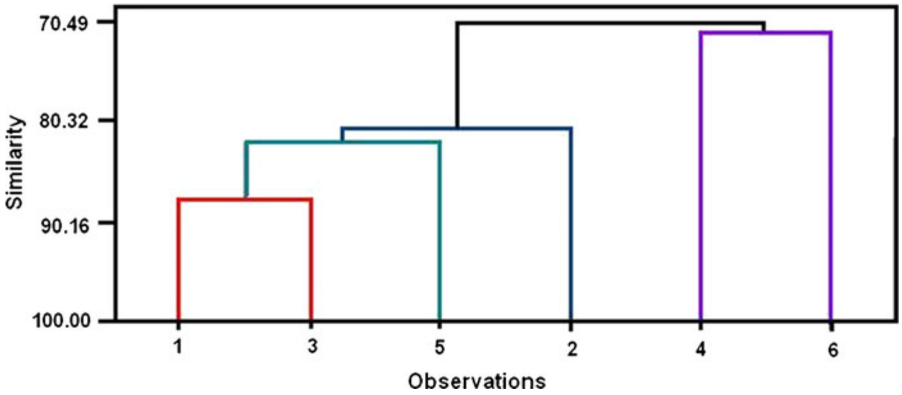

Fig. 3 Hierarchical cluster analysis of mangrove sediments stations

Grain size and its effect on metal concentration

The average concentration of heavy metals in different fractions (Φ2, Φ3, Φ4, and Φ5) along the studied locations is presented (Fig. 4). The present study reveals that the highest percentages of Mn and Co (38% and 34%, respectively) are recorded in the finest fraction Φ5, nearly doubles those in the greatest fraction Φ2. The percentage of Cu in the finest fraction Φ5 (60%) is considerably higher than that of the other fractions. The greatest fraction Φ2 shows the lowest percentage of Cd (20%), whereas Φ4 accumulates the highest percentage of Cd follows by Φ5. In contrast, Φ2 contains the highest percentage of Pb (36%), follows by the finest fraction Φ5 (27%). However, Ni shows no significant variation with changes in grain size. These results indicate that Cu, Co, Mn, and to a lesser degree Cd increased in concentration with finer size (Φ5). The results suggest that these metals are bound in the silt and clay fractions than the sand-sized fraction of the sediment. Indeed, it is well-established that grain size is one of the important controlling factors in the abundance of trace metals in natural sediments (Horowitz and Elrick 1987). In most sediment, the fine-grained fraction contained higher concentrations of heavy metals than the sand-sized fraction and has been used to examine metal contamination in the whole sediment sample (Tam and Wong 2000). However, the phenomenon of heavy metals sorption by clays was due to the high specific surface area of the smaller particles (Loring 1991; Summers et al. 1996; Ragbirsingh and Norville 2005). Accordingly, this enrichment is probably due to the surface adsorption and the ionic attraction (Horowitz and Elrick 1987). Interestingly, Tam and Wong (2000) designed a study to compare the concentrations of heavy metals bound in the fine-grained fraction (<63 μm) and the sand-sized fraction (2 mm-63 μm) of the sediments. They found that the highest percentage of heavy metals in sediment (43%) was in the fine-grained fraction. They suggested that the concentrations of organic matter in the fine-grained fraction of the sediment were often higher than that in the sand-sized. Regarding Ni and Pb, the preferential accumulation of metals in the silt and clay fractions rather than the sand-sized did not exist in the present study. This is in accordance with Tam and Wong (2000), who stated that the trend of more metal being accumulated in the fine-grained of the sediment may not be universal for all metals and may be varied between metal species.

Table 5 Pearson correlation for the studied heavy metals in the studied mangrove sediment stations

Metals	Mn	Ni	Cu	Co	Cd
Ni	0.777[a]				
	0.000				
Cu	0.583[a]	0.301			
	0.003	0.153			
Co	0.465[a]	0.198	0.412[a]		
	0.022	0.354	0.045		
Cd	0.133	0.280	0.037	−0.021	
	0.536	0.185	0.864	0.923	
Pb	0.219	0.197	0.154	0.263	0.127
	0.304	0.356	0.473	0.214	0.554

[a] Significant values ($p<0.05$; significant level=95%)

Comparison between the levels of metals in the studied mangrove sediments with those in the previous studies

Table 6 shows the ranges and the mean concentrations of the present studied metals, some previous studies, and the Sediment Quality Guidelines. According to

