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ORIGINAL RESEARCH ARTICLE

Spatial and temporal distribution of heavy metals in coastal core sediments from the Red Sea, Saudi Arabia

Bandar A. Al-Mur [a,b], **Andrew N. Quicksall** [b,*], **Ahmed M.A. Al-Ansari** [a]

[a] *Department of Environmental Sciences, King Abdul-Aziz University, Jeddah, Saudi Arabia*
[b] *Civil and Environmental Engineering, Southern Methodist University, Dallas, USA*

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Summary Jeddah is the most industrialized city on the west coast of Saudi Arabia and is under increasing influence of human activities. Heavy metals data were obtained from four near-coast Red Sea sediment cores in close proximity to Jeddah. Chromium, manganese, iron, copper, zinc, and lead were analyzed from depth-resolved sections of each core via heavy acid digestion and inductively coupled plasma-mass spectrometry (ICP-MS). The average concentrations of all four sites were 245.96 mg kg^{-1}, 478.45 mg kg^{-1}, 8506.13 mg kg^{-1}, 251.82 mg kg^{-1}, 623.09 mg kg^{-1}, and 362.75 mg kg^{-1}, respectively. The depth-resolved results showed that highest concentrations of Mn, Cu, and Pb were found in the top 15 cm of the core profile distributions compared to other depth sub-samples. Heavy metal concentrations in core sediments are increased near central Jeddah and have become higher in recent years. The results of enrichment factor calculations indicate little anthropogenic supply of Mn and Cr while Pb, Zn, and Cu show strong anthropogenic input. The Pollution Load Index was higher in the two sites closer to central Jeddah where power and desalination plants and wastewater release are known. This indicates that the area has suffered from heavy metal pollution compared to other non-industrialized sites in the Red Sea. Heavy metal contaminations due to anthropogenic activity should be taken into account to protect the Red Sea during future growth. The results of this work should be considered as a baseline for heavy metals monitoring in the sediments of the Red Sea coast near Jeddah, Saudi Arabia.

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[*] Corresponding author at: Civil and Environmental Engineering, Southern Methodist University, Dallas, TX 75275, USA. Tel.: +214 768 3252; fax: +214 768 2164.

E-mail address: aquicksall@smu.edu (A.N. Quicksall).

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1. Introduction

Heavy metal contamination is a primary environmental concern in sediments due to potential remobilization and bioaccumulation in aquatic organisms (Nemati et al., 2011). Sediments are the primary carrier of heavy metals in the marine environment due to their chemical-physical properties, such as particle characteristics, and processes including precipitation and adsorption/desorption (Fukue et al., 2006; Rath et al., 2009). Natural sources include weathering, erosion, and volcanic eruptions (Shang et al., 2015). Besides natural processes, additional heavy metal inputs to the aquatic environment are from anthropogenic activities (Rath et al., 2009). The difference in heavy metal concentration in the marine environment can be caused by industry, domestic sewage, boating activities (Chatterjee et al., 2007), mining, and refining (Shang et al., 2015). Heavy metal distribution in aquatic environments are positively correlated to population density (Conrad et al., 2007) and urbanization (Shang et al., 2015) via the large uncontrolled input from industrial activates (Louriño-Cabana et al., 2011). Heavy metal is able to accumulate in marine sediments and may affect human health through the food chain via benthic organisms (Shang et al., 2015).

Determination of heavy metal distribution in core sediments can provide valuable information about the current and background levels of contamination and may provide historical evidence of the anthropogenic effect in the aquatic environment (Al-Najjar, 2011; Chatterjee et al., 2007; Tang et al., 2010). Such sediment core studies of various elements have been shown to track natural background concentrations and anthropogenic activities through deviations from a background (Cho et al., 2015; Li et al., 2012; Veerasingam et al., 2015). The study of core sediment, therefore, provides a historical record of heavy metal distribution over time (Williams and Block, 2015). It gives levels of heavy metals in sediments representative of pre-industrial (bottom sediments) and recent times (surface sediments) in the marine environment (Ferati et al., 2015). Sediment cores can provide chronologies of contaminant distribution and a record of the changes in concentrations of chemical indicators in the environment over a period of time (Conrad et al., 2007; Li et al., 2012). Coastal areas are attractive targets for researchers to study heavy metal changes in the marine environment due to these areas sensitivity to anthropogenic impact from human activities (Dai et al., 2007). The coastal areas of Saudi Arabia on the Red Sea have been exposed to contaminations from land-based activities due to rapid growth in industrialization for several decades (Badr et al., 2009). The problem is greatly magnified by the production of numerous toxic chemicals that are harmful in trace concentrations (Usman et al., 2013). A small number of studies have focused on heavy metal levels in the sediments of the Red Sea close to Jeddah, yet little information is available about this area. These previous studies determined total metals concentration in water (Saad, 1996) sponges and sediments (Pan et al., 2011), surface sediment (Basaham, 1998; Ghandour et al., 2014), and only one study on sediment cores in Jeddah (Badr et al., 2009). The study of depth-resolved heavy metals in coastal sediments is needed to provide useful information on human activities in the Jeddah area of the Red Sea. More knowledge of the spatial and temporal distribution of the heavy metals from sediment cores can help detect the source of the contamination (Shang et al., 2015). Jeddah is the area of study and the most industrialized city on the west coast of Saudi Arabia on the Red Sea. Anthropogenic sources including electrical power generation plants, wastewater treatment works, desalination facilities, oil refinery, and commercial harbor activities may elevate heavy metal concentrations near Jeddah. In the present study, four Red Sea sediment cores were collected near Jeddah to investigate heavy metal distributions in the Red Sea. The objectives of this study were to (i) assess the spatial and temporal distribution of Cr, Cu, Mn, Zn, Pb, and Fe, and (ii) identify the origin of heavy metal pollutants in the sediments of the Red Sea in the coastal area of Jeddah.

