# ROLE OF FLOODPLAIN SEDIMENTATION IN NUTRIENT AND CONTAMINANT TRANSFER

A Thesis Submitted by

**MOHAMMAD ASAD HUSSAIN**

In partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering



DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA

SEPTEMBER 2003

**BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY**
**DEPARTMENT OF CIVIL ENGINEERING**

## CERTIFICATE OF APPROVAL

We hereby recommended that the thesis titled **"Role of Floodplain Sedimentation in Nutrient and Contaminant Transfer"** submitted by **Mohammad Asad Hussain,** Roll Number 100004106(P) be accepted as fulfilling this part of the requirements for the degree of Master of Science in Civil Engineering.

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Department of Civil Engineering, BUET

**Dr. Md. Rezaur Rahman** : **Member** (External)
Associate Professor
Institute of Water and Flood Management, BUET

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This is to certify that the thesis on "**Role of Floodplain Sedimentation in Nutrient and Contaminant Transfer**" has been performed by me and neither this thesis nor any part thereof has been submitted elsewhere for the award of any degree of Diploma.

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Dedicated

To

My Parents

# ACKNOWLEDGEMENT

My sincere gratitude to all the individuals and institutions who provided support, advice and encouragement during this study.

I am delighted to express my heartiest gratitude and sincerest indebtedness to my teacher Dr. M. Ashraf Ali, Associate Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, who served as thesis supervisor. He provided information, useful suggestion, criticism and encouragement that enabled me to carryout this study. Specially, for his support during my times of difficulties, I wish to extend my deep gratitude and regards to Dr. M. Ashraf Ali.

I am deeply grateful to Dr. Md. Rezaur Rahman, Associate Professor, Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET), Dhaka, for providing the idea for this research. I am also grateful to him for providing valuable suggestions and generous help during this work.

Many thanks to Dr. A.B.M. Badruzzaman, Professor, Department of Civil Engineering, BUET, for his valuable suggestions and help during the laboratory work.

Special mention of my friend and colleague Mr. Md. Abed Hossain, Lecturer, IWFM, BUET, for his suggestions and help during sample collection and laboratory experiments.

I am grateful to Mr. A. M. Ibrahim from CEGIS for sharing his experience regarding this study. Also the help and suggestions of Dr. Mahbub, Associate Professor, Department of Soil, Water and Environment, Dhaka University is gratefully acknowledged.

Many thanks to Md Salim Bhuiyan, Executive Engineer, Flood Forecasting and Warning Center, Bangladesh Water Development Board for providing useful data. Also, the help of Mohammad Idris Ali from SRDI is gratefully acknowledged.

Thanks to Mr. Akhter Hossain Chowdhury, Ph.D. student Department of Civil Engineering, BUET, for his sharing his experiences in sample collection. Thanks to Mr. Md. Abdullah Al Masud, Mr. Md. Ehsan Habib, Mr. Md. Kamruzzanman (Shabuj), Mr. M. Azizur Rahman (Robel), Rouf Bhai, Marjan Bhai - all M.Sc. students of the Department of Civil Engineering, BUET, for their help and suggestions during the laboratory work.

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example, the decrease in dissolved lead concentration and increase of sediment-bound lead after the flood may be related to the higher partitioning of lead from aqueous phase to the solid phase due to increased pH level after flood.

Results of batch experiments, which were conducted to simulate the field condition during flood, suggest that bio-geochemical processes occurring within the inundated floodplains may have a significant impact on soil as well as river water quality. 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. Immobilization of phosphorus under the reducing environment of batch experiments was also consistent with the river water quality data.

A significant proportion of sediment-bound arsenic was found to be associated with iron-oxyhydroxide fraction of the sediments, which was determined by extraction with 0.2M oxalic acid. Results from batch experiments suggest that this fraction of arsenic could be easily mobilized under reducing environment that may be created during inundation of floodplains. However, chromium and lead were not found to be associated with iron-oxyhydroxides and these metals are not likely to be easily mobilized from the floodplain soils.

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.

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**CHAPTER ONE**

# INTRODUCTION



## 1.1 General

Floodplains have been extensively used and exploited over millennia as important locations for settlement and agriculture, and in many of today's landscapes this remains 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. The temporal character of flooding or hydrological connectivity influences the exchange of materials between the main river channel and floodplain patches (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.

River pollution, contamination and thus water quality issues have received increased attention among scientists worldwide. 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 nonpoint source pollution by agricultural and residential activities (Ismail *et al*, 2002).

River sediments frequently act as a sink for heavy metals, which enter the fluvial system form 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 (Figure 1). 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 (FAP 16/FAP19, 1995). 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 waters 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.

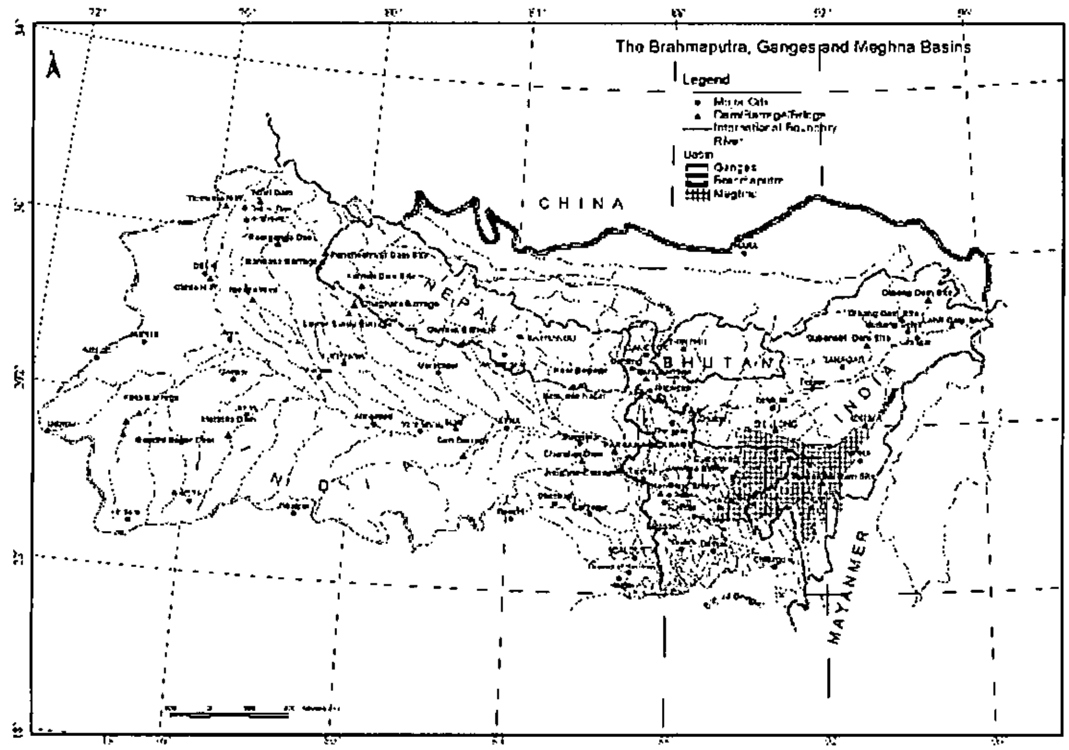


Figure 1.1 Ganges-Brahmaputra-Meghna basins

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. Recent accelerated floodplain development have created an urgent need to improve the state of knowledge about floodplain sedimentation (FAP16/FAP19, 1995).

## 1.2 Objectives of the Study

The overall objective of this study is to improve basic understanding of the role of river sediments in nutrient and contaminant transfer. Specific aims of this study include:

(a) To determine dissolved nutrient and contaminant contents in two river systems
(b) To determine nutrient and contaminant contents of suspended sediments from two river systems
(c) Assessment of nutrient and contaminant contents of floodplain soil samples collected before and after flood
(d) Assessment of floodplain sedimentation in regulating nutrient contents of floodplain soil
(e) To ascertain the role of floodplain sedimentation in contaminant transfer to the floodplain soil
(g) Assessment of the effect of bio-geochemical processes within the floodplain on floodplain soil and river water characteristics

## 1.3 Scope of the Study

In this study, four sites were selected, two each from the river floodplains of the Jamuna and the Padma, for detailed characterization of water, suspended sediment and floodplain soil samples. Samples were collected before, during and after flood. 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. During this study a total of fourteen water samples, six sets of suspended sediment samples and sixteen floodplain soil core samples were collected before, during and after the flood season.

Water samples were analyzed for a total of twenty-three parameters including eleven nutrients and three heavy metals. Suspended sediment samples and floodplain soil samples were analyzed for a total of fifteen parameters including nine nutrients and three heavy metals. Possible role of biological activities (e.g., blue green algae) was evaluated indirectly. It was assumed that the reducing environment created in the floodplain during inundation by floodwater, in the presence of organic matter is the principal geochemical process governing mobilization of nutrients and contaminants. Batch experiments were setup in the laboratory to simulate such a reducing environment.

## 1.4 Organization of the Thesis

This thesis consists of six chapters. Apart from this introductory chapter, the remainder of the thesis has been divided into five chapters.

Chapter Two consists literature review covering some background information on floods and floodplains in Bangladesh, sedimentation, nutrients and then contaminants or heavy metals. Previous research regarding nutrient and contaminant transfer in Bangladesh as well as in other countries are briefly discussed here.

A brief description of the methodology applied in the work is presented in Chapter Three. The study area; sampling locations and sampling program; sample collection, preservation and storage, preparation and analysis have been described in this chapter. Also processes of batch experiments are included in this chapter.

Chapter Four and Chapter Five present analyses of the nutrient and contaminant data respectively, obtained during the study.

Finally major conclusions of the study and recommendation for further study are deliberated in Chapter Six.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.1 Introduction

This chapter reviews some relevant literatures on nutrient and contaminant transfer and floodplain sedimentation in Bangladesh as well as in some other countries. Relevant information regarding extent and types of floodplains in Bangladesh are also provided. Before these, some background on floods and floodplains, sediments and nutrients are given in this chapter.

## 2.2 Flood, Floodplain and Sedimentation

***Flood:*** This is an overflow or inundation that comes from a river or other water body and causes or threatens damage. Any relatively high stream flow overtopping the natural or artificial banks in any reach of a stream is termed as flood.

The floods in Bangladesh are divided into monsoon river flood, flash flood, local rainfall flood and storm surge flood. The main source of monsoon river flooding is the bank overflow from the major rivers the Ganges, the Brahmaputra and the Meghna, and their tributaries and distributaries during June to September. A broad strip of land adjacent to the rivers is subjected to this type of flood (Chowdhury *et al.*, 1996). Flash flood occurs only in the northeastern Bangladesh in the period pre- to post-monsoon forced by intense rainfall in the Meghalaya Hills and in parts of eastern Bangladesh in the post-monsoon. Local rainfall flood is, as the name states, forced by local heavy rainfall over a location inside Bangladesh. Storm surge flood is a coastal phenomenon forced by cyclones hitting the Bangladeshi coastline.

***Floodplain:*** This is the flat, low-lying area subject to flooding by a stream at some specified size of flood event. It is an area where permanent structures should not be built and where rivers often meander and change their channel position regularly.

operations, gardens, lawns, forests, bulk and petroleum storage areas, heavily vegetated lakes and streams, and landfills.

***Contamination/pollution:*** This indicates that substances or organisms have been introduced into the water, by natural or human activities, in sufficient quantities to have an adverse effect on the quality of the water for a specified use.

## 2.3 Plant Nutrients

Sixteen chemical elements are known to be important to a plant's growth and survival (Smith, 1999a). These sixteen elements are divided into two main groups: non-mineral and mineral.

***(A) Non-Mineral Nutrients*** are hydrogen (H), oxygen (O) and carbon (C). These are found in air and water. Through photosynthesis plants use energy from the sun to change carbon dioxide ($CO_2$) and water ($H_2O$) into starches and sugars. These starches and sugars are the plant's food.

***(B) Mineral Nutrients*** normally comes from soil. The thirteen mineral nutrients are divided into two groups:

*(1) Macronutrients:* these are again divided into two groups:

*(i) Primary Nutrients:* These are nitrogen (N), phosphorus (P) and potassium (K). Plants use large amounts of these for their growth and survival.

*(ii) Secondary Nutrients:* These are calcium (Ca), magnesium (Mg) and sulfur (S). Sulfur is usually found in sufficient amounts from the slow decomposition of soil organic matter, an important reason for not throwing out grass clippings and leaves.

*(2) Micronutrients:* Micronutrients are those elements essential for plant growth which are needed in only very small (micro) quantities. These elements are sometimes called minor elements or trace elements, but the American Society of Agronomy and the Soil Science Society of America encourage use of the term

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growth. Soil minerals, organic material, fertilizers, and dolomitic limestone are sources of magnesium for plants.

***Sulfur (S):*** Sulfur is essential plant food for production of protein. It promotes activity and development of enzymes and vitamins. It improves root growth and seed production. Sulfur helps in chlorophyll formation. It also helps with vigorous plant growth and resistance to cold. Sulfur may be supplied to the soil from rainwater. It is also added in some fertilizers as an impurity, especially the lower grade fertilizers. The use of gypsum also increases soil sulfur levels.

**Micronutrients:**

***Boron (B):*** Boron helps in the use of nutrients and regulates other nutrients. It aids in production of sugar and carbohydrates. Boron is essential for seed and fruit development. Sources of boron are organic matter and borax.

***Copper (Cu):*** Copper is important for reproductive growth. It helps in root metabolism and helps in the utilization of proteins.

***Chloride (Cl):*** Chloride aids plant metabolism. Source of chloride is soil.

***Iron (Fe):*** Iron is essential for formation of chlorophyll. Sources of iron are the soil, iron sulfate and iron chelate.

***Manganese (Mn):*** Manganese functions with enzyme systems involved in breakdown of carbohydrates and nitrogen metabolism. Soil is a source of manganese.

***Molybdenum (Mo):*** Molybdenum helps in the use of nitrogen. Soil is a source of molybdenum.

***Zinc (Zn):*** Zinc is essential for the transformation of carbohydrates. It regulates consumption of sugars. It is a part of the enzyme systems, which regulates plant growth. Sources of zinc are soil, zinc oxide, zinc sulfate and zinc chelate.

