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RESEARCH ARTICLE

Heavy metal pollution and risks in a highly polluted and populated Indian river–city pair using the systems approach

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Abstract

A sectorial approach for assessing heavy metal pollution in rivers neglects the inter-relationship between its environmental compartments and thus fails to report realistic pollution status and associated ecological and human health risks. Therefore, a systems approach was adopted to assess heavy metal pollution and associated risks in the Yamuna River (Delhi, India), one of the world's most polluted and populated river–city pairs. Sampling sites selected along the river with distinct land use were uncultivated natural floodplain vegetation, marshy area, invasive community, arable land, and human settlements. The multivariate analysis identified sources of pollutions (Pb, Cd, Cr, and Ni [anthropogenic]; Fe and Zn [geogenic]). Across the land use, a high log K_p value of Zn and Pb in water–soil phase than in water–sediment phase indicates their long-range transfer, whereas low log K_p (water–soil) of Cd suggests river sediments as its reservoirs. Comparison of pollution indices of Cd, Cr, and Pb in water, sediment, and soil across the land use suggested the role of vegetation in reducing pollution in the environment. Ecological risk also gets reduced progressively from water to sediment to the soil in naturally vegetated sites. Similarly, in river water, Cr, Cd, Ni, and Pb pose carcinogenic and non-carcinogenic risks to adults and children, which are also reduced in sediments and soil of different vegetation regimes. This study showed the eco-remediation services rendered by natural vegetation in reducing pollution and associated ecological and human health risks. To conclude, using a systems approach has significance in assessing pollution at the ecosystem level, and focusing on riverbank land use remains significant in developing methods to reduce pollution and ecological and human health risks for sustainable riverbank management.

Keywords Ecological and health risk · Land use · Pollution index · Environmental compartment · Integrative approach

Introduction

Heavy metal pollution in rivers has emerged as a key challenge for ecosystem and human health globally. Rivers constitute ~ 2% of the total surface freshwater available on earth and serve as the backbone of the global economy, driving urbanization and industrialization (UNESCO 2016; Dempsey et al. 2018). Initially, healthy rivers facilitated urbanization via enhanced agriculture production, industrial and infrastructure development, and power generation. However, over time, the extensive extraction of water by cities and the discharge of untreated wastewater rich in heavy metal from cities have damaged the synergism between the river–city pair (Kumar et al. 2019; Li et al. 2020; Zhou et al. 2020) as evident in case of Yamuna–Delhi and Gomti–Lucknow of India, Citarum–Jakarta of Indonesia, and Yangtze–Shanghai of China (Upadhyay et al. 2011; Floehr et al. 2013; Luo et al. 2019; Khan et al. 2021a). Nearly 145 capital cities within different countries are located on river banks, and most of them are struggling with heavy metal–associated health and ecological risks (Seifi et al. 2019; Usman et al. 2021). In urban centers, heavy

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