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Health risk associated with airborne particulate matter and its components in Jeddah, Saudi Arabia

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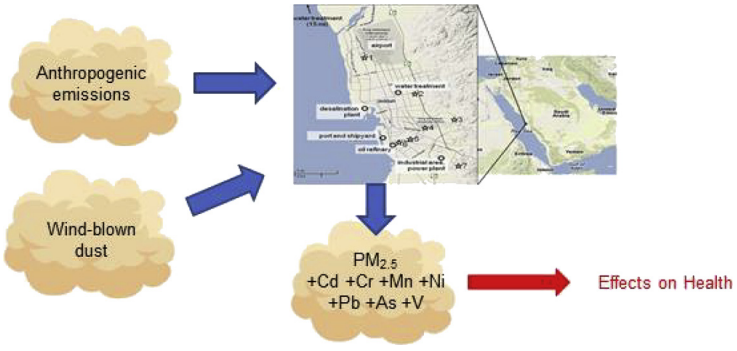
HIGHLIGHTS

- Concentrations of PM and trace elements measured across Jeddah
- Spatial gradients relate to local industries.
- Health risks from $PM_{2.5}$ exceed those of chemical constituents.
- Concentrations of $PM_{2.5}$ are mapped across Jeddah.
- Premature mortality due to $PM_{2.5}$ exposure is estimated.

GRAPHICAL ABSTRACT



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ABSTRACT

Samples of $PM_{2.5}$ and PM_{10} have been collected in all of four seasons at seven sites within the city of Jeddah, Saudi Arabia. The samples have been analysed for a range of trace elements. There is a large loading of wind-blown dust and the majority of elements are predominantly associated with coarse particles. Enrichment factors, however, show that some elements are markedly enriched above crustal abundance. Using mean data for the $PM_{2.5}$ and PM_{10} fractions from each of the seven sampling sites, health risks have been estimated for particulate matter mass, the elements Cr, Mn, Ni, Pb, As, Cd and V measured in this study, and polycyclic aromatic hydrocarbons using data from an earlier study within Jeddah. Cancer risks are calculated from mean airborne concentrations and cancer slope factors for the carcinogenic metals and PAH, but the cancer risks are relatively modest compared to the lifetime risk of mortality due to $PM_{2.5}$ exposure. The risks associated with exposure to V and Mn are considered to be small, while concentrations of cadmium far exceed the European Union Limit Value and World Health Organisation guideline. Cadmium shows a very high crustal enrichment factor but is present predominantly in the coarse particle fraction suggesting that local soils and surface dusts are unusually enriched in Cd

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relative to the global average. Using national data for mortality rates, the excess mortality due to $PM_{2.5}$ exposure has been calculated and amounts to over 1100 deaths annually for the city of Jeddah.

1. Introduction

Saudi Arabia is a country with a fast growing population enumerated as 30.8 million in 2014. The population is heavily focussed on the major cities and especially Riyadh and Jeddah. The city of Jeddah is located on the Red Sea coast of Saudi Arabia and has a population of 3.98 million (in 2014). In addition to its resident population, the sea port and airport of Jeddah act as a gateway for pilgrims entering Saudi Arabia for the traditional Hajj and Umrah in the Holy City of Makkah. Jeddah extends considerably further from north to south than from east to west (see Fig. 1) with the Red Sea on its western border. However, to the north, south and east of Jeddah lie large areas of desert which provides an extensive source for wind-blown dusts.

While there have been air quality studies in the inland city of Makkah (Al-Jeelani, 2009; Simpson et al., 2014), and the coastal town of Yanbu to the north of Jeddah (Khalil et al., 2016), these have focussed largely on gas phase pollutants and only the latter study provides limited data for particulate matter concentrations. Mean concentrations of PM_{10} and $PM_{2.5}$ in Yanbu based on six years of observations are reported as 70 μg m^{-3} and 60 μg m^{-3} respectively (Khalil et al., 2016). The small differential between $PM_{2.5}$ and PM_{10} measured between 2000 and 2005 in Yanbu is rather surprising and diverges from the experience of many other sites in western Saudi Arabia (e.g. Khodeir et al., 2012).

There have been a number of studies within and close to the city of Jeddah. Kadi (2014) reports measurements of total suspended particulate matter (TSP) collected with high volume samplers together with analyses of Al, Ba, Ca, Cu, Mg, Fe, Mn, Zn, Ti, V, Cr, Co, Ni, As and Sr. These were made at seven sites within Jeddah, and concentrations of the various metallic components and crustal enrichment factors are reported. Enrichment factors of elements at the more polluted sites range approximately from 10 to 60 whilst for Cu and Zn, these are much higher at some of the sites with a peak value of over 700 for Cu at a site influenced by light industry and road transport activities. The data show very large inter-site differences for the majority of the elements analysed. In another paper, the same author (Kadi, 2009) also determined soil composition and reports a strong elevation in lead and zinc content at heavily trafficked sites.

