

Metal Speciation (Cd, Cu, Pb and Zn) in Sediments from Al Shabab Lagoon, Jeddah, Saudi Arabia

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Abstract. A four-step sequential extraction technique was used to determine the chemical association of heavy metals (Cd, Cu, Pb, Zn) with major sedimentary phases (exchangeable and carbonates, manganese and iron oxides, sulphides and organic matter and residual minerals) in samples from Al Shabab Lagoon, Jeddah, S.A. The total metal content was also determined. The results of the present study indicate that the bottom sediments of the lagoon contain high concentrations of heavy metals such as Cd, Cu, Pb and Zn. The partitioning characteristics of the lagoon sediments also show that the percentages of metals associated with the non-residual fractions are notably greater than the residual fraction, for all studied metals, indicating the polluted nature of the sediments. The Risk Assessment Code reveals that about 30-45% of Cd at most of the sites exist in exchangeable and carbonate bound fraction and therefore comes under the high risk category and can easily enter the food chain. A sizable portion of Pb and Zn (4.6-15.4 and 2.5-14.5% of Pb and Zn, respectively) is found in exchangeable and carbonate bound fraction thus posing low to medium risk for the aquatic environment. Fractionation pattern of Cu shows no to low risk to aquatic environment.

Keywords: Speciation, Partitioning, Metals, Sediments, Al Shabab Lagoon, Red Sea.

Introduction

Jeddah is one of the largest Red Sea coastal cities and the economic hub of Saudi Arabia. It lies at the central part of the eastern coast of the Red Sea and extends for about 100 km. The population of the city is approaching 3 million inhabitants and its area is greatly increasing (MCI,

2006; PERSGA, 2006). Since the seventies the city is seeing a vast human and economic expansion. Industrialization is growing rapidly and is mainly represented by refineries, petrochemicals and food processing. As a trade center, the city is connected to the other parts of the world through a highly developed maritime transport network and its Islamic Port is one of the biggest ports of the Red Sea.

The City of Jeddah has a vast network to collect urban wastes (750 km long according to Mandura *et al.*, 1994). The collected sewage is treated in several Sewage Treatment Plants (STPs), however, due to the rapid expansion of the city and its population the treatment capacity of the STPs is normally lacking and this allows the untreated or partially treated sewage discharge in the sea, as is the case in the Southern Corniche area (El Sayed and Niaz, 1999, El Sayed, 2002 a&b), Al Arbaeen Lagoon (El Rayis, *et al.*, 1984, Basaham, 1998; El Sayed, 2002c) and in Al Shabab Lagoon (Turki *et al.*, 2002; El Sayed, 2002c; Turki, 2006).

The presence of heavy metals of natural or anthropogenic origin in sediments of aquatic system represents one of the most important environmental problems nowadays, especially when these sediments represent an important reservoir of these elements and other polluting substances (Ridgway and Shimmiel, 2002). Metals of anthropogenic origin introduced in estuaries are usually in dissolved or particulate forms and are quickly incorporated into organo-metallic compounds or some mineral phases. In general, from the total metal concentration of a metal present in either the sediment or the suspended particulate matter (SPM), only the most labile fraction is capable of affecting organisms (López-González *et al.*, 2006).

Sediments are the final destination of trace metals, as a result of adsorption, precipitation, diffusion processes, chemical reactions, biological activity and a combination of those phenomena (Ramirez *et al.*, 2005). Sediments are an important sink for heavy metals but when some physical disturbance occurs, or there is diagenesis and/or changes in pH or redox potential, they can become a source of metals, releasing them in the overlying water column. This phenomenon can occur even long after the end of the direct discharge and its extent depends on the metal association with different mineralogical fractions of the sediments, defined as "solid speciation". Therefore, metals behaviour and availability strictly depends upon their chemical form and their speciation (Jones and Turki, 1997).

To assess the environmental impact of polluted sediments, information on total metal concentrations alone is not sufficient as heavy metals are present in different chemical forms in sediments (*e.g.* metal carbonates, oxides, sulfides, organometallic compounds, etc.) (Stecko and Bendell-Young, 2000; Bendell-Young *et al.*, 2002). Only fraction of metal can be easily remobilized. Thus, the chemical form of the metals in the sediment is of great significance in determining their remobilization potential (Rauret *et al.*, 1988; López-González *et al.*, 2006).

Studies on the distribution and speciation of heavy metals in sediments can provide not only information on the degree of pollution, but especially the actual environmental impact on metal bioavailability as well as their origin.