2. Material and methods

Chemical acid (70% HNO_3) and hydrofluoric acid (HF) were acquired from Fisher Scientific, Pittsburgh, PA. The HNO_3 and deionized water, 18.2 MΩ distilled, were used for dilution, blank samples, and quality control standards. Hydrofluoric acid and HNO_3 were used for trace metals analysis.

2.1. Sampling sites

Four Red Sea sediment cores were collected offshore of Jeddah from three impacted locations (Prince Naif, the Downtown area, and Al-Khumrah) and an upstream reference site (Salman Gulf) in January 2015. Sites were chosen to cover the coastal area, which is known to be affected by land-based activities. Al-Washmi (1999) studied the mineralogy of the sediments of the Red Sea close to Jeddah and found two dominant types of sediments: carbonate in the northern part and muddy sediments in the southern part (Al-Washmi, 1999). Fig. 1 shows a location of the study area and sampling sites. Detailed descriptions of the location of collected sediments cores from the four studied areas are as follows: Core 1 was collected in North Jeddah at Salman Gulf, where low discharge is expected in the marine environment. Core 2 was collected nearest Prince Naif. Some green algae blooms were observed on the surface of the water. The Downtown area, core 3, had some signs of sediment contamination as shown by the investigated heavy metals. The water depth of this site was relatively shallow, about 2 m. A large quantity of storm water discharge was observed to be flowing while sampling. Core 4 was collected from the Al-Khumrah area, which is south of the Saudi Naval facility. The water in this area is approximately 40 m in depth, and the only known active primary point source in this area is the discharge pipe of the industrial city wastewater treatment plant.

2.2. Sample collection

Each sampling location was determined using a GPS and located between 21°51′52″N and 39°9′26″E. Table 1 represents the location of the collected cores, their distance from the coastline, water depth, and the core length. Sediment cores were collected by scuba divers, using PVC tubes of 50 cm long and 4.5 cm in diameter. The cores were kept in an icebox at 4°C until delivered to the laboratory for analysis. After core samples were obtained at selected locations