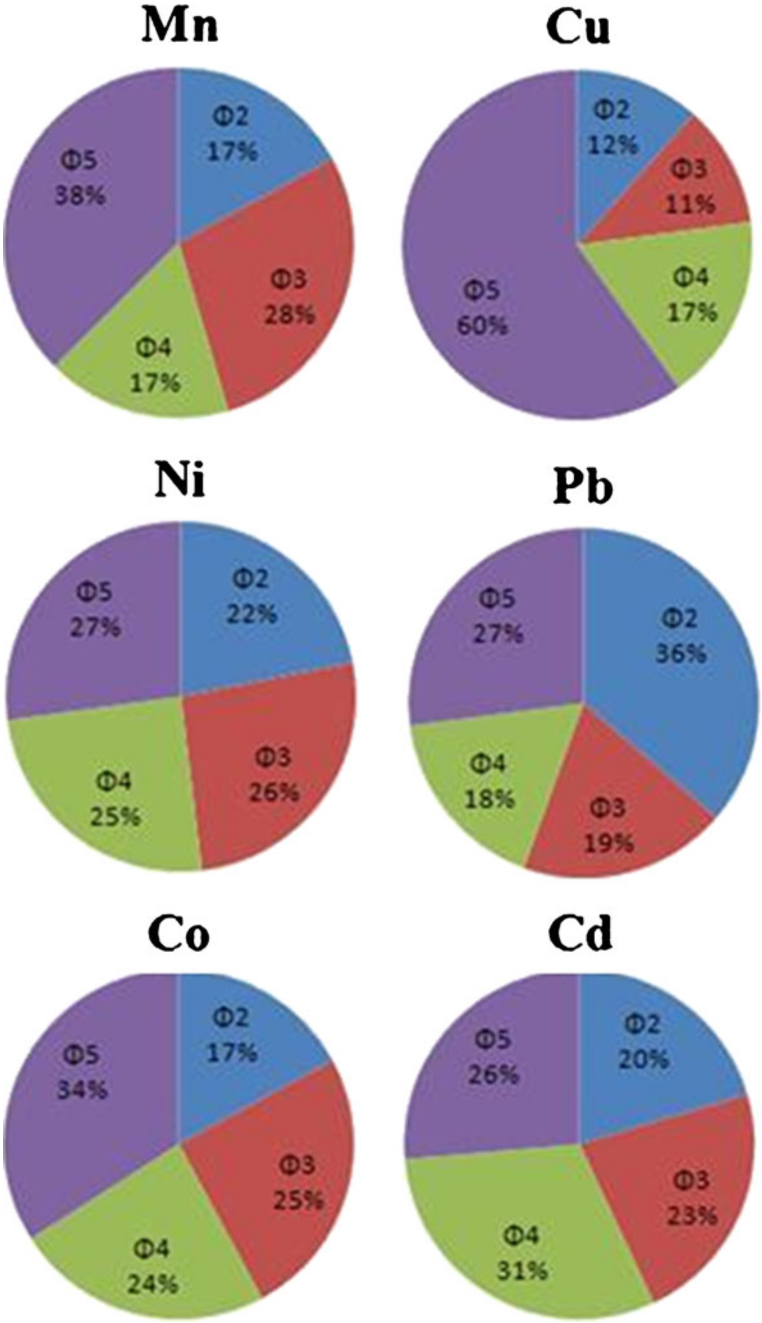

Fig. 4 Average heavy metal concentrations for the six mangrove sediments stations

these data, manganese has the highest mean value (133±97 mg/kg), followed by copper (49.9±46.0 mg/kg), nickel (28.1±11.8 mg/kg), lead (19±13 mg/kg), cobalt (6.7±4.0 mg/kg), and cadmium (3.327±1.280 mg/kg). This trend differs partially than that observed by Defew et al. (2005; Mn>Pb>Ni>Cu>Cd) for mangrove sediments collected from Punta Mala Bay, Panama. Our results of Mn concentrations appear considerably lower than those reported for the contaminated mangrove environments (Perdomo et al. 1998; Ramanathan et al. 1999; Defew et al. 2005). However, the ranges of Cu concentration in the present study are higher than those reported previously (Shriadah 1999; Dar and El-Saharty 2006) and its mean concentration was about 1 order of magnitude higher than the values reported for the clean mangrove

Table 6 Comparison between the heavy metal levels (mg/kg dry weight) of studied mangrove sediments with those from mangrove sediments around the world and with those of the Sediment Quality Guidelines in the world

