Risk assessment of metal species in sediments of the river Ganga

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ABSTRACT

The present study deals with the geochemical fractions of nine heavy metals [chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb)] present on the river sediments using sequential extraction process (SEP) and total acid digestion (TAD). This work was conducted on Ganga river sediments at Varanasi. A ten kilometer stretch of the river Ganga from Samne Ghat to Varuna-Ganga confluence was selected to perform this study. Pollution Load Index (PLI) varied from 1.2 to 3. Geo-accumulation index (I_{geo}) and Risk Assessment Code (RAC) showed higher concern for Cd and Pb whereas Mn, Fe and Ni showed negative accumulation index at all sampling stations. Lead, cadmium, copper and nickel were present significantly in available fraction; however, the I_{geo} of Ni was found negative at all stations. Various sources of the metal pollution in the city include domestic, industrial and agricultural untreated wastewater draining into the river. Geochemical fractions of the metals–pH relation study, using Medusa Hydra chemical equilibrium software, revealed the presence of different species of metals at different pHs.

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1. Introduction

Metals ultimately get adsorbed and deposited on the sediments in aquatic ecosystems. Sources of metals in the environment may be natural (erosion, weathering, volcanic activity), anthropogenic (agricultural runoff, industrial discharge, rapid urbanization, mining etc.) or a hybrid of both. Metals do not degrade naturally with the passage of time like many organic pollutants (Jain, 2004). Metals from the anthropogenic activities may be transported and distributed up to a long distance and affect the soils and sediments of riverine floodplains (Graf et al., 2007; Kabala and Singh, 2001; Laing et al., 2009; Lair et al., 2008; Lu et al., 2005; Ma and Rao, 1997; Marchand et al., 2012; Nannoni et al., 2011; Nowack et al., 2010; Rennert et al., 2010; Voegelin et al., 2008). Total elemental concentration would not provide a precise picture of metal load and pollution. The idea to assess the different geochemical fractions of metals was given by Goldberg (1954) and Jain (2004). Tessier and co-workers suggested metal speciation analysis using sequential extraction process (SEP), a wet and multi-step extraction procedure which is quick and has reproducibility (Doelsch et al., 2008; Tessier et al., 1979).

In an untouched ecosystem, metals are almost immobile as they are bound to silicates and minerals but under the influence of human interference, metals may be found in oxides, carbonates, hydroxides, and sulfides and in other labile forms (Passos et al., 2010; Roussiez et al., 2011). Stability and fragility of elemental species depend upon the external physico-chemical properties viz. temperature, sediment grain size, pH and redox potential, presence of ligands and chelating agents etc. (Förstner, 1987; Gu et al., 2013; Gunn et al., 1988; Guo et al., 1997; Salomons and Förstner, 1984; Singh et al., 2005). Metal species can be classified into 4 categories i.e. acid extractable, reducible, oxidizable and residual forms.

It has been well established by a number of studies that metal speciation analysis in sediments helps to assess the long-term and immediate pollution level in the study region i.e. Gangetic plain (Purushothaman and Chakrapani, 2007). The present study deals with the study of geochemical fractionation of heavy metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb) in sediments of the river Ganga. Ganga, the national river of India, is suffering from severe pollution due to high anthropogenic pressure. Agricultural runoff, untreated sewage disposal, defecation and untreated industrial effluent are few examples of anthropogenic factors for pollution. The present study was conducted to assess the long-term heavy metal pollution load on the sediments, so that risk assessment of metal species can be done.

2. Materials and method

2.1. Study region

The river Ganga originates from Gangotri glacier (Garhwal Himalaya) and flows through five states (Uttarakhand, Uttar Pradesh, Bihar,

Jharkhand and West Bengal) of India covering nearly 2525 km. Ganga forms the Indo-Gangatic plain of alluvial deposit before joining the Bay of Bengal where it forms the Ganga–Brahmaputra Delta (GBD) (Shukla et al., 2012). The river Ganga covers a vast area (861,404 km^2) with runoff of 525 km^3 year^{-1} and specific yield of 609 mm year^{-1} having 5.9×10^{11} m^3 year^{-1} mean annual flow and huge sediment load of 1600×10^{12} g year^{-1} (Purushothaman and Chakrapani, 2007; Subramanian, 2007).

Varanasi (25°16′55″N 82°57′23″E, 76 m asl) is situated at the left bank of Ganga. Varanasi is known for its number of temples, narrow lane and dense population, and it sustains high anthropogenic pressure. Ganga pollution is not new to the world and numerous workers have worked on Ganga water pollution monitoring and remediation technologies (Dutta et al., 2005; Singh et al., 2002; Tripathi, 1991; Tripathi and Tripathi, 2011; Tripathi et al., 1991). Diesel locomotive works, fabric, textile and dye industries, small and medium scale metal industries, and glass and paint industries are some of the prominent industrial setups at Varanasi (DIP, 2013). Discharge of nearly 153 million liters per day (MLD) of untreated sewage and effluent from residential colonies and industries is the root cause of pollution at Varanasi (Tripathi and Tripathi, 2011). However, a systematic study of geochemical fractions of heavy metals in sediments of the river Ganga has not been reported till date.