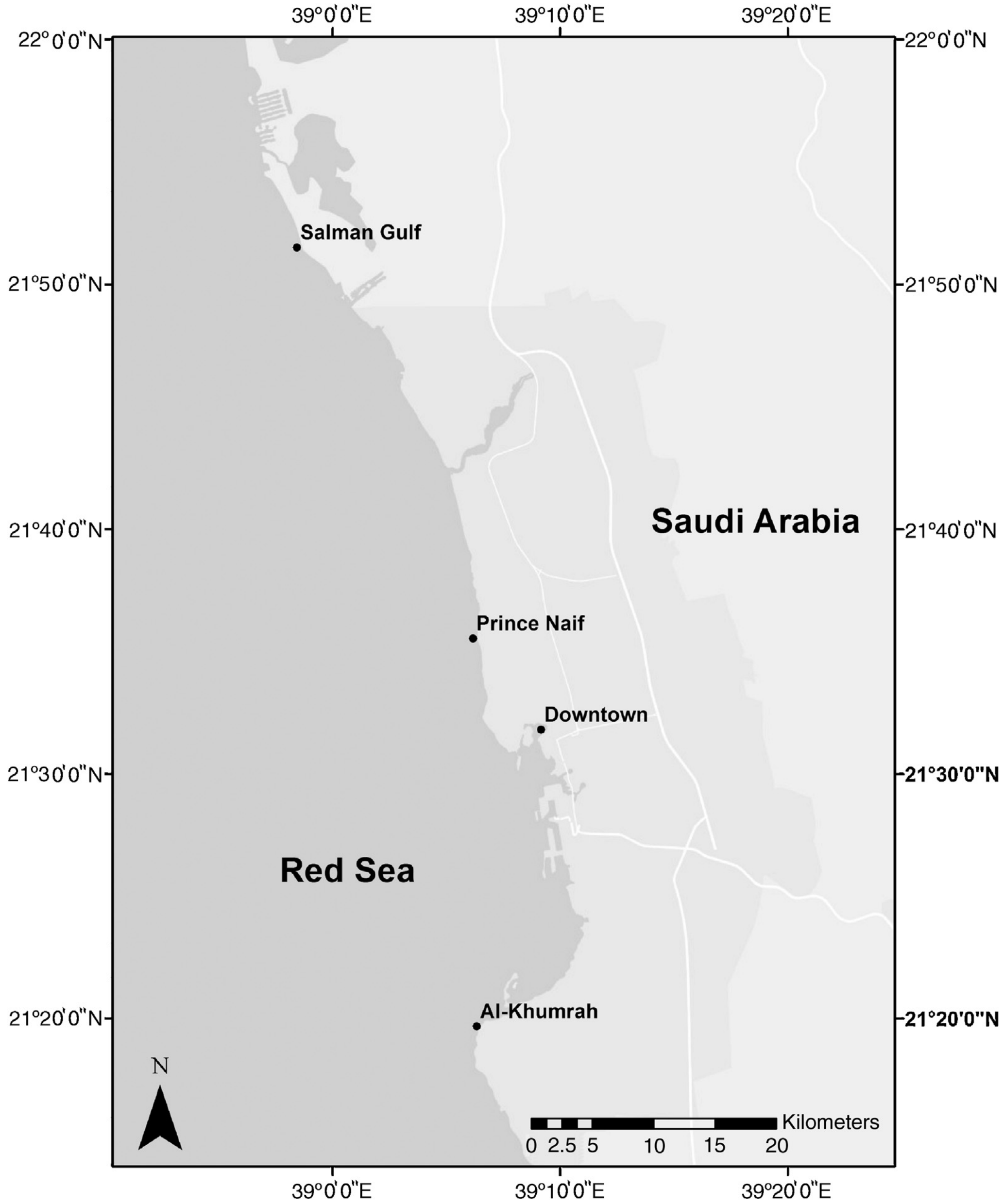

Figure 1 Map of four sampling location in the west coast of Saudi Arabia on the Red Sea. The locations are Salman Gulf, Prince Naif, Downtown area, and Al-Khumrah.

Table 1 Geographic locations of sampling sites and data of collecting cores samples.

Sampling site	Location		Distance from shore [m]	Depth [m]	Core length [cm]
	Latitude	Longitude			
Salman Gulf	21°51′2″	38°58′38″	1000	2	50
Prince Naif	21°35′33″	39°6′21″	1000	25	50
Downtown	21°31′45″	39°9′26″	10	2	50
Al-Khumrah	21°19′35″	39°6′22″	1000	40	50

across the study area, samples were stored frozen at −20°C for 24 h. Sediments were recovered from the PVC tubes and sliced at 2 cm intervals. Each layer was homogeneously mixed and stored in plastic vials, labeled, and kept frozen at −20°C until they were shipped to the U.S.A.

2.3. Sample preparation

Sediment samples were prepared according to an adapted USEPA 3050B method to determine the total heavy metals for Cr, Mn, Fe, Cu, Zn, and Pb in core sediments (USEPA, 1996).

The method was altered by using approximately 0.20 g of the sample as described by Badr et al. (2009). Briefly, samples were dried in an oven at 105°C and ground into a powder using a mortar and pestle. Nitric acid (70% HNO_3) and hydrofluoric acid (HF) were used for the total metal dissolution. Sediment samples were digested in heavy acid with 3:1 mixture of HNO_3 and HF acid. Nine ml of HNO_3 and three ml of HF were added to the sediment samples inside a fume hood. Sediment samples plus HNO_3 and HF acid were digested at 100°C on a hot plate until dryness.

2.4. Inductively coupled plasma-mass spectrometry (ICP-MS) analysis

Each digested sample was transferred to a 10 ml polypropylene tube and filled up to 10 ml with 5% HNO_3 acid in 18.2 MΩ distilled, deionized water. The metal determinations were performed on ICP-MS in collision cell mode with kinetic energy dispersion (CCT-KED). ICP-MS is one of the most widely used methods for determining the total element concentration with a high sensitivity and wide dynamic range (de Carvalho et al., 2015). To insure the quality and precision of metal measurements and establish calibration curves, a multi-element standard (CLMS-2A, from SPEX CertiPrep, Metuchen, NJ, USA) was used with a range from 0.5 to 75 ppb. Each sediment interval was analyzed in triplicate. A blank (5% HNO_3) was analyzed every 10 samples. Furthermore, a final concentration of each metal was reported in mg kg^{-1} dry weight.