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where nutrients can enter groundwater. The forms of nutrient, which usually leach, are those, which are not readily retained by soil through processes such as cation exchange. Leaching of nitrogen usually occurs when nitrogen is in the nitrate ($NO_3^-$) form. Phosphorus does not usually leach through soil, except for soils with a high sand content, because it readily reacts and is retained by other soil components.

***Surface Runoff:*** When soil erosion occurs losses of nutrients from surface runoff can be significant. Nutrients may be in a dissolved form, attached to eroded soil particles, or contained in organic matter that is flushed away in the run off.

***Gaseous Losses and Gains of Nutrients:*** The processes of volatilization, denitrification and oxidation/reduction cause losses of nutrients through transformations to gaseous nutrient forms. Ammonia volatilization occurs under hot, windy conditions in alkaline soils converting it to ammonia gas. Denitrification is favored in wet soils with a large amount of organic matter present converting nitrate to gaseous nitrogen forms. Under extremely wet conditions, nutrients can also be reduced into gaseous forms, for example: the release of hydrogen sulfide ($H_2S$) from low-lying wet areas. Nitrogen fixation is the biological conversion of gaseous nitrogen to inorganic nitrogen in the soil and it results in a gain of nitrogen in the soil.

## 2.5 Nutrient Deficiency and its Impacts

A general recommendation is: All soils are short on nitrogen (Smith, 1999b). Shallow rooted plants need extra phosphorus and potassium; iron and sulfur are often deficient, especially around acid loving plants. Usually, the soil contains enough of the other nutrients, although some may be deficient in certain parts.

Nitrogen encourages leaf growth. Phosphorus encourages roots and flowers. Potassium encourages general vigor. If one of these nutrients isn't available, then plant growth will be slower or stunted, and leaves will be discolored. For example, lack of nitrogen causes the old leaves to turn yellow. Lack of iron causes the new leaves to be yellow. Nutrient deficiencies will form patterns on the leaves that follow the vein patterns: sometimes along the veins, sometimes between the veins. Disease symptoms don't follow the veins.

## 2.6 Importance of Soil pH, Electrical Conductivity and Organic Matter Contents

### Soil pH

Soil pH is a measure of hydrogen ion concentration. It is tested either with a chemical pH test, or by a pH meter. 7.0 is neutral. 4.0 is very acid. 10.0 is very alkaline. High rainfall and high organic matter produces acid soil. Low rainfall and high lime or sodium produces alkaline soils. Soils in the Willamette Valley naturally have a pH between 4.5 and 5.5 which is fine for acid loving plants such as rhododendrons, azaleas, camellias and conifers. Lawns, roses, lilacs, fruit trees, vegetables and many other palnts prefer a soil pH near neutral, 6.5 to 7.0. The majority of plant nutrients are most available at slightly acid to neutral, though iron is more available as soil is more acid. Soil can be made less acid by adding lime (calcium carbonate), or more acid by adding sulfur or aluminum sulfate.

Soil pH influences availability of nutrients to plants, activity of useful and parasitic soil organisms, potency of toxic substances present in soil (Alam *et al.* 1991). Therefore the value of pH measurement is not only to see whether the soil acidic or alkaline, but also to have an idea about associated soil properties, particularly phosphorus availability, base status etc. in short:

- Macronutrients tend to be less available in soils with low pH.
- Micronutrients tend to be less available in soils with high pH.

For these reasons the pH value remains the most important single measurement made upon soils.

### Electrical Conductivity of Soil

The term 'soluble salts' as applied to salts refers to the inorganic soil constituents that are appreciably soluble in water (Alam *et al.* 1991). Water soluble salts occurring in soils over 0.1% usually consist principally of the four cations $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$, linked mainly to $Cl^-$ and $SO_4^{2-}$, and sometimes to $NO_3^-$ and $CO_3^{2-}$ and to a limited extent to $HCO_3^-$. Soil salinity problems frequently arise from $Na^+$, $Cl^-$, $SO_4^{2-}$ but seldom from $Ca^{2+}$, $Mg^{2+}$ or $CO_3^{2-}$.

**Organic Matter of Soil**

Organic matter is considered the flesh while the sand, silt and clay are known as the skeleton of a soil (Alam *et al.* 1991). A soil without organic matter is not considered as soil from edaphological point of view.

The organic component of the soil is made up of living and dead plants and animals (Smith, 199b). They include - living bacteria, fungi, insects, worms, and roots; all of these as they decay; and humus: dead organic matter that has decomposed until it is very fine, black and sticky.

Bacteria and fungi extract nutrients from the soil minerals and make them available to plants (Smith, 199b). Insects and worms create air passages deep into the soil. The carbon dioxide produced by roots becomes carbonic acid, which breaks down minerals to make nutrients available. Dead organic material provides rich nutrients for the living plants. It also holds the nutrients from applied fertilizers until the plants can use them. Humus sticks the soil particles into larger crumbs so there are bigger spaces for air and water.

Dead organic matter is decaying continually, so it needs to be replenished every year. Excessive nitrogen fertilizer can cause the dead organic matter to decay even faster; so more organic matter will have to be applied. Also, careless use of pesticides may harm or kill the living organisms and damage the soil.

Organic matter status of soil is linked to its fertility thereby imparting its influences on the productivity. As assessment of the organic matter status is done by determining the organic carbon present in a soil. The sources of carbon in soils is thus, both organic and inorganic. The greater part of the soil carbon is usually found in organic matter and in some cases in carbonate minerals. The organic fraction of soil carbon includes the remains of plants, animals and microorganisms in all stages of decomposition but consists mainly of strongly altered materials of unrecognized origin.

## 2.7 Previous Research on Floodplain Sedimentation

Nutrients play an important role in regulating primary productivity in flood-plain systems (Brinson et al. 1983; Spink et al. 1998). Pinay, *et al.* (1992) suggested carbon and nutrients can be transferred to floodplains in association with sediments during overbank flows. This can occur via adsorption on to sediment particles; hence their transfer is directly related to proportion of fine sediment (silt-clay) deposition. Phosphorus is commonly associated with clay particles. Carbon, nitrogen and phosphorus can also be bound to organic matter and thus the content of organic matter in floodwaters will influence the exchange of these nutrients between a river channel and a floodplain (Walling et al. 1997).

Studies by Pinay *et al.* (1992, 1995) and Brunet *et al.* (1997) have demonstrated the importance of erosion and deposition in the distribution of nutrients in overbank flows. Their study highlighted the importance of floods as a cost-effective and natural fertilizing mechanism for flood plain environments. Concentrations of carbon, nitrogen and phosphorus in the deposited sediment tended to increase across the flood plain in this study but displayed no direct relationship to sediment texture. This was contrary to the findings of Asselman and Middlekoop (1995), who demonstrated an association between the distribution of some nutrients and sediment texture. In their study, increases in carbon and nitrogen concentrations were highly correlated with sediments that were dominated by clay sized material; this explained the highly variable distributions of nutrients across the Meuse flood plain in Australia.

Schwarz *et al*, (1996) suggested that phosphorus is strongly associated with clay particles and it was used to explain the spatial distribution of phosphorus deposition on flood plain surfaces by Pinay and DeCamps (1988). However Brunet *et al.* (1997) and Walling *et al.* (1997) suggested concentrations of carbon and nitrogen are inversely proportional to rates of sedimentation. In both studies, low concentrations of nutrients were recorded in floodplain areas adjacent to the river channels (Thomas *et al.*, 2000).

Thorp and Delong (1994) emphasized the importance of locally derived sources of organic matter through the Riverine Productivity Model. An understanding of the sources and fates of carbon and nutrients is essential for the sustainable management of healthy floodplain river ecosystems (Thomas *et al.*, 2000).

Sharma (2002) showed increases in soil nutrient concentrations of floodplain soils of the Brahmaputra, Barak and Manipur rivers, taken before and after flooding, as given in Table 2.1. In all cases increases in soil nutrient concentrations are recorded, For example, concentrations of nitrogen, phosphorus and potassium in soil samples following flooding increased by 148.8%, 233.2% and 151.1% respectively. Substantial increases in extractable Zn and Mg were also observed after the floods. However there was no significant change in the Cu and Fe content of the floodplain sol. Cation exchange capacity increased significantly as did the organic matter content. He suggested, these changes in the chemical composition of the soil after a flood are considered to be advantageous to subsequent crop production.

**Table 2.1 Nutrient status of floodplain soils of the Brahmaputra, Barak and Manipur rivers taken before and after floods**

| Nutrient | Before floods | After floods |
|---|---|---|
| Average N (kg/ha) | 170 | 253 |
| Average $P_2O_5$ (kg/ha) | 6 | 14 |
| Average $K_2O$ (kg/ha) | 135 | 204 |
| Average Zn (kg/ha) | 2.7 | 3.8 |
| Average Mn (kg/ha) | 6.8 | 9.1 |
| Average Cu (kg/ha) | 0.5 | 0.5 |
| Average Fe (kg/ha) | 4.6 | 3.9 |
| Cation exchange capacity [emol(p+)$kg^{-1}$] | 6.7 | 11.5 |
| Organic Matter (%) | 0.8 | 2.2 |

From the same study, suspended sediment concentrations and the chemical composition of floodwater taken at different river stages in the Brahmaputra, Barak and Manipur river are given in Table 2.2.

**Table 2.2 Suspended sediment characteristics in flood waters of the Brahmaputra, Barak and Manipur**

| Soil/Nutrient | Range (mg/L) | Nutrient | Range (mg/L) |
|---|---|---|---|
| Soil | 1500-30000 | Cu | 0.1-0.3 |
| $NO_3$-N | 6.4-25.8 | Fe | 6.3-18.4 |
| P-$PO_4$ | 2.3-8.5 | Ca | 2.5-6.4 |
| $K_2O$ | 15.4-33.8 | Mg | 6.5-14 |
| Zn | 0.3-1.6 | $SO_4$ | 5.0-8.5 |
| Mn | 0.8-2.4 | | |

Sharma (2002) concluded, a webbed network of tributaries of the Brahmaputra and Barak rivers characterizes the flood-prone areas of the northeastern areas of India and although they can cause much havoc as a result of flood damage, floods increase soil fertility. Conveyance loss of sediment and nutrient to the floodplain during over bank flows plus the recycling of soil and nutrients has an important influence on the chemical properties of the temporary storage as well as on the physical status.

He suggested floodplains are one area where food production can be increased tremendously provided judicious agricultural practices are followed. The potential in agricultural production from the floodplain ecosystem must be trapped to supply the future demand for food grains. The floodplain ecosystems are constrained by a number of biotic and abiotic stresses that limit crop yields. The prevalent socio-economic structure and its strong association of the people determine the type of technology required by the farmers. There is a need for judicious use and management of inputs, product diversification and farm consolidation in lowland areas.

Beudert (1997) from his work suggests that the phosphorus loading of streams from agricultural land is clearly predominated by phosphorus bound to sediment particles. Also, the removal of phosphorus from agricultural land is considered important by Sharpley (1985) from both water quality and soil fertility aspect.

The lateral exchange of water, sediment and nutrients between river channels and their flood plains is an important ecosystem process. The flood-pulse concept of Junk *et al.* (1989) suggests that the character of the flood-event (pulse) controls the delivery of nutrients to and from the flood plain. However, the rate and pattern of sediment accumulation have also been demonstrated to reflect surface topography and its roughness as well as flow conditions (Asselman and Middelkoop, 1995; Brunet *et al.* 1994; Walling and He, 1998). However, general trends have been reported, such as the decrease in the size of deposited sediments across floodplain surfaces (e.g. Marriot, 1992). While much is known of sediment accumulation in flood-plain areas, little is known of the fate of nutrients during overbank flows, by comparison (Thomas *et al.*, 2000).

Phosphorus and nitrogen are also correlated with organic matter (Pinay *et al.*1995; Schwarz *et al*, 1996; Walling *et al.* 1997). Therefore the deposition of organic matter will influence the observed pattern in phosphorus and nitrogen concentrations across flood plain surfaces. In this study higher concentrations of TOC were found on the distal flood plain surfaces. This may be evidence of a "bath-tub ring effect". During overbank flows, debris consisting mainly of organic matter is deposited on the fringes of the floodplain when the floodwaters recede. Therefore the supply of this material will be an important factor influencing the spatial distribution of associated nutrients deposited onto floodplain surfaces. Alternatively, Thorp and Delong (1994) stresses the importance of fringing vegetation (local sources) as an input of organic matter and therefore as a control on other nutrients (Thomas *et al.*, 2000).

Schreier *et al.* (2000) mentioned that the soil fertility-degradation-erosion-sediment transport cycles are likely to be restricted to micro-scale watersheds where the human imapacts can be isolated. At the meso- to macro-scale of watershed, these relationships become very difficult to isolate because cumulative effects and compounding factors influence the processes of distribution and re-deposition of sediments and nutrients. Schreier *et al.* (2000) also reported that nutrient status in a watershed in Bela watershed in Nepal was poor as the majority of non-irrigated agricultural fields had nutrient budgets that showed large phosphorus deficits ranging between 34 and 98 kg/ha/year per 15 centimeter soil depth. Erosion rates from agricultural fields were substantial, averaging 18-20 t/ha/year, but sediment re-deposition in irrigated fields was beneficial because it enriched these sites with extractable phosphorus. Land degradation and accelerated erosion played a significant role in phosphorus cycling. Extractable phosphorus in the sediments was significantly lower from degraded sites and had little nutrient value if recaptured in lowland irrigation. Insufficient nutrient input into non-irrigated agriculture on steep slopes was likely to be responsible for long-term productivity decline and increased soil degradation.

Thomas *et al.*, (2000) from his work concluded how larger floodplain rivers function as ecosystems is poorly known and there is considerable debate about the source of nutrients. It has been argued (Walker *et al.*, 1995; Robertson *et al.* 1999; Thomas and Sheldon 2000) that current ecosystem models for large flood plain model rivers, namely the River Continuum Concept (Vannote *et al.* 1980), the Flood Pulse Concept (Junk *et al.* 1989) and the Riverine Productivity Model (Thorp and Delong, 1994), are not adequate for large river floodplain systems such as the River Murry of Australia. He suggested flow and its interaction with floodplain geomorphology might influence the flux of carbon and other nutrients between a river channel and its floodplain in these environments.

