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Floodplain sedimentation in nutrient and heavy metal transfer in Jamuna and Padma rivers

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Abstract

Four sites in the Jamuna and the Padma rivers and their floodplains were selected for detailed characterization of river water, suspended sediments and soil samples, collected before, during and after the flood season of 2002. Results suggest that river water quality changes significantly with time. Total solids and suspended solids as well as turbidity of river water reached their peaks during flood season. However, total dissolved solids, electrical conductivity and hardness of river water samples collected after flood were higher than those collected during the flood season. River water samples were found to be more alkaline after flood. Sedimentation during flood appears to play an important role in regulating floodplain soil characteristics. Floodplain soils became more alkaline at top layers after the flood season, which indicated new sedimentation. In floodplain soil, all the micronutrients either decreased or remained virtually unchanged after flood season. Among the macronutrients, nitrogen, potassium and magnesium in floodplain soil decreased by 60%, 4.1% and by 4.2%, respectively; while phosphorus and calcium increased by 41% and 83%, respectively after flood season. Copper, iron, manganese and zinc in floodplain soil decreased by 17%, 2%, 5% and 7%, respectively. Increase in phosphorus content at the topsoil may be attributed to sedimentation, since suspended sediments during flood showed very high phosphorus contents. Arsenic, chromium and lead contents of the floodplain soil increased after flood by 31%, 25% and by 30% on an average, respectively, possibly due to partitioning of these heavy metals from the aqueous (river water) phase to soil e.g., by adsorption. Results of batch experiments, which were conducted to simulate the reducing condition in the floodplains during inundation by floodwater, suggest that such reducing condition may have a significant impact on soil as well as river water quality. For example, decrease in nitrogen content at the topsoil of floodplains and increase in dissolved nitrogen in river water were found to be consistent with the results of batch experiments. Estimates made in this study suggest that huge quantities of nutrients and heavy metals are transported through the Jamuna and the Padma river systems, both in dissolved and suspended forms.

Keywords: Floodplain sedimentation, soil nutrients, heavy metals

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1. Introduction

Floodplains have been extensively used and exploited over millennia as important locations for settlement and agriculture, and in many of today's landscapes, these remain their primary functions. In terms of scientific and applied research, floodplains have gained recognition as vital components of the fluvial ecosystem. Floodplain research is now considered crucial to the study of whole catchment ecosystems, from the perspective of material fluxes, contaminant storage, and riverine ecology.

Floodplain wetlands have simultaneously been described as the "kidneys of the landscape" and as "biological supermarkets" (Mitsch, 1995) illustrating the importance of their role in the ecological functioning of most river systems. Exchanges of water, sediment and associated nutrients between river channels and floodplains are important for the ecological functioning for large floodplain-river ecosystems (Thomas *et al.*, 2000). The ecological integrity of floodplain-river is dependent upon hydrological connections between the main river channel and adjacent floodplain. These connections, which take place during the floods, facilitate the exchange of carbon and nutrients and influence productivity (McGinness *et al.*, 2002).

Water plays an important role in connecting landscape patches in dynamic spatial mosaics of floodplain-river ecosystems (Spink *et al.*, 1998). During inundation, dissolved organic carbon and nutrients are released from floodplain sediments and plant matter and may be transported into the river channel. Carbon is an important food source for riverine organisms, and forms the base of the food web in floodplain-river ecosystems (Robertson *et al.*, 1998). Hence its exchange between river and floodplain patches is important for the productivity of these systems. Human activities such as urbanization, agricultural and industrial development changes water pathways and the supply of materials to river systems. Anthropogenic activities especially those related to agriculture often result in increased nitrate in the aquatic environment and nitrate is now considered to be a widespread pollutant in aquatic ecosystems. It is typical of non-point source pollution by agricultural and residential activities (Ismail *et el.*, 2002).

River sediments frequently act as a sink for heavy metals, which enter the fluvial system from weathering of bedrock, from diffuse agricultural and urban sources, or as point source industrial pollution. Horowitz (1991) argues that suspended sediment commonly contains substantially higher concentrations of trace elements than are found in solution. Studies of channel and floodplain sediments are therefore important if we are to understand the transport and storage of contaminants within terrestrial and aquatic ecosystems (Carton *et al*, 2000).

Bangladesh is a lower riparian country of the three greatest rivers of the world - the Ganges, the Brahmaputra and the Meghna. The total catchment area of the Ganges-Brahmaputra-Meghna river system stands at 1.76 million square kilometers covering areas of China, India, Nepal, Bhutan and Bangladesh, of which only 8 per cent lies within Bangladesh. The floodplain of these rivers and their numerous tributaries and distributaries covers about four-fifths of the country. The major part of Bangladesh is deltaic, which was built up and gradually raised through several million years by the silt carried by the rivers from the mountains on the three sides of the Bengal Basin, and mainly from the Himalayas. As a result of flat topography of the floodplain, one-fifth to one-third of the country is annually flooded by overflowing rivers during monsoon when the rainfall within the country is also very high. This annual phenomenon of river flooding plays a vital role in the floodplain ecosystem.

Two distinct sedimentation processes contribute to this delta's formation. The most obvious occurs when shifting of river channels deposit volumes of river-borne sediments in a single monsoon season (lateral accretion). Another process occurs when sediment-laden water spill onto the floodplains and finer suspended sediment particles settle as the floodwater recedes (vertical accretion).

These natural sedimentation processes have been and continue to be disrupted by the construction of roads, bridges and culverts, embankments, and flood control or water management structures. The effects these interventions have on the complex hydrology and environment of Bangladesh are of growing interest to planners and resource managers.

While existing literature contains considerable information on deltas and their formation, hard data on floodplain sedimentation are scarce, and the subject is not well understood. Reliable data and knowledge about the complex sedimentation processes of Bangladesh's floodplains are particularly rare. Studies that have attempted to measure floodplain sedimentation rates in the country are few and have yielded little quantitative information. Also poorly understood, although long debated, is the role deposited sediments play in soil fertility and agricultural production in Bangladesh.

The overall objective of this study was to improve basic understanding of the role of floodplain sedimentation in nutrient and contaminant transfer in the Jamuna and Padma river-floodplain systems. Specific aims of this study include:

(i) Determination of dissolved nutrient and contaminant contents in water samples from Jamuna and Padma rivers.
(ii) Determination of nutrient and contaminant contents of suspended sediments from Jamuna and Padma rivers.
(iii) Determination of nutrient and contaminant contents of soil samples collected from the floodplains of the Jamuna and Padma rivers, before and after flood.
(iv) Assessment of the role of floodplain sedimentation in regulating nutrient and contaminant contents of floodplain soil.
(v) Assessment of the effect of biogeochemical processes within the floodplain on floodplain soil and river water characteristics.

2. Methods

2.1 The study area

The Jamuna and the Padma rivers carry the highest sediment load among all the major river systems of Bangladesh. The measured sedimentation over the floodplain of the Jamuna was 1 to 4 mm in the year 1995 (Delft, 1996). The study of Jamuna floodplain sedimentation by Delft (1996) indicates that majority of the floodplain sediment originates in the Jamuna river and more than 90% of the sediments in the over bank flow will deposit (Chowdhury et al., 1996). The seasonal flooding characteristics have an important influence on the physical and biological properties of soil and, as a result, a significant bearing on land-use and agricultural potential.

The water level of Brahmaputra-Jamuna starts rising in March/April due to snow melt in the Himalayas and attains a peak in June (Chowdhury et al., 1996). It rises again and reaches the annual peak in late August due to heavy monsoon rainfall. The maximum peak discharge was 98,300 cumec in 1988 and minimum low flow discharge was 2,860 cumec in 1971. The Ganges-Padma starts rising in June/July and attains the peak in late August or early September (Chowdhury et al., 1996). When this peak coincides with the peak of

Brahmaputra, as it did in 1988, severe flooding occurs. The maximum peak discharge of the Ganges was 76,000 cumec in 1987 and minimum low flow discharge was 261 cumec in 1993.

2.2 Sampling locations

In this study, four sites, two each from the floodplains of the Jamuna and the Padma rivers, were selected for detailed characterization of floodplain soil (see Fig. 1). The factors considered in selecting sampling site included proximity to the river, flood regime, disturbance of natural conditions by roads, embankments, etc. The accessibility of the sites during floods and at other times was also taken into account.

For the Jamuna floodplain, a village named Nelpur under Shibalaya *thana* of Manikganj district was selected for sampling, which is located approximately one kilometer upstream of the Aricha ferry *ghat*. For the Padma river floodplain, a village named Paturia under Harirampur *thana* from the same district was selected, which is at the downstream of the Paturia ferry *ghat*. The river along the Paturia village carries the combined flow of the Jamuna and the Padma (Fig. 1). Besides, Bashilghat village of Srinagar *thana* under Munshiganj district was included in the study as a rainwater-inundated floodplain site.