To date, it has generally been accepted that the most appropriate methods to evaluate solid speciation—defined as the identification and quantification of the different species, forms or phases present in sediment—are selective extraction procedures (Kot and Namiesnik, 2000; Ramirez *et al.*, 2005). Selective extractions are widely used in sediment analysis to evaluate long-term potential emission of pollutants and to study the distribution of pollutants among the geochemical phases (Rauret, 1998), and to determine the metals associated with source constituents in sedimentary deposits (Van der Sloot *et al.*, 1997).

Several methods for determining the different forms of metals in sediments are described in scientific literature (Kersten and Forstner, 1991). The most widely used methods are based on sequential extraction procedures, where several reagents are used consecutively to extract operationally-defined phases from the sediment in a set sequence (Lopez-Sanchez *et al.*, 1993). There are many such schemes (Stover *et al.*, 1976; Tessier *et al.*, 1979; Forstner, 1982) among which the most widely used is the one proposed by Tessier *et al.* (1979).

Speciation is not only very useful for determining the degree of association of the metals in the sediments and to what extent they may be remobilized into the environment (Forstner *et al.*, 1990), but also for distinguishing those metals with a lithogenic origin from those with an anthropogenic origin. According to Rubio *et al.* (1991), metals with an anthropogenic origin are mainly obtained in the first extractions, while in the last stage of the process the residual fraction is obtained, corresponding to metals with lithogenic origins (Izquierdo *et al.*, 1997).

Available data concerning trace metal pollution in Al-Shabab lagoon (Turki *et al.*, 2002; Turki, 2006) demonstrate the association of high

concentrations of trace metals with the bottom sediments; however, the association mode has never been investigated. Despite the fact that the data on total concentrations are informative, however, the real environmental risk could not be assessed without carrying on a more comprehensive study on the speciation of the metals in the bottom sediments.

The aims of this work, therefore, are to assess both the concentration of Cd, Cu, Pb and Zn in the sediments of the lagoon, and the chemical forms in which they occur. The speciation method of Tessier *et al.* (1979) as modified by Ajayi and van Loon (1989) and Chester *et al.* (1994) is followed, providing information on four fractions, namely, exchangeable and carbonates; reducible; oxidizable; and residual.

Material and Methods

The Study Area

A complete description of the study area, Al Shabab lagoon, is given in El Rayis and Moammar (1998) and Turki (2006). Briefly, Al Shabab lagoon is one of the coastal lagoons of Jeddah coast (Fig. 1), that lies near the city center and was one of the maritime recreational places. This body of water has been exposed to contamination from wastewater as the city has grown. It receives about 35,000 m³ of treated and raw sewage daily, and communicates with open water through a narrow channel. The effluent discharge pipe is situated at the landward extremity of the lagoon. According to El Rayis and Moammar (1998), the permanent water exchange with the open water is taking place in the top two-meter surface layer, which is the depth of the sills. The subsurface water is accidentally exchanged during rough weather. This situation leads to the accumulation of organic matter and the creation of anoxic conditions in the bottom layer (El Rayis and Moammar, 1998). The installation of anoxic conditions was certainly accelerated by the daily dumping of about forty thousand cubic meters of treated and raw sewage into the lagoon for several years. Since 1996, dumping is officially stopped and the sewage effluent has been directed and evacuated to the south of the city. However, a recent study (El Sayed, 2002c) demonstrated that sewage discharge is still taking place and the condition of the lagoon is continuously deteriorating.

Recently, the new extension of the Islamic Port constitutes a new barrier for water circulation. An external lagoon is being created; its water is composed of a mixture of seawater and wastewater discharged into Al Shabab and Al Arbaeen lagoons. The water appears very turbid

and smelling badly. Most of the islets that represent a transient land for some migratory and resident birds have disappeared under the new platforms.

Sample Collection, Preparations and Analysis

Twenty-two surface sediment samples were collected from the bottom of the lagoon, in January 2006, using a grab sampler and immediately placed in sealed polyethylene bags. Sampling locations are shown in Fig. 1.