2.5. Statistical analysis

The statistical and correlation analysis were performed using SAS JMP Pro 10. In order to establish the relationship between heavy metals, linear regression analysis was carried out to compare heavy metal concentrations in the sediment cores. The correlations between the elements were evaluated for Cr, Mn, Fe, Cu, Zn, and Pb using all depth samples (n = 25) in each core.

2.6. Estimating pollution impact

An overall assessment of sediment cores was determined to evaluate the degree of metal contamination from the natural and anthropogenic sources of metals in the Red Sea. In the present study, three approaches were employed to evaluate sediment contamination with metals: (i) Enrichment Factor (EF), (ii) Contamination Factor (CF), and (iii) Pollution Load Index (PLI) (Li et al., 2013). To assess the possibility of anthropogenic influences in the study area, EFs were calculated for the investigated six total heavy metals. The essential reason for using geochemical studies is to determine differences of metals from anthropogenic activities and those from natural sources. The commonly applied technique is known as normalization, where metal concentrations are normalized (Chatterjee et al., 2007). Several normalizing elements, such as aluminum (Chatterjee et al., 2007; Li et al., 2013), iron (Abrahim and Parker, 2008; Ghandour et al., 2014), lithium (Khalil et al., 2013) have been used to calculate EF. In this study, lithium (Li) and rubidium (Rb) were used as reference elements to normalize the metal concentration and differentiate its natural from anthropogenic sources in sediments. The EF where calculated using the following equation:

$$\mathrm{EF}_{\mathrm{Me}} = \frac{(\mathrm{Me}/\mathrm{Li\ or\ Rb})_{\mathrm{sediment}}}{(\mathrm{Me}/\mathrm{Li\ or\ Rb})_{\mathrm{background}}}. \quad (1)$$

Me represents the metal concentration in the sediment and in the background. The background levels of Fe (47,200 $\mu g\ g^{-1}$), Mn (850 $\mu g\ g^{-1}$), Cr (90 $\mu g\ g^{-1}$), Cu (45 $\mu g\ g^{-1}$), Zn (95 $\mu g\ g^{-1}$), and Pb (20 $\mu g\ g^{-1}$) reported for sedimentary rocks were considered as the background values of these elements (Turekian and Wedepohl, 1961). The EF values $<$1.5 indicate the metal is relative to the background from crustal materials or natural weathering processes, whereas EF values $>$1.5 the metal is relative to both the background and anthropogenic sources (Ghandour et al., 2014; Khalil et al., 2013; Zhang and Liu, 2002). The EF values from this study are presented in Table 4. However, the CF is introduced to determine the degree of anthropogenic heavy metals contamination, which is calculated as following (Li et al., 2013):

$$\mathrm{CF} = \frac{\mathrm{Me}_{sample}}{\mathrm{Me}_{background}}. \quad (2)$$

The PLI was calculated to investigate the pollution state in the study area using the following equation (Tomlinson et al., 1980):

$$\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_2 \times \ldots \mathrm{CF}_n)^{(1/n)}. \quad (3)$$

where PLI = pollution load index; CF = contamination factor which is equal the metal concentration divided by its background; and N = number of metals investigated. The CF represent the ratio between the concentration of the metal in a sediment sample and its background level. The following four contamination categories were adopted to describe the level of metal contaminations: $\mathrm{CF} < 1$ considerable low contaminations; $1 < \mathrm{CF} < 3$ considerable moderate contaminations; $3 < \mathrm{CF} < 6$ considerable contaminations, and $\mathrm{CF} > 6$ very high contaminations. The PLI value of $>$1 is considerably polluted while $<$1 is considerable no pollution on a study site. CF and PLI results are presented in Tables 5 and 6.

3. Results and discussion

Heavy metal concentration variations at different depths for sediment cores are shown in Fig. 2. Heavy metal distributions at four different locations with depths between 0 and 50 cm were evaluated throughout this study. The highest concentration of heavy metals in the uppermost segments of the sediment cores compared to lower depth sub-samples for most of metals suggests increases in metals delivery to sediments in recent years (Fig. 2). These high concentrations likely correspond to an increase in anthropogenic pollutant inputs from rapid urbanization and industrialization. Similarly, the highest concentration of heavy metals in the upper part of core sediments showed in Mandovi estuary in India. They showed enrichment of Fe, Mn, Cu, Cr, Co, Pb and Zn in the uppermost layers of core sediments and suggested that it was due to an excess of anthropogenic loading in the recent past (Veerasingam et al., 2015).

