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Geochemical baseline determination and pollution assessment of heavy metals in urban soils of Karachi, Pakistan

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ABSTRACT

Karachi is one of the most populated urban agglomerations in the world. No categorical study has yet discussed the geochemical baseline concentrations of metals in the urban soil of Karachi. The main objectives of this study were to establish geochemical baseline values and to assess the pollution status of different heavy metals. Geochemical baseline concentrations of heavy metals were estimated using the cumulative frequency distribution (CDF) curves. The estimated baseline concentrations of Pb, Cr, Cu, Zn and Fe were 56.23, 12.9, 36.31, 123.03 and 11,776 mg kg^{-1}, respectively. The pollution status of heavy metals in urban soils was evaluated using different quantitative indices (enrichment factor–EF, Geo-accumulation Index–I_{geo}, and pollution index–PI). Enrichments factors of the selected heavy metals determined by using Fe as a normalizer showed that metal contamination was the product of anthropogenic activities. The urban soils of Karachi were found to have a moderate to moderately severe enrichment with Pb, whereas Cr and Cu has moderate and Zn has minor enrichment. I_{geo} results indicated moderate soil contamination by Pb at some of the sampling locations. PI for Pb, Cr, Cu and Zn was found in the range of 0.04–3.42, 0.19–1.55, 0.27–2.45 and 0.32–1.57, respectively. Large variations in PI values of Pb revealed that soil in those areas of the city which are influenced by intensive anthropogenic activities have exceptionally high concentrations of Pb. The findings of this study would contribute to the environmental database of the soil of the region and would also facilitate both at the local and the international scales, in a more accurate global environmental monitoring, which will eventually facilitate the development of management and remediation strategies for heavy metal contaminated urban soil.

1. Introduction

Soils in the urban environment tend to be affected by a wide range of anthropogenic activities. Vehicular emissions, industrial wastes and wastewater sludge have a noticeable impact on the heavy metal contamination of urban soils (Li et al., 2004; Ali and Malik, 2011; Wang et al., 2012; Kardel et al., 2012). Non-exhaust emissions due to wear and tear of vehicle parts such as brake, tire and clutch are an important source of trace metals in the urban environment (Thorpe and Harrison, 2008; Pant and Harrison, 2013). Industrial sources for the heavy metal (Cu, Pb, Zn and Cr) contamination in the urban soil include electroplating, petrochemicals, dyes, pigments, ceramic, tanning and textile industries. Contamination of urban soils by heavy metals is therefore a matter of major concern at local, regional and global level owing to its adverse effect on the urban ecosystem.

There are very limited published data on the soil contamination in urban areas of Pakistan. Malik et al. (2010) investigated the metal contamination in urban soil of Sialkot and concentrations of Cd, Ni, Cr, Zn, and Pb were found to exceed the permissible limits of surface soils. Spatial distribution of metals in top soils of Islamabad also revealed elevated concentrations of Pb, Ni, and Zn in built-up areas and it was largely influenced by the vehicular emissions and waste disposals (Ali and Malik, 2011). The spatial variation in the concentrations of Cu, Zn and Pb metals seemed to be the result of increased atmospheric deposition from road traffic in the urban soil of Karachi (Karim et al., 2014). The potential health risk due to lifetime exposure to Cu, Pb, Cr and Zn in urban soil of Karachi was evaluated by Karim and Qureshi (2014). Risk assessment indicated that the overall results for the carcinogenic risk were insignificant. It was also found that children were more susceptible to non-carcinogenic health effects of trace metals compared to adults.

The geochemical or natural background is a relative measure to differentiate between natural element or compound concentrations and anthropogenically-influenced concentrations in a given environmental sample (Matschullat et al., 2000). Owing to the

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natural variability and widespread anthropic input, practically it is almost impossible to quantify a true background value beyond doubt. Geochemical baseline concentration is therefore more useful, because statistically it is 95% of the expected range of background concentrations (Gough et al., 1994; Chen et al., 1999; Facchinelli et al., 2001). Several studies were conducted in different regions of the world to estimate geochemical background and baseline concentration of heavy metals (Wei and Wen 2012; Rodrigues et al., 2013; Blonda and Valenzano, 2014). However, no categorical study has yet discussed the geochemical baseline concentrations of metals in the urban soil of Karachi (Pakistan). The findings of this study would therefore facilitate the concerned authorities for monitoring the impact of anthropogenic activities on heavy metal contamination of urban soil and for the development of proper management strategies for urban environment pollution control and for the remediation of heavy metal contaminated soils of Karachi city.

The main objectives of this study were to estimate the baseline values and pollution status of different heavy metal in urban soils of Karachi using enrichment Factor (EF), geo-accumulation index (I_{geo}), and pollution index (PI).

2. Materials and methods

Karachi is the largest city of Pakistan in terms of population, industrialization and urbanization. The city has an estimated population of over 18 million. Major industries include textile, pharmaceutical, automobiles, chemicals, leather tanning, paints and pigment, paper, rubber, ceramics, plastic, cement, food and dairy products etc. The total number of vehicles registered in Karachi till 2011 were 2.6 million.

Fig. 1 represents the most urbanized part of the city, comprising 20 administrative towns with population densities ranging from 10,000 km^{-2} to almost 100,000 km^{-2} (Karim et al., 2013).

