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Baseline evaluation of sediment contamination in the shallow coastal areas of Saudi Arabian Red Sea

Pedro Ruiz-Compean, Joanne Ellis, João Cúrdia, Richard Payumo, Ute Langner, Burton Jones, Susana Carvalho*

King Abdullah University of Science and Technology (KAUST), Red Sea Research Center (RSRC), Biological and Environmental Sciences and Engineering (BESE), Thuwal 23955-6900, Saudi Arabia

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A B S T R A C T

Despite the growing recognition of the importance of water and sediment quality there is still limited information on contamination levels in many regions globally including the Red Sea. This study provides a comprehensive assessment of three classes of contaminants (Polycyclic Aromatic Hydrocarbons - PAH; metals; plastics) in coastal sediments along the Saudi Arabian Red Sea mainly collected using grabs. Background concentrations are provided for metals in the region. Concentrations of metals and PAH were generally low in comparison to international guidelines. A clear relationship between the concentration of metals and anthropogenic sources was not always apparent and dust and vegetation may be relevant players in the region. Microplastic items (mainly polyethylene) were abundant (reaching up to 1 g m^{-2} and 160 pieces m^{-2}) and in general associated with areas of high human activity. This study provides critical information for future monitoring and the development of national policies within the Red Sea region.

1. Introduction

Intensive anthropogenic activities including habitat modification, pollution, and overexploitation of living resources adversely affect global biodiversity levels and ultimately the provision of ecosystem services (Diaz et al., 2004). Historically, human civilization, including the development of settlements and trading routes, has been concentrated in coastal areas where access to water promoted trade, commerce, and disposal of wastes (e.g., van Andel, 1981). As a consequence, human alteration of natural ecosystems is profound in coastal areas (Borja and Dauer, 2008). Estuarine and coastal ecosystems worldwide have experienced rapid degradation in the last 150–300 years, following long periods of slow decline (Lotze et al., 2006). Anthropogenic stressors responsible for degradation in coastal marine ecosystems include increasing levels of contaminants released from urban and rural sources that can accumulate in marine sediments (van der Oost et al., 2003). Because sediments play a major role in the transport and storage of contaminants, they are frequently used to identify sources of toxicants, determine dispersion pathways, and locate contaminant sinks in aquatic systems (Mann and Lintern, 1983; Rule, 1986; Sarmani et al., 1992; Murray, 1996). Sediments have been found to record and time-integrate the contaminant status of an environment (Bubb and Lester, 1994; Murray, 1996) and are economically attractive to use as a monitoring tool. Sediment monitoring is, therefore, employed in the early phases of environmental assessments of aquatic systems (Birch et al., 2001).

Internationally, there has been an increasing use of both water and sediment quality guidelines aiming to manage the ecological health of marine ecosystems. Increasingly, legislation is being adopted worldwide to determine the ecological integrity of waters, including estuaries and coastal ecosystems such as the Oceans Act 2000 of the USA, the U.S. Clean Water Act (1972), the European Water Framework Directive (Borja, 2005), and the European Marine Strategy Framework Directive (Borja, 2006). These frameworks include the measurement of physico-chemical conditions such as metals and organic compounds influencing biological quality. For sediment contaminants, managers tend to rely on sediment chemical guidelines developed from toxicity testing databases to assess whether contaminants pose a risk to species and ecosystems (MacDonald et al., 1996). Guideline threshold values represent concentrations below which the probability of inducing biological effects is low, and above which the probability of effects is high (Long et al., 1995; ANZECC, 2000; Choueri and Abessa, 2010; Simpson et al., 2013).

The identification of general response patterns of contamination in the marine environment will be critical for reliable assessments of ecosystem health (O'Brien and Keough, 2014). For some regions there is less knowledge on background contaminant levels or local species

* Corresponding author.
E-mail address: Susana.Carvalho@KAUST.EDU.SA (S. Carvalho).

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responses to pollutants against which to assess environmental changes over time. This can be more noticeable in tropical and sub-tropical systems or regions where marine monitoring programs have not been established or are in their infancy. We, therefore, explore in this paper the steps required to establish background contaminant levels in areas with limited prior knowledge of regional contamination effects.

