Marine Pollution Bulletin xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Baseline

Effects of pollution on the geochemical properties of marine sediments across the fringing reef of Aqaba, Red Sea

Saber Al-Rousan [a,*], Ahmed A. Al-Taani [b], Maen Rashdan [b]

[a] The University of Jordan-Aqaba, Faculty of Marine Sciences, Department of Coastal Environment, P. O. Box 2595, Aqaba 77110, Jordan
[b] Department of Earth and Environmental Sciences, Faculty of Science, Yarmouk University, Irbid 21163, Jordan

ARTICLE INFO

Article history:
Received 9 February 2016
Received in revised form 12 May 2016
Accepted 16 May 2016
Available online xxxx

Keywords:
Sedimentation rate
Marine sediment
Phosphate pollution
Trace metals
Gulf of Aqaba
Red Sea

ABSTRACT

The Gulf of Aqaba is of significant strategic and economic value to all gulf-bordering states, particularly to Jordan, where it provides Jordan with its only marine outlet. The Gulf is subject to a variety of impacts posing imminent ecological risk to its unique marine ecosystem. We attempted to investigate the status of metal pollution in the coastal sediments of the Jordanian Gulf of Aqaba. The distribution of Cd, Cr, Zn, Cu, Pb, Al, Fe, and Mn concentrations were determined in trapped and bottom-surface sediments at three selected sites at different depths. In addition, monthly sedimentation rates at varying water depths were also estimated at each sampling site using sediment traps. The high concentrations of Cd, Cr, Zn were recorded at the Phosphate Loading Birth (PLB) site followed by the Industrial Complex (IC) site indicating their dominant anthropogenic source (i.e., the contribution of industrial activities). However, Fe, Al, and Mn contents were related to inputs from the terrigenous (crustal) origin. Except for Al, Fe and Mn at the PLB site, the concentrations of metals exhibited a decreasing trend with increasing water depth (distance from the shoreline). The PLB site also showed the highest sedimentation rate which decreased with increasing water depth. The Enrichment factors (EFs) showed that Cd was the most enriched element in the sediment (indicating that Cd pollution is widespread), whereas the least enriched metal in sediments was Cu. EF values suggested that the coastal area is impacted by a combination of human and natural sources of metals, where the anthropogenic sources are intense in the PLB site (north of Gulf of Aqaba). The MSS area is potentially the least polluted, consistent with being a marine reserve. The IC sediments have been found to be impacted by human activities but less intensely compared to the PLB area. These results suggested that there are two sources of metals in sediments; the primary source is likely closer to PLB, while the secondary is nearby the IC.

The Gulf of Aqaba is the northeastern extension of the desert-enclosed Red Sea, it is a semi-isolated basin separated from the Red Sea proper by the Straits of Tiran. The area is extremely arid with high evaporation (~400 cm/year) and negligible precipitation (~2.2 cm/year) and runoff (Reiss and Hottinger, 1984). However, flash floods through major wadis in winter may transport terrestrial material into the Gulf, resulting in large deltas and incision of submarine canyons (Reiss and Hottinger, 1984). Extremely oligotrophic conditions are prevailing in the Gulf due to this arid climate and because it receives its waters from the nutrient-depleted Red Sea surface waters through the Straits of Tiran. However, the extensive sunlight, clear visibility, deep light penetration, and the warm water lead to a tremendous development of corals (Schuhmacher et al., 1995; Al-Horani et al., 2006).

Coral reefs in the Gulf of Aqaba are present on the upper limit of coral distribution in the world (29°32′ N), they show a very diverse ecosystem, in which more than 180 species of hard corals flourish (Al-Horani, F.A. personal communication) and about 512 fish species have been recorded (Khalaf, 2005) in addition to many thousands of other reef associated organisms.

The Jordanian coast is fringed by a discontinuous belt of reefs along 13 km of the shoreline. Well developed reefs on the Jordanian coast have the typical structure of the four zones: lagoon, reef flat, fore reef, and reef slope (Mergner and Schuhmacher, 1985).