Soil samples at depth of 0–10 cm were collected from 30 different sampling locations. Five replicate samples were collected from each sampling site within a 2 m × 2 m grid using a stainless steel auger, thoroughly mixed to obtain a bulk composite sample. Samples were air-dried, ground and passed through a 2-mm nylon sieve. Total concentrations of Pb, Cr, Cu, Zn and Fe in soil samples were determined using a strong acid (HNO_3–$HClO_4$) pseudo-total digestion method (Lee et al., 2006; Karim et al., 2014) and analysed by using an AAnalyst 700 Perkin–Elmer Flame atomic absorption spectrometer.

The cumulative frequency distribution (CDF) curves of the metal's data sets were used to estimate baseline metal concentrations. Usually, a CDF curve is plotted with the data on abscissa and the corresponding estimated percentiles on ordinate. The reverse convention, as in the present study, can also be used if percentile/s following certain sample value is to be found.

The CDF curves were drawn by statistical software Minitab 16®. The normality of the distribution of metals' data was investigated by performing one-sample Kolmogorov–Smirnov test (or the K–S test of normality). It was found that datasets of metals were either normally (for Cr and Fe) or log-normally distributed (for Cu, Zn and Pb). The data of Cu, Zn and Pb was therefore log-transformed prior to the CDF plotting. Then, CDF curves for Fe and Cr were drawn by

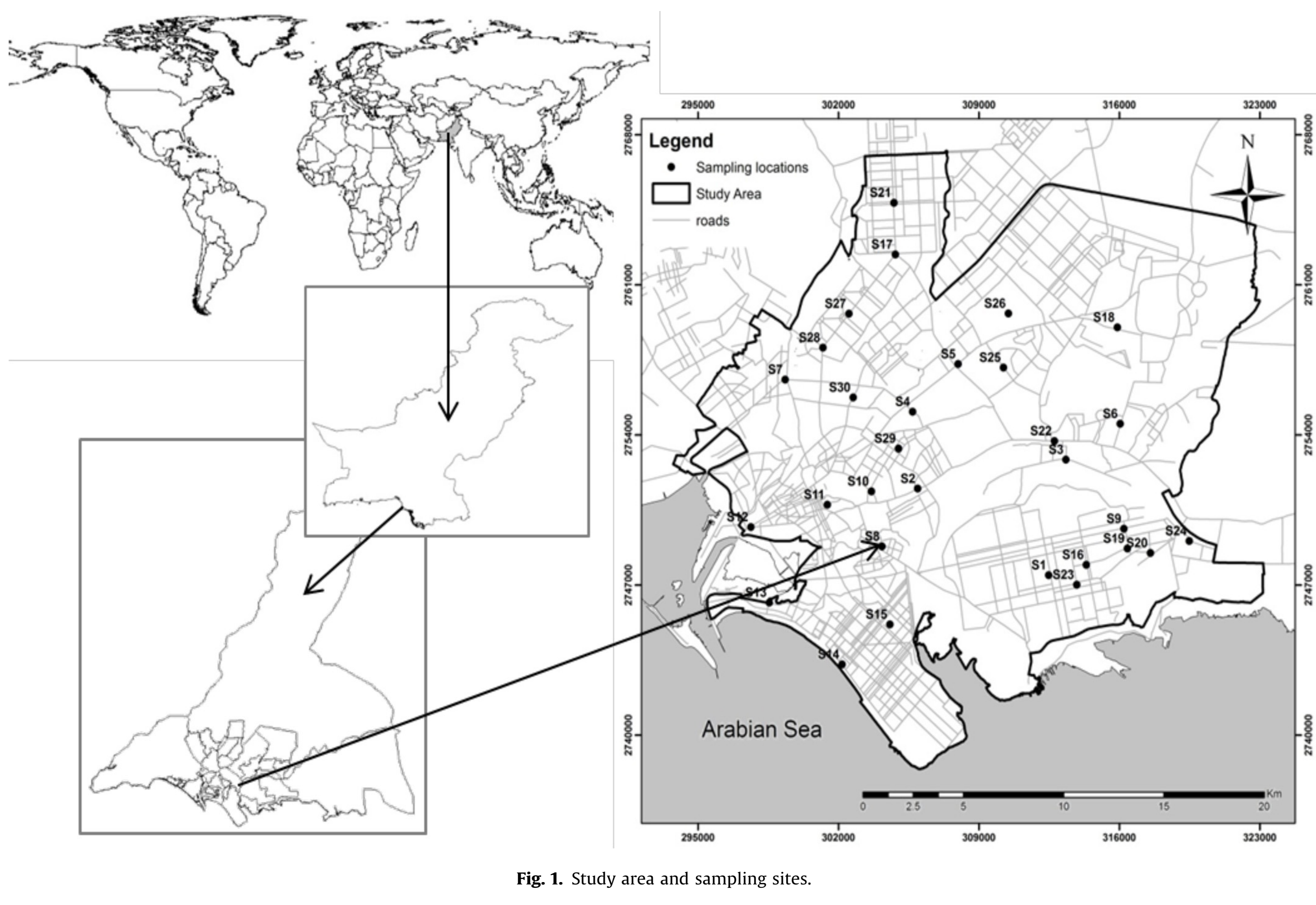

Fig. 1. Study area and sampling sites.