Location	Mn	Cu	Ni	Pb	Co	Cd	
Red Sea, Egypt (range)	16–368	6.8–190.2	5.5–52.4	5.0–56	0.2–14.4	0.650–5.750	Present study
Arabian Gulf, United Arab Emirates[a]	28.8–169	5.31–29.40	14.8–109	13.2–49.8	5.70–14.0	3.12–6.94	Shriadah (1999)
Red Sea, Egypt	61.63–296.48	2.85–55.13	–	2.11–20.00	–	0.10–0.24	Dar and El-Saharty (2006)
Red Sea, Egypt (mean)	133±97	49.9±46.0	28.1±11.8	19±13	6.7±4.0	3.327±1.280	Present study
Cienaga Grande, Colombia[a]	623	23.3	32.5	12.6	–	1.92	Perdomo et al. (1998)
Pichavaram, India[a]	941	43.4	–	11.2	–	–	Ramanathan et al. (1999)
Port Jackson, Australia[b]	–	102	–	443	–	–	MacFarlane (2002)
Hawksbury, Australia[b]	–	18.9	–	26.4	–	–	MacFarlane (2002)
Punta Mala Bay, Panama[a]	295	56.3	27.3	78.2	–	<10	Defew et al. (2005)
Hong Kong[c]	96.00	2.60	2.90	31.20	–	0.32	Tam and Wong (2000)
Brazil[c]	–	3.82	–	–	–	0.6	Harris and Santos (2000)
Port Hacking, Australia[c]	–	1.1	–	2.5	–	–	MacFarlane (2002)
Sediment Quality Guidelines							
Canadian Sediment Quality Guidelines (TEL)	–	18.7	–	30.2	–	0.7	Canadian Council of Ministers of the Environment (2002)
Canadian Sediment Quality Guidelines (PEL)	–	108	–	112	–	4.2	Canadian Council of Ministers of the Environment (2002)
Swedish Environmental Protection Agency			>100				Greaney (2005)

[a] Sites suffered from anthropogenic activities

[b] Hawksbury and Port Jackson, Australia were reported to be polluted mangroves with regard to metal pollution

[c] Documented as clean mangrove sites (noted in italics)

sediments of Brazil (Harris and Santos 2000). Our Ni values are lower than those observed for the Arabian Gulf mangrove sediments (Shriadah 1999) and the mean value is close to the levels reported for the contaminated areas (Perdomo et al. 1998; Defew et al. 2005). The Pb values obtained are considerably higher than the literature value of MacFarlane (2002) and similar to the other literature values (Shriadah 1999; Perdomo et al. 1998; Ramanathan et al. 1999). There is a consistency between the ranges of Co in the present study with those obtained earlier for the Arabian Gulf mangrove sediments by Shriadah (1999). The values of Cd in the present study are somewhat comparable with those reported by Shriadah (1999) and Defew et al. (2005) but are higher than those reported by Perdomo et al. (1998) and Dar and El-Saharty (2006).

Table 7 Individual potential ecological risks factors and potential ecological risk index (RI) of heavy metals for each mangrove station

E_i (station number)	E_i (st.1)	E_i (st.2)	E_i (st.3)	E_i (st.4)	E_i (st.5)	E_i (st.6)	RI
Cu	35.5	43.7	40.7	51.1	49.1	65.2	285.4
Ni	5.8	11.8	8.3	19.1	11.2	12.5	68.7
Pb	15.0	21.3	10.7	20.9	18.3	13.3	99.4
Cd	1,352.7	2,244.5	2,175.0	2,362.5	2,223.0	1,620.0	11,977.7

Table 8 Contamination factor and pollution load index of heavy metals for each mangrove station

Station	Mn	Cu	Ni	Pb	Co	Cd	PLI
$CF_{St.1}$	0.4	7.1	1.2	3.0	5.2	45.1	3.6
$CF_{St.2}$	1.2	8.7	2.4	4.3	5.4	74.8	5.9
$CF_{St.3}$	0.6	8.1	1.7	2.1	2.0	72.5	3.7
$CF_{St.4}$	2.1	10.2	3.8	4.2	4.3	78.8	7.0
$CF_{St.5}$	0.8	9.8	2.2	3.7	3.6	74.1	5.1
$CF_{St.6}$	1.6	13.0	2.5	2.7	4.4	54.0	5.7
Range	0.4–2.1	7.1–13.0	1.2–3.8	2.1–4.3	2.0–5.4	45.1–78.8	3.6–7.0
Average	1.1	9.5	2.3	3.3	4.2	66.5	5.2
S.D.	0.6	2.1	0.9	0.9	1.2	13.6	1.3

Sediment quality

According to background values from the Hong Kong Environment Protection Department (clean mangrove environments; Tam and Wong 2000; Table 6), concentrations of Mn and Pb measured in the studied mangrove sediments are low and do not cause hazard to the mangrove system. However, the concentrations of Cu, Ni, and Cd are high and may consider as a high level of contamination to the mangrove ecosystem. The Swedish Environmental Protection Agency stated that the level of Ni contamination is >100 mg/kg (Greaney 2005), which is considerably higher than the levels of Ni in the present study. This agency is responsible for a wide range of issues including pollution control, nature conservation, etc.