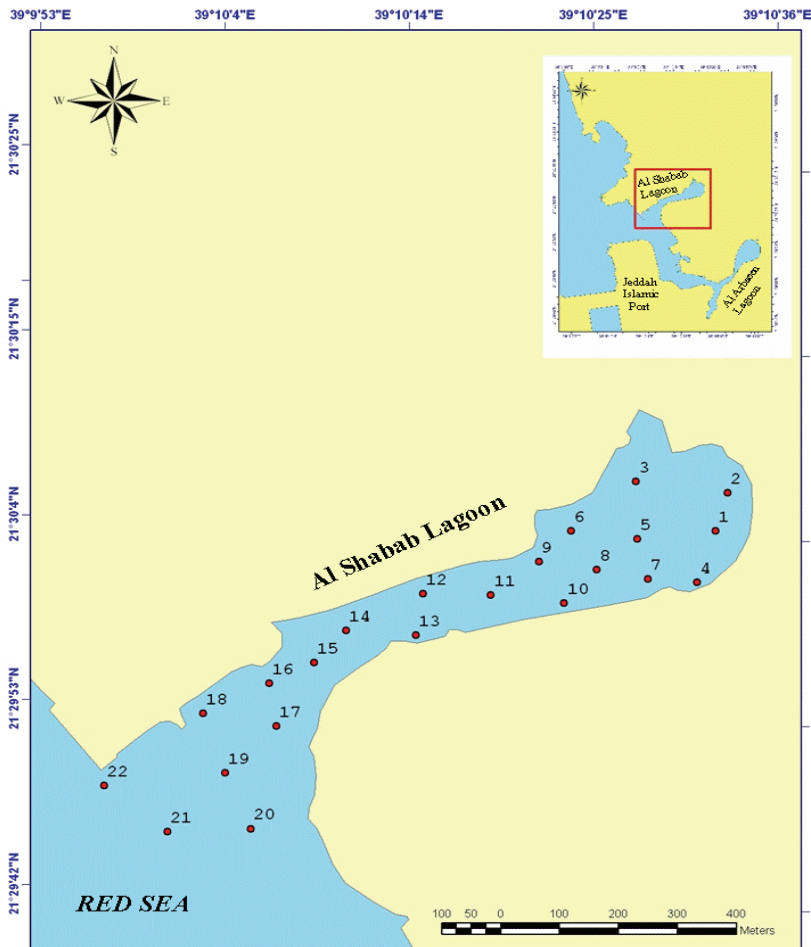


Fig. 1. Map of the study area, showing sampling stations.

One sub-sample was used to determine total metal contents. For this purpose it was subject to digestion, using a nitric / hydrofluoric / perchloric acid mixture, in the ratio 3 / 3 / 1 (v/v) (Jones and Turki, 1997).

The other sub-sample was subjected to the sequential extraction procedure. Following this procedure 1g of dry sediment was used for the extraction. Descriptions of the four fractions obtained with this method, as well as the operative conditions used for each extraction, are illustrated in Table 1.

Table 1. Time of mechanical agitation and temperature at which the sequential extraction was performed.

Geochemical phase	Extraction reagent	Extraction condition	Final volume	Extracted sediment components
Fraction 1 (F1: Exchangeable + Carbonate)	1 M NaOAc adjusted to pH 5 with HOAc	Shake at room temperature for 5 h.	25	Exchangeable ions and carbonates
Fraction 2 (F2: Reducible)	0.25 M NH ₂ OH.HCl in 25% (v/v) HOAc	Shake at 96°C for 6 h.	25	Mn-Fe oxides
Fraction 3 (F3: Oxidizable)	0.02 M HNO ₃ + H ₂ O ₂ (pH2 with HNO ₃). On cooling add 3.2 M NH ₂ OAc in 20% (v/v) HNO ₃ .	Shaken occasionally at 85°C for 5 h then shaken on addition of NH ₄ OAc for a further 0.5 h (see note 1 below)	25	Organic matter and sulphides
Fraction 4 (F4: Residual)	HNO ₃ - HF - HClO ₄	See note 2 below	100	Lithogenic crystalline minerals

Note 1: To the residue (from F2) 3 ml of HNO₃ and 2 ml of H₂O₂ were added, and the maximum was allowed to stand at room temperature until the initial reaction subsided. The remaining 3 ml of H₂O₂ was added to the sample, to make the first 5 ml of H₂O₂ recommended in the method, and the mixture was heated at 85°C for 2 hours with occasional agitation. A second 3 ml was then added and the sample was heated again to 85°C for 3 hours with intermittent agitation. After cooling, 5 ml of NH₄OAc was added and the sample was diluted to 20 ml and agitated continuously for 30 minutes.

Note 2: Residual fraction: the residue (from F3) was digested as described for total metal concentration.

