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ORIGINAL RESEARCH ARTICLE

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

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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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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