## 2.9 Previous Research on Contaminant Transfer

Carton *et al.*, (2000) investigated the spatial and temporal variability of chromium content of suspended and floodplain sediments in River Aire of Yorkshire. They suggested that natural sediment properties such as particle size and organic carbon content are unable to account for the variations in the chromium content of fluvial sediment in th Aire River, which was heavily polluted.

Krein. and Symader (2000), assessed the source and transport processes of sediment associated pollutants. Also they investigated the influence of the travel distance on pollutant concentrations and in-stream sources. They suggested, via adsorption and precipitation reactions the concentrations of metals change with increasing reach length. Throughout the hydrograph the solids are sorted by grain size, which influences the distributions of toxic substances. They concluded that the grain size is an important factor governing pollutant transport. In general the concentrations of particle-bound heavy metals increased with decreasing grain size and are most abundant in the clay fractions. The river bed is both a source and sink for sediment-bound heavy metals.

## 2.10 Floodplain Sedimentation in Bangladesh: State of the Knowledge

### Bangladesh as a Floodplain Country

About four-fifths of Bangladesh is floodplain. Again four-fifths of this floodplain is cultivable area. 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. The high fertility of these alluvial floodplains has supported an expanding population of the country having an area of approximately 144,900 square kilometer (Chowdhury *et al.* 1996).

It is basically a land of rivers, criss-crossed by around 200 rivers most of which are either contributory or distributary to the three major rivers: the Ganges, the Brahmaputra and the Meghna (ESCAP, 2000). Fifty seven rivers originate outside the boundary of Bangladesh. The total length of the river courses is approximately 24,000 km and their area covers 9,770 $km^2$ or 7% of the country area. The ecological characteristics of the Bangladesh Delta are strongly influenced by the hydraulic and morphological processes associated with this delta system of the three major rivers. The catchment inside the country can be inundated to about 6 meters by river water carried from outside the country each year, which is further aggravated by rainfall inside the country which can add another 2 meters of water. Huge amounts of sediments are carried by alluvial rivers which build new land, fill in subsidence and improve soil fertility.

As the flood spreads out on to the floodplain, decreasing overbank flow velocity reduces its sediment transport competence (FAP 24, 1996a). Working in combination with convection and diffusion processes, this causes an exponential decrease in size of the particles deposited further from the channel. This process forms a coarser grained natural levee near the channel, grading with distance into a finer grained floodplain.

**Table 2.3 Comparison of floodplain sedimentation characteristics of some major international rivers**

| River | Year | Inundation period (days) | Inundation depth (m) | SS conc. in river (mg/L) | Deposition rate in floodplain (mm) |
|---|---|---|---|---|---|
| Rhine | 1993 | 2-7 | 0.3-2 | >150 | 0.2-1 |
| Meuse | 1993 | 3 | 0.6 | 400 | 0.2-1 |
| Mississippi | 1973 | 60 | 4 | - | 5-9 |
| Jamuna | 1995 | 40-99 | 2-2.8 | 500-600 | 1-4 |

*SOURCE*: FAP 24 (1996a)

***Types of Floodplain Landscape of Bangladesh***

Four main types of landscape can be recognized (Brammer, 1996) in the floodplain areas of Bangladesh. They are briefly discussed below,

(i) *Piedmont plains*: These are characterized by gently sloping land, composed of mainly sandy deposits, at the foot of hills with riverain colluvial and alluvial deposits and a drainage pattern of a braided river. The main areas occupied by them are most parts of Dinajpur (Old Himalayan piedmont plain) and northwestern part of Rangpur region (Teesta floodplain)

(ii) *Meander floodplains*: These floodplains have been formed by the big meandering rivers which deposit sediments within the channel on river beds and also alongside the channels. Gradually high river banks (levees) build up. A meandering river constantly shifts its course, eroding the outside banks of bends and depositing new sediments on the inside bends. This process goes on repeatedly and accounts for the complex patterns of relief and sediments and abandoned channels. Meander floodplains cover greater part of the Teesta, Atrai-Karatoya, Brahmaputra, Jamuna, Ganges and Meghna river floodplains.

(iii) *Tidal floodplains*: They cover mainly the South-west part of the country (Ganges Tidal Floodplain) and part of Chittagong Coastal plain. These are characterized by distinctive, almost level landscape crossed by innumerable, interconnecting tidal rivers and creeks following zigzag patterns and flood levels lower than on meander plains. Inundation lands happens twice a day at high tide and most of the area is flooded during spring tide.

(iv) *Estuarine floodplain*: The cover most parts of Comilla and Noakhali regions, adjoining parts of Barisal, Patuakhali and Faridpur and the recently developing Meghna Estuary. They are characterized by almost horizontal level underlain by silts deposited uniformly both in the lateral and vertical directions under estuarine conditions.

**Previous Research in Bangladesh**

FAP16/FAP19 'A Study of Sedimentation in the Brahmaputra-Jamuna Floodplain' was a major project regarding floodplain sedimentation in this country. FAP16/FAP19 reported that there appear to be four possible sources of plant nutrients in floodplain soils in addition to those that may be provided by new sediment deposits (Brammer, 1995): (1) the contribution of nitrogen by blue-green algae (BGA) living on the soils and in the floodwater; (2) decomposition of leaves and other plant remains, including submerged lower leaves of paddy, jute, and weeds; (3) release of nutrients from weatherable minerals in the seasonally flooded topsoils, some of which are dissolved in the flood-water and transferred to other sites; and (4) increased availability of phosphorus when topsoils are submerged. The two latter phenomena are associated with cyclical chemical changes occurring in seasonally flooded soils. The contribution or the importance of these processes in controlling soil fertility is not clearly understood.

FAP16/FAP19 suggested as one of its findings that the soils receiving significant amounts of new sediments do not appear to have higher nutrient contents than soils where sedimentation is insignificant or absent. It added, if flood control projects reduce the the depth and duration of seasonal flooding on certain protected lands, then the fertility benefits derived from biological sources could be significantly affected and earlier studies indicated that BGA can contribute significantly to the fertility of Bangladesh's floodplain soils, especially on deeply flooded land.

FAP 16/FAP19 also reported that soil nutrient levels determined by laboratory analysis generally are lower in young soils, which receive periodic increments of river sediments, than in older soils, which receive little or none.

It added, BGA activity is greater in clear water than in silty water. Therefore the contribution of nitrogen by BGA is greater in older floodplain areas flooded by clear water than it is in Active and Young floodplain areas where floodwater is clouded by silt.

The study recommended, that growing wetland crops in the dry season might lead to continuous wet conditions of the soil. This may lead to deficiencies of nutrients especially zinc (Zn) and sulfur (S) that results in reduced yield per unit area. Growing of one dryland crop between two wetland crops can mitigate this.

The report suggests in sediments, the laboratory data indicate considerably higher levels of nitrogen, phosphorus, and sulfur than the assumed crop requirements, but levels of potassium are considerably below requirements. However, for various reasons, these results should be treated with caution, not least because they do not correspond to farmers' fertilizer practices in the area. It is possible that the higher levels of organic matter and major plant nutrients present in sediment samples than were found in adjoining topsoil samples reflect the fact that the algal residues on the surface formed a much higher proportion of the total sample in the thin sediment deposited than in 10 cm-thick topsoil samples.

Comparison of the laboratory data for soil profiles from different physiographic units showed that soil nutrient status is not directly linked with sedimentation. Soils on the active and young Jamuna floodplains, which receive the most new sediment, do not have higher nutrient contents than soils on older floodplains, which receive negligible amounts of sediments. Also, young, unleached soils do not necessarily have higher nutrient contents than older soils with acid topsoils. The higher nutrient contents of soils on the older floodplain probably is linked to higher contents of clay and organic matter. This study did not measure the contributions of the blue-green algae and other biological agents to soil fertility.

The report concluded, sampling sites in 1994 (study year) may have yielded unrepresentative levels of organic matter and plant nutrients; little relationship apparently exists between laboratory data and soil fertility status; and soil nutrient levels determined by laboratory analysis generally are lower in soils that receive sediment increments than in those that do not. But, it would be unsafe to extrapolate the study's findings to other floodplain areas because of differences in physiography, hydrology, and mineralogy between floodplain regions.

Two of the study's findings have important implications for the planning and operation of flood protection works. One is that the bulk of river sediments are deposited on narrow strips along active river channels with substantially lesser amounts being deposited in young floodplains; most older floodplain land receive little or no new sediments. The other is that the soils receiving significant amounts of new sediment do not have higher nutrient contents than soils that do not receive new sediment. It appears that reduction in sediments on the floodplain due to construction of embankments would, therefore, have a negligible direct effect on the nutrient status of most floodplain soils. However, protection works that reduced the depth and duration of seasonal flooding could reduce fertility benefits derived from biological sources, which may be significant but were not measured by that study.

Rahman *et al.* (1990) suggested floodplain soils vary from calcerous to strongly acid in different regions. The Gangetic alluvium is rich in calcium, magnesium and potassium. They also contain free calcium carbonate. Their soils are characterized by nitrogen and phosphate deficiency and locally by strong alkalinity. The pH range is 7.0 to 8.5. The teesta silt tract soils are sandy to sandy loam in texture, without any profile development. They are flooded every year and as a result are replenished by fresh deposit every year. The pH varies from 5.5 to 6.8.

ISPAN (1992) reports floodwater in its unique way keeps the floodplain fertile. The river-borne sediments, which are dispersed over the floodplain, are valuable sources of soil nutrients.

However, Brammer, (1995) suggested that standing rainwater provide the conditions for nitrogen fixing blue-green algae to proliferate in the water column, the remnants of which release nutrients to plant roots. Natural long stemmed rice in contrast with modern high yielding variety of rice also produces significant amounts of crop residue, which act as natural fertilizer. Agriculture in the floodplain has therefore prospered for centuries without the use of agro-chemicals. Although natural soil fertility has declined over the years due to extensive agriculture practices, physical properties of the soils still remain highly favorable for plant growth in Bangladesh (Rahman, 1994).

Chowdhury *et al.*, (1996) suggests as a consequence of flood control projects, many floodplain wetlands are shrinking. This is causing harm to the biodiversity and ecosystem and damaging indigenous production systems. Also, flood provides natural fertilization to the soil. The FCDI projects deprive soil within its command area from its natural rejuvenation. FCDI projects have promoted rice mono-cropping which can cause depletion of soil nutrient. He added that the traditional practice of cultivating mix of crops need to be brought back for maintaining soil productivity and for better nutrition value of such crops. Floodplain zoning can be developed with the aim of preserving floodplain resources. Adverse Impacts of flood control projects on floodplain resources include; decrease in capture fisheries, loss of agriculturally productive F1 land due to its conversion to F0 type land, decline in soil fertility, loss of crop diversity and loss of wetlands and bio-diversity due to prevention flooding and draining out water (Chowdhury *et al.*, 1996).

EGIS (1998) evaluated in its Khulna-Jessore Drainage Rehabilitation Project (KJDRP), the sediment characteristics of the Hari River and suggested that the they were rich in magnesium, manganese, sulfur, copper and calcium but deficient in nitrogen, phosphorus and organic matter. The sediments also possessed high Cation Exchange Capacity (CEC), which helps maintaining high soil fertility. It recommended the use of the dredged material from the river to spread over the agricultural land up to a reason able depth to enhance soil's potential for agriculture.

Limited data suggest significant concentration of arsenic in sediment samples collected from Jamuna and Padma Rivers (Chowdhury, 2003). Some recent river water quality data of Bangladesh Water Development Board (BWDB) reported significantly high levels of chromium in river waters. However, data in this regard are scant. In many arsenic affected areas, huge quantities of arsenic are deposited in agricultural land as a result of irrigation with arsenic-contaminated water. During inundation, this deposited arsenic can be mobilized along with nutrients such as phosphate. Such mobilization can have significant influence on fate of arsenic or other metal ions (especially long-term retention) in agricultural soil. Besides, phytoxity due to increased arsenic in soil/water and its long-term impact on agricultural yield is a major concern (Ali, *et al.*, 2003). Ali *et al.*, (2003) also reported significant reduction of arsenic concentration in soil (at Srinagar) after flood. However, these processes are not clearly understood.

The sediment and the water column primarily control distribution and transport of metals in aquatic environments, respectively (Ashfaque, 1999). Mobilization of metals, or lack of it, from bed sediments depends upon the physical texture and chemical nature of sediments, which in turn determine the amount and strength of metal binding.

Ashfaque (1999) suggests, soils generally have a considerable capacity to retain heavy metals. The retention of added heavy metals to soils is often well correlated with soil organic matter. The organic component of the soil constituents has a high affinity for heavy metals because of the presence of ligands or carboxyl, phenolic, alcoholic and carbonyl groups which can form chelates with these metals. The formation of organic complexes with divalent metal ions is of considerable environmental importance as it may render them relatively unavailable to plants and to subsequent leaching.

# CHAPTER THREE
# METHODOLOGY

## 3.1 The Study Area

The study areas selected for field investigation during this study were the floodplains of the Jamuna and the Padma Rivers. These rivers carry the highest sediment load among all the major river systems of Bangladesh. Floodplain sedimentation takes place as floods spread out onto the floodplain, with coarser sediments (sand) being deposited near the bank with the highest thickness, eventually forming natural levee standing up to 3 meters above floodplain over 1 km width as cited from Bristow (1987). 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. Table 3.1 shows data on discharge and sedimentation of the various rivers of Bangladesh.

