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REVIEW ARTICLE

Heavy metal, trace element and petroleum hydrocarbon pollution in the Arabian Gulf: Review

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Abstract The Arabian Gulf environmental status was assessed based on studies conducted in Bahrain, Kuwait, Oman, Saudi Arabia, Qatar, and United Arab Emirates (UAE) during 1983–2011. This review examines all sorts of pollutions in the Arabian Gulf area over the last three decades. Approximately 50 published studies were reviewed in order to determine the pollution status in the Arabian Gulf regarding heavy metals and organic substances. Three types of environmental pollutions including marine and coastal, soil, and air were addressed in this review as well as sources of pollutants and their effect on biological systems, marine organisms, and human health. Emphasis is placed on marine pollution, particularly toxic metal, and petroleum hydrocarbon contaminations. Major parts of this review discuss the consequences of the 1991 Gulf War on the environment, and the substantial changes associated with the marine habitats. The effects of oil field fires in Kuwait following the 1991 Gulf War were evaluated through studies that investigated hydrocarbons concentration and trace metals in samples of near shore sediments, bivalves, and fish collected from Kuwait, Saudi Arabia, Bahrain, UAE, and Oman. Total petroleum hydrocarbons (TPH) and polycyclic aromatic hydrocarbons (PAHs) were discussed in biota (fish and various bivalves) and coastal sediments from six countries in the Gulf. The review has revealed different concentrations of pollutants, low, moderately, and chronically contaminated areas from oil and metals. It has also outlined effective sustainable management measures and goals as a first step in the evaluation of coastal, marine, soil, and air environment in the Arabian Gulf area.

1. Introduction

Many species function in the Arabian Gulf close to physiological limits (Sheppard, 1993), and thus, added stress imposed by diverse input of pollutants into the marine environment (e.g. terminals, tanker accidents and spills due to wars, offshore oil exploration and land based industrial and urban sources, recreational and agricultural development) is likely to have severe consequences (Madany et al., 1995; Al-Saleh et al., 1999; Sheppard et al., 2010). It is well known that seafood in the Arabian Gulf including fish and shrimp is of value for both local consumption and export revenue. Therefore, maintaining good marine environmental quality is crucial for several socio-economic reasons (Price et al., 1993; Sadiq et al., 2002; Sheppard et al., 2010). Furthermore, sea water quality issues are of extreme importance due to the fact that many of the

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Gulf countries depend on desalinated seawater as a source of potable water for domestic and industrial use.

Water, air, and soil contamination by organic and inorganic pollutants is a major issue in the countries of the Arabian Gulf. The Arabian Gulf is an extension of the Indian Ocean located in the southwest of Asia between the Islamic Republic of Iran and the Arabian Peninsula (UN, 2006). The peninsula is made up of seven countries; Bahrain, Kuwait, Oman, Saudi Arabia, Qatar, United Arab Emirates (UAE), and Yemen. Six countries in the list above in addition to Iraq and Iran accounts for around one-fourth of the world's oil production (Khan, 2002). The Arabian Gulf is relatively shallow with an average depth of 35 m; rarely exceeding 100 m. It is a semi-enclosed body of water that only connects to the open waters through the Strait of Hormuz (Reynolds, 1993; Sheppard, 1993; Massoud et al., 1996; Khan, 2002). The Arabian Gulf contains a variety of relatively fragile ecosystems that are associated with an environment that is naturally highly stressful with very high evaporation rates, poor flushing characteristics, elevated temperatures, salinity and UV exposure. Therefore, contaminants are more likely to undergo limited dilution, slower dispersion, and residing in the area for a longer time (Madany et al., 1996a; de Mora et al., 2004).

The Arabian Gulf was the scene of three wars during the last three decades; the Iraq–Iran War in 1980–1988, the first and second Gulf War in 1991and 2003 respectively. As a result, the Arabian Gulf was subjected to a massive oil spill in 1991 in which 6–8 million barrels of Kuwait crude oil were released in the Arabian Gulf as well as various spills from normal oil operation and tanker-related spills (Kureishy, 1993; Literathy, 1993; Madany et al., 1996a; Sheppard et al., 2010). The oil spill associated with the 1991 Gulf War was considered the largest oil spill in the history. Therefore, large number of studies focused on the fate of this spill and provided evidence that the oil spill effect was limited to 400 km from the spillage point to Saudi Arabian coastline and that the main contaminants were rapidly degraded (de Mora et al., 2010).

Although, the division of pollution into categories such as air, water, land etc. has not been favored by some scientists who believe that every pollutant tends to end up in the ocean (William, 1996), the following review is divided into three sections: (1) marine and coastal pollution, (2) soil pollution, and (3) air pollution. Marine, soil and air contaminations will be the focus of this review which aims at identifying all sorts of pollutants, their sources, levels, and distributions in sediments, soil, organisms, and air during the last three decades. It is important to find out the degree of contaminations and its effect on marine life, fisheries, and human health. The present work examines 30 years of monitoring data in the Arabian Gulf for metals and petroleum hydrocarbons providing invaluable baseline information for future assessment.

