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Original Research

Distribution, source identification and risk assessment of selected metals in sediments from freshwater lake

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A B S T R A C T

This study is based on the assessment of distribution, source apportionment and risk assessment of selected metals in freshly deposited sediments from freshwater lake, Pakistan. Composite sediments were collected and processed to assess $Ca(NO_3)_2$-extractable and acid-extractable levels of the metals in the sediments using flame atomic absorption spectrophotometry. Enrichment factors (EF), geoaccumulation indices (I_{geo}), contamination factors (C_f) and degree of contamination (C_{deg}) were computed to estimate the degree of contamination. The potential ecological risk was assessed using sediment quality guidelines and mean-ERM-quotient (m-ERM-Q). On the average basis, acid-extractable metals followed the decreasing concentration order: Ca > Mg > Fe > K > Mn > Na > Sr > Zn > Pb > Cr > Co > Cu > Li > Cd, whereas, the $Ca(NO_3)_2$-extractable levels were: Na > Pb > Cd > Sr > Co > Cr > K > Mg > Cu > Zn > Li > Ca > Fe > Mn. The highest $Ca(NO_3)_2$ extractable concentrations were observed for Na, Pb and Cd, while that of Ca, Fe and Mn were the least. EF showed very high and extremely high enrichment of Pb and Cd, respectively, while Ca, Co, Cr, Li, Mg, Mn, Sr and Zn manifested moderate enrichment; the I_{geo} results revealed moderate to strong and strong to extreme pollution for Pb and Cd, respectively; and the C_f study showed moderate, considerable and very high contamination by Co, Pb and Cd, respectively. The C_{deg} revealed very high degree of contamination in the sediments as a whole. Principal component analysis (PCA) and cluster analysis (CA) showed considerable anthropogenic contributions of Cd, Pb, Co, Mn, K, Zn and Li in the sediments. Measured levels of Cd and Pb exceeded ERL values, manifesting occasional adverse biological effects to the dwelling biota. Moreover, the m-ERM-Q study manifested 21% probability of toxicity in the sediments.

1. Introduction

The exponential development of human activities during the last century has caused a severe impact on all environmental compartments, including aquatic ecosystems. Among numerous anthropogenic pollutants, heavy metals comprise a major source of pollution (Tessier et al., 2011). These metals can enter the water reservoirs through the discharge of industrial and municipal wastes, storms, run-offs, dry deposition, mine discharge, waste incineration, and other diffused sources (Besser et al., 2009; Cheng & Hu, 2010a,b; Cheng et al., 2009; Dai et al., 2007; Davutluoglu et al., 2011; Hosono et al., 2010; Hosono et al., 2011; Kennish, 2002; Meng et al., 2008; Tanner et al., 2000; Zhang et al., 2008). Once in the water column, metals are promptly adsorbed onto particles, deposited and accumulated in sediments, which therefore, act as a sink for these pollutants. Various studies have explicated that sediments are not only a sink but also a possible source of contamination to the water column due to desorption and remobilization processes (Kalnejai et al., 2010; Kabir et al., 2011; Kim et al., 2006; Reczynski et al., 2010; Sultan & Shazili, 2010; Saulnier & Mucci, 2000; Tankere-Muller et al., 2007; Zoumis et al., 2001). The toxicity and mobility of heavy metals in sediments vary greatly among different chemical forms (Cuong & Obbard, 2006; Fan et al., 2008; Yu et al., 2010), hence, evaluation of the metals distribution and their mobility/bioavailability in surface sediments is an important step to gauge the degree of pollution of an aquatic environment (Bertolotto et al., 2005; Martin et al., 2009; Sprovieri et al., 2007). The estimation of biologically available fractions of the metals helps to assess their potential for mobilization and availability to other organisms (An & Kampbell, 2003; Rodrigues et al., 2010). Many chemical extraction methods have been suggested to estimate the levels of metals in sediments, which may be

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directly or indirectly available to organisms. Generally, weak acids/electrolytes are used to extract the bioavailable metal content in sediments (An & Kampbell, 2003).

A comprehensive study on both the status of selected metal's pollution and their bioavailability in the aquatic environment of Rawal lake was important for the long-term improvement of public health. Specifically, the objectives of this study were: (1) to determine the levels of selected metals (Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Pb, Sr and Zn) in the sediments; (2) to identify the possible sources of these metals via principal component analysis and cluster analysis; (3) to deduce the bioavailability and the mobility of selected metals in the sediments; and (4) to assess the potential ecological risk of the metal pollution in the sediments. The conceivable association between the contamination of the sediments and the adverse biological effects to benthic fauna based on the sediment quality guidelines would also be envisaged.