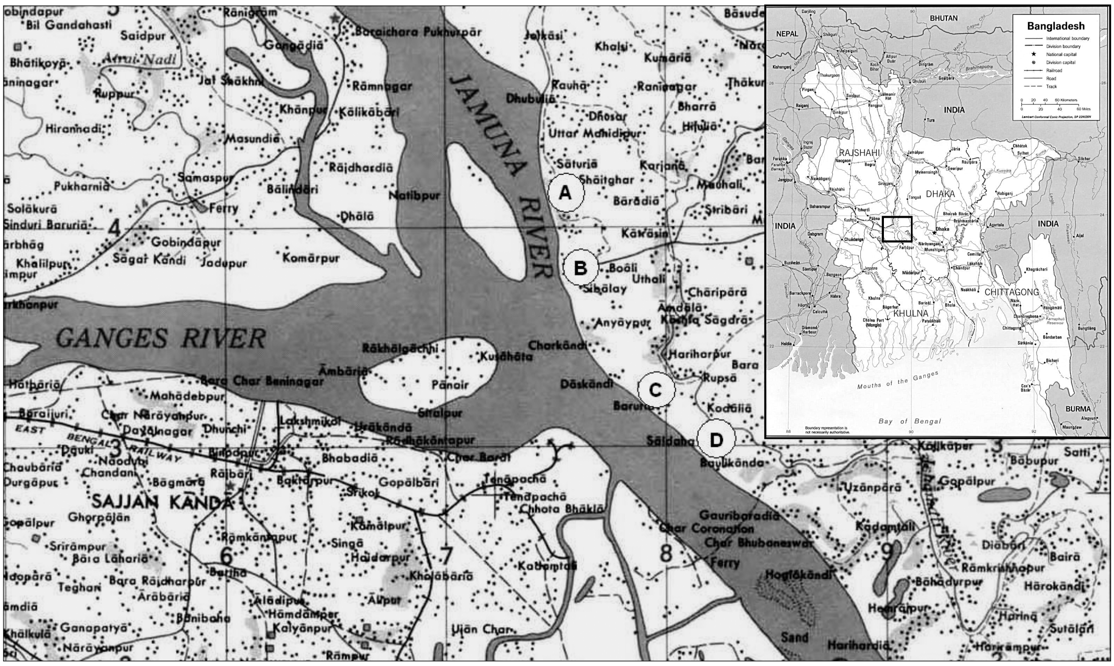


Fig. 1. Site location map; A: Jamuna Shibalaya, B: Jamuna Aricha, C: Padma Paturia Ghat, D: Padma Paturia Village (Source: http://www.lib.berkeley.edu/EART/india/250k.html, prepared by Army Map Service, Corps of Engineers, U.S. Army)

Floodplain soil samples collected from the Nelpur village (location "A" in Fig. 1) were identified as 'Jamuna-Shibalaya', and those collected from the downstream location (near Aricha; location "B" in Fig. 1) were identified as 'Jamuna-Aricha'. Floodplain soil samples collected from near the Paturia ferry *ghat* (location "C" in Fig. 1) were identified as 'Padma-Paturia *ghat'*, and those collected from the downstream location (location "D" in Fig. 1) were identified as 'Padma-Paturia village'. Water and suspended sediment samples were collected from the stretches of the Jamuna and Padma flowing along the Nelpur village (approximately between locations A and B in Fig. 1) and Paturia village (approximately between locations C and D), respectively. General information regarding these two *thanas* are listed in Table 1.

Table 1
General information of sampling locations

	Shibalaya	Harirampur
Location	23^{0}44'~23^{0}54'N 89^{0}42'~89^{0}57'E	23^{0}38'~23^{0}48'N 89^{0}50'~90^{0}03'E
Area (square km)	187.76	248.9
River Area (square km)	34.16	102.1
Monsoon Season	May-October	May-October
Maximum temperature	42.2^{0}C, April/May	42.2^{0}C, April/May
Minimum temperature	5.6^{0}C, January	5.6^{0}C, January
Land type	25% High-land-only inundated in due to drainage congestion due to heavy rainfall (<15days), 70% Medium high land-inundated by river water for up to 2/3 months, inundation depth up to 90 cm, 5% Household	65% Medium high land-inundated by river water for up to 1/2 months, inundation depth up to 90 cm, 30% Medium high land- inundated by river water for up to 3/4 months, inundation depth from 90 cm up to 180 cm, 5% Household

Source: SRDI (1999) and SRDI (2002)

2.3 *Flooding and inundation during the study period*

The flooding that occurred during the study period of 2002 was of moderate scale and it caused inundation in approximately 15000 square kilometer, which is about 10.2% of the total area of the country. These areas by convention exclude the permanent water-areas of the country, which cover approximately 20% area of the country. Figure 2 shows the comparison of the flooding of 2002 with those during the past fifty years.

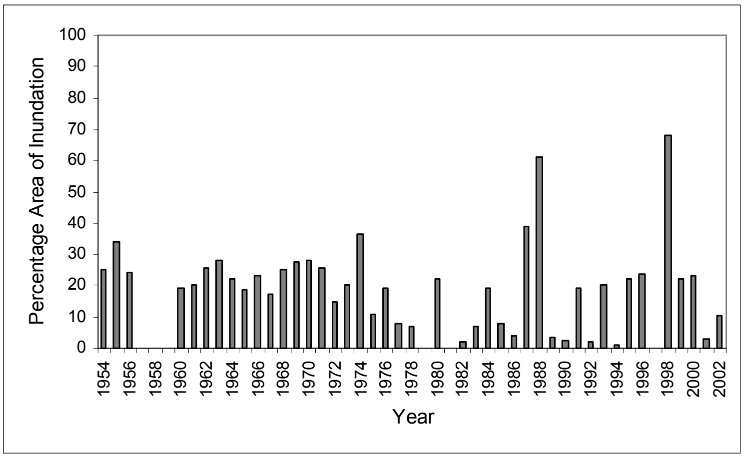


Fig. 2. Percentage area of inundation in Bangladesh during flood season from 1954 to 2002

2.4 Sampling program

Sampling dates were fixed after analyzing the hydrographs of the Jamuna and the Padma for the previous two years. Sampling of river water, suspended sediment and floodplain soil samples were carried out according to the schedule shown in Table 2. Since characteristics of river water, suspended sediment and floodplain soil may vary significantly both spatially and with time, intensive sampling is usually required to characterize such systems. However, due to time and resource constraints, such intensive sampling could not be performed in this study.

Table 2
Schedule for sample collection

Sampling Period	Sampling Date	Samples Collected
Before Flood	16 May, 2002	Floodplain soil, River water
During Flood	13 August, 2002	Suspended sediment, River water
After Flood	26 October, 2002	Floodplain soil, Suspended sediment, River water

2.5 Collection and analysis of river water samples

River water samples were collected for the determination of selected dissolved nutrients and heavy metal ions. During each sampling operation, from each river, water samples were collected from two separate locations (approximately 15~20m away) from a depth of about 30 cm below the water surface. From each location, samples were collected in two 1.5L pre-washed plastic bottles. Water sample in one bottle was acidified in the field with concentrated nitric acid (2 ml per liter of water), which was later used for analysis of metal ions.

The river water samples were analyzed for eleven mineral nutrients, three heavy metals (As, Cr, Pb) and a number of other water quality parameters. The mineral nutrients included six macronutrients (N, P, K, Ca, Mg, S) and five micro-nutrients (B, Cu, Fe, Mn and Zn). The other water quality parameters analyzed included pH, electrical conductivity, turbidity, TS, TDS, TSS and hardness.

Concentrations of Ca, Mg, K, Cu, Fe, Mn, Zn, As, Cr and Pb were determined using an Atomic Absorption Spectrophotometer (Shimadzu, AAS 6800). Phosphate, sulfate, sulfide, ammonia, nitrate and boron were measured using a Spectrophotometer (Hach, DR/4000U). Sulfide was determined using the Methylene Blue method, ammonia by the Nessler method, nitrate by the Cadmium Reduction method, and boron by the Carmine method. The pH of water samples was determined in the laboratory with a pH meter attached with a glass electrode (Hach); electrical conductivity was measured with conductivity meter (CMD8500 WPA). Turbidity was determined using a portable turbidity meter. Hardness was determined by the EDTA titration method. Total, dissolved and suspended solids were measured following standard methods (APHA, 2003)

2.6 Collection of suspended sediment and floodplain soil samples

Suspended sediment samples were collected from an engine boat with a sediment sampler. During the first sampling operation, before flood, suspended sediment could not be collected successfully as sediment concentration was very low. During the flood season, for each river (the Jamuna and the Padma), suspended sediments were collected from two locations - close to the riverbank and away from the riverbank. After the flood season, suspended sediments were collected from the rivers from locations away from the riverbank.

