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Assessment of bioavailable metals in the sediments of Yamuna flood plain using two different single extraction procedures

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ABSTRACT

Though flood plains are considered as most fertile areas across the world but they have come under severe stress due to the flow of untreated domestic and industrial effluents and therefore, needed attention for its characterisation and subsequent treatment plans. The sediment samples, collected at 0–15, 15–35 and 30–60 cm depth levels during pre and post monsoon season from east and west sides of the river Yamuna around the national capital region of Delhi, were assessed for bioavailability of lead (Pb), zinc (Zn) and nickel (Ni) using Ethylene Diamine Tetra Acetic Acid (EDTA) and acetic acid. The average concentrations of Zn (25 ± 6 mg kg^{-1}) and Pb (33 ± 6 mg kg^{-1}) leached in EDTA were higher than that of in acetic acid (Zn: 22 ± 6 mg kg^{-1}; Pb: 24 ± 5 mg kg^{-1}) whereas Ni (24 ± 6 mg kg^{-1}) leached more in acetic acid compared to EDTA (Ni: 21 ± 4 mg kg^{-1}). The bioavailable concentrations of metals were comparable among 0–15 and 15–35 cm depth samples but decreased in 35–60 cm depth samples. The post monsoon samples contained lower amounts of total metals in comparison to pre-monsoon samples, an indication of washout/dilution effects of flood/high water flow during monsoon season. The percentages of metals, with reference to their respective total concentrations, in the flood plain sediments as extracted by EDTA were in the range of 14–47% for Pb, 17–54% for Zn, and 15–39% for Ni. The Zn, Ni and Pb were soluble in acetic acid in the range of 12–39%, 16.7–36.5% and 14–36%, respectively. The chemical nature of extracting agent affected the metal leaching. Acetic acid, a weak acid, extracted the metals that were present in exchangeable fraction and easily movable whereas EDTA, hexa-dentate complexing agent, extracted metals from carbonate and organically bound fractions of the sediment samples. This could result in metal accumulation in the floodplains, biomagnification, adverse effects on water quality, sediments, aquatic lives and the vegetables grown in the flood plains. Steps should be taken to stop the direct flow of untreated waste into the river to safeguard the floodplains and life forms.

1. Introduction

The flood plains have been the most fertile farmlands, and thus have experienced large settlements resulting in high population density and increased industrial activities. At the same time, the rivers and river floodplains around the urban and industrial cities are treated as obvious sink for the sewage and domestic waste as well as industrial effluents. Heavy metals, one among many pollutants added by such waste inflow to the flood plains, are of serious concern as metals do not undergo biodegradation and persist for long time in the environment. Heavy metals undergo bioaccumulation as well as biomagnifications as they become part of food chain. Problem becomes acute when a large population consumes contaminated fishes and vegetables grown on such polluted floodplains. Recent studies have indicated high build up of metals [1,2] and organic compounds [3] in the vegetables grown in the vicinity of urban and industrial areas in India. Some of these heavy metals are essential for plant metabolism but become toxic when present in higher quantities. Soils of the flood plains act as sink for heavy metals through adsorption or sedimentation processes. Further, metals are loosely bound to soil matrix through

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electrostatic adsorption and/or ion exchange and become bioavailable with changing redox potential in the environmental systems [4].

River Yamuna passes north-south through Delhi on its eastern side the capital city of India, and receives wastewater from nearly 17 large drains and 25 small drains on year round basis. Due to its high fertility and easy access to the markets, the flood plains on either side of the river also used for agriculture activities, particularly for growing vegetables as cash crops throughout the year except during monsoon season (July–September) when flooding of low laying areas makes farming difficult. During rest of the year, the river behaves more or less like a small drain with water in the central channel.

Most of the previous work on biogeochemistry of river Yamuna has remained focussed on total heavy metal concentrations in sediments and water [5–9]. Information about the amount and proportion of bioavailability of heavy metals compared to total metal content is not available whereas it is the bioavailable form of the metals that have direct consequences to aquatic life, water quality and biomagnifications [10,11]. A recent report has revealed high levels of heavy metal concentrations in the sediments of Yamuna river along the stretch it passes through Delhi [12]. The present work was undertaken to fill this knowledge gap for the bioavailability of heavy metals in the floodplains of river Yamuna, one of the holy rivers of India. Investigations of heavy metal bioavailability using single extraction procedures have been commonly applied on sediments [13,14]. Different workers have used mineral acids at various pHs, chelating agents like ethylene diamine tetra acetic acid (EDTA), buffered salts like, NH_4OAc, neutral salts like $CaCl_2$, NH_4NO_3 and acetic acid (AA). The EDTA and AA extractable metals components are indicative of their easy availability to the plants and aquatic lives. The AA, being weak acid, used to simulate the effects of an acidic input (through rain water or accidental spills or drains with low pH) onto the sediments and removes or held at ion-exchange positions in the sediments [15]. Therefore, the AA extractable phase is expected to contain the easily mobile and bioavailable fractions of metals, which are released into the solution with slight change in pH of soil/sediments. Whereas EDTA solution is a multi-dentate complexing agent and extracts metals from non-silicate phases in sediments such as carbonate and organically bound fractions [15]. In present work, the sediment samples were collected at 0–15, 15–35 and 35–60 cm depth from the surface during pre and post monsoon season from east and west sides of the river Yamuna and analysed in laboratory for total concentrations of lead (Pb), zinc (Zn) and nickel (Ni) and their bioavailable fractions using EDTA and AA extraction procedures. The primary objectives of this study were to assess the effect of wastewater on the concentration of heavy metals in the Yamuna floodplain sediments and the metal toxicity potential of flood plain sediments.