**Table 3.1 Discharge and sedimentation of the various rivers of Bangladesh.**

| River | Avg. Q (cumec) | $\alpha_Q(-)^*$ | $V^{**}(10^6$ tons) |
|---|---|---|---|
| Jamuna | 20400 | 1.2 | 200 |
| Ganges | 10600 | 1.2 | 190 |
| Padma | 28400 | 1.15 | 370 |
| Upper Meghna | 4500 | 1.3 | 1 |
| Old Brahmaputra | 550 | 1.3 | 2 |
| Dhaleswari | 1000 | 1.3 | 3 |
| Gorai | 1200 (?) | 1.3 | 17 |
| Arial Khan | 2570 | 1.3 | (?) |

$^*\alpha_Q(-)$ : Correction for variability of Discharge in a river

$^{**}$V: Sediment transport integrated over the year ($m^3$), *SOURCE:* FAP 24 (1996b)

## 3.2 Sampling Locations

Shibalaya thana of Manikganj district was selected as the sampling site from the Jamuna floodplain and, Harirampur thana from the same district was selected from the Padma floodplain. For the Jamuna floodplain, a village named 'Nelpur' was selected for sampling, which is located approximately one kilometer upstream of the Aricha ferry ghat. For the Padma River floodplain, 'Paturia' village 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 as it is at the confluence of the two rivers (Figure 3.1).

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 prospective sampling sites during floods and at other times was also taken into account. For recording, samples collected from the village 'Nelpur' were identified as 'Jamuna-Shibalaya', and samples collected from the downstream location (near Aricha) were identified as 'Jamuna-Aricha'. Also, samples collected near the Paturia ferry ghat were identified as 'Padma-Paturia Ghat', and samples collected from the downstream location were identified as 'Padma-Paturia Village'. General information regarding these two thanas are listed in Table 3.2. Besides these

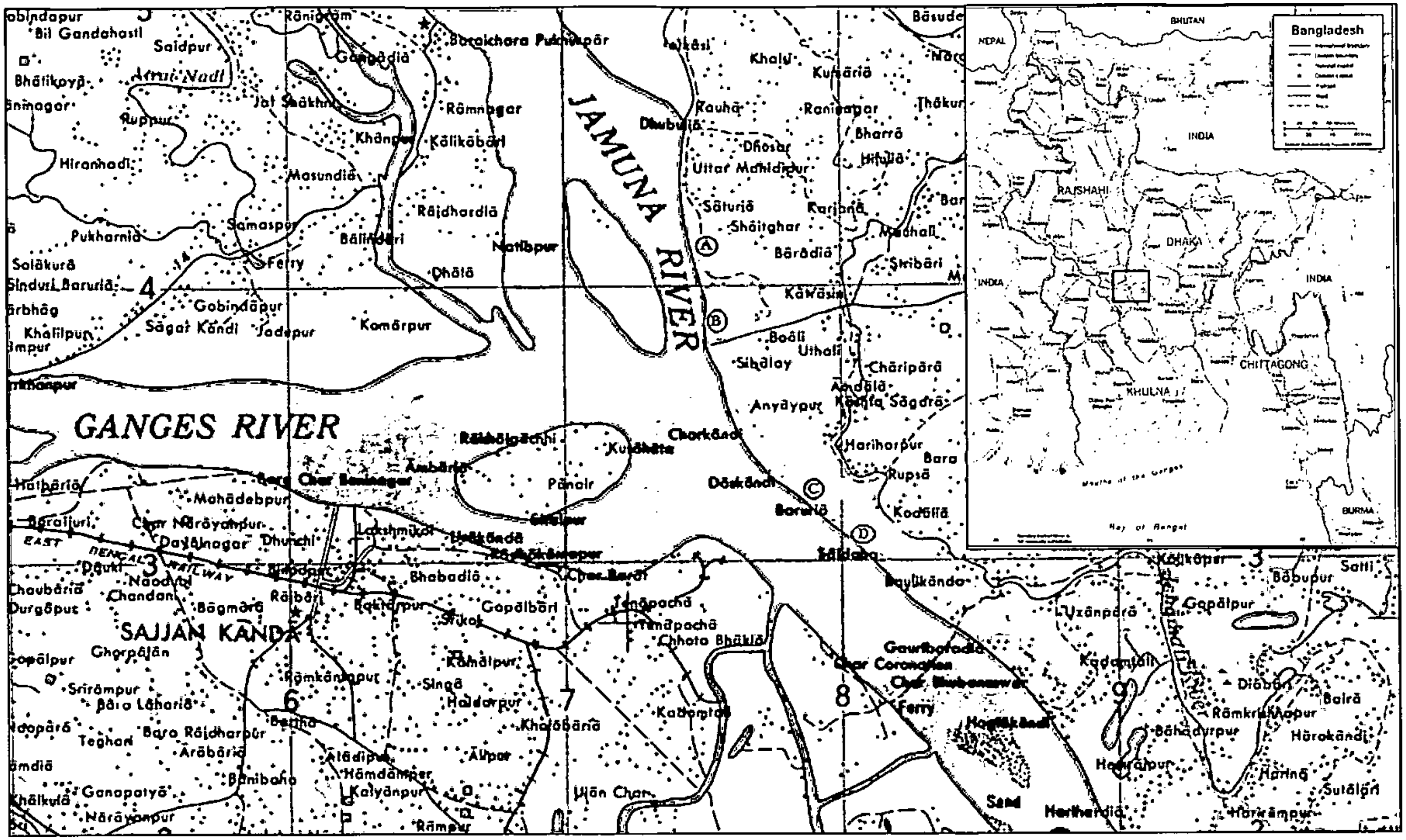



Figure 3.1 Site location map; A: Jamuna Shibalaya, B: Jamuna Aricha, C: Padma Paturia Ghat, D: Padma Paturia Village
(Source: http://www.lib.berkeley.edu/EART/india/250k.html, prepared by Army Map Service, Corps of Engineers, U.S. Army)

sites, Bashilghat village of Srinagar Thana under Munshiganj District was included in the study as a rainwater-inundated floodplain site.

**Table 3.2 General information of sampling locations**

| | Shibalaya | Harirampur |
|---|---|---|
| Location | $23^0$44'~$23^0$54'N<br>$89^0$42'~$89^0$57'E | $23^0$38'~$23^0$48'N<br>$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),<br>70% *Medium high land*-inundated by river water for up to 2/3 months, inundation depth up to 90 cm,<br>5% *Household* | 65% *Medium high land*-inundated by river water for up to 1/2 months, inundation depth up to 90 cm,<br>30% *Medium high land*-inundated by river water for up to 3/4 months, inundation depth from 90 cm up to 180 cm,<br>5% *Household* |

*SOURCE:* SRDI (1999) and SRDI (2002)

## 3.3 Sampling Program

Sampling dates were fixed after analysis of the hydrographs of the Jamuna and the Padma form the last two years. Sample collection was performed as per the schedule given in Table 3.3. Besides, Srinagar site was visited on the 22$^{nd}$ June 2002. Top soil samples and water samples were collected from this site.

**Table3.3 Schedule for sample collection**

| Season | Sampling Date | Samples Collected |
|---|---|---|
| Before Flood | 16th May, 2002 | Top soil |
| | | River water |
| During Flood | 13th August, 2002 | Suspended sediment |
| | | River water |
| After Flood | 26th October, 2002 | Top soil |
| | | Suspended sediment |
| | | River water |

### 3.4 Flooding and Inundation during the Study Period

The flooding that occurred during the study year (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 is assumed on average as 20% of the country. Figure 3.2 shows the comparison of the flooding of 2002 with those during the past fifty years. Figure 3.3 shows the inundation map of Bangladesh, as on the 14th August 2002. The hydrographs for the Jamuna River at Aricha and the Padma River at Goalondo (the opposite bank of Paturia in the Padma River) are given in Appendix I.

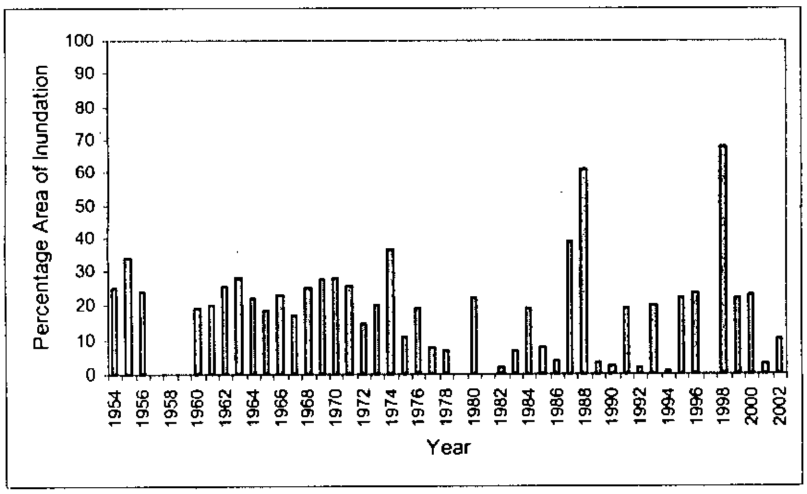



**Figure 3.2 Percentage area of inundation in Bangladesh during flood season from 1954 to 2002**

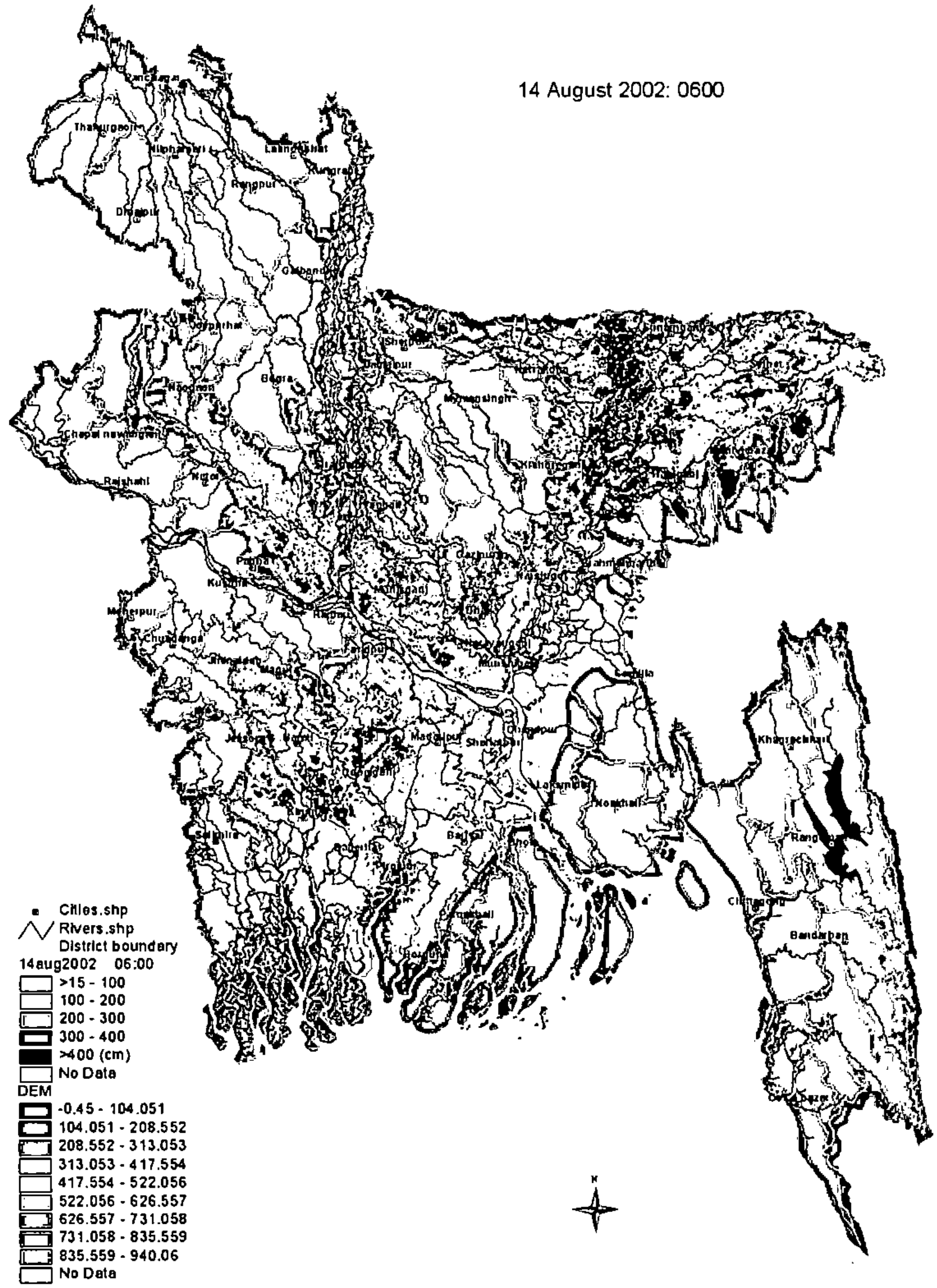



Figure 3.3 Inundation map as on the 14th August, 2002 (Source: www.ffwc.net)

## 3.5 Sampling Technique

### *3.5.1 Collection of River Water Samples*

River water samples were collected for the determination of dissolved nutrients and heavy metal contaminants. During each sampling operation, from each site, water samples were collected from an engine-boat at two separate locations (approximately 15~20m away) from a depth of 30 cm below the water surface. From each location, samples were collected separately in two plastic bottles: one for metal analysis and the other for determining concentrations of anions and some other parameters. For cationic nutrient and metal analysis water samples were filtered in the field and were acidified with nitric acid, immediately after they were brought to the laboratory ($HNO_3$: 2ml/L). A total of 12 water samples were collected

### *3.5.2 Collection of Suspended Sediment Samples*

Suspended sediments 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 separately with two sampling operations: one close to the riverbank and the other away from the riverbank. Finally, after flood season, suspended sediment sample was collected from each river away from the bank.

### *3.5.3 Collection of Floodplain Soil Samples*

Soil samples were collected before and after flood from the Jamuna and Padma floodplains. During the flood season soil samples could not be collected as the sampling sites were inundated with floodwater. Soil samples were collected with six-inch (15 centimeter) diameter PVC pipes up to a depth of around one-foot (30 centimeter). Before flood, a total of, 6 samples were collected: 2 each from Jamuna, Padma and Srinagar floodplains. After flood, a total of 10 samples were collected: 4 each from Jamuna and Padma floodplains and 1 each from the uninundated sites of Jamuna and Padma floodplains.

## 3.6 Preservation and Storage of Samples

Since almost all preservatives interfere with some of the tests, sample preservation is difficult. Before analysis, duration of storage of samples is likely to affect some determinations more than the others. Certain constituents are subjected to loss by adsorption on the sides of glass container walls. So, polythene bags were used for storage of samples for analysis of metal ions, as these bags are less likely to contaminate the sample than glass bottles.