Floodplain soil samples were collected from the Jamuna and the Padma floodplains before and after flood. During the flood season soil samples could not be collected as the sampling sites were inundated with floodwater. Floodplain soil core samples were collected by inserting into the soil, a 15cm diameter PVC pipe sampler, about 450 mm in height. A 3-pound hammer was used to insert the pipe sampler to required (~ 30cm) depth. After withdrawing the sampler along with the soil core, both its ends were sealed with tape to reduce contact with air and then transported to the laboratory. Before flood (May 2002), two soil core samples were collected from location “A” of Jamuna floodplain (see Fig. 1) and two from location “C” of Padma floodplain. Two soil core samples were collected from the Srinagar site in Munshigonj district on June 22, 2002. After flood (October 2002), a total of 10 soil core samples were collected: 4 each from Jamuna and Padma floodplains (two from each sampling locations A, B, C and D), and 1 each from Nelpur (Jamuna floodplain) and Paturia (Padma floodplain) village areas, which remain un-inundated during flood.

2.7 Analysis of soil and suspended sediment samples

Suspended sediment samples and floodplain soil core samples were analyzed for five macro-nutrients (N, P, K, Ca, Mg), four micro-nutrients (Cu, Fe, Mn, Zn), and three heavy metals (As, Cr, Pb). Besides, pH, electrical conductivity, and organic carbon content of the sediment and soil samples were also determined.

Before analysis, each soil core sample was divided into several segments. Soil core samples collected before flood were divided into three segments: first segment consisting of the top 7.5 cm, second segment the next 7.5 cm, and the third segment consisting of the rest of the core. Soil core samples collected after flood were divided into five segments: top 2.5cm, next 2.5cm, next 2.5 cm, next 7.5 cm and the last segment consisting of the rest of the core.

For analysis of metal ions, the soil and sediment samples were digested with aqua-regia. For digestion, 5g of oven-dried (at 110°C for 24 hours) sample was mixed with 2.5 ml concentrated nitric acid and 7.5 ml concentrated hydrochloric acid in a 500 ml volumetric flask. The sample was kept overnight in the flask and then it was heated for two hours. The contents of the flask were stirred for 5 minutes, then cooled and filtered using a filter paper. The volume of the filtrate was adjusted to 500 ml with de-ionized water. It was then used for analysis of metal ions (Cu, Fe, Mn, Zn, As, Cr, Pb) using an Atomic Adsorption Spectrophotometer (Shimadzu, AAS 6800). Arsenic was analyzed using Graphite Furnace (GF), while the rest of the metal ions were analyzed using Flame Emission technique.

Besides, oxalate extractable metal ion (As, Cr, Pb) concentrations were determined, following the method described in Keon *et al.* (2000), in order to assess the amount of these metals associated with iron-oxyhydroxides. Here, 25 ml of 0.2M oxalic acid solution was added to 2.5g of soil sample and thoroughly mixed for two hours by tumble shaking. Then the mixture was centrifuged for 20~25 minutes and the supernatant was decanted. Then another 25 ml oxalic acid solution was added to the soil and the whole procedure was repeated. The extraction liquid was used for analysis of arsenic, chromium, lead and iron using an AAS (Shimadzu, AAS 6800).

NO_3-N of soil and sediment samples was measured following the method described in Alam et al. (1991), after mixing soil samples with distilled water at a ratio of 1:5 (soil : water). Then

NO_3-N concentration was determined by the Cadmium Reduction Method using a spectrophotometer (Hach, DR/4000U). Plants absorb phosphorus from soil in the forms of $H_2PO_4^{1-}$, HPO_4^{2-} and PO_4^{3-} ions. Under ideal conditions plants take up chiefly the monovalent or the ortho-phosphate ion $H_2PO_4^-$ from soil. It is one of the three macro-anions used by plants, the other two being nitrate and sulfate (Alam et al. 1991). In this study, phosphorus concentration in suspended sediment and soil samples was determined by the Molybdophosphoric blue color method. This method is based on the principle that in an acid molybdate solution containing orthophosphate ($H_2PO_4^{1-}$) ions, a phosphor-molybdate complex forms that can be reduced by stannous chloride ($SnCl_2.2H_2O$) and other reducing agents to a molybdenum blue color. The intensity of blue color varies with phosphorus concentration. Details of the procedure are available in Alam et al. (1991) and Hussain (2003).

The pH for soil and sediment samples was measured with pH paper, and also with a pH meter attached with a glass electrode in a soil-water (1:2.5) suspension, following the method described in Alam et al. (1991). Electrical Conductivity was determined in filtered soil-water (1:5) suspension as described in Alam et al. (1991). Organic Carbon in soil was measured by the Dry Combustion Method, where carbon in soil is oxidized to CO_2 at very high temperature in a furnace (Alam et al., 1991). The difference in weight (lost) provides an estimate of the amount of organic carbon present in the soil. Then the total amount of organic matter can be obtained by using the “Van Bemmelen Factor” of 1.724, on the assumption that organic matter of average soil contains 58% of organic carbon.

For assessing the effect of biogeochemical processes within the floodplain on floodplain soil and river water characteristics, batch experiments were set up to simulate the reducing environment that may develop in floodplain during inundation by floodwater, especially in the presence of vegetation (organic) matters, and possible mobilization of nutrients and heavy metals under such reducing condition was assessed. These experiments were carried out with soil core samples collected from the Jamuna and Padma floodplains before flood.

Mobilization of the nutrients from the floodplain soil samples was evaluated under four different geochemical conditions: (i) inundation with rainwater, (ii) inundation with deionized water, (iii) inundation with rainwater mixed with glucose and (iv) inundation with deionized water mixed with glucose. Glucose was used to simulate effect of organic matter on possible mobilization. Two hundred and fifty grams of top soil (from the top 7.5cm of collected soil cores) was taken in a 1-liter glass beaker and kept inundated with the 500 ml of specific inundation water (as noted above) for a period of 21 days. After the 21-day inundation period, water samples were collected from the beakers and analyzed for ten nutrients (N, P, K, Ca, Mg, S, Cu, Fe, Mn, Zn) and three heavy metals (As, Cr, Pb).

3. Results and discussion

3.1 General characteristics of river water, suspended sediment and floodplain soil

3.1.1 pH value

Table 3 shows the pH values of river water samples collected during this study. Water samples were slightly alkaline for both Jamuna and Padma rivers throughout the season and they became more alkaline after the flood season. Suspended sediment samples collected during the flood season were slightly acidic for both the Jamuna and the Padma rivers (Table 4). The pH values remained more or less unchanged after the flood.

Table 3
Changes of river water pH with flood season

	Jamuna River	Padma River
Before Flood	7.44 - 7.59	7.30 - 7.38
During Flood	7.53 - 7.59	7.12 - 7.50
After Flood	7.88 - 7.91	7.94 - 7.98

Table 4
Suspended sediment pH during and after flood

	Jamuna River	Padma River
During Flood	6.73	6.23
After Flood	6.75	6.25

The FAP 16/FAP19 (1995) suggested, as one of its findings, that soils that receive new sediments are near neutral to alkaline in reaction. Older soils, which are not receiving significant amounts of new alluvium, have a lower pH in the topsoil than in subsoil layers. Table 5 shows pH values of floodplain soil core samples collected before and after flood, as a function of depth. It shows the top 0-7.5cm soil layer to be more alkaline after the flood, possibly due to new sedimentation.

Table 5
pH of floodplain soil core samples before and after flood

	Jamuna Floodplain		Padma Floodplain	
Depth(cm)	Before Flood	After Flood	Before Flood	After Flood
0-7.5	6.0 - 6.2	6.3 - 7.7	6.5 - 6.9	6.5 - 7.8
7.5-15.0	6.2 - 6.5	6.5 - 7.5	6.4 - 6.7	6.5 - 7.0
15.0-below	6.5 - 6.7	6.5 - 7.3	6.0 - 6.6	6.5 - 7.3

It should be noted that the soil samples from un-inundated sites of Jamuna and Padma floodplains had slightly acidic to neutral pH values (6.5-7.2), whereas those from the Srinagar floodplain, which is primarily inundated by rainwater, had moderately acidic pH values (4.2-4.8).

3.1.2 Solids content

TS, TDS and TSS along with turbidity of the water samples collected from the two rivers during the study period are shown in Fig. 3. It shows that suspended solids concentration increased markedly after the flood with a corresponding increase in turbidity.

Suspended solids concentrations varied from 9.5 mg/l to 36 mg/l before flood, whereas during flood it increases by almost 13 times, varying between 263.5 mg/l to 297.5 mg/l. Dissolved solid concentration also increased significantly during flood, from 43 - 76.5 mg/l before flood to 132 - 133 mg/l during flood. Dissolved solids continued to increase after flood, reaching 191 - 228.5 mg/l, which is consistent with the increase in electrical conductivity (Table 6).