Metal content was determined using Varian 250 plus flame atomic absorption spectrophotometer (AAS) fitted with D₂ background correction. Cd, Cu and Pb were measured using the thermal atomization technique GFAA. Samples were introduced in the graphite tubes using an automatic sample dispenser. The other element (Zn) was measured using the flame atomization technique. In both cases concentrations were obtained from peak height compared to standard solutions prepared for each element.

All reagents were Merck[®] analytical grade or Suprapur quality. Standard working solutions of the different metals analysed were prepared from the corresponding 1000 mg l⁻¹ Merck Titrisol solutions. All standards and reagent solutions were stored in polyethylene bottles.

Results and Discussion

Total Metal Content

Metal concentrations in the surface sediments of Al Shabab Lagoon are shown in Table 2. It can be seen from the data that the concentrations of the four metals varied as follows: Cd, 0.80-11.80 ug g⁻¹; Cu, 52.10-286.30 ug g⁻¹; Pb, 32.90-206.10 ug g⁻¹; Zn, 99.3-304.7 ug g⁻¹. The high concentrations of the studied metals, are lower than those in other area, of similar environment, such as Al Arbaeen Lagoon (Basaham, 1998), but higher than those of the southern Corniche of Jeddah (El Sayed and Niaz, 1999). In addition, the mean concentrations of all metals (Table 2) are relatively similar to those reported in a previous study by Turki (2006), for the inner part of the lagoon (5.79, 144.0, 121.0 and 19.3 ug g⁻¹ for Cd, Cu, Pb and Zn, respectively), but are higher than those reported for unpolluted sediments (Basaham and El Sayed, 1998). The mean metal concentrations in Al Shabab lagoon decrease in the order Zn>Cu>Pb>Cd.

To estimate the possible environmental consequences of the studied metals, results obtained in the present study were also compared to US NOAA's sediment quality guidelines (Ramirez *et al.*, 2005; and reference therein). In this study the effects range-low (ERL) and effects range-median (ERM) concentrations are considered. The ERL represents chemical concentrations below which adverse biological effects were rarely observed, while ERM represents concentrations above which effects were more frequently observed. Generally, adverse effects occurred in less than 10% of studies in which concentrations were below

the respective ERL values, and were observed in more than 75% of studies in which concentrations exceeded EMR values (Long *et al.*, 1997).

Table 2. Concentration of macro and trace elements ($\mu\text{g g}^{-1}$) in the sediments of Al Shabab Lagoon.

Sample No.	Cu ($\mu\text{g g}^{-1}$)	Zn ($\mu\text{g g}^{-1}$)	Cd ($\mu\text{g g}^{-1}$)	Pb ($\mu\text{g g}^{-1}$)
1	286.30	304.7	4.37	201.3
2	230.20	222.7	3.00	150.5
3	217.50	141.8	6.94	111.6
4	220.40	133.9	4.00	131.4
5	280.00	290.4	9.50	203.0
6	268.00	284.5	7.00	194.5
7	217.80	248.1	11.80	108.7
8	237.60	260.4	9.33	190.8
9	229.3	259.5	11.25	188.4
10	155.8	253.1	9.25	189.8
11	145.40	202.7	6.97	176.2
12	168.00	145.8	2.60	206.1
13	122.60	141.9	1.97	72.0
14	62.60	109.5	1.79	80.1
15	86.9	129.5	0.80	40.9
16	98.2	130.9	1.60	53.9
17	52.1	99.3	0.95	32.9
18	98.5	103.1	2.00	34.1
19	102.4	106.3	1.35	39.8
20	89.8	107.7	1.44	44.8
21	118.3	149.4	2.30	57.1
22	105.1	126.3	2.09	51.9
<i>S.D.</i>	74.51	71.31	3.64	67.37
<i>Mean</i>	163.31	179.61	4.65	116.35

ELR and EMR values for the metals are reported in Table 3. Comparing results of the present study (Table 2) with ERL and ERM values, all metals, apart from Cd, showed higher concentrations than ERL. In the case of Cd, though, all the studied sites, except sites 15 and 17, showed higher concentrations than the ERL values. In contrast, all metals with the exception of Cd, at sites 7 and 9, and Cu, at sites 1 and 5, showed lower concentrations compared to the ERM values. In particular Cd, at sites 7 and 9, and Cu, at sites 1 and 5, concentrations were slightly

higher than ERM values. Considering that toxicity is a function also of the degree to which data exceed ERM values, some environmental or toxicological effects of Cd and Cu at some sites, can be expected.