## 3.7 Analysis for Nutrients and Heavy Metals

### *3.7.1 Water Samples*

**Metal ions:** Concentrations of calcium, magnesium, potassium, copper, iron, manganese, zinc, arsenic, chromium and lead in the acidified water samples were determined by Atomic Absorption Spectrophotometer (SHIMADZU Corporation, AAS 6800).

**pH and Conductivity:** pH of water samples were determined as soon as the samples were brought to the laboratory with an electrode pH meter (*Session1/HACH*). Electrical conductivity was measured with conductivity meter (CMD8500 WPA).

**Phosphate:** $PO_4$ concentration was determined through PhosVer 3 (Ascorbic Acid) method for the range 0-2.500mg/L using a spectrophotometer (HACH DR/4800U). The method is equivalent to USEPA method 365.2.

**Sulfate:** $SO_4$ concentration was determined through SulfaVer 4 method for the range 0-70.0mg/L using a spectrophotometer (HACH DR/4800U). The method is equivalent to USEPA method 375.4.

**Sulfide:** Sulfide concentration was determined through the Methylene Blue method for the range 0-800μg/L using a spectrophotometer (HACH DR/4800U). The method is equivalent to USEPA method 376.2.

**Ammonia:** $NH_3$-$NH_4$ concentration was determined through Nessler method using a spectrophotometer (HACH DR/4800U) for the range 0-2.500mg/L.

**Nitrate:** $NO_3$-N concentration was determined with HACH DR/4800U and HACH DR/2010 spectrophotometers through Cadmium Reduction Method (High Range: 0-30.0mg/L)

**Boron**: Boron was determined with HACH DR/2010 spectrophotometer through Carmine Method (0-14.0mg/L)

**TS, TDS, TSS:** Total Dissolved Solids and Total Solids were determined through standard procedures. Total Suspended Solids was then determined by subtracting Total Dissolved Solids from Total Solids.

**Turbidity and Hardness:** Turbidity of water samples was determined using a portable turbidity meter (DR*LANGE* Trubungsphotometer LTP5). Hardness was determined through EDTA titration method.

### *3.7.2 Soil and Suspended Sediment Samples*

Soil samples of different locations and of different depths were marked separately. Each core sample was divided into several segments. Core samples collected before flood, were divided into three segments: first segment top 7.5 cm, second segment next 7.5 cm (i.e., 7.5cm to 15 cm depth) and the rest consisting the third segment. Samples collected after flood were divided into five such segments: first top 2.5cm, next 2.5cm, next 2.5 cm, next 7.5 cm and the rest consisting the last segment (Figure 3.4).

**Metal ions:** To convert all the metallic forms into ionic state, soil samples were digested. For digestion of soil samples, 5-gram of oven-dried ($110^0$C, 24hours) sample was mixed with 2.5-milliliter nitric acid and 7.5-milliliter hydrochloric acid and then it was kept overnight. The digested sample was then extracted for two hours under reflux conditions. Afterwards the cooled sample was filtered and the filtrate was made up to the mark to 500ml with de-ionized water. The sample was then ready for analysis using Atomic Adsorption Spectrophotometer. The metal content of the soil sample in mg/kg of dry weight was then calculated by,

$$M = C \times (L / W) \times 100 \quad (3.1)$$

where,

M = Metal concentration in mg/kg in soil or sediment samples

C = Metal concentration in ppm found by AAS

L = Volume of sample in liter (0.50 liter in this case)

W = Mass of soil or sediment in gram (5.0 gm in this case)

Tests for Arsenic were performed using Graphite Furnace (with supply of Argon gas) and the rest of the metals (Ca, Mg, K, Cu, Fe, Mn, Zn) using Flame Emission technique (with Acetylene gas).

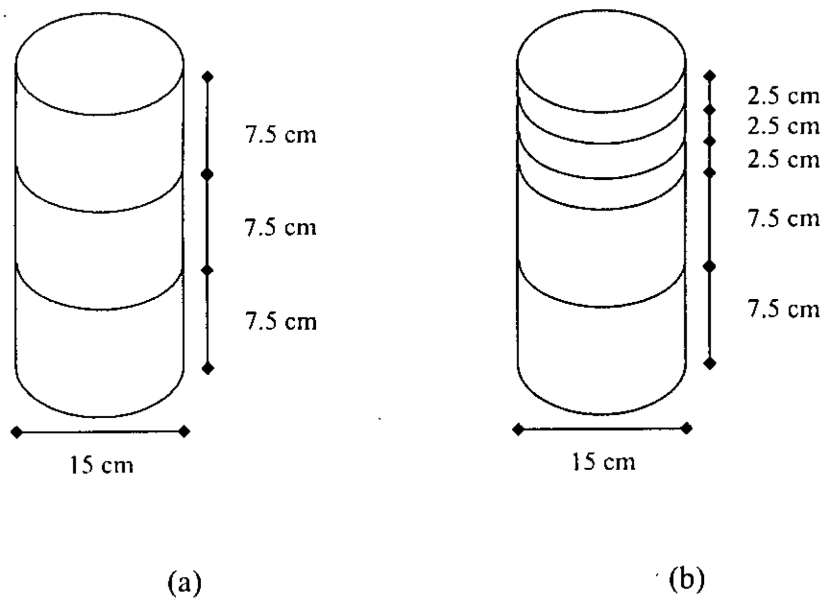



Figure 3.4 Core sample segments: (a) before flood and (b) after flood

**pH and Conductivity:** pH for soil and sediment samples was first measured with pH paper. Also, soil and sediment pH were measured using a glass electrode pH meter (*sension1*) in a 1:2.5 soil: water suspension (Alam *et al.* 1991 and FAP 16/FAP19). For this purpose 20 gram soil/sediment sample was mixed with 50ml distilled water and for the next 30 minutes the suspension was stirred thoroughly. Then the pH of the suspension was measured with a glass electrode pH meter (*sension1*). Electrical Conductivity of soil was determined from extracts of soil: water ratio of 1:5, where the sample was filtered through filter paper (Alam *et al.* 1991). For this purpose 30 gram soil/sediment sample was mixed with 150ml distilled water and kept over night. Then electrical conductivity of the suspension was measured with conductivity meter (CMD8500 WPA).

**Nitrogen:** Plant growth is limited by nitrogen more than by any other element. Most of the nitrogen in soil is in organic form. At any time more than 90% of soil nitrogen is in organic form and relatively small amount ordinarily occur as available nitrogen. The available nitrogen in soil refers to the ammoniacal ($NH_4^+$) and nitrate ($NO_3$) forms of nitrogen. These are the principal forms of nitrogen, which plants take up for their tissue building. These forms of nitrogen are mainly formed through mineralization of organic nitrogen by a number of heterotrophic microorganisms and also small amount through precipitation (Alam *et al.* 1991).

$NO_3$-N of soil and sediment samples was measured after samples were mixed with distilled water at a ratio of 1:5 (Alam *et al.* 1991). Then $NO_3$-N concentration was determined with HACH DR/4800U and HACH DR/2010 spectrophotometers through Cadmium Reduction Method (High Range: 0-30.0mg/L)

**Phosphorus:** With the possible exception of nitrogen, no other element has been as critical in the growth of plants in the field as phosphorus. Plants absorb phosphorus from soil in the forms of $H_2PO_4^-$, $HPO_4^{2-}$ 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).

Most soil phosphorus determinations have two distinct phases: first the preparation of a solution containing soil P or fraction thereof, and the second, the quantitative determination of the phosphorus in this solution. Two colorimetric methods are used for determination of available phosphorus;

*Method 1*: Molybdophosphoric blue color method in sulfuric acid system

*Method 2*: Vanamolybdophosphoric yellow color method in nitric acid system

During this study Method 1 was followed, which is described in detail in Appendix II. This method is based on the principle that in an acid molybdate solution containing orthophosphate ($H_2PO_4^-$) ions, a phosphomolybdate 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 P- concentration but it is affected also by other factors such as acidity, arsenates, silicates, and substances, which influence the oxidation-reduction conditions of the system. The reduction between ammonium sulfomolybdate and orthophosphate and the product of reaction with stannous chloride can be shown in the following way:

Ammonium sulfomolybdate + Orthophosphates
= Ammonium phosphorus molybdate (oxidised) ......(a)
(*Colorless compound*)

Ammonium phosphomolybdate + stannous chloride
= Ammonium phosphomolybdate (reduced) ..........(b)
(*Blue color*)

For this purpose measurement was taken in HACH DR/4800U spectrophotometer with single $\lambda$ measurement and wavelength set at 660 nm.

**Organic Matter:** Organic Carbon in soil can be measured through *Dry Combustion Method,* where the carbon in soil is oxidized to $CO_2$ at very high temperature in a furnace (Alam *et al.* 1991). The differences in weight (lost) give the amount of organic carbon present in the soil. Then the total amount of organic matter can be obtained by using *Van Bemmelen Factor* of 1.724 on the assumption that organic matter of average soil contains 58% of organic matter.

For this purpose 25~30 gram soil was oven dried overnight at $110^0C$ (until constant weight) and then initial weight ($W_1$) was taken. Then the dried soil was burnt in a buffer furnace (CARBOLITE) at $440^0C$~$450^0C$ for six hours (AASHTO 267, equivalent to ASTM 2974). Final weight ($W_2$) was then taken to calculate the percentage of organic carbon in the soil sample. Then

$$\% \text{ Organic Carbon} = (W_1 - W_2)*100/W_1$$

**Metal Ions Associated with Iron Oxyhydroxides:** Amount of metal ions (As, Cr, Pb) associated with iron-oxyhydroxides was determined by 0.2 M oxalic acid (Keon *et. al.* 2000). 2.5gram soil sample (raw) was added with 25 ml of 0.2M oxalic acid solution and thoroughly mixed for two hours by tumble shaking. Then the samples were centrifuged for 20~25 minutes. After the supernatant was decanted 25 ml more oxalic acid was added and the whole procedure repeated. This extractant was used for arsenic, chromium, lead and iron analysis after proper dilution of the samples.

## 3.8 Batch Experiments to Assess mobilization of Nutrients/Metals under Inundation

Batch experiments were performed using the topsoil samples collected before flood. 250 gram topsoil was inundated with 500 ml distilled water and rainwater for a duration of 21 days in 1liter beaker. One sample from each floodplain (Jamuna and Padma), collected before flood, was used in this experiment. After this set of experiment was completed similar procedure was followed with mixing 5 gram of glucose to distilled water or rainwater to investigate the effect of organic content of water on nutrient or contaminant mobilization. Glucose was mixed to simulate the effect of organic matter content in floodwater as well as floodplain (vegetation) matter.

# CHAPTER FOUR
# NUTRIENTS IN RIVER SYSTEMS AND FLOODPLAIN SOIL

## 4.1 Introduction

Nutrients are transported by the river systems in dissolved phase and also in association with the suspended sediments and are transferred to floodplains during the periods of inundation. In this study transport of twelve nutrients (out of total sixteen plant nutrients) through the Jamuna and Padma rivers were evaluated through the analysis of water and suspended sediment samples collected at different times during this study. In addition effect of floodplain sedimentation on floodplain soil characteristics has also been evaluated. Besides nutrients, a number of important parameters e.g., pH, electrical conductivity, solids content of water, were also analyzed. In this chapter, at first the general characteristics of water, suspended sediment and floodplain soil samples are presented. Variation of concentrations of the nutrients with flood season in dissolved and sediment-associated forms are presented in this chapter. Effects of inundation of floodplains and possible sedimentation on the topsoil of floodplains during the flood season on floodplain soil characteristics were evaluated through the analyses of topsoil samples collected before and after flood. Possible effects of geochemical process occurring in the floodplain on floodplain soil as well as on river water characteristics were also evaluated through batch experiments. Amount of different types of nutrients transported annually through the two selected rivers have also been estimated.

## 4.2 General Characteristics of the River Water, Suspended Sediment and Floodplain Soil Samples

### pH

***Water Samples:***

Table 4.1 gives a summary of pH values of river water samples collected during this study (details in Appendix III). Water samples were slightly alkaline for both the rivers throughout the season and they became more alkaline after the flood season.

**Table 4.1 Changes of river water pH with flood season**

| | Jamuna River | Padma River |
|---|---|---|
| **Before Flood** | 7.52 | 7.34 |
| **During Flood** | 7.56 | 7.31 |
| **After Flood** | 7.90 | 7.96 |

***Suspended Sediment Samples:***

Suspended sediment samples, collected during the flood season, were slightly acidic for both the Jamuna and the Padma Rivers. The pH values of sediment samples during and after the flood remains almost the same.

**Table 4.2 Suspended sediment pH during and after flood**

| | Jamuna River | Padma River |
|---|---|---|
| **During Flood** | 6.73 | 6.23 |
| **After Flood** | 6.75 | 6.25 |

***Soil Samples:***

The most consistent parameter that can be used to indicate whether or not soils are receiving significant amounts of new river alluvium is topsoil reaction. The FAP 16/FAP19 (1995) suggested, as one of its findings, that soils that do 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. General characteristics of the floodplain core soil samples are given in detail in Appendix III. Table 4.3 gives a summary of pH values, which shows more alkaline topsoil, is an evidence of new sedimentation.

**Table 4.3 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 uninundated sites are slightly acidic to neutral in reaction (Appendix III.C.2), whereas those from the Srinagar floodplain (Appendix III.C.1), which is primarily inundated by rainwater, are moderately acidic (4.2~4.8).

The pH of soil and suspended sediment samples measured through the procedure described by Alam *et al.* (1991) are not reported here. These measurements were not done immediately after collection of samples showed pH between 7.90~8.18, which might be due to improper soil sample preservation.

**Electrical Conductivity**

***Water Samples:***

Electrical conductivity of river water samples (Table 4.4) showed marked increase after flood for both the Jamuna and the Padma.

**Table 4.4 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 |

***Suspended Sediment Samples:***

Suspended sediments collected during flood from the Jamuna River showed higher electrical conductivity than that from the Padma River, but after flood it was about the same for the two rivers as shown in Table 4.5.

