Chemosphere 185 (2017) 1090–1111

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Spatial distribution, ecological and health risk assessment of heavy metals in marine surface sediments and coastal seawaters of fringing coral reefs of the Persian Gulf, Iran

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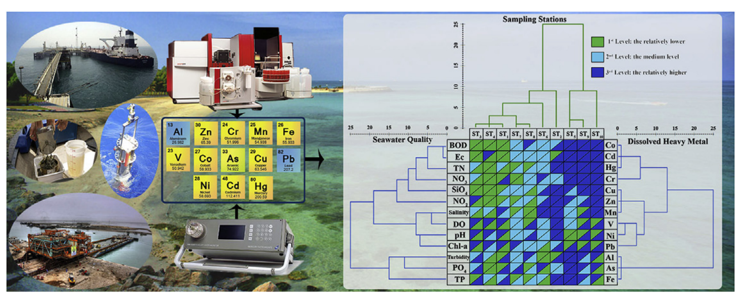
HIGHLIGHTS

- East part of the Persian Gulf is less contaminated as compared to the west part.
- The main source of the HMs in the Persian Gulf is oil/industrial activities.
- Compared to another indices, the CSI and TRI indicated much more sensitivity.
- Non-cancer and cancer risks posed by all the 13 dissolved HMs are minimal.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 March 2017
Received in revised form
12 July 2017
Accepted 20 July 2017
Available online 23 July 2017

Handling Editor: Petra Petra Krystek

Keywords:
Heavy metal
Reef surface sediment and coastal seawater
Multivariate statistical analysis
Pollution indices
Persian Gulf

ABSTRACT

Concentrations of 13 heavy metals (Al, Fe, Mn, Zn, Cu, Cr, Co, Ni, V, As, Cd, Hg, Pb) in 360 reef surface sediments (0–5 cm) and coastal seawater samples from ten coral Islands in the Persian Gulf were analyzed to determine their spatial distribution and potential ecological risks. Different sediment quality indices were applied to assess the surface sediment quality. The mean concentrations of metals in studied sediments followed the order: Al > Fe > Ni > V > Mn > Zn > Cu > Cr > Co > As > Cd > Pb > As. Average Cd and Hg exceeded coastal background levels at most sampling sites. With the exception of As, concentrations of heavy metals decreased progressively from the west to the east of the Persian Gulf. Based on the Enrichment Factor (EF) and Potential Ecological Risk Index (RI), concentrations of V, Ni, Hg and Cd indicated moderate contamination and is of some concern. The mean values of heavy metals Toxic Units (TUs) were calculated in the following order: Hg (0.75)> Cr (0.41)> Cd (0.27)> As (0.23)> Cu (0.12)> Zn (0.05)> Pb (0.009). Furthermore, the mean contributing ratios of six heavy metals to Toxic Risk Index (TRI) values were 79% for Hg, 11.48% for Cd, 6.16% for Cr, 3.27% for Cu, 0.07% for Zn and 0.01% for Pb. Calculated values of potential ecological risk factor, revealed that the risk of the heavy metals followed the order Cd > Pb > Ni > Cr > V > Cu > Zn. The results reflected that the level of heavy metals, especially Hg and Cd, are on rise due to emerging oil exploration, industrial development, and oil refineries along the entire Gulf. Fe, Mn, Cu, Zn, V and Ni concentrations in seawater were significantly higher ($p < 0.05$) than the other detected dissolved heavy metals in the sampling sites. A health risk assessment using the

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http://dx.doi.org/10.1016/j.chemosphere.2017.07.110
0045-6535/

hazard quotient index (HQ) recommended by the USEPA suggests that there is no adverse health effect through dermal exposure, and there is no carcinogenic and non-carcinogenic harm to human health.