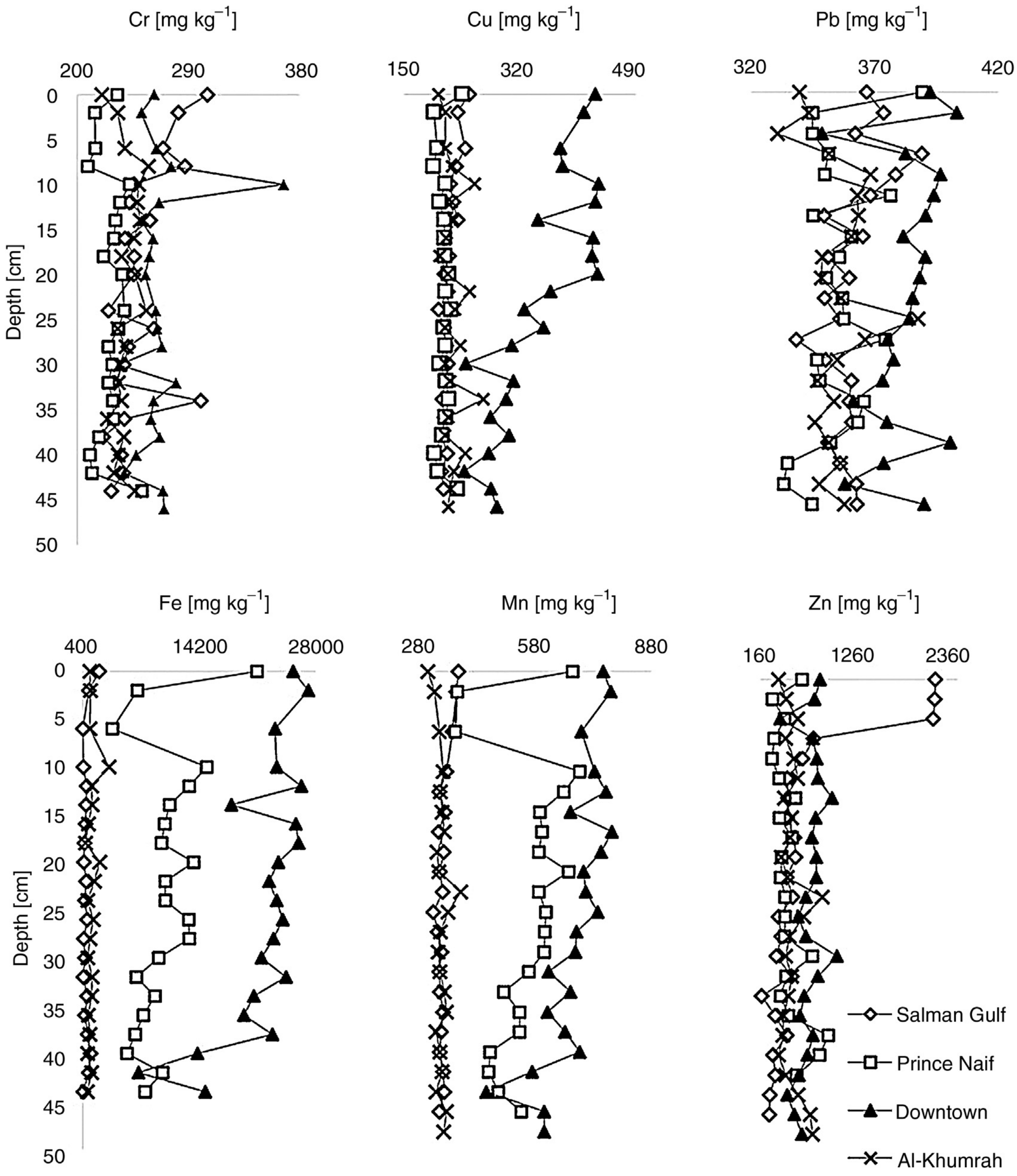

Figure 2 Vertical distribution of heavy metal concentrations in different depth of four sediment cores on the Red Sea offshore Jeddah coast.