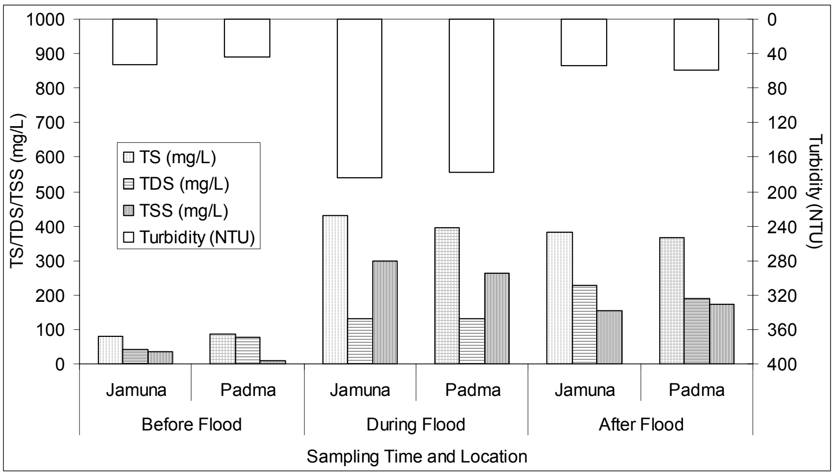


Fig. 3. Variation of TS, TDS, TSS and Turbidity of river water samples during the study period

Table 6. Changes of river water electrical conductivity (EC) with flood season

	Electrical Conductivity (µS/cm)	
	Jamuna River	Padma River
Before Flood	91.0	91.0
During Flood	89.5	88.5
After Flood	125.5	116.5

3.1.3 Organic matter

Table 7 shows organic matter contents of suspended sediments collected from the Jamuna and Padma during and after flood. Organic contents of suspended sediments were low to moderate. Table 8 shows organic matter contents of floodplain soil samples from the Jamuna and the Padma floodplains and their changes after the flood.

Table 7
Suspended sediment organic matter content during and after flood

	Organic Matter (%)	
	Jamuna River	Padma River
During Flood	1.69	0.47
After Flood	1.23	1.16

Organic matter content of topsoil of the Jamuna floodplain was low to moderate (0.7-2.63%) after flood; FAP 16/FAP19 (1995) also reported similar values (0.5-1.1%) for organic matter contents of Jamuna floodplain soil. For the Padma floodplain, organic matter content of topsoil varied between 0.5-2.06% for samples collected after flood. Organic matter contents of soil samples from the un-inundated floodplain (village) sites and the Srinagar site were relatively higher (Hussain, 2003), which is consistent with the data (~2.5%) reported by FAP 16/FAP19 (1995).

Table 8
Organic matter content (%) of floodplain soil core samples before and after flood

	Jamuna Floodplain			Padma Floodplain		
Depth(cm)	Before Flood	After Flood	% Change	Before Flood	After Flood	% Change
0-7.5	1.198	1.451	+21.2%	1.103	1.331	+20.7%
7.5-15.0	1.151	1.166	+1.30%	1.263	1.521	+20.5%
15.0-below	1.231	0.585	-52.5%	1.413	1.650	+16.8%

The increase in organic matter contents of the topsoil layers of the floodplains cannot be attributed to floodplain sedimentation, as the suspended sediments were not rich in organic matter content. Therefore, some other bio-geochemical processes such as algal activity may be responsible for this increase. According to Brammer (1995), standing water provide the conditions for nitrogen fixing blue-green algae to grow rapidly, the remnants of which release nutrients to plant roots.

3.2 Nutrient contents of river water

Dissolved nutrient contents of river water samples, collected before, during and after flood from the Jamuna and Padma rivers are presented in Table 9. It shows that only dissolved nitrogen and boron contents of river water samples increased during the flood, whereas changes in the other dissolved nutrient contents are minor. Nitrogen concentrations increased significantly, about 4 to 5 times, both during and after flood compared to their levels before flood. Boron concentration also increased significantly during flood season for both the rivers.

Among the nutrients experiencing minor changes, phosphorus concentration increased for the Jamuna while it decreased for the Padma during flood. Potassium concentration for Jamuna continued to increase throughout the flood season, but for Padma it rose during flood and fell again after flood. Calcium, magnesium and sulfur increased after flood for both the rivers. Iron and zinc showed similar pattern - very little variation with flood season while manganese concentration increases during flood for both the rivers. Copper concentration decreased with the flood season for both the Jamuna and the Padma.

3.3 Nutrient contents of suspended sediments

Nutrient contents of suspended sediment samples collected from the Jamuna and the Padma are shown in Table 10. It shows that sediment associated nitrogen (in the form of NO_3-N) increased quite significantly after the flood for both the rivers, with much larger increase in the Jamuna. This observation is consistent with that reported by FAP16/FAP19 (1995). Phosphorus concentration in suspended sediments of Padma decreased (up to 63%) after flood, but in case of the Jamuna phosphorus concentration increased (about 8%). After flood, Copper and Manganese concentrations in suspended sediments decreased slightly (8~9%) in the Jamuna, but increased significantly (98~126%) in Padma. Average Zinc concentration decreased in the Jamuna by 46%, but increased in the Padma by 83% after flood. Changes in other nutrient contents of the suspended sediments were minor. In both the rivers, Potassium concentration in sediments increased slightly (1.5~7%) after flood. Calcium and Magnesium concentrations decreased in Jamuna but increased in Padma after flood; iron concentration increased in both Padma (by 13%) and Jamuna (by 0.6%). The increase in the concentration of sediment-bound copper, manganese and zinc in the Padma may be attributed to the increase in pH of river water after the flood (Table 3), which favors partitioning (adsorption) of metal cations to solids.

Table 9
Nutrient contents of river water samples collected from the Jamuna and the Padma

	Jamuna River			Padma River		
	Before Flood	During Flood	After Flood	Before Flood	During Flood	After Flood
N^1 (mg/L)	0.5395	2.961	1.8065	0.5485	2.216	2.015
P^2 (mg/L)	0.1075	0.1180	0.0605	0.1375	0.0975	0.1005
K (mg/L)	3.0383	3.2987	4.3420	2.9640	3.2235	3.1584
Ca (mg/L)	2.8939	3.0840	3.9044	2.9368	3.0893	3.5989
Mg (mg/L)	1.8860	1.8952	1.9990	1.8854	1.9056	1.9994
S^3 (mg/L)	14.556	12.8155	38.71	14.706	13.357	22.7685
B (mg/L)	0.1000	0.3500	0.0000	0.0000	0.0500	0.9000
Cu (mg/L)	0.2270	0.2088	0.1894	0.2435	0.1935	0.1717
Fe (mg/L)	0.2515	0.2483	0.2290	0.2390	0.2674	0.2542
Mn (mg/L)	0.0022	0.0046	0.0047	0.0023	0.0046	0.0042
Zn (mg/L)	0.2489	0.2557	0.2561	0.2417	0.2589	0.2537

[1] Dissolved Nitrogen as NH_3-N and NO_3^-N; [2] Dissolved Phosphorus as PO_4^{3-}; [3] Dissolved Sulfur as SO_4^{2-} and S^{2-}

Table 10
Nutrient contents of suspended sediment samples collected from the Jamuna and the Padma

	Jamuna River		Padma River	
	During Flood	After Flood	During Flood	After Flood
N^1 (mg/kg)	0.65	6.00	2.40	6.10
P^2 (mg/kg)	13.99	15.16	12.57	6.74
K (mg/kg)	1401	1422	1305	1393
Ca (mg/kg)	113	97	85	133
Mg (mg/kg)	175	172	168	175
Cu (mg/kg)	61	57	29	57
Fe (mg/kg)	1744	1755	1555	1754
Mn (mg/kg)	45	41	19	43
Zn (mg/kg)	174	93	51	93

[1] Sediment associated Nitrogen as NO_3-N; [2] Sediment associated Phosphorus as available P,

3.4 Nutrients in floodplain soil and impact of flooding on its characteristics

Figures 4, 5 and 6 show average profiles of nine nutrients for the soil core samples collected from the Jamuna and the Padma floodplains before and after flood. These figures show that among the macro-nutrients, phosphorus and calcium contents increased in the top soil layers of both the floodplains after flood, whereas nitrogen and magnesium concentrations decreased. Potassium, copper and manganese concentrations in the topsoil layers of Padma floodplain increased after flood, but they decreased for the Jamuna floodplain. After flood, iron content decreased significantly for soil core samples from the Jamuna floodplain, but very little change was observed for the soil cores from Padma floodplain (Fig. 6). Zinc decreased at the lower layers for the Jamuna floodplain soil cores, but remained more or less unchanged for the Padma floodplain (Fig. 6).