2. Study area

The River Yamuna originates from Yamunotri glacier near *Banderpoonch* peaks (38°59′ N and 78°27′ E) in Mussourie range of the lower Himalayas at an elevation of about 6387 m above mean sea level and covers a total distance of 1370 km from origin before its confluence to Ganga in Allahabad in Uttar Pradesh. Yamuna emerges in plains from hilly terrain after Tajewala dam in Haryana. In the downstream, it starts receiving industrial and urban effluents especially in Delhi and Agra region [5]. The pollution level has been alarming even after the execution of Yamuna Action Plan (YAP I and YAP II) by Government of India. This stretch of 80 km provides opportunity to learn the adverse effects of urbanization because the most upstream sampling location does not have much input from industries and urban sectors. The midstream region, nearly 22 km, start receiving pollutants through 17 large and small drains falling on both banks of the river and is the worst affected part accounting for 70% of total pollution in only 0.4% catchment area of the entire river. The river stretch in its passage through Delhi (Fig. 1) receives 2.7 m^3 d^{-1} of sewage from these industrial and domestic sectors. The site selection was based on the drain entry points on both sides of the river and the accessibility conditions in the area.

3. Methodology

Yamuna flood plain sediment (YFPS) samples were collected up to a depth of 60 cm from surface as an intact profile using stainless steel augur from a total seven locations. However, the sediments collected at the locations W1, W3, W5, W6 and W7 along west bank, and E1, E3, E5 and E6 along east banks of the rivers were only considered in this study (Fig. 1). The W1 sample represented the upstream location and all other locations were considered based on the major drains entering into the river. Three samples corresponding 0–15, 15–35 and 35–60 cm depth were separated from each profile using thin plastic wire and stored in plastic zip bags marked as A1, A2 and A3, respectively. All samples were sun dried in plastic trays and obvious undesirable objects like pebbles etc. were removed by hand picking method. Nearly 30 gm of representative sample was taken from the bulk sun dried samples following the homogenization using coning and quartering

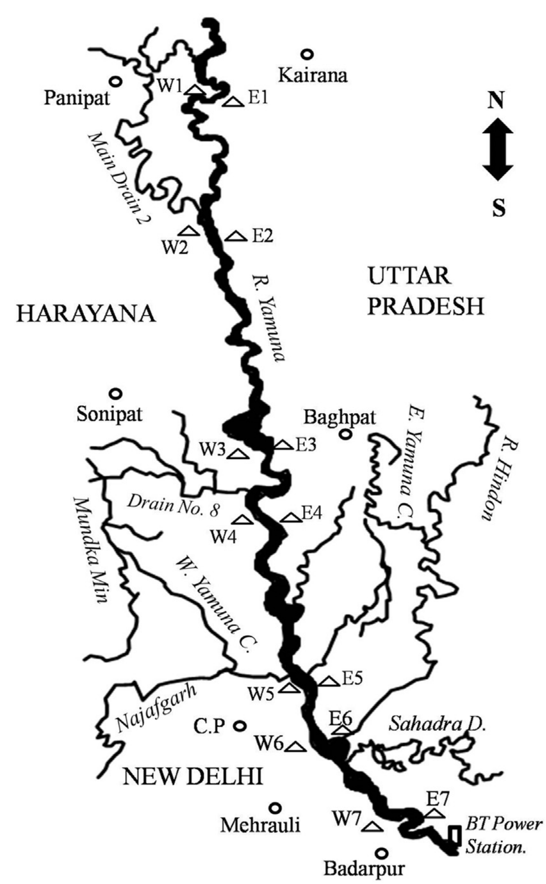

Fig. 1. Study area map (not to the scale) showing sediment sampling locations in the flood plain of river Yamuna. The sediment samples with codes W1, W3, W5, W6, W7 and E1, E3, E5, E6 were only studied for metal extraction using single extraction techniques. The sample code E and W represent the eastern and western sides of the river, respectively.