2.2. Sampling and analysis

Sediment sampling in the river Ganga in Varanasi was done at fifteen stations from Samne Ghat to Ganga–Varuna Confluence (Fig. 1, Table 1). Sampling was done at an interval of 15 days (2 times a month) for six months (January–June 2012). A total of 180 samples were collected for the analysis. Sediment samples were collected with the help of a sediment core sampler (self made) at the depth of 30–60 cm. Sediment solution (1:5 w/v) was prepared to measure pH, EC and redox potential on the site (Pansu and Gautheyrou, 2006). Samples were packed in air tight plastic bags (250 g) and carried to the laboratory in an ice box. Sediment samples were oven dried (110 °C) to assess the moisture content by mass (ASTM D2216, 2010). For further analysis, air dried sediments were kept in an oven for a brief period of time (15–20 min) to obtain absolute moisture free samples. Samples were crushed in agate pestle mortar and sieved (75 μm sieves) to get homogenized samples. Loss on ignition (LoI) of the samples was estimated as discussed elsewhere (Kelderman and Osman, 2007). Analytical grade chemicals have been used during the experimental analysis. Grain size analysis was done with the help of Malvern Mastersizer 2000. Teflon vessels were used for acid digestion. Metal estimation was carried out by a flame atomic absorption spectrophotometer (AAnalyst 800—Perkin Elmer). Four geochemical fractions (acid extractable, reducible, oxidizable and residual) of the studied metals were obtained by
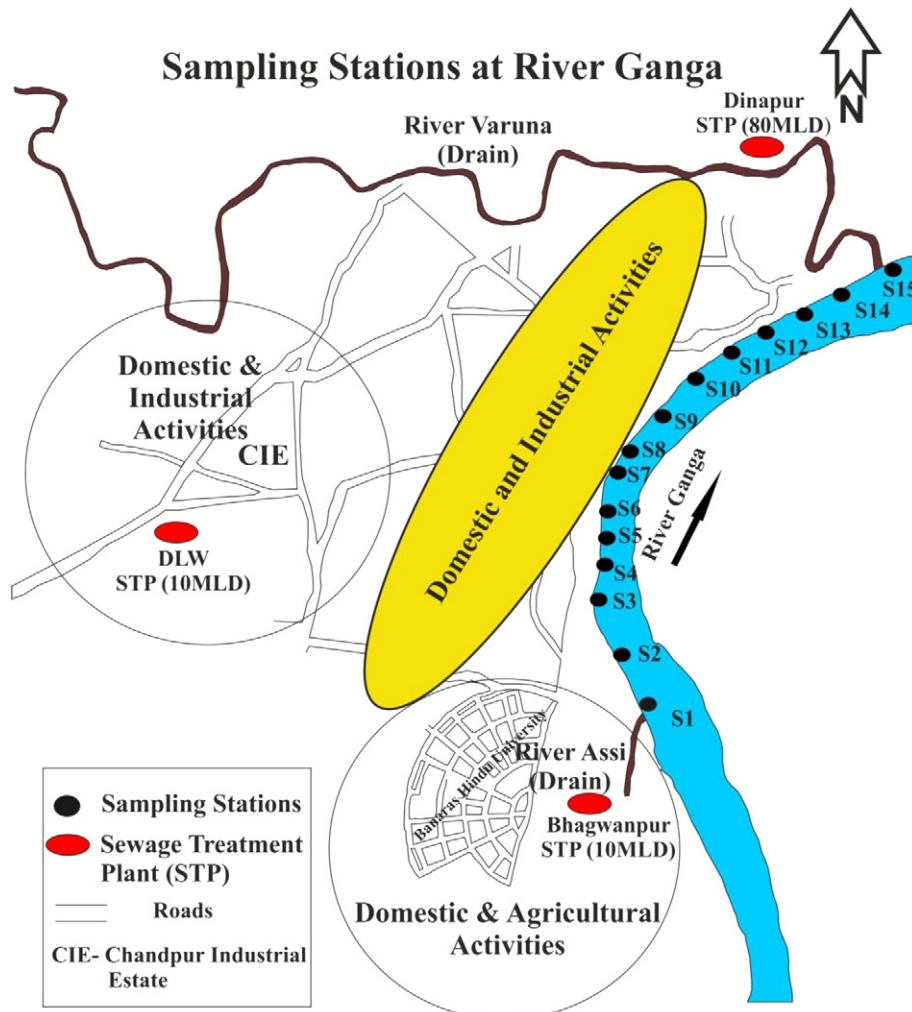

Fig. 1. Sampling stations.