Khodeir et al. (2012) report data from seven sampling sites within Jeddah from samples collected in 2011. They report overall mean mass concentrations of 28.4 ± 25.4 μg m^{-3} for $PM_{2.5}$ and 87.3 ±

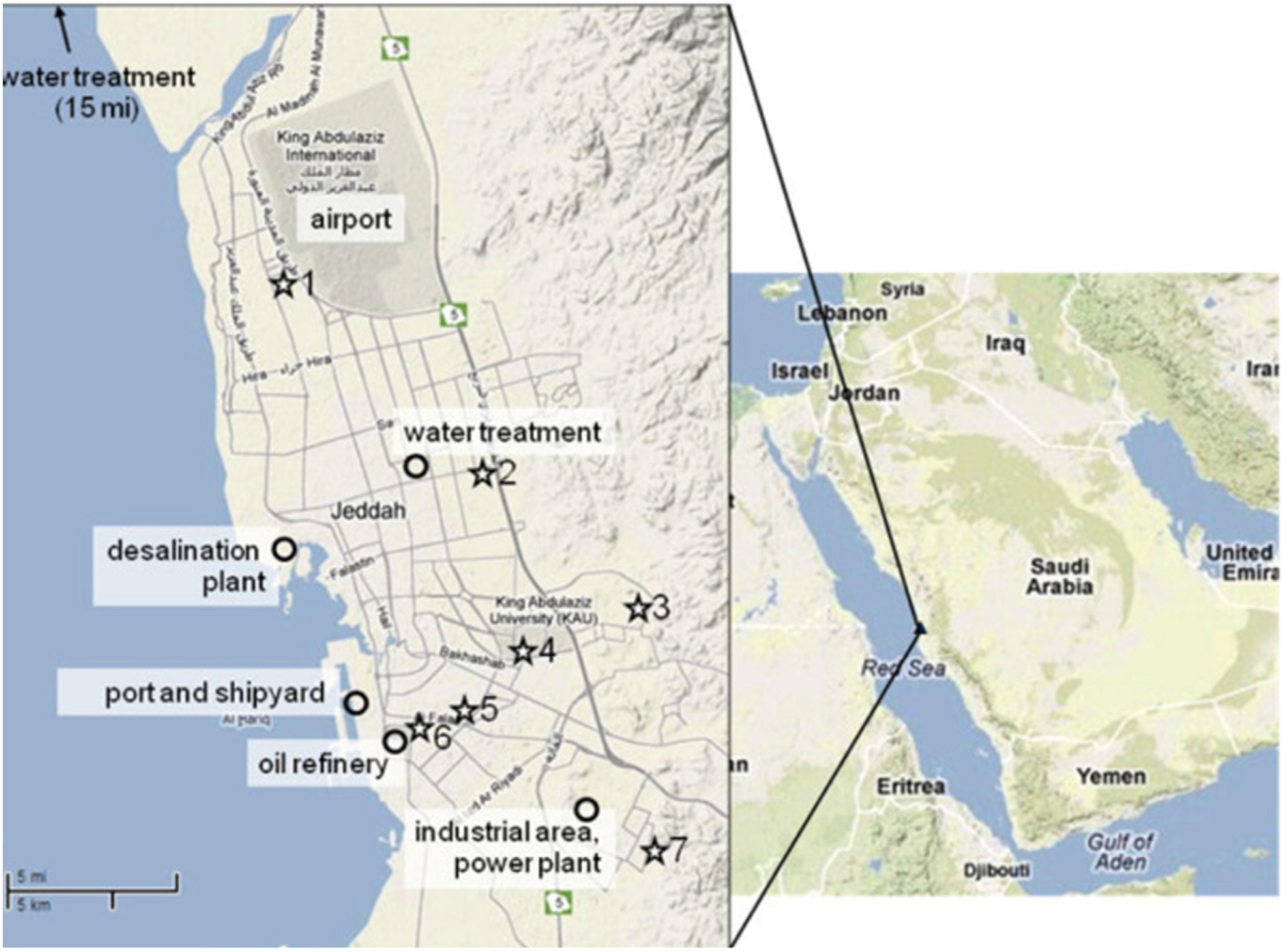

Fig. 1. Location of sampling sites (stars) and major industrial sources (circles) in Jeddah, Saudi Arabia.

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