**Table 4.5 Suspended sediment electrical conductivity (µS) during and after flood**

| | Electrical Conductivity (µS/cm) | |
|---|---|---|
| | Jamuna River | Padma River |
| During Flood | 64 | 36 |
| After Flood | 55 | 55 |

***Soil Samples:***

Figure 4.1 shows changes in electrical conductivity in two floodplains after flood. Electrical conductivity of soil segments collected before flood from the Jamuna floodplain, decreased with depth, but the trend was opposite for the Padma floodplain. After flood, EC of soil samples from the Jamuna floodplain, decreased throughout the profiles up to an average of 42%. For the Padma floodplain, conductivity showed little variation with depth after flood. The EC of soil samples from the Srinagar floodplain were significantly low (e.g., 32~34 μS at topsoil) compared to those from the two river floodplains, and the EC of soil samples from the uninundated sites were significantly high (e.g., 262~454 μS at topsoil) compared to the inundated sites.

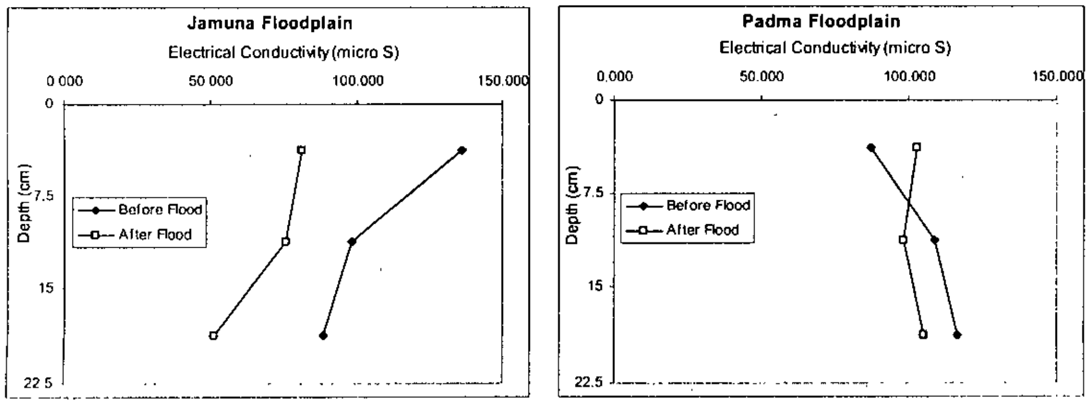



**Figure 4.1 Changes in electrical conductivity of soil after flood in the Jamuna and Padma floodplains**

The decrease in floodplain soil EC can be correlated (correlation coefficient 0.79) with the increase in EC of river water after flood season (Table 4.4). This might be due to the fact that during inundation the soluble salts present in the topsoil of floodplain soil are dissolved and as a result the electrical conductivity of topsoil is reduced and as the floodwater recedes from the floodplains EC of river water increases.

**Organic Matter**

***Suspended Sediment Samples:***

Table 4.6 shows Organic matter contents of suspended sediments collected during and after flood. Organic contents of suspended sediments were low to moderate.

**Table 4.6 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 |

***Soil Samples:***

Table 4.7 shows organic matter contents of floodplain soil samples from the Jamuna and the Padma floodplains and its changes after the flood. Figure 4.2 shows percent of organic matter content before and after flood at the two floodplains with depth.

**Table 4.7 Organic matter content and its variation before and after flood**

| Depth(cm) | Jamuna Floodplain | | | Padma Floodplain | | |
|---|---|---|---|---|---|---|
| | 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% |

Note: Average values shown, all data are presented in Appendix IIIC.

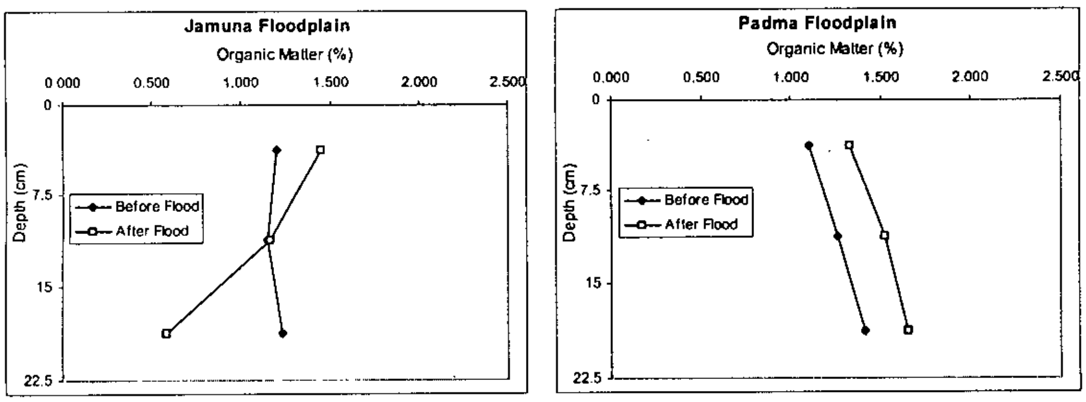



**Figure 4.2 Organic matter content before and after flood in the Jamuna and Padma floodplains**

Organic matter contents of topsoil of the Jamuna floodplain were low to moderate (0.7~2.63%) after flood which is in agreement with the data reported by FAP 16/FAP19 (1995) as 0.5~1.1%. For the Padma floodplain organic matter content of topsoil varied between 0.5~2.06% for samples collected after flood. The uninundated floodplain sites and Srinagar site were relatively higher in organic matter content which is also in agreement with the data reported by FAP 16/FAP19 (1995) as 2.5%.

The increase in organic matter contents of the topsoils of the floodplains cannot be attributed to floodplain sedimentation, as the suspended sediments were not rich in organic matter content. So some other bio-geochemical processes such as algal activity may be responsible for this increase. As discussed in the Chapter 2, standing water provide the conditions for nitrogen fixing blue-green algae to grow rapidly, the remnants of which release nutrients to plant roots (Brammer, 1995a).

### *TS, TDS, TSS and Turbidity of Water Samples:*

TS, TDS and TSS along with turbidity of the water samples collected from the two rivers during the study period are shown in Figure 4.3 (detail data in Appendix III.A). Suspended solids concentration remains less than dissolved solids concentration both before and after flood but it increase markedly during flood with corresponding increase in turbidity.

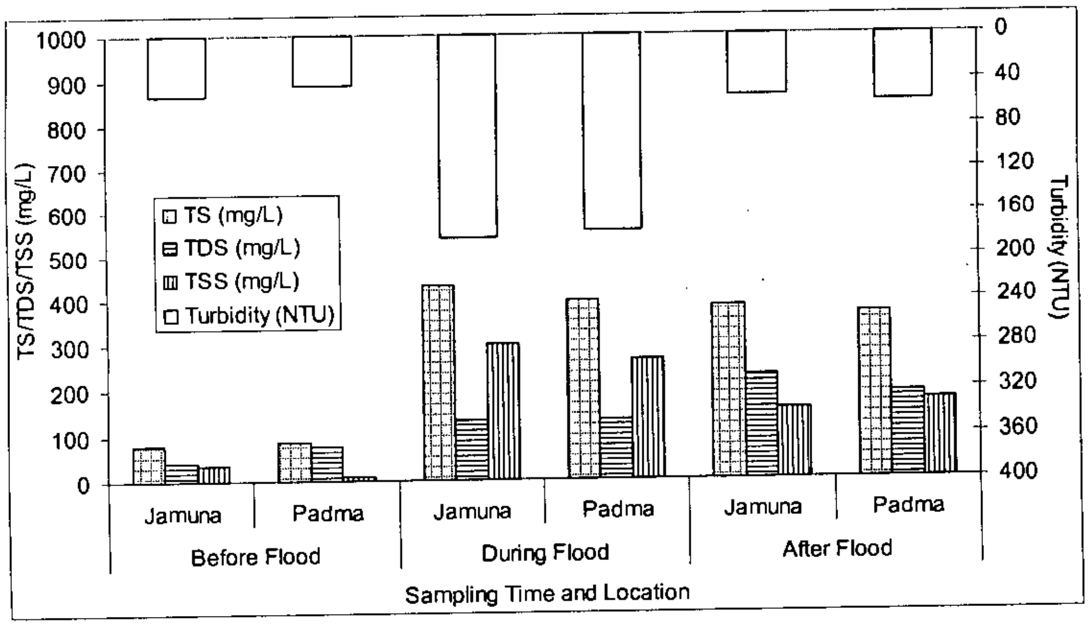



**Figure 4.3 Variation of TS, TDS, TSS and Turbidity of river water samples during study period**

Suspended solids concentrations varied from 9.5mg/L to 36mg/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 mg/L to 76.5 mg/L before flood to 132 mg/L to 133 mg/L during flood. Dissolved solids continued to increase after flood up to 191 mg/L to 228.5 mg/L, which is also consistent with the increase in electrical conductivity discussed earlier.

***Hardness of Water Samples:***

Hardness of the river water samples (measured through EDTA titration method) are presented in Table 4.8. As expected, hardness has high correlation with Calcium and Magnesium content of water samples. Hardness of river water samples appear to increase after flood. The possible reason for such increase is discussed in section 4.6.

**Table 4.8 Changes of river water hardness with flood season**

| | Jamuna River | Padma River |
|---|---|---|
| **Before Flood** | 30 | 28 |
| **During Flood** | 31 | 30 |
| **After Flood** | 42 | 38 |

## 4.3 Nutrient Contents of River Water

Dissolved nutrient contents of water samples, collected before, during and after flood for the two river systems are presented in Table 4.9 and in Figure 4.4.

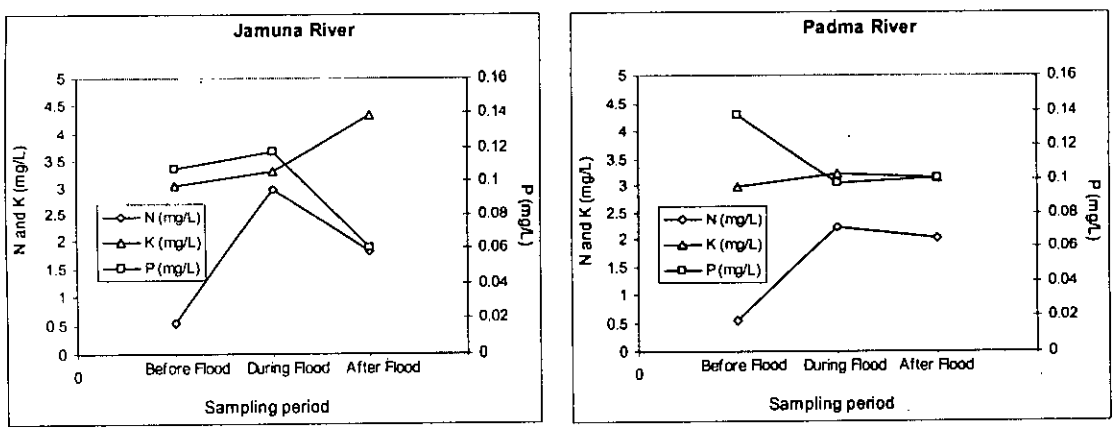
**Table 4.9 Changes of river water quality (nutrients) with flood season**

| | 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 |
| 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 |
| S[3] (mg/L) | 14.556 | 12.8155 | 38.71 | 14.706 | 13.357 | 22.7685 |

[1]Dissolved Nitrogen as $NH_3$-$NH_4$ and $NO_3$,

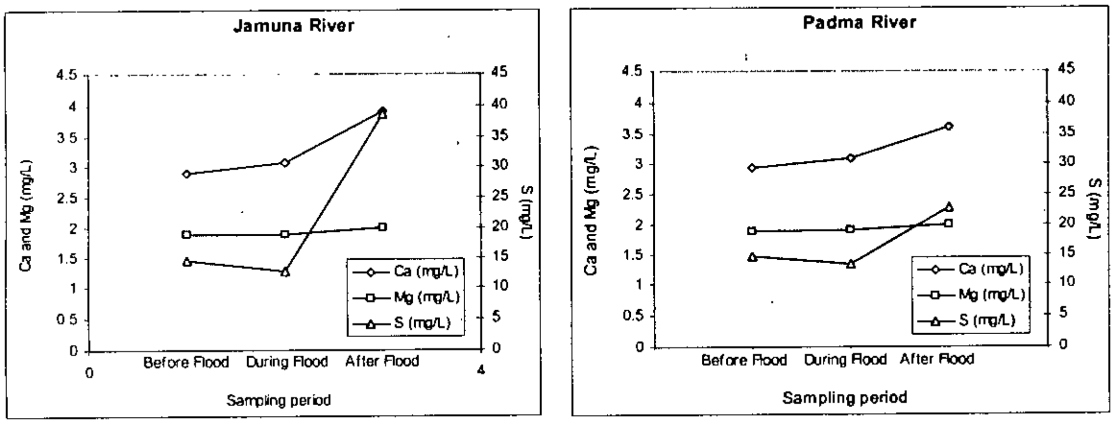
[2]Dissolved Phosphorus as $PO_4$,

[3]Dissolved Sulfur as $SO_4$ and $S_2$

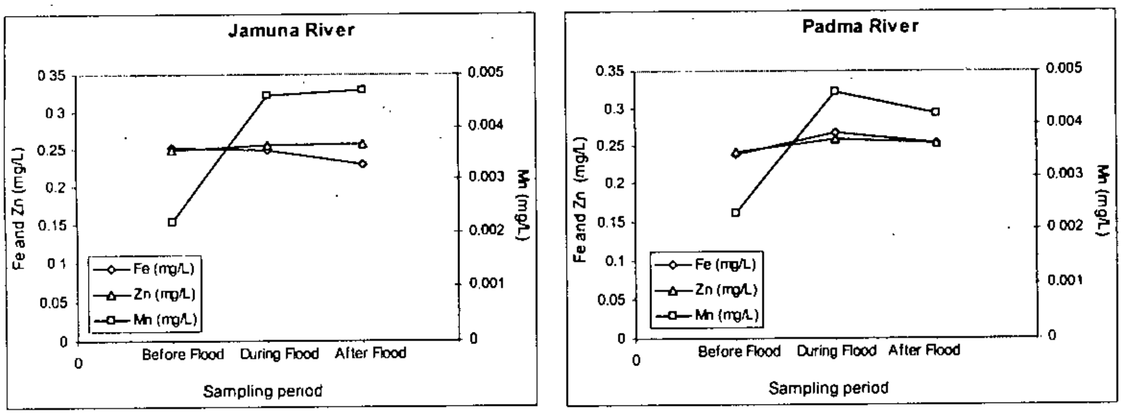



(a)