Table 11 shows nutrient contents of only the top 0-7.5cm segment of soil core samples collected from the Jamuna and Padma floodplains. Among the nutrients, nitrogen, phosphorus, calcium and copper show significant changes at topsoil after flood. Nitrogen concentration decreased 50%, on an average, at the two floodplains. Phosphorus concentration increased by 67% at the Jamuna floodplain and by 42% at the Padma floodplain. At the Jamuna floodplain, calcium concentration increased by 82% while at the Padma floodplain the increase was 47%. For copper, the changes showed opposite patterns for the two floodplains; for Jamuna floodplain it decreased by 39%, but for Padma floodplain in increased by by15%.

Other than these, magnesium, potassium, iron, manganese and zinc showed insignificant changes at the top 0-7.5cm segment of soil. At the Jamuna floodplain magnesium increased slightly, but at the Padma it decreased by 7.4%. Potassium and manganese decreased by 6.5% and 3.3%, respectively at the Jamuna floodplain; but showed opposite trend (i.e., increased by 2.5% and 7.3%, respectively) at the Padma floodplain. Iron decreased slightly at both the floodplains, while zinc increased by 4.6% and 1.6% for the Jamuna and Padma floodplains, respectively.

Table 11
Nutrient content floodplain topsoil before and after flood

Top Layer 0-7.5 cm	Jamuna Floodplain		Padma Floodplain	
	Before Flood	After Flood	Before Flood	After Flood
N[1] (mg/kg)	5.22	2.50	5.87	2.95
P[2] (mg/kg)	8.38	13.98	6.93	9.84
K (mg/kg)	1448	1353	1305	1338
Ca (mg/kg)	94	171	93	136
Mg (mg/kg)	226	228	227	210
Cu (mg/kg)	65	39	36	41
Fe (mg/kg)	1762	1758	1727	1723
Mn (mg/kg)	42	40	34	36
Zn (mg/kg)	92	96	84	85

[1]Nitrogen as NO_3-N, [2]Phosphorus as available P

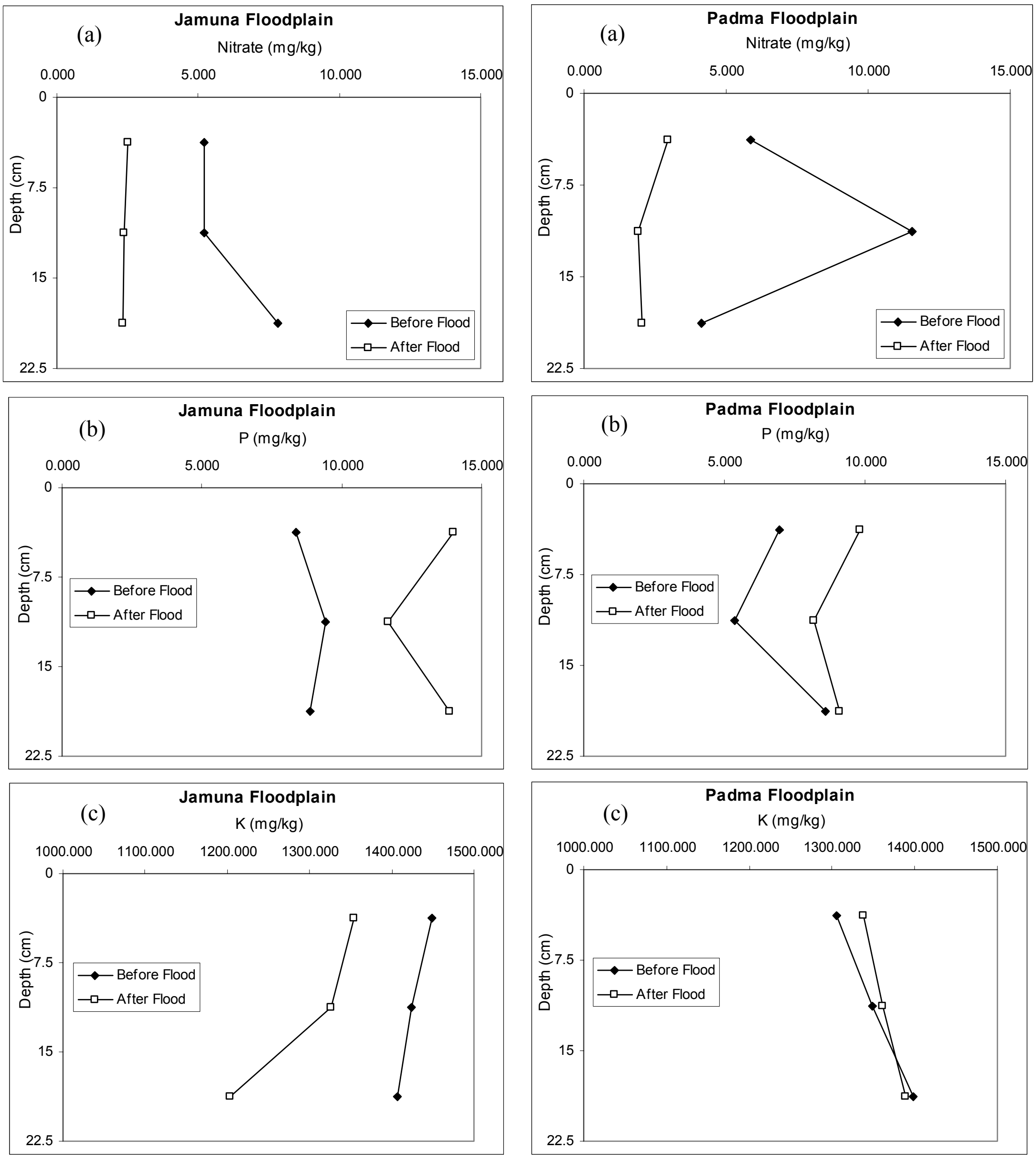


Fig. 4. Average profiles of primary macro-nutrients (a) Nitrate, (b) Phosphorus, and (c) Potassium for soil core samples collected from the Jamuna and Padma floodplains

3.5 *Heavy metals in river systems and floodplain soil*

Apart from nutrients, contaminants are also transported through river systems, either in dissolved state or in association with suspended sediments, and are transferred to floodplain by sedimentation through adsorption-desorption and/or other processes. In this study, transport of three heavy metals - arsenic, chromium and lead - through the selected rivers were evaluated by measuring their concentrations in river water and suspended sediment samples collected at different times. Effect of floodplain sedimentation on the concentration of these metals in the topsoil was assessed through analyses of topsoil samples collected before and after the flood season. An estimation of the amounts of these heavy metals transported through the river system has also been made.

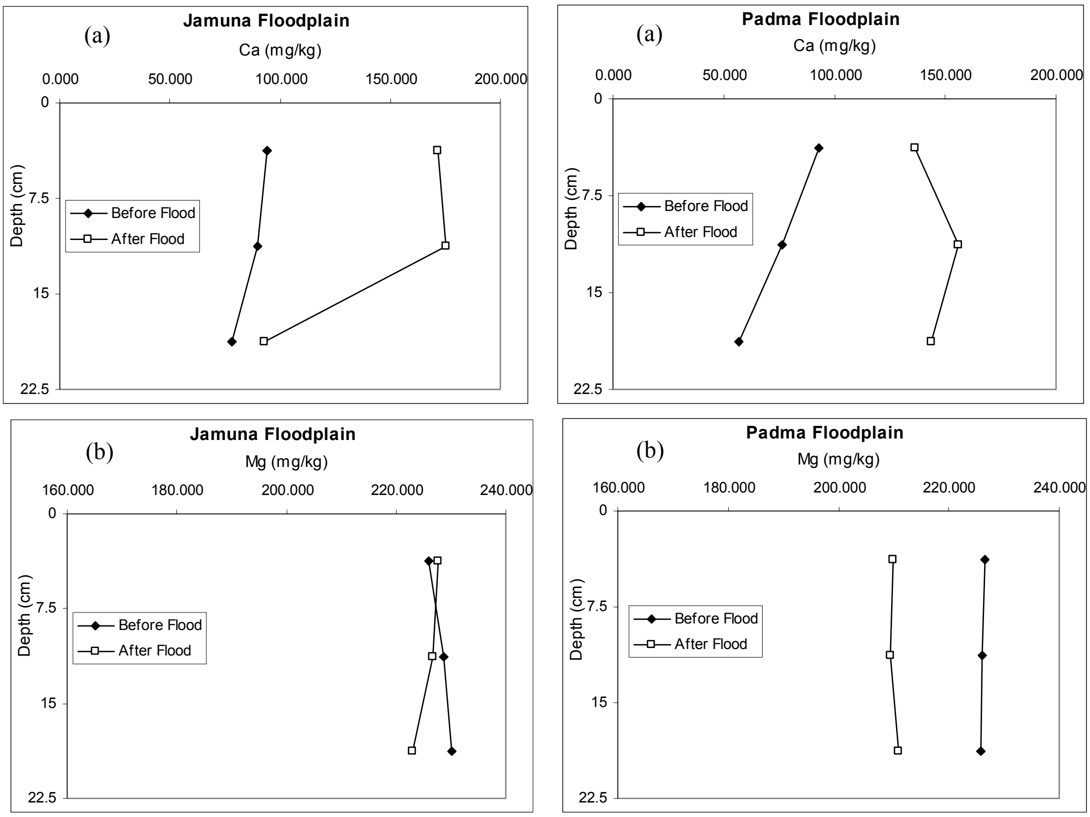


Fig. 5. Average profiles of two secondary macro-nutrients (a) Calcium and (b) Magnesium for soil core samples collected from the Jamuna and Padma floodplains