The mean concentrations of Cu, Pb, and Cd in the present study are also compared with those of the Canadian Sediment Quality Guidelines. However, these guidelines are used as an interim measure to assess whether the concentrations of heavy metals in sediments could have adverse biological impacts (Table 6). Two levels are generally considered: the threshold effect level (TEL), below which adverse biological effects are expected to occur rarely, and the probable effect level (PEL), above which adverse effects are expected to occur frequently. These concentrations were established by the Canadian Council of Ministers of the Environment, and are routinely used as screening tools by different stakeholders involved in sediment management activities (Canadian Council of Ministers of the Environment 2002). It is observed that the mean concentrations of Cu and Cd are higher than those of the TEL values, whereas the mean concentration of Pb is lower. However, the PEL values are higher than those of Cu, Pb, and Cd. The present results shows that the levels of Cu, Cd, and Ni are high, however, could not be considered to present serious threat to the mangrove ecosystem. It is suggested that any further investigations within the Egyptian mangrove sediments should include organic pollutants and a lot of metals measurements as an aid for better understanding of mangrove ecosystems and, hopefully, to enable us to mitigate any detrimental effects.

Table 9 Geo-accumulation index (I_{geo}) values of heavy metals for each mangrove station

Station	I_{geo}Mn	I_{geo}Cu	I_{geo}Ni	I_{geo}Pb	I_{geo}Co	I_{geo}Cd
1	−1.94	2.24	−0.38	1.00	1.80	4.91
2	−0.36	2.54	0.66	1.51	1.85	5.64
3	−1.38	2.44	0.15	0.51	0.44	5.59
4	0.47	2.77	1.35	1.48	1.53	5.71
5	−0.82	2.71	0.57	1.29	1.26	5.63
6	0.11	3.12	0.73	0.82	1.56	5.17
Average	−0.65	2.64	0.52	1.10	1.41	5.44

For the calculations of potential ecological risk index (Hakanson 1980; Wang et al. 2011), Ni and Pb show low potential ecological risk of E_i and RI, values smaller than 40 and 150, respectively (Table 7). On the other hand, Cu gives moderate potential ecological risk along almost the stations, however, E_i and RI, values are of values within the ranges 40–80 and 150–300, respectively. Only station 1 is of low potential ecological risk. Generally, Cd shows a dangerous case in all stations sediments; however, E_i and RI, values are greater than 320 and 600, respectively (Adami et al. 2000).

Contamination factor and pollution load index calculations are illustrated (Table 8). Mn and Ni heavy metals have moderate contamination values, since their average CF values are of 1.1 and 2.3 values within 1≥CF ≥3 range. Pb and Co show considerable contaminated sediments with values of 3≥CF ≥6. Cu and Cd are of CF>6 values along all the studied stations. Accordingly, these two heavy metals are dangerously contaminated and their disparate behavior is affected by the anthropogenic sources. PLI values above 1 may indicate the progressive deterioration of these sites (Tomlinson et al. 1980).

The calculated geoaccumulation index values of all the studied metals in mangrove sediments are tabulated (Table 9). The mangrove sediments are of low pollution degree for Mn and Ni heavy metals. The I_{geo} values for Pb and Co heavy metals show moderate pollution in most the sediments samples. Cu gives I_{geo} values of moderate pollution. The I_{geo}Cd values show that the mangrove sediments are extremely polluted with Cd. The geoaccumulation index values for Cu and Cd possibly refer to the human activities.

Conclusions

The concentrations of some metals (Mn, Cu, Ni, Pb, Co, and Cd) were determined totally and fractionally (Φ2, Φ3, Φ4, and Φ5) in mangrove sediments selected from some ecosystems along the Egyptian Red Sea shoreline. Cu, Co, Mn, and Cd heavy metals were bounded in the silt and clay fractions than the sand-sized fraction of the sediment. Based on the average values, the concentrations of Mn and Pb were low and showed no possibility of detrimental effects on the local environment. On the other hand, the levels of the other metals (Cu and Ni) were high and their concentrations may not make any deleterious or harmful effects to the mangrove system. Among the studied heavy metals, Cd was the only heavy metal that may cause risk to the ecological systems. Accordingly, the heavy metals must be monitored to ensure their harmless levels along the mangrove ecosystems.

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