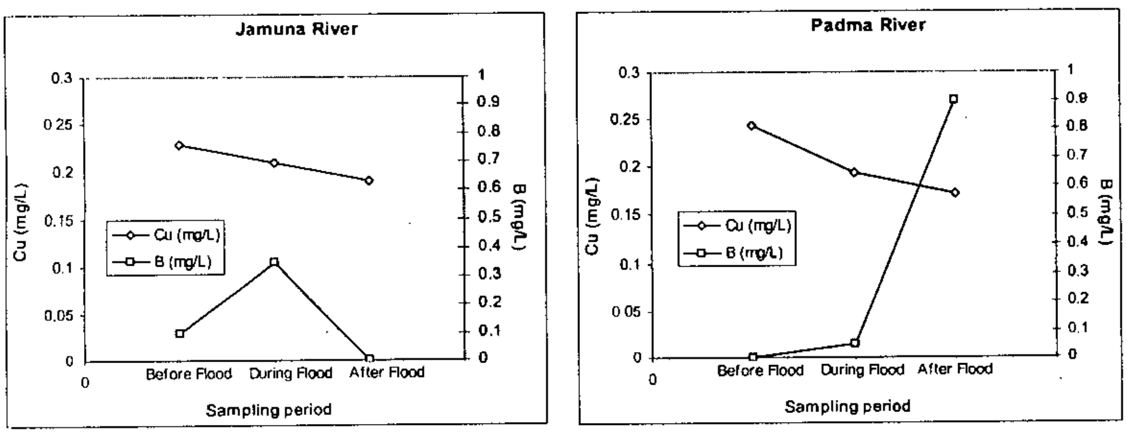
**Figure 4.4 Variation of nutrient concentration in the Jamuna and the Padma during the study period: (a) N, P, K**




(b)




(c)




(d)

**Figure 4.4 Variation of nutrient concentration in the Jamuna and the Padma during the study period: (b) Ca, Mg, S (c) Fe, Mn, Zn (d) Cu, B**

Table 4.9 shows that only dissolved nitrogen and boron contents of river water samples increases during the flood, whereas changes in the other dissolved nutrient contents are minor.

Nitrogen concentration increased significantly, about 4 to 5 times. 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 continues to increase throughout the flood season, but for Padma it rises during flood and falls again after flood. Calcium, magnesium and sulfur increase after flood for both the rivers. Iron and zinc show 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.

### 4.4 Nutrient Contents of Suspended Sediments

Suspended sediment qualities during and after flood are summarized in Table 4.10. It shows that sediment associated nitrogen (in the form of $NO_3$) increased quite significantly for both the rivers, with much larger increase in the Jamuna River. This information is consistent with that reported by FAP16/FAP19 (1995). Phosphorus concentration in suspended sediments of the Padma, decreased (up to 63%) after flood, but in case of the Jamuna phosphorus concentration increased (about 8%). Copper and Manganese concentration in sediments decrease slightly (8~9%) in the Jamuna but increase significantly (98~126%) in the Padma after flood. Average Zinc concentration decrease in the Jamuna by 46% but increase 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 slightly increased (1.5~7%) after flood. Calcium and Magnesium concentration decreased in the Jamuna but increased in the Padma after flood. There was slight increase (13%) in iron concentration after flood in the Padma and also in the Jamuna (increased by 0.6%).

**Table 4.10 Changes of suspended sediment quality (nutrients) after flood**

| | 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 |

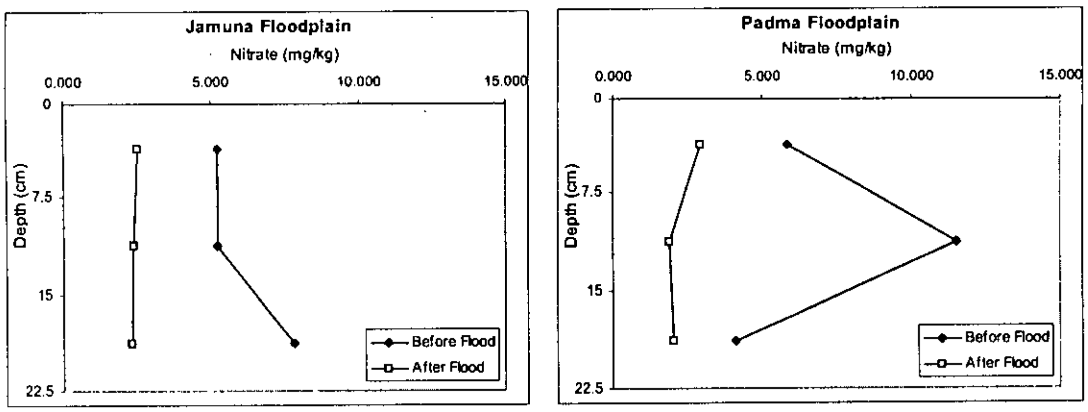
[1]Sediment associated Nitrogen as $NO_3$-N,

[2]Sediment associated Phosphorus as available P,

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 4.1), which favors partitioning of metal cations to solids.

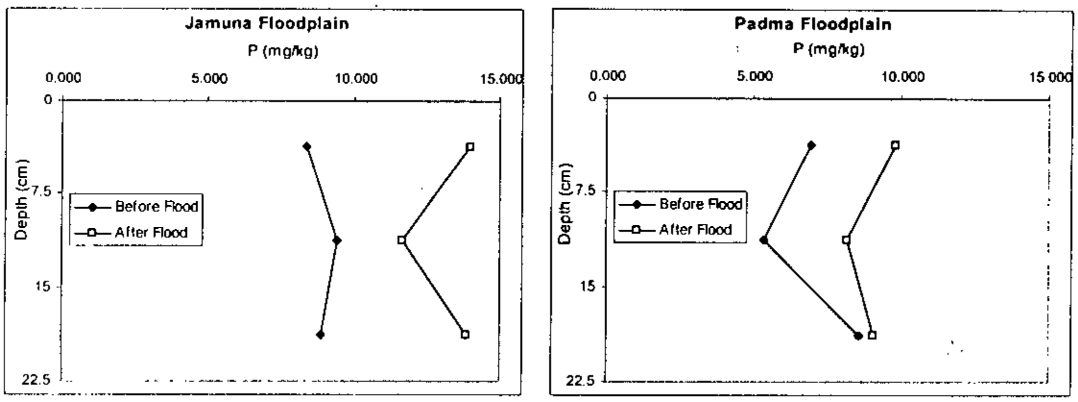
## 4.5 Nutrients in Floodplain Soil and Impact of Flooding on its Characteristics

Figure 4.5 shows average profiles for the nutrients for the Jamuna and the Padma river floodplains before and after flood.

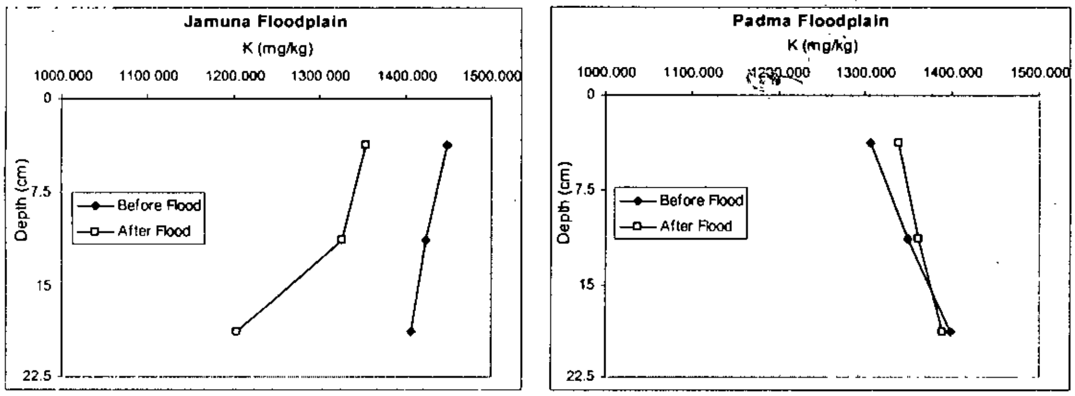



(a)

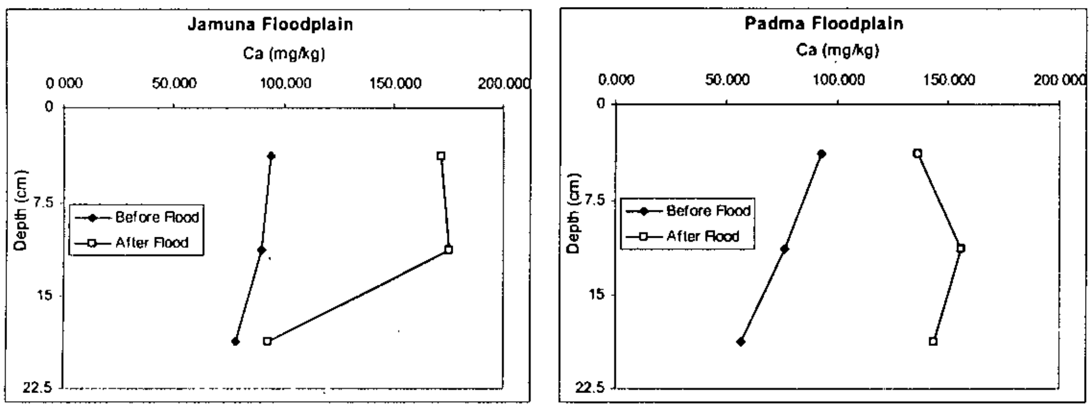
**Figure 4.5 Average profiles for (a) Nitrate for the two river floodplains before and after flood**




(b)

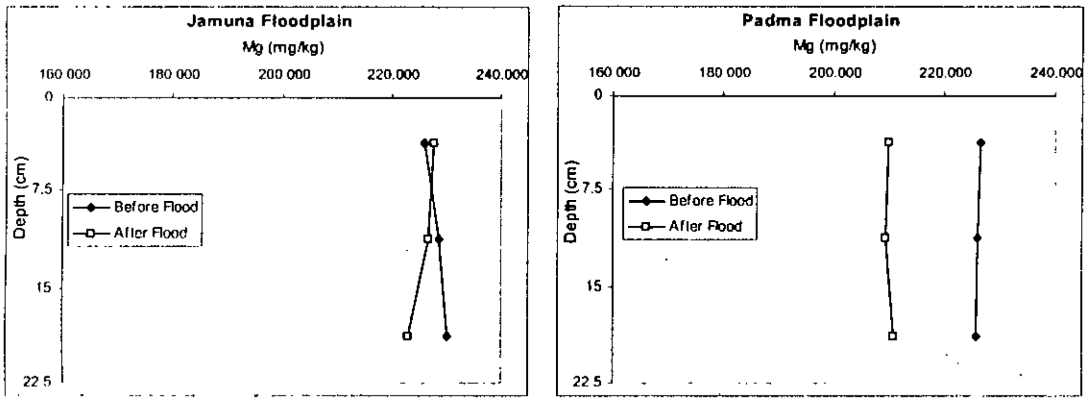



(c)

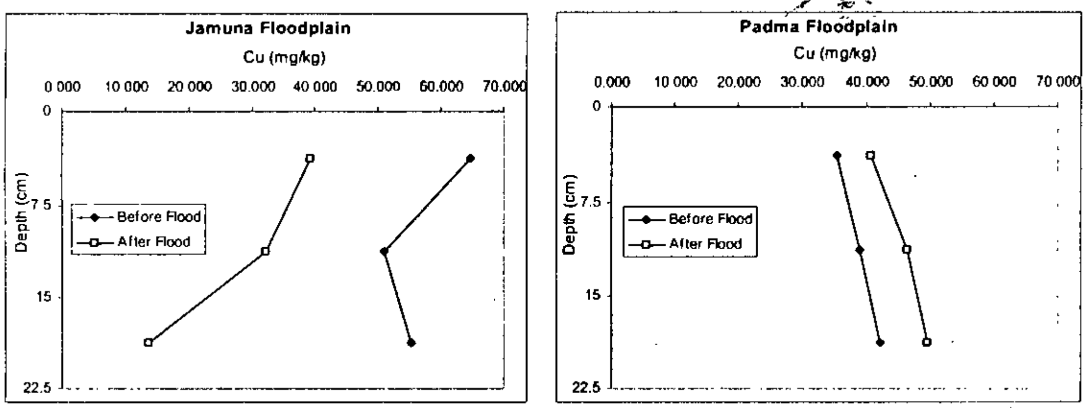



(d)

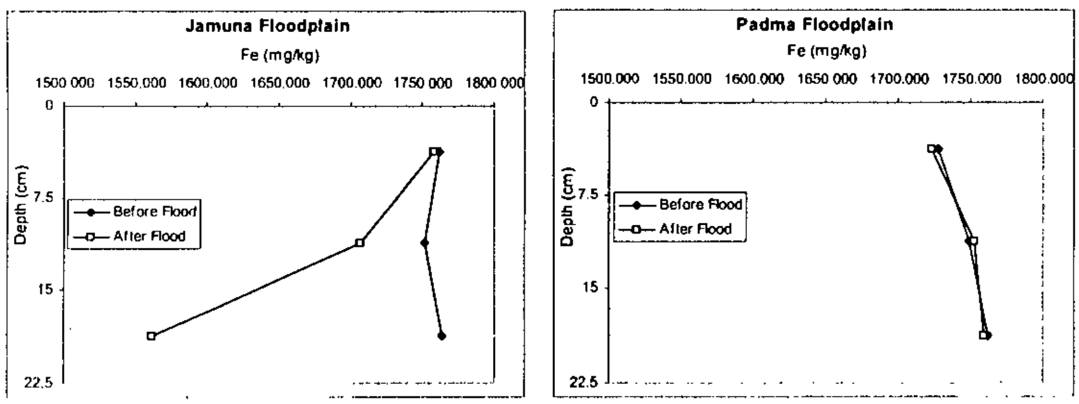
**Figure 4.5 Average profiles for (b) Phosphorus (c) Potassium and (d) Calcium for the two river floodplains before and after flood**