3.5.1 *Heavy metal contents of river water*

Concentration of dissolved arsenic, chromium and lead in water samples collected from the Jamuna and the Padma rivers before, during and after flood are presented in Table 12. Concentration of dissolved arsenic in both the Jamuna and Padma rivers appear to be very low. These results are in agreement with those reported by Chowdhury et al. (2003).

Table 12
As, Cr and Pb contents of river water samples collected from the Jamuna and the Padma

	Jamuna River			Padma River		
	Before Flood	During Flood	After Flood	Before Flood	During Flood	After Flood
As (mg/L)	0.0007	0.0005	0.0011	0.0007	0.0004	0.0008
Cr (mg/L)	0.0120	0.0138	0.0054	0.0114	0.0042	0.0120
Pb (mg/L)	0.1643	0.0861	0.0156	0.1304	0.0365	0.0052

Dissolved arsenic concentration for both the rivers takes a dip during the flood season and rises after flood. Dilution of river water through addition of arsenic free rainwater during the flood season may be responsible for lowering of arsenic concentration. Chromium concentration shows a different pattern for the two river systems. It rises marginally for the

Jamuna and falls for the Padma river during the flood season. After flood, dissolved chromium decreases for the Jamuna and increases for the Padma River. Dissolved lead concentration in both the rivers decrease during flood and this trend continues after the flood. Lower dissolved concentration of lead after the flood may be related to the higher partitioning of lead from aqueous phase to the solid phase, as can be seen from significantly higher level of lead in suspended sediments samples after the flood. This higher partitioning (probably due to adsorption) of lead after the flood may be due to the apparent increase of pH values of river water after flood (Table 3), which favors adsorption of metal cations on to solids.

3.5.2 Heavy metal contents of suspended sediments

Table 13 shows concentrations of arsenic, chromium and lead in suspended sediment samples collected from the Jamuna and Padma rivers during and after flood. In general, heavy metal contents of suspended sediments increased after flood. Arsenic concentration in suspended sediments increased moderately (6~21%) after flood in the Jamuna River, but in the Padma the increase was quite significant (74~114%). Chromium concentration in sediments remained almost the same in the Jamuna, while for the Padma it increases by up to 107%. For both the rivers sediment associated lead concentration increased significantly (by 80~233%) after flood. As noted earlier, the increase in the concentration of sediment-bound lead may be attributed to the increase in pH of river water after the flood (Table 3), which favors partitioning of metal cations to solids.

3.5.3 Heavy metals in floodplain soil and impact of flooding on its characteristics

Figure 7 shows average profiles for arsenic, chromium and lead for the Jamuna and the Padma river floodplains before and after flood. It shows that, in general, concentration of arsenic, chromium and lead in the floodplain soil increases after flood. For the Jamuna floodplain, arsenic content increases in upper layers by over 50%, while decreases by 22% in the lower layer. In the Padma floodplain, arsenic content increases in all three layers by 31~40%. Chromium concentrations show similar trends for both the floodplains. In both floodplains, lead concentration increases in all three soil layers after flood. For the Jamuna floodplain, the change is 4%, 57% and 68%, and for the Padma it is 18%, 8% and 21% for the three top soil layers.

Table 13
As, Cr and Pb contents of suspended sediment collected from the Jamuna and the Padma

	Jamuna River		Padma River	
	During Flood	After Flood	During Flood	After Flood
As (mg/kg)	1.34	1.62	0.83	1.77
Cr (mg/kg)	20.93	20.27	10.80	22.31
Pb (mg/kg)	4.96	9.39	3.13	10.43

The increase in heavy metal content of floodplain soils that were inundated during flood may be attributed to the sedimentation process. However a comparison between Table 13 and Fig. 7 reveals that heavy metal (As, Cr, Pb) contents of floodplain topsoil layers are higher than that of the suspended sediments collected during the flood; whereas they are comparable or slightly less than those of the suspended sediments collected after the flood. Hence the increase in heavy metal contents of floodplain soils cannot be attributed to just the