2. Materials and methods

2.1. Study area

Rawal lake in Islamabad, Pakistan is an artificial reservoir created in 1962 that provides the water needs for the cities of Rawalpindi and Islamabad (PakEPA, 2004). This lake covers an area of 8.8 km^2 (Fig. 1). The catchments area of the lake is 275 km^2, while the crest level and length are 531 m and 210 m, respectively, with maximum height of 40.7 m. The discharge capacity of the lake is 2300 m^3/s. Its live storage capacity is 5.3×10^7 m^3 and dead storage is 5.6×10^6 m^3 whereas, the gross capacity is 5.9×10^7 m^3. It discharges water by two canals: left bank canal having length of 5 miles and capacity of 1.1 m^3/s while, right bank canal with length of 1.5 miles and capacity of 2.0 m^3/s. Its drinking water supply capacity is 19.5 million gallons/day for Rawalpindi and 2.5 million gallons/day for Islamabad. The lake is located within an isolated section of the Margalla Hills National Park in an area that forms the northeast part of the Pothowar Plateau. The area around the lake has been planted with flowering trees and laid out with gardens, picnic spots, and secluded paths. The lake is an important resource as a sports and commercial fishery. The terraced garden and the lake are used for picnics, fishing, boating, sailing, water skating and diving facilities. Fish yields in the lake have been declined in recent years (PakEPA, 2004). Untreated urban wastewater effluents, run offs from agricultural activities and poultry farms, deforestation, soil erosion, sedimentation, eutrophication and pollutants released during the recreational use of motorboats are among the sources suspected of contaminating the lake water (PakEPA, 2004). Murree hills, Chattar park, lake view park and many other attractive places in the catchment area of Rawal lake are other contributing sources of pollution. Agricultural practices as terrace cultivation are continued in the catchment areas and the water run off from such areas enters into the lake to pollute its water. The temperature at Rawal lake varies from a minimum of 3 °C to a maximum of 34 °C.

2.2. Sample collection and preservation

A total of 50 composite surface sediments from Rawal lake, Islamabad, were collected in December, 2008. Each sediment sample was made up of a composite of three sub-samples from an area of 10 m^2 and collected using a snapper (⌀ 5 cm) in the layer 1–10 cm (top layer). The snapper was made up of stainless steel corer (⌀ 5 cm) with long pipe to collect the surface sediments. Before transferring the samples in pre-cleaned Ziploc polythene bags using plastic spatula, the above water was decanted. The samples were kept in airtight large plastic ice-cold containers at 4 °C. Then sediment samples were oven dried at 105 ± 2 °C to constant weight (Sakan et al., 2011), sieved through a <2 mm mesh, grounded, homogenized and sealed in cleaned polythene bags and stored in a refrigerator at 4 °C (Iqbal & Shah, 2011; Radojevic & Bashkin, 1999).

Background soil samples in triplicate from a remote area of Margalla Hills National Park (50 km north of Islamabad) were collected in pre-cleaned ziplock polythene bags with the help of a plastic scoop. Small stones, gravels, and debris were removed manually from the soil samples. The samples were oven dried at

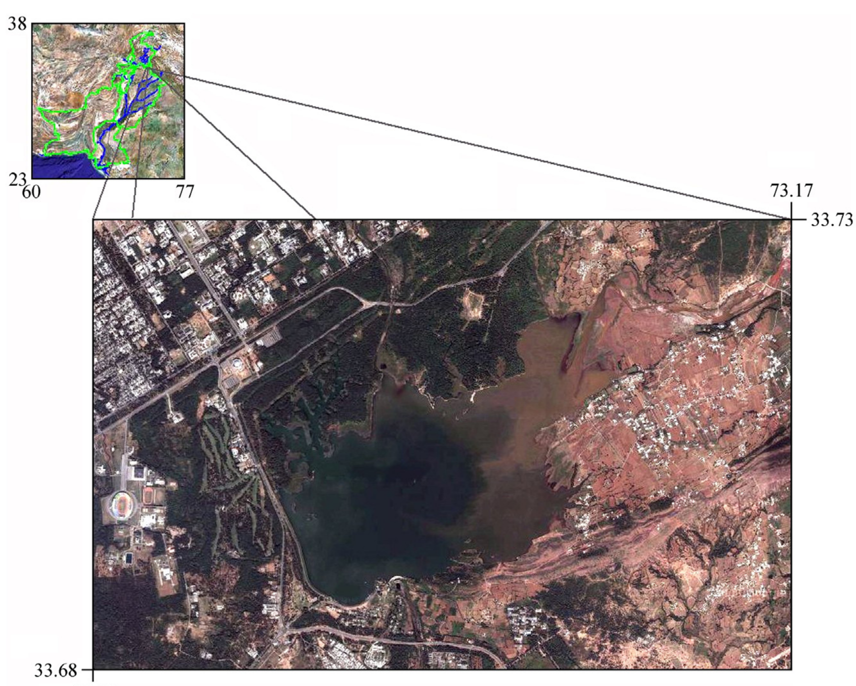

Fig. 1. Location map of the study area.