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First report of geochemical fractionation distribution, bioavailability and risk assessment of potentially toxic inorganic elements in sediments of coral reef Islands of the Persian Gulf, Iran

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ABSTRACT

Metal contamination is a serious environmental concern in the Middle East. Herein, geochemical fractionation distribution and potential sources of thirteen metals (Fe, Al, Mn, Zn, Cu, Co, Cr, Ni, V, As, Hg, Pb and Cd) were investigated in sediments from ten coral reef Islands in the Persian Gulf, Iran. To properly assess availability and mobility of elements, enrichment factor (EF), pollution load index (PLI), pollution index (PI), contamination index (CI), sediment pollution index (SPI) and ecological risk assessment were provided. Sediment grain size showed an outstanding role in controlling the levels of potentially toxic inorganic elements (PTIEs). The highest values of total organic matter (TOM) were detected in Kharg and Lavan Islands. Different metals fractionation distribution was found across sites. As was noticed in carbonate (F_2), exchangeable (F_1), Fe-Mn oxy-hydroxide (F_3), organic (F_4) and residual (F_5) fractions, Hg primarily associated with F_2 and F_1, whereas Pb and Cd with F_2, followed by F_1, F_3, F_5 and F_4. Conversely, Ni and V accumulated in F_1, suggesting their high mobility and bioavailability, and thus environmental risk to aquatic biota. All metals (except Al, Fe and As) had geological and anthropogenic sources. Based on modified risk assessment analysis, the sediments from Kharg, Lavan, Siri and Lark Islands showed medium adverse effects. Overall, results from this study corroborate that petroleum industry is the main source of pollution of PTIEs in the Persian Gulf, and offer a scientific basis for monitoring and preventing metal pollution in the environment.

1. Introduction

Human activities severely affect ecosystem integrity. Metal pollution has aroused far-reaching attention worldwide due to metal toxicity, persistence and bioaccumulation in terrestrial and aquatic areas (Brandão et al., 2015; Bacha et al., 2017; H. Wu et al., 2017; J. Wu et al., 2017; Cappello et al., 2016a, 2016b; Ranjbar Jafarabadi et al., 2017c; Zhang et al., 2017a). Once released into aquatic environments, metals can be adsorbed onto particles or be re-mineralized through various biogeochemical cycles, causing lethal or sub-lethal effects on the ecosystem. Sediments act as potential scavengers and hereafter as a secondary cause of contamination in aquatic areas by discrepant physico-chemical processes including precipitation, adsorption and chelation (Equeenuddin and Pattnaik, 2017; Lee et al., 2017; Zhang et al., 2017b), and have the potential to release metals back into the water column, where become available to organisms, by sediment resuspension, redox reaction and desorption (Equeenuddin and Pattnaik, 2017). Dissolved metals highly threaten aquatic life as well as human health owing to their toxicity, mobility, bioaccumulation through the food chain and long-biological half-lives (Ciacci et al., 2012; De Domenico et al., 2013; H. Wu et al., 2017; J. Wu et al., 2017; Gong et al., 2017; Maisano et al., 2017; Ranjbar Jafarabadi et al., 2017c; Zuzolo et al., 2017), therefore an accurate assessment of their levels in aquatic environments is desperately required.

In the Persian Gulf, Iran, the health of coral reef communities has been adversely impacted by metal contamination since coral Islands, recognized as sinks for metals, are close to petroleum industry sites (Neyestani et al., 2016; Ranjbar Jafarabadi et al., 2017c). Earlier studies documented water quality and pollution in this area (Akhbarizadeh et al., 2017; Delshab et al., 2017), and recently it was demonstrated that oil spills and ballast water discharges of oil tankers are the major sources of petrochemical contamination in the Persian Gulf (Ranjbar Jafarabadi et al., 2018a, 2018b, 2018c, 2017a, 2017b, 2017c).

Determination of the total metal concentrations in sediments

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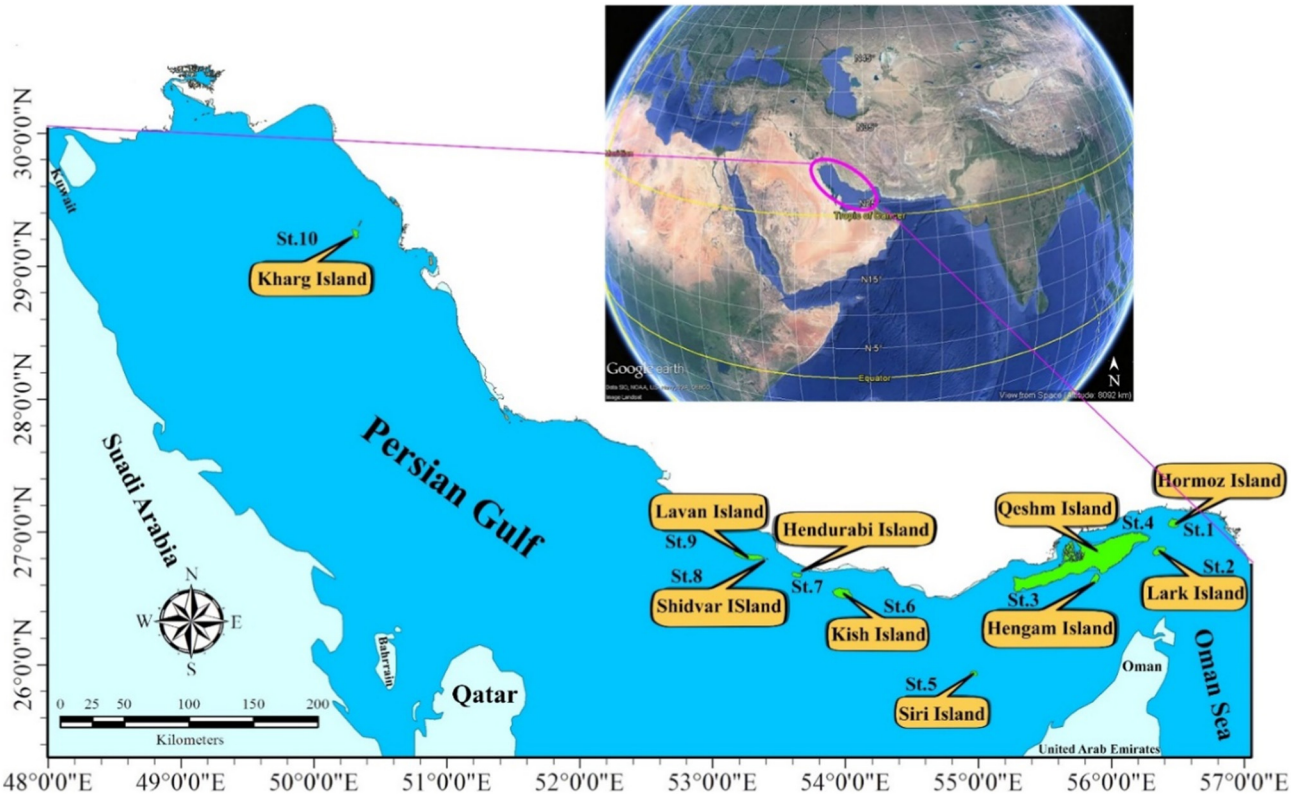