The average concentrations of heavy metals in core sediments at four different sites of the Red Sea and compared in an international contest are summarized in Table 2. In this study, the results show that the average total concentrations are as follows: Cr (245.96 mg kg^{-1}), Mn (478.45 mg kg^{-1}), Fe (8506.13 mg kg^{-1}), Cu (251.82 mg kg^{-1}), Zn (623.09 mg kg^{-1}), and Pb (362.75 mg kg^{-1}). In general, the higher concentrations of Mn in core sediments in the present study areas were similar to those found in the Red Sea sediments by Abu-Hilal et al. (1988) and Ghandour et al. (2014) in sediment composition of an arid coastal environment. In comparison with other studies in the Red Sea, little information on Fe concentration has been reported. The results of higher levels of Fe were higher than the other Badr et al. (2009) results at the Prince Nife and Downtown areas and less than the world average concentration (48,000 mg kg^{-1}) (Venkatramanan et al., 2015). The increase of Zn concentration in the upper sediment layers was similar to the results obtained by Zalewska et al. (2015) in the Baltic Sea Sediments (Zalewska et al., 2015). Levels of Zn concentration in Salman Gulf, Prince Naif, and the Downtown areas were high from 15 cm to the surface area and significantly higher in Salman Gulf in the same vertical distribution as shown in Fig. 2. The higher concentrations start from the top 15 cm to the surface area are indicative of being influenced by human activities from hidden non-point sources in recent years or could be natural due to the high carbonate present in this area as $ZnCO_3$ (Othmani et al., 2015).

Table 2 Mean concentrations [mg kg^{-1}] and their ranges of metals in sediment samples compared with other areas.

Site	Cr	Mn	Fe	Cu	Zn	Pb	Reference
Salman Gulf	251 (221—305)	340 (315—380)	817 (408—2320)	218 (202—248)	681 (180—2234)	360 (338—389)	This study
Prince Naif	227 (209—252)	557 (372—694)	10,118 (3907—21,012)	211 (194—238)	512 (304—971)	345 (333—389)	
Downtown	265 (234—366)	678 (452—777)	21,688 (6984—27,055)	352 (241—444)	747 (399—1073)	382 (349—403)	
Al-Khumrah	240 (220—258)	335 (301—386)	1400 (703—3490)	224 (202—269)	540 (379—898)	354 (331—387)	
Average	**245.96**	**478.45**	**8506.13**	**251.82**	**623.09**	**362.75**	
Sharm Obhur	144 (84—203)	674 (542—929)		47 (26—57)	82 (54—100)	5 (0.5—8.5)	Ghandour et al. (2014)
Jeddah, Red Sea				82	179	69	Pan et al. (2011)
Jeddah, Saudi Arabia	12—23	34—205	2.032—2671	17—24	52—76	80—99	Badr et al. (2009)
Aqaba, Jorden		136		377	423	201	Abu-Hilal et al. (1988)
Guwahati, India	122.9			124.4	286	170.5	Mahanta and Bhattacharyya (2011)
Hainan, China	15—186	53—655		7—27	31—260	83—225	Qiu et al. (2011)
Baltic Sea					230	77	Zalewska et al. (2015)
Persian Gulf, Iran	5.7—52.4	50—466		1.9—304.8	5.1—123.6	1—14.5	Delshab et al. (2017)
World average	100	1050	48,000	100	350	150	Venkatramanan et al. (2015)