Metal Speciation

Different impacts on environmental conditions are depending on the chemical features of the metals present in polluted sediments. The chemical partitioning of Cd, Cu, Pb and Zn in sediments from Al Shabab lagoon, summarized in Table 4 and Fig. 2 provide an approximation to their mobilization capacity. The most labile bounds are metals associated

Table 3. US NOAA's ERL and ERM concentrations for the studied metals (values are in $\mu\text{g g}^{-1}$ dry weight) (after Ramirez *et al.*, 2005).

	ERL ($\mu\text{g g}^{-1}$)	ERM ($\mu\text{g g}^{-1}$)
Cd	1.2	9.6
Cu	34	270
Pb	46.7	218
Zn	150	410

Table 4. Chemical fractionation of heavy metals in AlShabab Lagoon sediments.

		Exchangeable+ Carbonate bound	Reducible	Oxidizable	residual
Cd	Mean, SD	37.3 ± 4.2	17.3 ± 4.3	5.0 ± 3.8	40.4 ± 4.7
	Median	36.9	16.4	4.8	39.8
	Range	30.0-45.0	10.5-25.8	0.0-11.0	33.3-50.0
Cu	Mean, SD	0.2 ± 0.5	2.4 ± 1.4	71.7 ± 8.4	25.7 ± 7.2
	Median	0.0	2.1	74.8	22.9
	Range	0.0-1.4	0.7-4.9	58.5-82.4	16.1-39.4
Pb	Mean, SD	10.9 ± 2.9	50.6 ± 3.8	5.7 ± 3.1	32.8 ± 7.1
	Median	11.3	50.0	6.7	32.2
	Range	4.6-15.1	42.3-58.0	1.3-10.2	27.0-44.8
Zn	Mean, SD	7.4 ± 3.2	41.6 ± 3.4	15.5 ± 5.0	36.0 ± 7.1
	Median	7.0	39.5	16.8	32.6
	Range	2.5-14.5	33.1-47.6	7.1-24.7	27.5-46.3