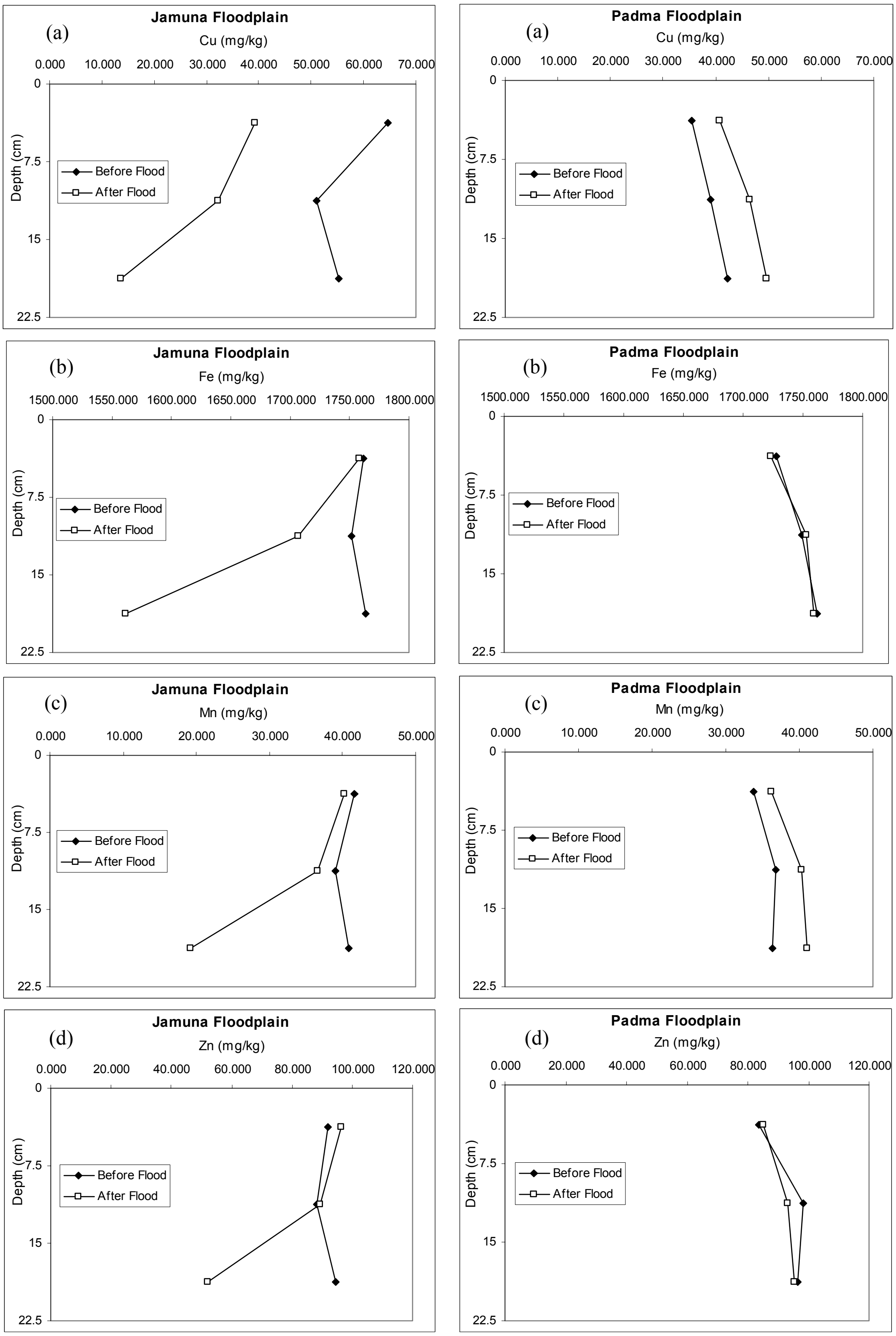
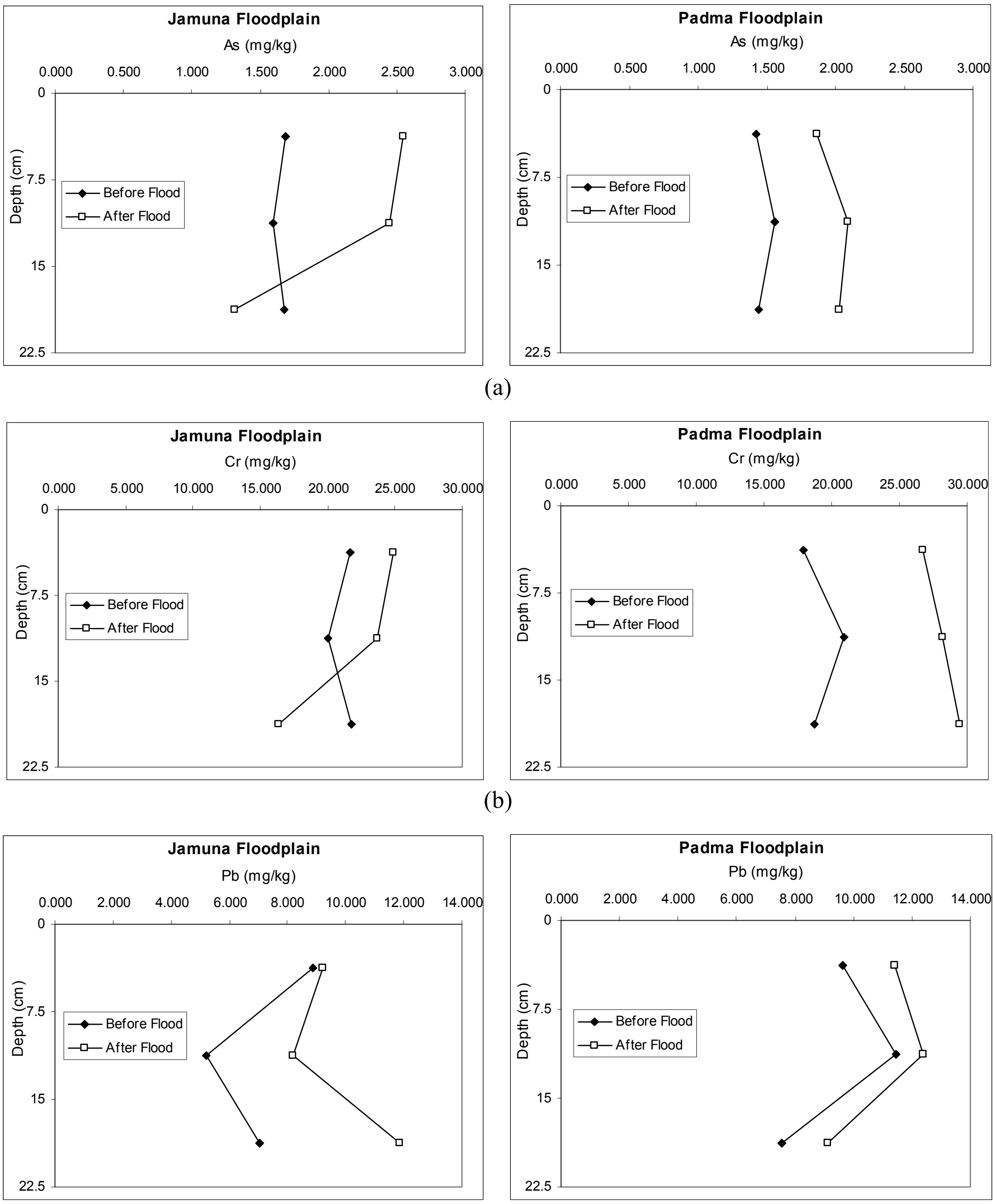


Fig. 6. Average profiles of four micro-nutrients (a) Cu, (b) Fe, (c) Mn and (d) Zn for soil core samples collected from the Jamuna and Padma floodplains



(a)

(b)

(c)

Fig. 7. Average profiles for (a) Arsenic, (b) Chromium and (c) Lead for the two river floodplains before and after flood

accumulation of new sediments. Geochemical processes, primarily partitioning of the heavy metals from the aqueous (river water) phase to soil (e.g. by adsorption), may be responsible for the increase in the heavy metal content of floodplain soils.

Besides total metal contents of the floodplain soil core samples, experiments were conducted to assess the concentration of easily mobilized metals in the soil core samples. As explained earlier, easily mobilized metals were determined by extraction with 0.2 M oxalic acid, which primarily provides an estimate of metal ions associated with iron-oxyhydroxides. No oxalic acid extractable lead or chromium could be detected in the floodplain soil samples. Thus, the lead or chromium does not appear to be associated with iron-oxyhydroxide content of soil. However, oxalic acid extractable arsenic was detected in the floodplain soil core samples. The oxalic acid extractable arsenic content varied from 7~30% of the total (aqua-regia extractable) arsenic contents.

3.6 Mobilization of nutrients and heavy metals from floodplain sediments

Batch experiments were conducted to assess mobilization of the nutrients and heavy metals from the floodplain soil samples under different geochemical conditions. These conditions included: (i) inundation with rainwater, (ii) inundation with deionized water, (iii) inundation with rainwater mixed with glucose, and (iv) inundation with deionized water mixed with glucose; glucose was added to simulate effect of organic matter.

Results from the batch experiments on mobilization of nutrients are presented in Tables Tables 14a through 14d, and those on mobilization of heavy metals are presented in Table 14e. The results from batch experiments show significantly increased mobilization of nitrogen, calcium, iron and manganese. The data also show slight mobilization of magnesium, potassium, copper and zinc. But mobilization of phosphorus and sulfur decreased after addition of glucose.

Table 14a
Results of batch experiments: Mobilization of the nutrients N, P and S

Topsoil Sample	Inundated with	N^1 (mg/L)		P^2 (mg/L)		K (ppm)	
		Without OM	With OM	Without OM	With OM	Without OM	With OM
Jamuna	DW	3.885	8.510	0.010	0.000	7.031	10.025
Padma	RW	3.125	11.255	0.000	0.000	7.440	10.485
Jamuna	DW	2.420	9.470	0.013	0.000	6.364	10.402
Padma	RW	2.145	13.430	0.000	0.000	5.094	10.642

[1] N as NO_3 and NH_4, [2] P as PO_4,

Table 14b
Results of batch experiments: Mobilization of the nutrients Ca, Mg and K

Topsoil Sample	Inundated with	Ca (ppm)		Mg (ppm)		S^3 (mg/L)	
		Without OM	With OM	Without OM	With OM	Without OM	With OM
Jamuna	DW	3.935	8.509	1.465	1.591	44.600	31.806
Padma	RW	4.065	8.673	1.478	1.608	47.201	28.802
Jamuna	DW	3.026	8.796	1.440	1.565	43.903	31.273
Padma	RW	2.981	8.568	1.372	1.582	17.104	14.843

[3] S as SO_4 and S_2

Table 14c
Results from batch experiments: Mobilization of the nutrients Fe and Mn

Topsoil Sample	Inundated with	Fe (ppm)		Mn (ppm)	
		Without OM	With OM	Without OM	With OM
Jamuna	DW	0.639	17.306	0.000	1.365
Padma	RW	0.522	16.284	0.000	1.342
Jamuna	DW	0.542	15.516	0.000	1.289
Padma	RW	0.432	15.958	0.000	1.320

Table 14d
Results from batch experiments: Mobilization of the nutrients Cu and Zn

Topsoil Sample	Inundated with	Cu (ppm)		Zn (ppm)	
		Without OM	With OM	Without OM	With OM
Jamuna	DW	0.045	0.064	0.057	0.136
Padma	RW	0.047	0.071	0.000	0.137
Jamuna	DW	0.048	0.059	0.034	0.086
Padma	RW	0.033	0.052	0.000	0.078

Table 14e
Results from batch experiments: Mobilization of As, Cr and Pb

Topsoil Sample	Inundated with	As (ppm)		Cr (ppm)		Pb (ppm)	
		Without OM	With OM	Without OM	With OM	Without OM	With OM
Jamuna	DW	0.0027	0.0263	0.0864	0.0888	0.0052	0.0052
Padma	RW[3]	0.0006	0.0075	0.1007	0.0911	0.0417	0.0209
Jamuna	DW	0.0006	0.0084	0.0983	0.0888	0.0522	0.0209
Padma	RW	0.0005	0.0044	0.0923	0.0995	0.0678	0.0365

OM=Organic Matter, DW=Deionized Water, RW=Rain Water

Decrease in nitrogen content at topsoil of floodplains (Table 11) and increase in dissolved nitrogen in river water (Table 9) are consistent with the results of batch experiments. Immobilization of phosphorus under reducing environment also appears to be consistent with the river water quality data (Table 9). The increase in phosphorus content at topsoil after flood may be attributed to sedimentation during the inundation period. The phosphorus content of suspended sediment samples collected during flood was much higher than those at the topsoil, which may be responsible for the increase in phosphorus concentration of floodplain soil of both the rivers.

