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FULL LENGTH ARTICLE

Comprehensive risk assessment of heavy metals in surface sediments along the Egyptian Red Sea coast

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Abstract The contamination of heavy metals (Fe, Zn, Mn, Cu, Ni, Pb, Cd, Co, Cr, and Hg) in 16 surface sediment samples collected from the Suez Gulf, Aqaba Gulf and the Red Sea Proper was studied to evaluate their distribution and potential ecological risk. The concentrations of the studied metals decreased in the order of Fe > Mn > Zn > Cr > Ni > Co > Pb > Cu > Cd > Hg (3490.2, 115.77, 28.66, 18.47, 11.40, 9.70, 3.26, 1.94, 6.10, 0.02 μg/g dry weight). Based on the effect-range classification (ERL–ERM, TEL–PEL, LEL–SEL), the studied heavy metals did not pose any environmental risks for all investigated stations except Marsa Alam and El-Quseir stations, which may pose an environmental risk for Cr and Ni. The ecological risk assessment for metals in surface sediments was evaluated using the metal pollution index (MPI), geoaccumulation index (I*geo*), and potential ecological risk index (E_{RI}). Multivariate techniques including Pearson correlation, hierarchical cluster and principal components analysis were used to evaluate the metal sources.

Introduction

Rapid industrialization and urbanization have led to the high accumulation of heavy metals and organic pollutants in soil, water, sediment, street dust, as well as organisms in urban areas (El-Hasan et al., 2002; Wei and Yang, 2010; El Nemr, 2011; Chaudhari et al., 2012; Hou et al., 2013; Hu et al., 2013; Li et al., 2013; Sedky et al., 2013). Due to their toxicity, bioaccumulation, persistence, and biomagnifications through food chains, heavy metals posed a potential threat to ecological system and human health, and gradually drew a wide concern (El-Sikaily et al., 2004, 2005; Luo et al., 2012).

Heavy metals in aquatic environments are increasingly recognized as important intermediate sources for subsequent pollution in aquatic ecosystems or public health. Considerable efforts have been expended to assess their presence in harbors and estuaries (Khaled et al., 2006, 2010, 2012; Lin et al., 2013). After being released from natural background or anthropogenic sources near the land surface, e.g., rivers carrying significant metal loadings, soluble heavy metal species are immobilized and deposited onto the sediment surfaces through various mechanisms. The mechanisms of immobilization included adsorption on soil/sediments by coagulation, ion exchange with dissolved or suspended species in water (e.g., organic matter), incorporation into the mineral lattice structure, and precipitation due to forming insoluble species of

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heavy metals (Bryan and Langston, 1992; El Nemr et al., 2006, 2007; Du Laing et al., 2009). The aggregation of suspended particles may be enhanced by the high salinity of seawater, resulting in more rapid sedimentation of heavy metals (Du Laing et al., 2009).

Under certain environmental conditions, heavy metals might accumulate up to toxic concentrations levels, and cause ecological damage (Guven et al., 1999; Rietzler et al., 2001; Bai et al., 2011; El Nemr et al., 2012). Iron, zinc, copper and manganese are essential metals since they play important roles in biological systems (Hogstrand and Haux, 2001), but they become toxic at higher concentrations. Non-essential metals such as Pb, Cd and Hg are usually potent toxins even at relatively low concentrations and their bioaccumulation in tissues leads to intoxication, cellular and tissue damage, decreased fertility, dysfunction of a variety of organs and cell death (Oliveira Ribeiro et al., 2002; Damek-Proprawa and Sawicka-Kapusta, 2003). Only three metals, lead, cadmium and mercury, have been included in the regulations of the European Union for hazardous metals (EC, 2001), while chromium, arsenic and nickel are listed as hazardous metals by the United States Food and Drug Administration (USFDA) (USFDA, 1993).

The distribution of metals in sediments could be used to study anthropogenic impacts on aquatic ecosystems and assess the risks posed by waste discharges (Yi et al., 2011). The concentration of metals in sediments is not an isolated factor, but interacts with surrounding environmental factors. Investigation on the relations between heavy metals and various environmental factors is beneficial to comprehensively evaluate the impacts of heavy metals on the ecosystem and grasp the pollution characteristics of local environment. Although heavy

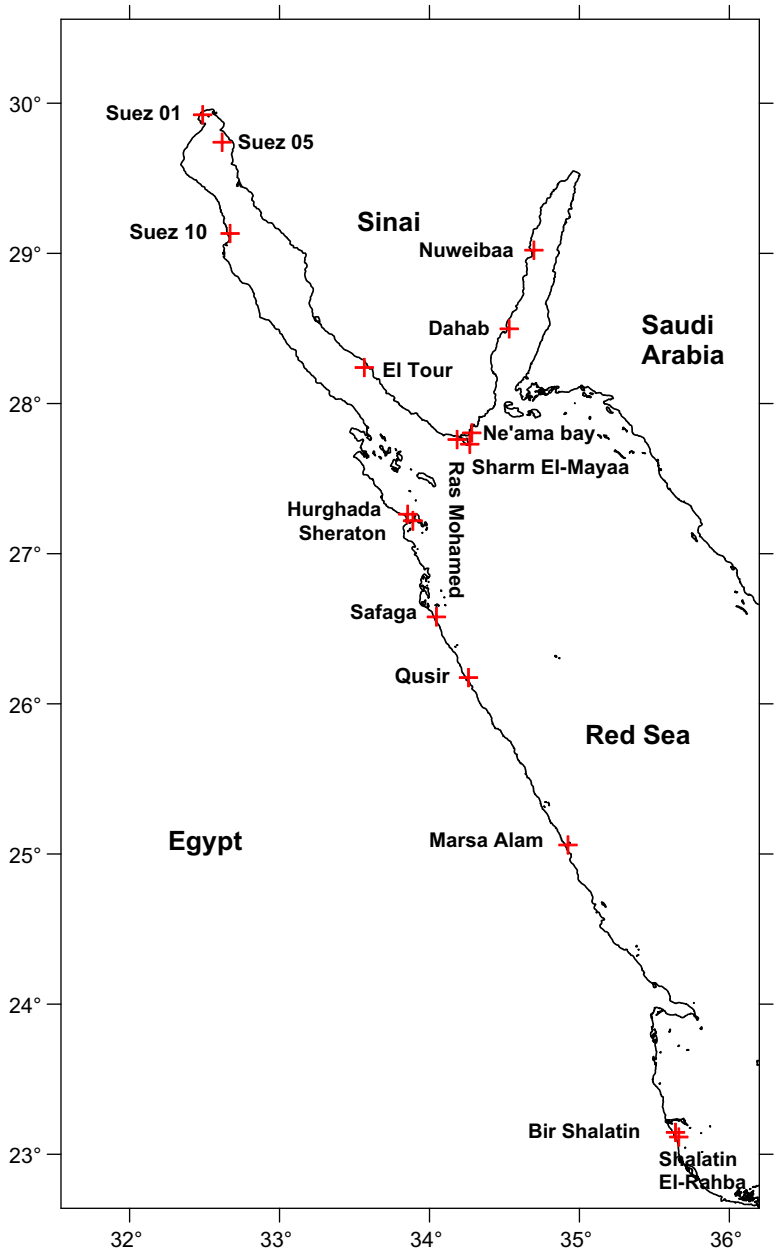

Figure 1 Map of locations.