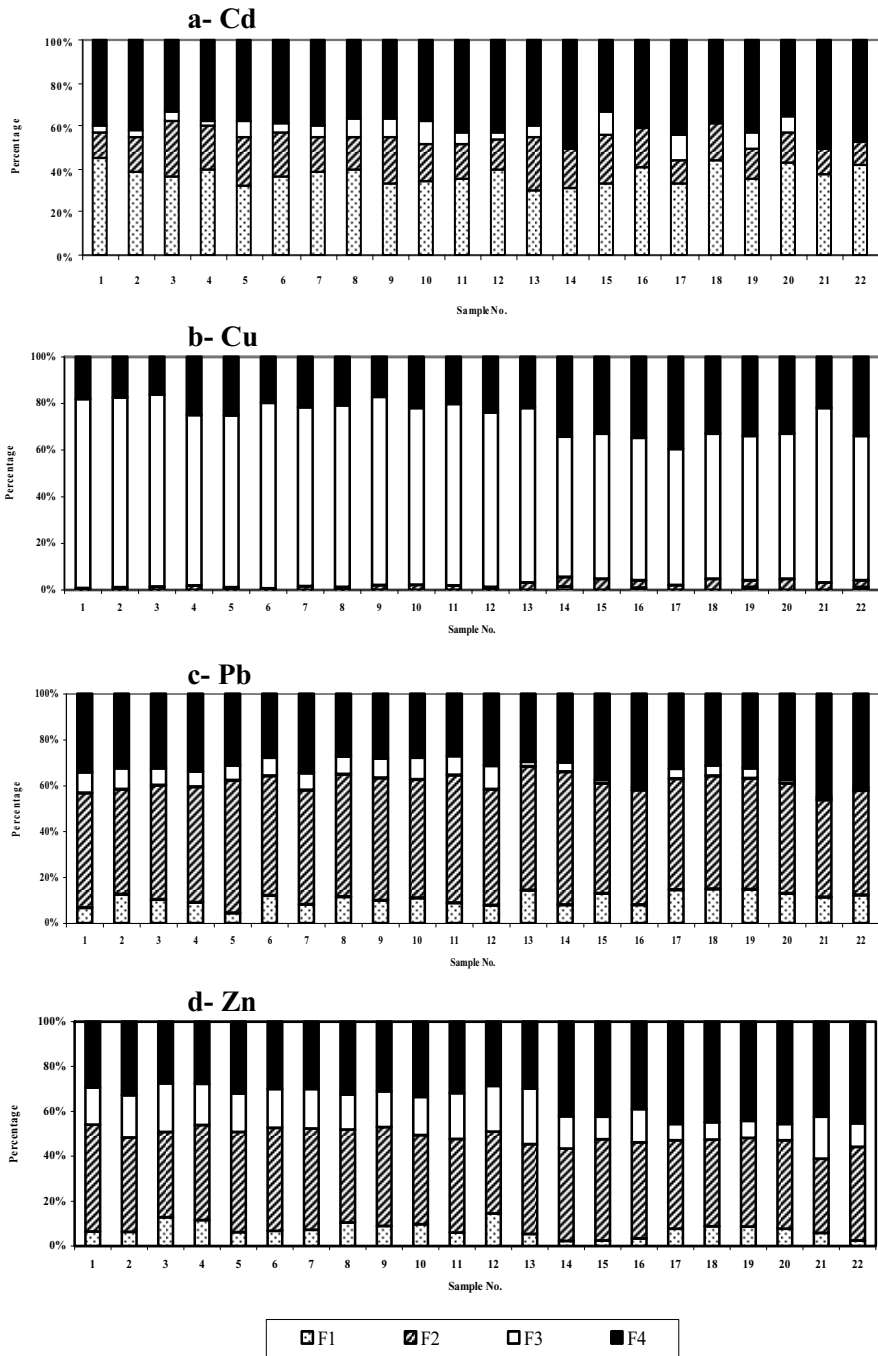


Fig. 2. Results of the percentage distribution of Cd, Cu, Pb and Zn in the four extracted phases in sediments from Al Shabab Lagoon.

with the exchangeable ions and carbonates that can be easily remobilized by changes in environmental conditions such as pH, salinity, etc (Perez *et al.*, 1991). Metals in reducible fraction can be released in the system only with a pH decrease, and also if sediments change from oxic to anoxic conditions and, in the same way metals bound to organic matter are liberated under oxidizing conditions. These three fractions are the most labile or exchangeable and constitute the most dangerous phases for the environment. They may change depending upon the surrounding physical and geochemical conditions (Tessier *et al.*, 1979; Ryan *et al.*, 2002; Wong *et al.*, 2007). Metals associated with residual fractions, usually form part of the crystalline structure of minerals, remain relatively stable and inert, and they are not easily released into the mobile and bioavailable phases (Tessier *et al.*, 1979; López-González *et al.*, 2006; Wong *et al.*, 2007).

Figure 2 shows, in percent bar graphs, the distribution of the heavy metals in the four fractions obtained by the sequential extraction procedure. The partitioning shows that the percentages of metals associated with the non-residual fractions (exchangeable and carbonate + reducible + oxidizable; Table 5) were notably greater (59.6% for Cd; 74.3% for Cu; 67.2 for Pb and 64.0% for Zn) than those of the residual fraction ((40.4% for Cd; 25.7% for Cu; 32.8 for Pb and 36.0% for Zn), suggesting that these metals are primarily derived from anthropogenic inputs rather than the geochemical background. Therefore, the results indicate that the metals are potentially more available for exchange and/or release into the marine environment. The studied trace metals in the non-residual fractions increased in the order of Cd < Zn < Pb < Cu.

Table 5. The mean proportion of metals (%) in the lithogenous and non-lithogenous fractions of the sediments from Al Shabab Lagoon.

Metal	Lithogenous Fraction ^a	Non-Lithogenous fraction ^b
Cd	40.4	59.6
Cu	25.7	74.3
Pb	32.8	67.2
Zn	36.0	64.0

^a = residual fraction.

^b = F1+F2+F3.

Amongst the studied metals, Cd was strongly associated with the residual and the exchangeable and carbonates bound fractions (Fig. 2a). The percentage of Cd associated with different fraction is in the order: residual > exchangeable and carbonates bound > reducible > oxidizable. The result is consistent with the findings in the wetland sediments from the Pearl River Estuary, China (Li *et al.*, 2007) and the coastal sediments from Kranji and Pulau Tekong, Singapore (Cuong and Obbard, 2006). Cd is also the only metal for which the exchangeable and carbonates bound fraction is significant, representing between 30 and 45% of the total Cd content (Table 4 and Fig. 2a), indicating its current anthropogenic sources. The trace metals in this fraction are adsorbed on sediments and/or on their essential components namely clays, Fe and Mn hydrated oxides, and humic acids. The Cd in the exchangeable and carbonate fraction is the most labile, hence, it may be available for uptake by the total biota. Higher concentration of metals in this fraction could be regarded as a pollution indicator (Forstner and Wittmann, 1981; Yuan *et al.*, 2004).