Increased mobilization of calcium and manganese after the addition of organic matter during batch experiments supports the water quality data of the two rivers, especially during and after flood showing increase in calcium as well as manganese contents. Increase in calcium content of floodplain soil after flood may be attributed partly to partitioning of dissolved calcium to topsoil during inundation.

Results from the batch experiments, presented in Table 14e, show increased mobilization of arsenic under inundation with water containing glucose. This increased mobilization is likely to be due to the fact that a significant portion of arsenic in the soil samples was present in association with iron-oxyhydroxides, which was easily mobilized under the reducing environment created by the addition of organic matter. Since such reducing environment can be developed in the floodplain during inundation with floodwater (especially in the presence of vegetation), it is possible that some soil-bound arsenic would be mobilized during inundation and would flow back to the rivers along with the receding water. This phenomenon may be responsible for the slightly elevated level of arsenic in the river sediment after the floods. However, more careful monitoring is required to ascertain this phenomenon.

Results of batch experiments show decreased mobility of lead under inundation with glucose (organic matter). Since lead is not associated with iron-oxyhydroxides content of soil, the reducing environment created by the presence of organic matter (which would promote dissolution of iron-oxyhydroxides) would not have any impact on the mobilization of lead. It is not clear which geochemical process lead to the decreased mobility of lead in the presence of glucose. However, the decreased mobility may have contributed to the decreased concentration of lead in the river water samples after the flood. Batch experiment results for chromium show negligible changes in its mobilization due to the addition of glucose.

3.7 Estimation of nutrient and heavy metal transport through the rivers

An estimate of the nutrient and heavy metal transported through the Jamuna and the Padma rivers was made from available information on annual discharge data and suspended sediment load of these rivers, and dissolved sediment associated nutrient/heavy metal contents measured during this study. For this purpose average annual water discharge for the Jamuna was taken as 20,400 m^3/s and for the Padma it was taken as 28,000 m^3/s (FAP 24, 1996a). Sediment transport integrated over the year was taken as 200 million tons for the Jamuna and 390 million tons for the Padma River (FAP 24, 1996b). Dissolved nutrient and heavy metal contents were averaged for all the water samples collected for each river. Average of all suspended sediment samples was taken to calculate sediment associated nutrient load. Calculated values for different nutrients and heavy metals are shown in Table 15. Sediment associated Boron could not be determined through laboratory experiments. So only the dissolved Boron content was used in calculation.

From the estimated nutrient load, it is evident that dissolved fractions are the major part of the nutrient load, with the exceptions of Iron and Manganese. For most of the nutrients sediment associated nutrient load is almost insignificant compared to the dissolved fractions. Sediment associated calcium varies between 0.9~1.5% of the total, magnesium varies between 2.7~3.7%, potassium between 11~16%, copper between 8.0~8.4% and zinc between 11~14% of total.

For iron and manganese, calculated sediment associated loads have been found to be higher than the dissolved portions. Sediment associated iron varies between 69~74% of total iron load and sediment associated manganese varies between 77~78% of total manganese load. As annual average water discharge of the Padma River is much higher than that of the Jamuna, nutrient load from the Padma is also much larger.

Unlike most of the nutrients, sediment associated arsenic and chromium load is quite significant compared to the dissolved fraction. Sediment associated arsenic load varies between 38~48% of total arsenic load, and for chromium it varies between 38~44% of total chromium load for the Jamuna and the Padma rivers. This is probably due to higher partitioning of heavy metals, compared to nutrients, to sediments. For lead though, sediment associated fraction is quite small and it is only 2.5% for the Jamuna and 4.9% for the Padma.

Table 15
Estimates of nutrient load through the Jamuna and the Padma Rivers
(all values in thousand tons per year)

Nutrient/ Heavy metal	Jamuna River			Padma River		
	Dissolved	Sediment Associated	Total	Dissolved	Sediment Associated	Total
N[1]	1138	1	1139	1427	2	1429
P[2]	61	3	64	100	4	104
K	2290	282	2572	2790	526	3316
Ca	2119	21	2140	2873	43	2916
Mg	1240	35	1274	1729	67	1796
B	97	NA[3]	97	284	NA	284
Cu	134	12	146	182	17	199
Fe	156	350	506	227	645	872
Mn	2	9	11	3	12	15
Zn	163	27	190	225	28	253
S[4]	14171	NA	14171	15175	NA	15175
As	481	297	778	561	508	1069
Cr	6691	4120	10811	8240	6455	14695
Pb	57032	1435	58467	51364	2644	54008

[1] Dissolved Nitrogen as NH_3-NH_4 and NO_3, and Sediment associated part as NO_3-N,
[2] Dissolved Phosphorus as PO_4, and Sediment associated part as available P,
[3] Data not available, [4] Dissolved Sulfur as SO_4 and S_2

4. Conclusions

The Ganges-Padma and Brahmaputra-Jamuna river systems carry a billion ton of sediment annually, yet the fate of this material as in most of the world's rivers, is not well understood. The primary objective of this study was to improve basic understanding of the role of river sediments in nutrient and contaminant transfer. The Jamuna and Padma river floodplains were selected for this study as they carry the highest sediment among all other major rivers in Bangladesh. Specific objectives of the study included, characterization of river water, suspended sediment and floodplain soil samples in terms of nutrients, heavy metals (As, Cr, Pb) and organic contents, and to assess the effect of the geochemical processes during inundation in the mobilization of nutrients and contaminants.

Results from the study suggest that river water characteristics change significantly with time. Total solids and total suspended solids as well as turbidity, reached their peaks during flood season. However, total dissolved solids after flood was higher than that during the flood season. River water samples were found to be more alkaline and electrical conductivity higher after flood. Hardness of river water also increased after flood.

Sedimentation during flood appears to play a significant role in regulating the composition of floodplain soil. However, it appears that besides sedimentation, other biochemical process may also play a significant role in regulating floodplain soil characteristics. It was found that the floodplain soils became more alkaline at top layers after the flood season, which indicated new sedimentation. In general electrical conductivity decreased and organic matter content increased after flood in the Jamuna and Padma floodplains. The increase in organic content, which is important from soil-fertility point of view, could not be attributed to sedimentation, as the suspended sediments were not significantly rich in organic content. Increased algal activity in the inundated floodplain might be responsible for the increase in organic matter content.

Among the nutrients nitrogen, phosphorus, calcium and copper shows significant changes at topsoil of floodplain after flood. Nitrogen concentration decreased 50%, on an average, at the two floodplains. Phosphorus concentration increased by 67% at the Jamuna floodplain and by 42% at the Padma floodplain. At the Jamuna floodplain calcium concentration increased by 82% while at the Padma floodplain the increase was 47%. For copper, the changes were in opposite pattern, at the Jamuna floodplain it decreased by 39%, but increased by 15% at Padma floodplain. Changes in magnesium, potassium, iron, manganese and zinc concentrations at the topsoil were insignificant. Decrease in nitrogen content at topsoil of floodplains and increase in dissolved nitrogen in river water was found to be consistent with the results of batch experiments. The increase in phosphorus content at topsoil after flood may be attributed to floodplain sedimentation, since phosphorus content of suspended sediments during flood was much higher than those at the topsoil.

Results from the study suggests that besides nutrients, significant amount of heavy metals (As, Cr, Pb) are also transferred through the river systems, in both dissolved form and in association with suspended sediments. Dissolved arsenic concentration in river water samples decreased during the flood season, probably due to dilution with arsenic free rainwater. Dissolved lead concentration continues to decrease after the flood season, probably due to the higher partitioning of lead from aqueous phase to solid phase. This is also reflected in the sediment associated lead concentration, which increased after the flood season. Sediment associated arsenic concentration also increased after flood season.

Determination of oxalic acid extractable metals in sediment and soil samples suggests that significant amount of arsenic (7~30% of total) in suspended sediment and floodplain soil is associated with iron-oxyhydroxides. Results from batch experiments suggest that arsenic can be easily mobilized under the reducing environment created in the floodplain during inundation, especially in the presence of organic matter. However, chromium and lead are not associated with iron-oxyhydroxides and these metals would not be easily mobilized from the floodplain soils. Geochemical processes occurring within floodplains appear to have an impact on the heavy metal contents of river water, as was evidenced by the increase in arsenic content and decrease in lead content in the river water after flood.

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