1. Introduction

Surface sediment constitutes a crucial component of the aquatic environments. The presence of heavy metals (HMs[1]) in the surface sediment system is progressively growing and is becoming a major subject of global concern. This is due to their abundance, non-biodegradable nature or long biological half-lives, inherent toxicity, vast sources, persistence and non-degradability, bio-accumulation, biogeochemical recycling, and ecological risks (Bastami et al., 2015b; Pejman et al., 2015; Xu et al., 2015; Zhang et al., 2015; Zhaoyong et al., 2015; Toro et al., 2016; Zhao et al., 2016a). Heavy metals in the surface sediments have been considered to be influential tracers for monitoring the effects of anthropogenic activities (Zaaboub et al., 2015; Ali et al., 2016; Duodu et al., 2016; Lin et al., 2016; Liu et al., 2016b; Xu et al., 2016; Zhao et al., 2016a). Numerous investigations have been conducted worldwide to assess the extent of metal pollution in the aquatic ecosystems and mostly originate from anthropogenic activities (Al-Rousan et al., 2016; Begy et al., 2016; Gu et al., 2016; Guan et al., 2016; Monferran et al., 2016; Neyestani et al., 2016; Zhang et al., 2016a). Anthropogenic activities can increase sediment runoff that can smother corals or render unusable coral recruitment sites resulting in adverse impact on coral ecosystems (Satpathy et al., 2012). In addition, these metals subsequently accumulate in the aquatic microorganisms, and eventually, enter the human food chain (Peng et al., 2009; Yi et al., 2011; Fu et al., 2013; Zhang et al., 2014; Guan et al., 2016). Although superficial sediments are the most crucial components of the aquatic ecosystems (Dong et al., 2012), they have higher deposits of heavy metals in the aquatic environments (Harikumar et al., 2009; Nasrabadi et al., 2010; Baborowski et al., 2012; Qiao et al., 2013; Toro et al., 2016). Sediments have been increasingly identified as the main reservoir for heavy metals and source of the pollution because they provide a substantial link between chemical and biological processes (Sheykhi and Moore, 2013; Weng and Wang, 2014). Furthermore, sediments are not only pollutants carrier but can potentially act as a secondary source of the pollutants (Shipley et al., 2011; Guan et al., 2016). Most coral reefs of the Persian Gulf are subjected to anthropogenic pressures including tanker traffic, shipping, petrochemical industry, coastal and urban development (Monikh et al., 2013). One of the important parameters controlling the accumulation and the availability of heavy metals in the sediment and seawater are physicochemical parameters of the environment (Bastami et al., 2012, 2015a; Ganguly et al., 2013; Ganguly et al., 2015). Ecosystem health is characterized by environmental parameters such as temperature, salinity, DO etc. along with sediment quality. In view of this, the physiochemical parameters (salinity, temperature, turbidity, pH and dissolved oxygen) and the concentrations of total heavy metals in sediment and seawater were determined at ten sampling sites within the Persian Gulf. Since only a few investigations have been conducted at the bioaccumulation, spatial and temporal variations, ecological risks and effects of anthropogenic activities on the enrichment levels of heavy metals earlier (Hu et al., 2015; Lin et al., 2016; Liu et al., 2016a; Zhang et al., 2016c; Zhao et al., 2016b), there is a paucity of data in the Persian Gulf. In order to provide more information about the lack of knowledge, this study was undertaken to: (1) Analyze the concentration of HMs in the reef surface sediments and seawaters. (2) Evaluate the spatial distribution patterns of the dissolved HMs in seawater with focusing on their distribution at both dissolved phase. (3) Explore HMs sources using multivariate statistics. (4) Evaluate seawater quality and hazard impacts on the human health posed by the HMs. (5) Assess contamination level and ecological environmental risk of the HMs in the reef surface sediments collected from ten coral reef Islands of Iran in July 2014. The results can be applied to mitigate the pollution load of the HMs, augment water management efficiency and assist to protection of water resources particularly the fragile coral reef systems.

2. Materials and methods

2.1. Study area and sample collection

In the Persian Gulf, contamination's effect on the marine ecosystems are well documented in the northwestern part of the Gulf (Pourang et al., 2005; Kazemi et al., 2012; Pejman et al., 2015). This study included ten coral reef Islands: Hormoz (ST_1), Lark (ST_2), Qeshm (ST_3), Hengam (ST_4), Siri (ST_5), Kish (ST_6), Hendurabi (ST_7), Shidvar (ST_8), Lavan (ST_9) and Kharg (ST_{10}) (Fig. 1). Some of these Islands have vicinity of several large commercial and industrial establishments. Siri Island which is positioned in the vicinity of many oil fields like Sivand and Dena, Nosrat, Alvand and the Esfand oil field combined with the Nasr offshore oil platforms. Moreover, Lavan Island has one of many four major terminals for export of crude oil in Iran alongside Kharg Island. Kharg Island provides a sea port for the export of oil and extends Iranian territorial sea claims into the Persian Gulf oil fields and finally Lark Island has been certainly one of Iran's major oil export points since 1987 are just few example of industrial establishments in the Persian Gulf. In July 2014, 360 RSS[2] samples were obtained using the Peterson grab sampler, three surface sediments were collected at 5 cm deep at each station (Fig. 1). Each sample was about 1 ± 0.2 kg. The samples were transferred and kept in airtight polyethylene bottles and placed in an ice-cooled isolated container. Similarly, a total of 360 surface seawater samples were collected by Nansen's water sampler and transferred in acid-washed low density polyethylene bottles and sealed from twelve prefixed locations at each coral Island from different environmental stresses in July 2014. Before sample collection, the sampling equipment were rinsed five times within seawater to avoid contamination from previous site (Chen et al., 2007; Wang et al., 2017). The samples were transported to laboratory to investigate seawater quality. Geographical positions of sampling sites were measured with a portable GPS system. During sampling, bottles labelled to avoid misidentification. For each reef habitat, 12 stations were selected. Some sampling points are located in vicinity of industrial operations (ST_5, ST_9, ST_{10}), near the harbor (ST_2, ST_3, ST_6, ST_8), and some are away from human interferences (ST_1, ST_4, ST_7).

[1] Heavy Metals.

[2] Reef Surface Sediment.