Copper is mainly bound to organic matter and sulfides, where the highest percentage was found in the oxidizable fraction (71.7%; Table 4 and Fig. 2b). Its percentage of partitioning distribution in Al Shabab Lagoon is in the order: oxidizable > residual > reducible > exchangeable and carbonate bound. These results correspond to the findings by Tessier *et al.* (1979) and Ramos *et al.* (1999). Rapin *et al.* (1983) reported that Cu was mostly bound with organic matter fraction (70-80%) in marine sediments in the highly polluted area of Villefranche Bay. This confirms the high affinity of Cu to organic matter, and it could in fact easily form complexes with organic matter due to the high stability of organic-Cu complex (Li *et al.*, 2001; Morillo *et al.*, 2004; Ramirez *et al.*, 2005). Several studies have also reported high concentration of Cu associated with organic matter in the sediment (Fernandes, 1997; Ramos *et al.*, 1999; Zhou *et al.*, 1998; Fytianos and Lorantou, 2004; Ramirez *et al.*, 2005; Arias *et al.*, 2007; Wong *et al.*, 2007). The amounts of Cu in the first and second fractions of the lagoon sediments are negligible. The higher percentage of Cu in the oxidizable step of the studied sediments can be explained because this area receives sewage from the city of Jeddah, which carries a large burden of organic matter. This agrees with the results of many studies (Baruah *et al.*, 1998; Morillo *et al.*, 2004), which states that organic matter favors the entry of Cu into the oxidizable

fraction through the formation of organic complexes of this element. Therefore, Cu mobility in the lagoon is less than that of Cd, since the organic fraction released in the oxidizable step is not considered very mobile or available. According to Sing *et al.* (1998) Cu is thought to be associated with stable high-molecular-weight humic substances that release small amounts of metals slowly. Cu association in the organic fraction of the studied sediments is highly considered, since Cu in this fraction accounted for 58.5-82.4% of the total Cu. Physical and geochemical changes of Al Shabab lagoon, such as removal of organic matter (*i.e.* reduction of municipal wastewater discharge) and oxidation of anaerobic sediments, could potentially trigger the release of Cu from the sediments, leading to an increase in dissolved Cu concentration in lagoon water. The results agree with the results of other studies (Lu and Allen, 2001; Wong *et al.*, 2007), which found a large portion of Cu in sediments is associated with the organic fraction.

The predominant chemical partitioning of Pb is the reducible (50.6%) and the residual (32.8%) fractions (Fig. 2c). The percentage of Pb speciation distribution is in the order: reducible > residual > exchangeable and carbonates bound > oxidizable. This is consistent with results obtained by several authors (Jones and Turki, 1997; Li *et al.*, 2001; Fan *et al.*, 2002; Fytianos and Lorantou, 2004; Morillo *et al.*, 2004; Peng *et al.*, 2004; López-González *et al.*, 2006; Wong *et al.*, 2007) who found that Fe and Mn hydrous oxides are important scavengers of Pb in sediments. Pb can form stable complexes with Fe and Mn oxides, and these compounds were even more stable than those of Zn (Ramos *et al.*, 1994). The metal in this fraction may be released if the sediment is subjected to more reducing conditions (Panda *et al.*, 1995; Yuan *et al.*, 2004; Singh *et al.*, 2005). This finding is of great interest since the sediment studied show high concentrations and, furthermore, it is a highly toxic element for aquatic organisms and fish (Routh and Ikramuddin, 1996).

The chemical partitioning of Zn (Fig. 2d) was similar to that of Pb. Zn, which is one of the most abundant metals in Al Shabab lagoon, is hosted largely by the reducible (41.6%) fraction, although the residual (36%) fraction carries a significant proportion of Zn. The percentage of Zn associated with different fraction is in the order: reducible > residual > oxidizable > exchangeable and carbonates bound. The partitioning pattern found for Zn is not unusual; high percentages of total Zn have

been found associated with the reducible fraction in other studies of polluted sediments (Fernandes, 1997; Jones and Turki, 1997; Li *et al.*, 2001; Fan *et al.*, 2002; Korfali and Davies 2004; Peng *et al.*, 2004). The Zn adsorption onto these oxides has higher stability constants than onto carbonates. Fe and Mn oxides were reported to be the main carriers of Zn from the fluvial environment to the lagoonal one (Fernandes, 1997; Li *et al.*, 2001).