2. Marine and coastal pollution

Heavy metal contamination in the marine environment of the Arabian Gulf was investigated in wide varieties of marine organisms. The effect of the Gulf War oil spill in 1991 on the concentration of heavy metals in marine organisms was the highlights of several studies. The concentrations of Cu, Pb, Zn, Cd, Fe, Mn, and Ni were determined in the tissues of the grouper fish *Epinephelus coioides* from different areas in the Arabian Gulf including UAE, Oman, Kuwait, and Bahrain from 1991 to 1996 (Fowler et al., 1993; Habashi et al., 1993; Al-Sayed et al., 1996; Madany et al., 1996a). Levels of all heavy metals investigated were within internationally accepted levels except for Pb and Zn that were in the higher side of these limits in Al-Sayed et al. study (1996) (Tables 1 and 2). Kureishy (1993) also investigated the contribution of the 1991 oil spill to heavy metal contamination in marine organisms around Qatar. This study concluded that no significant increase in the concentrations of Hg, Cd, Pb, Cu, Co or Ni was recorded in the muscle tissue of various benthic and semipelagic species studied.

The effects of oil field fires in Kuwait following the 1991 Gulf War were investigated by determining hydrocarbons concentration and trace metals in samples of near shore sediments, bivalves, and fish collected from Kuwait, Saudi Arabia, Bahrain, UAE, and Oman (Fowler et al., 1993). This survey revealed that hydrocarbon contamination was restricted to ~400 km from Kuwait with the highest contamination levels along the coast of Saudi Arabia between Ras Al Khafji and Ras Al Ghar. However, the study also indicated that much of the oil in the intertidal zone had degraded within few months of the spill and that the concentrations of petroleum hydrocarbons and trace metals in sediments and bivalves outside the immediate area of impact were as low as or even lower than those levels in samples collected from the same site before the war.

The levels of Cu, Zn, Pb, Mn, Ni, Cd, and Fe in seawater and the pearl oyster *Pincatada radiata* from two locations around Bahrain were determined by Al-Sayed et al. (1994) between March 1991 and March 1992. Metal concentrations were higher in oysters in comparison to seawater; however, they were within the World Health Organization (WHO) limits except for Pb and Cd (Tables 1 and 2).

Marine pollution in the territorial water of the kingdom of Bahrain was assessed by analyzing heavy metals As, Cd, Cu, Fe, Mn, Ni, Pb, V, Zn, and Hg in seawaters from 23 different sites known as fishing areas in the year 2007 (Juma and Al-Madany, 2008). The authors concluded that the concentrations of the elements studied were within the United Kingdom Quality Standards (UK standards) (As 25 $\mu g\,l^{-1}$, Cd 5 $\mu g\,l^{-1}$, Cu 5 $\mu g\,l^{-1}$, Fe 1000 $\mu g\,l^{-1}$, Ni 30 $\mu g\,l^{-1}$, Pb 25 $\mu g\,l^{-1}$, V 100 $\mu g\,l^{-1}$, Zn 40 $\mu g\,l^{-1}$, and Hg 0.3 $\mu g\,l^{-1}$) and the United States Environmental Protection Agency (USEPA) (As 36 $\mu g\,l^{-1}$, Cd 8.8 $\mu g\,l^{-1}$, Cu 3.1 $\mu g\,l^{-1}$, Fe 300 $\mu g\,l^{-1}$, Mn 50 $\mu g\,l^{-1}$, Ni 610 $\mu g\,l^{-1}$, Pb 8.1 $\mu g\,l^{-1}$, Zn 81 $\mu g\,l^{-1}$, and Hg 0.94 $\mu g\,l^{-1}$) recommended water quality criteria except for copper in all sites (4.53–119 $\mu g\,l^{-1}$) and mercury (0.38 $\mu g\,l^{-1}$) in one site and that the Kingdom of Bahrain's marine waters is of good water quality (Tables 1 and 2).

The metals (Cd, Co, Cr, Mo, Ni, Pb, V, and Zn) were measured in the clam (*Meretrix meretrix*), seawater, and sediments were collected from five stations on the Saudi coast during the period April–May 1991, after the 1991 Gulf war (Sadiq and McCain, 1993). The researchers compared metal concentrations in their study with those collected from the same stations in the same period in 1985. They concluded that metal concentrations in clams collected during 1985 and 1991 were similar in some stations but reduced or increased in others. However, the magnitude of increase was much greater in clams collected in 1991 from stations located toward the north (i.e. toward