Linear regression analysis showed the strong positive correlation between Mn and Cr and Fe in the Prince Naif and Downtown areas but no correlation in the Salman Gulf and Al-Khumrah areas. The strong significant positive correlation is found in the Downtown area among Mn and Fe ($r^2 = 0.94$), Cr and Fe ($r^2 = 0.6$) and Cr with Mn ($r^2 = 0.54$) (Table 3). Cr is a redox sensitive metal and found precipitated with Mn—Fe oxide (Pattan et al., 1995). Therefore, the correlation analysis indicates that Cr, Mn, and Fe have a significant positive correlation and could indicate a redox condition in the Downton area. Fe and Mn oxides have been recognized as playing a significant role in controlling the location of heavy metal pollution in sediments (Gasparatos, 2013). Usman et al. (2013) studied the heavy metal contamination in mangroves from the Red Sea coast. Their result revealed that Cu and Cr were highly bio-accumulative in mangroves (*Avicennia marina*) from the coast of the Red Sea. In this study, the results of Cu indicate that the Cu profile was following the same vertical profile of Mn and Pb, which was higher in the recent years (top 15 cm to the surface area) with a highly significant increase in the Downtown area (Fig. 2). The higher concentrations of Cu and organic matter in the Downtown area indicate complexes of Cu with organic matter (Tribovillard et al., 2006). The average concentrations of Cu were 25,182 mg kg^{-1} in the studied area. Sediments having higher concentrations of Cu than 60 mg kg^{-1} are classified as contaminated via the US EPA (Ingersoll and Nelson, 1990). The primary source of Cu in the marine environment is due to antifouling paints, used by most boaters and which has a high copper concentration (CuO $\sim$ 75%) (Srinivasan and Swain, 2007). Copper also easily enters into the marine environment through industrial discharge containing $CuSO_4$, which is used in areas of heavy boat operations and plating (Srinivasan and Swain, 2007). Levels of Pb were much higher than those reported by other researchers with work in the Red Sea as shown in Table 2 (Pan et al., 2011; Qiu et al., 2011). Mean concentrations of Pb in the studied sediment profiles showed high values in all cores (362.75 mg kg^{-1}) (Table 2). Othmani et al. (2015) reported that Pb is strongly complex with $CaCO_3$, which acts as a strong absorbent for Pb and can complex as $PbCO_3$. This is attributed to several sources such as boat exhaust systems, oil spills, sewage discharge, and atmospheric input of Pb (Abu-Hilal et al., 1988). The high level of Pb in the Red Sea may be due to the contamination from the use of gasoline as a possible reason of contamination (Usman et al., 2013). Other authors assign Pb contamination of marine sediments to boat exhaust emissions, leakage of oil from mechanized boats and sewage effluents (Badr et al., 2009). The influence of anthropogenic activities, such as fertilizers and sewage wastes are the primary metal sources on the marine environment (Qiu et al., 2011; Varol, 2011). Shang et al. (2015) results indicate significant positive correlation among Cu, Mn, Fe, and Zn. The sources of heavy metals in the considered areas are mainly natural as well as anthropogenic through the impact of oil refinery wastes, untreated sewage effluents, and cement plants, which have increased over the past years. The significantly positive correlations at the Downtown area of Fe ($r^2 = 0.94$), Cu ($r^2 = 0.74$), Zn ($r^2 = 0.73$) and Pb ($r^2 = 0.60$) with Mn (Table 3) showed that heavy metal pollutants were most likely derived from same source of contamination. Given the association of Mn, Cu, and Pb and copper's

Table 3 Correlation coefficient matrix (r^2) for heavy metal concentrations in four core sediments (n = 100) from coastal Red Sea.

	Cr	Mn	Fe	Cu	Zn	Pb
Salman Gulf						
Cr	1.00					
Mn	**0.57**	1.00				
Fe	0.33	0.29	1.00			
Cu	0.43	**0.69**	0.21	1.00		
Zn	0.40	**0.67**	0.24	0.41	1.00	
Pb	0.07	0.24	0.0	0.19	0.02	1.00
Prince Naif						
Cr	1.00					
Mn	**0.70**	1.00				
Fe	**0.63**	**0.83**	1.00			
Cu	0.49	0.48	0.27	1.00		
Zn	0.00	0.00	0.00	0.01	1.00	
Pb	0.46	0.22	0.12	**0.56**	0.00	1.00
Downtown						
Cr	1.00					
Mn	**0.54**	1.00				
Fe	**0.60**	**0.94**	1.00			
Cu	0.19	**0.74**	**0.69**	1.00		
Zn	0.29	**0.73**	**0.69**	**0.73**	1.00	
Pb	0.31	**0.60**	**0.50**	0.48	**0.54**	1.00
Al-Khumrah						
Cr	1.00					
Mn	**0.53**	1.00				
Fe	0.21	0.24	1.00			
Cu	0.09	0.36	0.11	1.00		
Zn	0.13	0.44	0.06	0.06	1.00	
Pb	0.66	**0.78**	0.23	0.27	0.33	1.00

Table 4 Enrichment factor normalized by Li and Rb in sediment of Red Sea.

Location	Cr	Mn	Cu	Zn	Pb
Normalized by Li					
Salman Gulf	1.57	0.28	3.35	5.30	12.48
Prince Naif	1.73	0.44	3.18	3.67	12.14
Downtown	1.65	0.44	4.35	4.44	10.60
Al-Khumrah	1.41	0.21	2.67	2.90	9.46
Normalized by Rb					
Salman Gulf	1.36	0.27	2.36	3.69	8.76
Prince Naif	1.18	0.31	2.18	2.51	8.28
Downtown	1.38	0.37	3.72	3.80	8.92
Al-Khumrah	1.29	0.19	2.42	1.97	8.61

use as an indicator of organic complexes (Tribovillard et al., 2006), Pb and Mn are, therefore, likely being delivered to the seafloor as organic matter complexes. Recognizing the speciation of these metals during and post-delivery may play a key role in potential mitigation and/or treatment.