It is evident from the results of the fractionation study (Fig. 2) that the metals in the sediments are bound to different fractions with different strength. The strength values can, therefore, give a clear indication of sediment reactivity, which in turn assess the risk connected with the presence of metals in an aquatic environment. This criteria (Risk Assessment Code; RAC; Jain, 2004) as given below (Table 6) indicates that a sediment which can release in exchangeable and carbonate fractions, less than 1% of the total metal will be considered safe for the environment. A sediment releasing in the same fraction more than 50% of the total metal has to be considered highly dangerous and can easily enter the food chain (Perin *et al.*, 1985; Jain, 2004).

Table 6. Risk Assessment Code (after Jain, 2004).

Risk Assessment Code (RAC)	Criteria (%)
No risk	< 1
Low risk	1-10
Medium risk	11-30
High risk	31-50
Very high risk	> 50

The code applied to the present study reveals that about 30-45% of Cd at almost all sites is exchangeable and carbonate bound and therefore comes under the high risk category and can easily enter the food chain. Because of the toxicity and availability of cadmium, it can pose serious problem to the ecosystem. Most of the copper at most of the sites is in the oxidizable fraction, except a small portion (1.2-1.4%) found at sites (14, 19 and 22) is in the exchangeable and carbonate bound fraction thus posing no to low risk for the aquatic environment. Speciation patterns of Pb and Zn (4.6-15.1 and 2.5-14.5% in the exchangeable and carbonate bound, for Pb and Zn, respectively) show low to medium risk to aquatic environment.

Conclusions

The sequential extraction results showed that Cd was mainly associated with the exchangeable and carbonates bound fraction. Cu was mostly bound with the oxidizable fraction, whereas Pb and Zn were mostly associated with the reducible fraction. The partitioning characteristics of the lagoon sediments also show that the percentages of metals associated with the non-residual fractions (exchangeable and carbonate + reducible + oxidizable) are notably greater than the residual fraction, suggesting that these metals are primarily derived from anthropogenic inputs rather than the geochemical background. Amongst the different studied metals, Cd concentrations was the lowest but a major portion of it (30-45%) is in the most mobile fraction (exchangeable and carbonate bound) and therefore can easily enter the food chain. About 4.6-15.4% of Pb exist in exchangeable and carbonate bound fraction while 2.5-14.5% of Zn is also found in exchangeable and carbonate bound and thus posing low to medium risk for the aquatic environment. Speciation pattern of Cu shows no risk for the aquatic environment at most of the sites, with the exception of sites 14, 19 and 22 which show low risk for the aquatic environment.

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أشكال العناصر (الكاديوم، والنحاس، والرصاص، والزنك) في رواسب بحيرة الشباب، جدة، المملكة العربية السعودية

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المستخلص. تم استخدام تقنية الاستخلاص المتسلسل في أربعة خطوات لتعيين التصاحب الكيميائي للعناصر الثقيلة (الكاديوم، والنحاس، والرصاص، والزنك) مع الحالات الرئيسة للرواسب (القابلة للتبادل والكربونات، وأكاسيد المنجنيز والحديد، والكبريتيدات والمواد العضوية والمعادن المترسبة) في عينات من بحيرة الشباب. كما تم أيضاً تعيين المحتوى الكلي لتلك العناصر. دلت نتائج الدراسة بأن رواسب البحيرة تحتوي على تراكيز مرتفعة من العناصر الثقيلة مثل الكاديوم، والنحاس، والرصاص، والزنك. كما أظهرت نتائج الدراسة أيضاً من صفات التجزئة لرواسب البحيرة، بأن نسب العناصر المصاحبة للأجزاء غير المترسبة أعلى من الأجزاء المترسبة لكل العناصر التي تم دراستها، مما يدل على التلوث الكبير للرواسب بتلك العناصر. اتضح من رقم تقييم الخطر بأن حوالي ٣٠-٤٥٪ من الكاديوم تتواجد في صورة قابلة للتبادل، وكربونات، والتي تم تصنيفها على أنها عالية الخطر، وتستطيع بسهولة أن تدخل السلسلة الغذائية. أجزاء مقاسة من الرصاص والزنك (٤,٦-١٥، و٢,٥-١٤,٥٪ من الرصاص والزنك، على التوالي) وجدت أيضاً في صورة قابلة للتبادل، وكربونات، وبالتالي لها خطر قليل إلى المتوسط على البيئة البحرية. بالنسبة لصفات تجزئة النحاس فقد أظهرت عدم وجود إلى وجود خطر قليل على البيئة البحرية.