Fig. 1. Study area and sampling sites in the Persian Gulf, Iran.

provides significant evidence about metal pollution in an ecosystem (Chaharlang et al., 2016; Maisano et al., 2017), but it may not be able to reflect physical and chemical behaviours of metals in the environment (H. Wu et al., 2017; J. Wu et al., 2017; Equeenuddin and Pattnaik, 2017). These are affected by multiple factors, such as metal chemical forms or fractionations in sediment (Islam et al., 2015), which implicate totally discrepant environmental bioavailabilities and performances of metals (Li et al., 2016; Mukhtar and Limbeck, 2013). Metal availability refers to the available quantity of its total content in sediment, comprising both its potential and actual fraction, which might be released from soil to pore water (Rivera et al., 2016). Sequential extraction procedure is recommended to assess the level of element in a variety of geochemical fractions (Buttafuoco et al., 2017; Sundaray et al., 2011), which determine how intensely elements are blocked into soil or sediment and how readily they may be released to the biosphere and hydrosphere (Lee et al., 2017), hence representing valuable tools for assessing long-term negative impacts of metals from sediment (Lee et al., 2017; Zhang et al., 2017b).

In marine sediments, metals exist in different chemical forms and exhibit different behaviour in term of biological availability, mobility, chemical interactions, and potential toxicity (Li et al., 2016). The different chemical forms of metals comprise exchangeable (F_1), carbonate (F_2), occluded with Fe, Al or Mn oxides (reducible) (F_3), organic (oxidizable) (F_4), and residual (F_5) fractions (Palleiro et al., 2016; Zhang et al., 2017a). The mobility and availability of metals mitigate in the order of $F_1 > F_2 > F_3 > F_4 > F_5$ (Li et al., 2016; Zhang et al., 2017a). F_1 may be directly absorbed by biota, while F_2, F_3 and F_4 could be transformed into active forms when sediment environment, such as pH, salinity and redox conditions, changes (Li et al., 2016). Thus, F_1 and F_2 can be categorized as fractions directly effective (Li et al., 2016; Sun et al., 2014), whereas F_5 appears relatively inactive since it incorporates into the crystalline lattices of sediment clay (Palleiro et al., 2016). Anthropogenic metals are mostly in F_1 when they enter into the sediments, while those from lithogenic sources occur as F_5 (Li et al., 2016; Palleiro et al., 2016). Hereupon, the determination of chemical fractions is useful for metal source identification and potential toxicity assessment, particularly for pristine and sensitive ecosystems like coral reefs.

Herein, potentially toxic inorganic elements (PTIEs) in sediments were surveyed in coral reef ecosystems of the Persian Gulf. In detail, the purposes of the study were (1) to investigate the role of reef sediment as a scavenger of 13 metals (Fe, Al, Mn, Zn, Cu, Co, Cr, Ni, V, As, Hg, Pb and Cd) in ten Iranian coral reefs of the Persian Gulf, (2) to determine the interrelations among metal concentration and physico-chemical features of coral Island sediments, (3) to evaluate the mobility and dynamics of elements in different geochemical fractions in sediment, (4) to recognize the bioavailability and assess the ecological risk of the examined elements, (5) to delineate the contributing sources of elements in reef sediments using risk assessment code (RAC), aquatic risk index ($RI_{Aquatic}$) and multivariate statistical analyses, and (6) to explore relationships among distribution and fractionation of metals. Overall, it was reported on sources, spatial variation and distribution, and contamination levels of metals in the surface sediments from coral reef Islands of the Persian Gulf. The outcomes reported herein offer a scientific basis for monitoring and preventing metal pollution in the environment.

2. Material and methods

2.1. Study area and sampling

The Persian Gulf (24–30°N, 48–57°E) is a semi-enclosed water body with a depth of 35–40 m, where water exchange occurs in 3–5 years. The impact of contaminants on this area has been well documented recently (Ranjbar Jafarabadi et al., 2018a, 2018b, 2018c, 2017a, 2017b, 2017c). Pollution from petrochemical, gas and oil industries enter the west and central part of the Gulf at Kharg, Lavan and Siri Islands (Ranjbar Jafarabadi et al., 2018a, 2018b, 2017b; Ranjbar