In the last three decades, industrial and human activities along the coastal area of the Saudi Arabian Red Sea have increased dramatically and resulted in the continuous input to the sea of different types of pollutants including metals (Badr et al., 2009) and Polycyclic Aromatic Hydrocarbons (PAH). Historically, marine pollution of the Red Sea by metals, PAH, and other contaminants had been related to several anthropogenic activities, such as sewage discharges and industrial waste effluents (Heba et al., 2004). Currently, there is no existing framework for ongoing monitoring of contaminants in the Red Sea marine environment. Further, publications on contaminant levels for this region are also limited (but see Hanna, 1992; Heba et al., 2004; Badr et al., 2009; AbdelHamid et al., 2011). To enable timely and effective management responses, signs of degradation need to be detected at an early stage. This requires knowledge of existing background levels and ongoing monitoring programs. We analyzed the spatial distribution of metals and PAH in the Saudi Arabian coastal sediments of the Red Sea to characterize the current status of contamination, set background levels of contaminants that can be integrated in future monitoring programs, and to evaluate the potential linkages to human activities (Table 1).

While metals occur naturally in marine sediments (Chen et al., 1999), it is important to differentiate the background concentrations from the contamination resulting from anthropogenic sources. Therefore, 14 metals (Aluminum, Barium, Cadmium, Cobalt, Chromium, Copper, Iron, Lead, Magnesium, Manganese, Nickel, Selenium, Vanadium, and Zinc) and one metalloid (Arsenic) were quantified from sediment samples along the coast of the Saudi Arabian Red Sea.

PAH are natural and ubiquitous organic compounds in the marine environment. They comprise a large group of diverse chemicals, ranging from simple structures, as two-ring naphthalenes and naphthalene derivatives to complex ring structures containing up to 10 rings (Hylland, 2006). PAH can originate from three different sources: from the incomplete combustion of organic matter, especially fossil fuels (pyrolytic origin), from the release of petroleum and its products (petrogenic origin) and the post-depositional transformation of biogenic precursors (diagenetic origin) (El-Nemr et al., 2013). Despite low levels of PAH naturally present in the marine environment, it is important to monitor these compounds, as PAH levels can increase considerably due to human activities (Al-Farawati et al., 2009). Several studies have already shown how carcinogenic PAH interact with biological systems, both through mammalian and ecotoxicological studies (Neff, 2003).

In addition to the assessment of the more traditional contaminants, the present study is the first to analyze the distribution of plastic debris

Table 1
Study areas from the north to the south of the Saudi Arabia Red Sea with indication of number of stations, sampling period and major activities (following Smith et al., 2016) and potential sources of impacts.

Region	No. stations	Sampling date	Major activities/potential sources of impacts
Duba-Tabuk	3	March 2016	Extraction of living resources (fishing) Production of living resources (aquaculture) Land-based industry (bulk plant terminal; desalination plant) Coastal and marine structure and infrastructure (port facilities) Transport ≈ 500,000 inhabitants
Rabigh	8	February 2016	Land-based industry (refinery) Coastal and marine structure and infrastructure (port facilities) Transport < 50,000 inhabitants
Thuwal	12	January–February 2014/2015	New urban area (King Abdullah University of Science and Technology; King Abdullah Economic City) Extraction of living resources (fishing) Land-based industry (small desalination plant) < 30,000 inhabitants
Jeddah	6	March 2014	Highly populated area (> 3 million people) Coastal and marine structure and infrastructure (main port in the Red Sea) Transport Land-based industry (desalination plants, industrial complexes; sewage treatment plants) Extraction of living resources (fishing) Extraction of non-living resources (e.g. maintenance dredging) Tourism/Recreation
Farasan Banks-Al Qahma/Al Qunfudhah	6	February 2014	Extraction of living resources (fishing) Land-based industry (desalination plants, Industrial complexes) Coastal and marine structure and infrastructure (ports) ≈ 250,000 inhabitants
Jazan Economic City	17	February 2014 September 2014	New urban area (under construction) Extraction of non-living resources (capital dredging) Land-based industry (power plant)
Jazan City	6	February 2014 September 2014	Land-based industry (bulk plant terminal) Production of living resources (aquaculture) Coastal and marine structure and infrastructure (port facilities) Extraction of living resources (fishing) Transport Agriculture ≈ 100,000 inhabitants
Farasan Islands	8	February 2014 September 2014 February 2015	Extraction of living resources (fishing) Land-based industry Tourism/Recreation Research and conservation (sanctuary; marine habitats not protected) ≈ 20,000 inhabitants