Results of calculated EFs for Cr, Cu, Mn, Zn, and Pb normalized by Li and Rb in the collected Red Sea sediments are relatively similar for these both reference elements (Table 4). These heavy metals are classified in the sediments of the Red Sea by their source into a natural source (<1.5) and anthropogenic sources (>1.5). The obtained results of EF calculations showed Cr and Mn to have EF values of less than 1.5 suggesting a natural origin of these heavy metals in the Red Sea sediment. However, the calculated EF values of Pb, Cu, and Zn exceeding 1.5 suggest anthropogenic sources for all four sites, with especially high enrichment of Pb. This enrichment from anthropogenic contaminants released into the study area is tracked by the rise in metal levels in the sediment (Dai et al., 2007; Ghandour et al., 2014). A similar result of Pb enrichment was obtained in the Baltic Sea Sediments with EF > 10 (Zalewska et al., 2015). Ghandour et al. (2014) suggested the enrichment of Pb due to oil leaking and the vicinity of the boat fuel station. Similar conclusions with high enrichment of Pb were reported by Basaham (1998) and Ghandour et al. (2014) for the surface sediments coast of Jeddah. In addition, enrichment of Pb in sediment at the present study is similar to the results obtained in coastal contamination study in China by Dai et al. (2007) study where they found that the accumulation of metals indicate that Pb is the most enriched metal in contaminated sediments collected from the Jiaozhou Bay, North China (Dai et al., 2007).

CF is used to determine the degree of heavy metal contamination in the study area. The average calculated CF of heavy metals are decreased in the following order: Pb > Zn > Cu > Cr > Mn > Fe all the four sediment of this study of the Red Sea (Table 5). The results of CF analysis support the same observation of EF and also show the high contamination with Pb, Cu, and Zn in the study area. From the EF and CF results, it can be observed that Pb is the primary pollutant that may cause relatively high contamination in all the sampled cores. This indicates that Pb is most likely anthropogenic from the automobile exhausts due to the highway extending along the coastline as well as fuel combustion addition to the marine environment (Badr et al., 2009). Values of PLI of the Red Sea sediments are given in Table 6. The PLI calculated was higher in all four sampling sites (hint PLI value of > 1 is polluted). The high PLI value may be related to the high concentration of heavy metals at all sites, especially at the Downtown site (3.29) and the Prince Nife (2.29). The sediment cores were sampled where power plant, desalination facility, and wastewater dumping are expected to have a potential impact on these two sites. The PLI values computed in our study are higher than the ones reported by Ghandour et al. (2014) from a study north of Jeddah on the Red Sea (1.64) (Table 6), and this indicates that this specific region has different levels of contamination with heavy metals.

Table 5 Contamination factor for metals in sediment of Red Sea.

Location	Cr	Mn	Fe	Cu	Zn	Pb
Sulman Gulf	2.79	0.40	0.02	4.85	7.58	18.02
Prince Naif	2.52	0.66	0.21	4.66	5.39	17.72
Downtown	2.95	0.80	0.46	7.96	8.13	19.09
Khumrah	2.66	0.39	0.03	4.98	5.41	17.71
Average	**2.73**	**0.56**	**0.18**	**5.61**	**6.63**	**18.14**

Table 6 PLI (Pollution Load Index) in some selected sediment s worldwide compared to the present study.

Location	PLI	Reference
Salman Gulf	1.44	Present study
Prince Naif	2.29	
Downtown	3.29	
Al-Khumrah	1.55	
Average	**2.14**	
Sharm Obhur, Red Sea	1.64	Ghandour et al. (2014)
Tigris River, Iraq	3.06	Hameed et al. (2014)
Dingzi Bay, North China	0.76	Pan et al. (2011)
Caspian Sea	0.47	Bastami et al. (2014)
Yellow Sea, East China	0.94	Li et al. (2012)

4. Conclusion

Heavy metal distributions in four sediments cores from the Red Sea near Jeddah were analyzed. The results showed high heavy metal concentrations of Mn, Cu, and Pb. Based on the heavy metal concentrations, this study indicates that heavy metals in the core sediments were much higher in the top 15 cm. The high level of metals in the upper 15 cm of core sediments, which represent recent years, is likely due to the discharge from industrial activities such as fertilizer use and sewage waste (Qiu et al., 2011; Varol, 2011). Heavy metal concentration in core sediments seems to be increasing toward the Downtown area and has become higher in the recent years. The EF and CF results classified metal sourcing into natural and anthropogenic sources. The results suggest that some areas may be impacted by anthropogenic sources with major contamination of Zn, Cu, and Pb. This work is the initial investigation to study the spatial and temporal distribution of heavy metals in collected core sediments in Jeddah. The results of this study could be used as a baseline for future studies on anthropogenic effects of toxic metals in the Jeddah area of the Red Sea. Future research would include isotopic data for sediment age dating by measuring the gamma emitting isotope ^{210}Pb. Sediment samples shall be analyzed by gamma spectrometry in order measure radioactive ^{210}Pb to assign an absolute age and sedimentation rates for Red Sea sediments.

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