The extremely limited Jordanian coast of the Gulf of Aqaba (~27 km) has to serve for all conflicting uses of the coastal area. Therefore, Aqaba city has a great environmental, economical and recreational value. Currently, many human activities that are of environmental concern are taking place along the Jordanian coast (Al-Horani et al., 2006; Abu-Hilal and Al-Najjar, 2009; Al-Rousan et al., 2012). In the near future, the area will host a wealth of mega coastal projects including new resorts, the Red-Dead Sea conduit, and ports relocation which will have direct and indirect impacts on the marine communities.

Jordan has the fifth largest reserve and the second largest exporter of phosphate in the world (Jordan Phosphate Mines Company, 2015). The phosphate port in Aqaba is used for exporting phosphate powder. During transportation, storage and loading, phosphate dust is lost and settled to the water which is considered as an important environmental

* Corresponding author.
E-mail address: s.rousan@ju.edu.jo (S. Al-Rousan).

http://dx.doi.org/10.1016/j.marpolbul.2016.05.038
0025-326X/

Please cite this article as: Al-Rousan, S., et al., Effects of pollution on the geochemical properties of marine sediments across the fringing reef of Aqaba, Red Sea, Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.05.038

problem in Aqaba (Abu-Hilal, 1985; Al-Rousan et al., 2006; Abu-Hilal and Al-Najjar, 2009).

Such human activities and coastal developments can result in increasing the delivered and suspended sediments from the anthropogenic and terrestrial origin to coastal reef with consequences of reducing light and affecting the primary productivity and coral growth (Telesnicki and Goldberg, 1995; Al-Rousan et al., 2007; Al-Rousan, 2012). In addition, sediments accumulation can eliminate coral recruitment sites, and even bury coral colonies (Edmunds and Spencer-Davies, 1989; Ogston et al., 2004). Besides this impact, there could be important contributions by contaminants associated with these sediments such as heavy metals (Bastidas et al., 1999).

Heavy metals are transported to marine environment as dissolved species in water or in association with suspended (particulate organic matter) sediments (Saouter et al., 1993). These pollutants will subsequently be deposited and accumulated in bottom sediments through complex physical and chemical adsorption mechanisms (Leivouri, 1998). Although the incorporation of these metals into sediments can limit their bioavailability, remobilization and resuspension of sediments may return contaminants to the water column even after external sources have been eliminated (Schlekat et al., 1992).

The present study aims to estimate the sedimentation rates in selected coral reef localities along the Jordanian coast of the Gulf of Aqaba, and to assess their contribution to metal pollution in these locations. The selected sites represent coastal areas with high input of phosphate dust particles and industrial wastes as well as protected areas as a reference site. The geochemical and physical characteristics of the deposited and bottom surface sediments at each locality were investigated.

Three transects along the fringing reef complex from the Jordanian coast were selected and sampled during a three-months period, of which two are potentially polluted, and one is unpolluted (control site). The first transect was selected near the Phosphate Loading Berth (PLB) that accommodates the single terminal for export of crude phosphate, the second was chosen next to the Marine Science Station (MSS) which is located about 5 km south of the PLB and is officially considered as a protected Marine Reserve area. The third transect was taken across the reefal area in the Industrial Complex (IC), which is located at about 16 km to the south of the MSS, the area hosts many heavy industrial activities. The location of these sites and their positions are shown in Fig. 1.

Bottom surface sediment samples were collected from each transect extending perpendicular to the shoreline over the reef flat, fore reef and the back reef. Within this transact, sediment samples were taken from the uppermost top 5 cm at depths of 2, 6, 14, and 20 m.

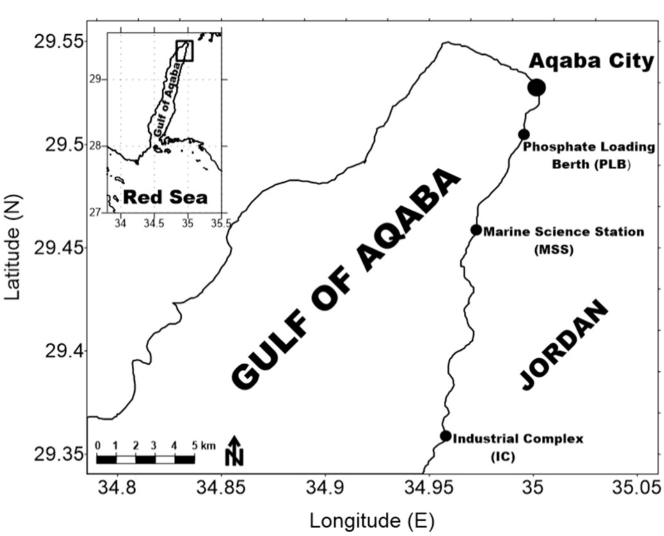

Fig. 1. Location map of the Gulf of Aqaba and sampling sites.

In addition, two bottom sediment traps were placed at each locality to collect sediment settling out through water column. The traps were fixed in a stable upright position at 1 m above the sea bottom in the fore reef area at water depths of 5 and 15 m. The sediment traps consist of four cavities where a ~10 cm diameter glass jars are placed inside. Both bottom surface sediments and sediment trap contents were collected at a monthly interval by SCUBA diving.

Five hundred grams of the bottom sediment (from each sampling location) were dried to a constant weight at 60 °C (for 24 h). Representative sub-samples were taken from the dried ones by quartering. Subsamples were then subjected to granulometric analysis by sieving (Folk and Ward, 1957) and the results were expressed as weight percentage of each of the classes separated.

For the sediment trapped samples, algae and other encrusting organisms were scraped off. Water in the trap (jars) was siphoned until about 400 ml remained. The remaining water and settled material were filtered through pre-weighted, pre-ignited 24 mm GF\C Whatman glass fiber filter. The filter was oven-dried at 60 °C for 24 h. Each filter was then re-weighted and the weight of trapped sediments and sedimentation rate were determined by weight difference.

The geochemical analyses were carried out for both sediment types in the grain size fraction <63 μm. Total organic matter was determined by sequential weight loss at 550 °C (Dean, 1974; ASTM, 2000). For the measurements of metals, samples were prepared according to the method described by Hesse (1972). Half a gram of the fine grained particles (<63 μm) were completely digested in a Teflon cup using a mixture of concentrated nitric (HNO_3), perchloric ($HClO_4$) and hydrofluoric acids (HF) with the ratio of 3:2:1, respectively, according to Oregioni and Aston (1984).

Concentrations of the selected metals (Cd, Cr, Zn, Cu, Pb, Al, Fe, and Mn) were analyzed by an atomic absorption spectrophotometer (NOVA A300, Analytik Jena, Leybold, Germany) at the Department of Earth and Environmental Sciences, Yarmouk University.

The total sedimentation rates are tabulated in Table 1. The results showed that the sedimentation rates varied significantly with variations in the sampling locations and depths, where the highest value (with an average of 8.03 $mg \cdot cm^{-2} \cdot day^{-1}$) was recorded at the PLB area at 5 m depth, and the lowest averaged value (of 0.48 $mg \cdot cm^{-2} \cdot day^{-1}$) was recorded at the MSS area at 5 m depth (Table 1, Fig. 2). These results also showed that the sampling period is a minor contributor to fluctuations in the sedimentation rates, with relatively similar rates were observed in different sampling periods (Table 1).

The total sedimentation rate at the PLB was higher than other locations during all of the sampling events, which is mainly attributed to the fine phosphate particles settled down into the water during the ship loading. Badran and Al Zibdah (2005) reported that the PLB received the highest sedimentation rates along the Jordanian coast of the Gulf of Aqaba. Similarly, Walker and Ormond (1982) reported that the sedimentation rate at the PLB area was 4 times higher than the average sedimentation rate at other coastal stations, associated with five times higher coral death, more than two times higher algal biomass, and three times higher density of sea urchins.

It was reported that phosphorus concentrations decreased both with depth and with distance from the loading berth, consistent with the argument that deposition during loading is the main source of recent

Table 1
Summary statistics of the monthly average sedimentation rate ($mg \cdot cm^{-2} \cdot day^{-1}$) across the coral reef off the PLB, MSS and IC at different water depths. The values are the averages of three months.

Site	PLB		MSS		IC	
Water depth	5 m	15 m	5 m	15 m	5 m	15 m
Range	4.14–10.99	2.26–3.99	0.10–0.86	0.47–0.83	0.40–2.30	0.52–0.83
Average	8.03	2.88	0.48	0.64	1.05	0.64
Std	3.52	0.97	0.38	0.18	1.08	0.16

Please cite this article as: Al-Rousan, S., et al., Effects of pollution on the geochemical properties of marine sediments across the fringing reef of Aqaba, Red Sea, Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.05.038