(e)

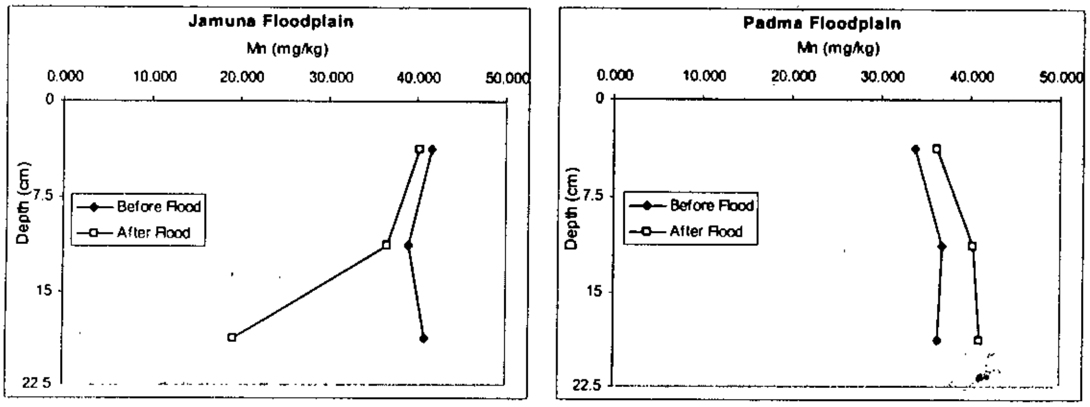



(f)

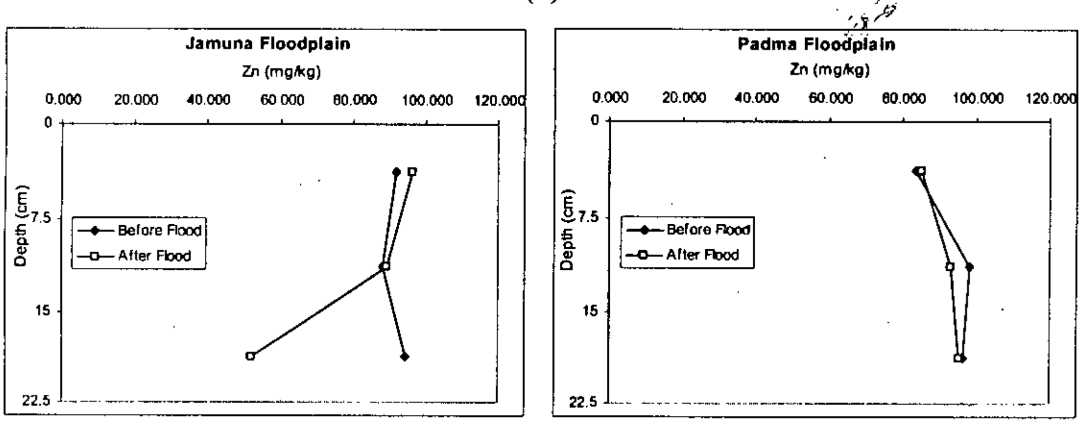



(g)

**Figure 4.5 Average profiles for (e) Magnesium (f) Copper and (g) Iron for the two river floodplains before and after flood**




(h)




(i)

**Figure 4.5 Average profiles for (h) Manganese and (i) Zinc for the two river floodplains before and after flood**

In general, Figure 4.5 shows that phosphorus and calcium contents increased in both the floodplains and nitrogen and magnesium decreased at both the sites. Apart from this, potassium, copper and manganese increased at the Padma floodplain but decreased at the other. Iron decreased significantly at the Jamuna floodplain but show very little change at Padma floodplain. Zinc decreased at lower layers for the Jamuna but shows almost no changes at the Padma floodplain after flood.

Table 4.11 shows the nutrient contents of topsoil samples from the floodplains before and after flood.

**Table 4.11 Changes in topsoil nutrient content after flood**

| Top Layer | Jamuna Floodplain | | Padma Floodplain | |
|---|---|---|---|---|
| 0-7.5 cm | 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,

Among the nutrients nitrogen, phosphorus, calcium and copper shows significant changes at topsoil after flood. Nitrogen concentration decreased 50%, in 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 at Padma floodplain by15%.

Other than these, magnesium, potassium, iron, manganese and zinc show insignificant changes at topsoil. At the Jamuna floodplain magnesium increased slightly (0.7%) but decreased at the Padma (7.4%). Potassium and manganese decreased (6.5% and 3.3% respectively) at the Jamuna but showed opposite trend (2.5% and 7.3% respectively) at the Padma. Iron decreased (0.3%) at both the floodplains while zinc increased (4.6% and 1.6% respectively) at both the sites.

Details of the nutrient data from the floodplain core soil samples are given in APPENDIX IV.C.

Tables 4.13 gives values of plant nutrients used for interpreting soil nutrient status, but direct comparison can't be made as the method for determining different elements are different from those used in this study. The limiting values of nutrients for different soil types are given in Table 4.14, where the methods of laboratory procedures are summarized.

**Table 4.12 Approximate values of plant nutrients used for interpreting soil nutrient status**

| Element | Low (≤) | Medium | Optimum |
|---|---|---|---|
| N (μg/g soil) | 75 | 76-150 | 151-300 |
| P (μg/g soil) | 12 | 12-25 | 26-75 |
| K (meq/100g soil) | 0.2 | 0.21-0.4 | 0.41-1.5 |
| Ca (meq/100g soil) | 2 | 2.1-4 | 4.1-18 |
| Mg (meq/100g soil) | 0.8 | 0.81-2 | 2.1-9 |
| Cu (μg/g soil) | 1 | 1.1-3 | 3.1-10 |
| Fe (μg/g soil) | 20 | 21-40 | 41-200 |
| Mn (μg/g soil) | 5 | 5.1-10 | 11-50 |
| Zn (μg/g soil) | 2 | 2.1-4 | 4.1-18 |
| B (μg/g soil) | 0.2 | 0.21-0.5 | 0.51-4 |
| S (μg/g soil) | 12 | 13-25 | 26-75 |

*SOURCE*: FAP16/FAP19

Table 4.13 Recommended limiting values of nutrients for different soil types

| Elements | Limiting Value for soil type | | | Extraction Method |
|---|---|---|---|---|
| | Upland Clayey | Upland Sandy | Wetland Clayey | |
| N (%) | 0.12 | 0.10 | 0.12 | Kjeldahl Method |
| Organic Matter (%) | C/N=10 | C/N=10 | C/N=10 | Dry Combustion Method |
| P (μg/g soil) | 10.0 | 8.0 | 8.0 | Modified Olsen Method (pH≥7) |
| P (μg/g soil) | 7.0 | 7.0 | 5.0 | Bray and Curz Method (pH<7) |
| K (meq/100g soil) | 0.12 | 0.08 | 0.10 | Ammonium Acetate Extraction |
| Ca (meq/100g soil) | 2.0 | 2.0 | 2.0 | Ammonium Acetate Extraction |
| Mg (meq/100g soil) | 0.5 | 0.5 | 0.5 | Ammonium Acetate Extraction |
| Cu (μg/g soil) | 0.2 | 0.2 | 0.2 | DTPA Method |
| Fe (μg/g soil) | 4.0 | 3.0 | 4.0 | DTPA Method |
| Mn (μg/g soil) | 1.0 | 1.0 | 1.0 | DTPA Method |
| Zn (μg/g soil) | 0.6 | 0.5 | 0.6 | DTPA Method |
| B (μg/g soil) | 0.2 | 0.16 | 0.2 | $CaHSO_4$ Extract/ Hot water Ext. |
| S (μg/g soil) | 10.0 | 8.0 | 12.0 | $CaHPO_4$ Extraction |

*SOURCE*: SRDI (1999) and SRDI (2002)

## 4.6 Mobilization of Nutrients from Floodplain Sediments

As explained in Chapter Three, batch experiments were conducted to assess mobilization of the nutrients 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; to simulate effect of organic matter on possible mobilization.

Results from the batch experiments, presented in Tables 4.15a through 4.15d, show significantly increased mobilization of nitrogen, calcium, iron and manganese. It also shows slight mobilization of magnesium, potassium, copper and zinc. But mobilization of phosphorus and sulfur are decreased after addition of glucose.

**Table 4.14a Results from Batch Experiments: Mobilization of Nutrients (N, P, S)**

| Topsoil Sample | Inundated with | N[1] (mg/L) | | P[2] (mg/L) | | S[3] (mg/L) | |
|---|---|---|---|---|---|---|---|
| | | Without OM[4] | With OM | Without OM | With OM | Without OM | With OM |
| Jamuna | DW[5] | 3.885 | 8.510 | 0.010 | 0.000 | 44.600 | 31.806 |
| Padma | RW[6] | 3.125 | 11.255 | 0.000 | 0.000 | 47.201 | 28.802 |
| Jamuna | DW | 2.420 | 9.470 | 0.013 | 0.000 | 43.903 | 31.273 |
| Padma | RW | 2.145 | 13.430 | 0.000 | 0.000 | 17.104 | 14.843 |

[1]N as $NO_3$ and $NH_4$, [2]P as $PO_4$, [3]S as $SO_4$ and $S_2$,

[4]OM=Organic Matter, [5]DW=Deionized Water, [6]RW=Rain Water

**Table 4.14b Results from Batch Experiments: Mobilization of Nutrients (Ca, Mg, K)**

| Topsoil Sample | Inundated with | Ca (ppm) | | Mg (ppm) | | K (ppm) | |
|---|---|---|---|---|---|---|---|
| | | Without OM[1] | With OM | Without OM | With OM | Without OM | With OM |
| Jamuna | DW | 3.935 | 8.509 | 1.465 | 1.591 | 7.031 | 10.025 |
| Padma | RW | 4.065 | 8.673 | 1.478 | 1.608 | 7.440 | 10.485 |
| Jamuna | DW | 3.026 | 8.796 | 1.440 | 1.565 | 6.364 | 10.402 |
| Padma | RW | 2.981 | 8.568 | 1.372 | 1.582 | 5.094 | 10.642 |

**Table 4.14c Results from Batch Experiments: Mobilization of 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 4.14d Results from Batch Experiments: Mobilization of 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 |

Decrease in nitrogen content at topsoil of floodplains (Table 4.11) and increase in dissolved nitrogen in river water (Table 4.9) is consistent with the results of batch experiments.

Immobilization of phosphorus under reducing environment is also consistent with the river water quality data. The increase in phosphorus content at topsoil after flood may be attributed to sedimentation during the inundation period. The phosphorus content of suspended sediments during flood was much higher than those at the topsoil, which may have resulted the increase in phosphorus concentration at the floodplains of both the rivers.

Slight mobilization of potassium, copper and zinc is also evident from the water quality data of the two rivers especially during and after flood.

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 at floodplain soil after flood may be attributed partly to partitioning of dissolved calcium to topsoil during inundation.

For iron and sulfur batch experiment results cannot be used to explain the water quality, suspended sediment or floodplain soil characteristics.

## 4.7 Estimation of Nutrient Transport through the Jamuna and the Padma Rivers

An estimate of the nutrient transported through the Jamuna and the Padma rivers was made from the annual discharge data and suspended sediment load of these rivers, dissolved nutrient content and sediment associated nutrient concentration measured during this study. For this purpose average annual water discharge for the Jamuna was taken as 20400 $m^3/s$ and for the Padma it was taken as 28000 $m^3/s$ (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, 1996a). Dissolved nutrient contents were averaged for all the water samples collected for each river. Average of all three suspended sediment samples was taken to calculate sediment associated nutrient load. Total annual nutrient load was estimated from the summation of these two components (dissolved and suspended) for each river. Briefly, for a particular nutrient and river, total annual load,

$$L_t = L_d + L_s \quad \ldots\ldots(4.1)$$

$$L_d = C_d * Q * f_d \quad \ldots\ldots(4.2)$$

$$L_s = C_s * S * f_s \quad \ldots\ldots(4.3)$$

where,

$L_t$ = Total annual nutrient load for a river (tons per year)

$L_d$ = Total annual dissolved nutrient load for a river (tons per year)

$L_s$ = Total annual sediment associated nutrient load for a river (tons per year)

$C_d$ = Annual average dissolved nutrient content (mg/L)

$C_s$ = Annual average sediment associated nutrient content (mg/kg)

Q = Annual average water discharge for the Jamuna or the Padma river ($m^3/s$)

S = Sediment transport integrated over the year (million tons per year)

$f_d$ = Factor for unit conversion for dissolved nutrient load (31.536)

$f_s$ = Factor for unit conversion for sediment associated nutrient load (1)

Calculated values for different nutrients are shown in Table 4.16. Sediment associated Boron could not be determined through laboratory experiments. So only the dissolved Boron content was used in calculation.

**Table 4.15 Nutrient Load Estimate through the Jamuna and the Padma Rivers**

**(All in thousand tons per year)**

| | Jamuna River | | | Padma River | | |
|---|---|---|---|---|---|---|
| Nutrient | Dissol-ved | Sediment Associated | Total | Dissol-ved | 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 |

[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 $S_2$

From the results of 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 part of 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 sediment samples only Nitrate was measured. Another important Nitrogen constituent Ammonium could not be measured due to laboratory limitations. So, sediment associated Nitrogen seems insignificant compared to the total Nitrogen load. Also for Phosphorus, only available phosphorus was measured for suspended sediment samples and dissolved phosphorus is the major portion of total phosphorus load.

For Iron and Manganese, sediment associated portions are 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.

# CHAPTER FIVE

# HEAVY METALS IN RIVER SYSTEMS AND FLOODPLAIN SOIL

## 5.1 Introduction

Apart from nutrients, contaminants are also transported through river systems, either in dissolved state or in association with suspended sediments, and are transferred through floodplain sedimentation by adsorption-desorption and/or other processes. In this study, transport of three heavy metals- arsenic, chromium and lead- through the selected river systems were evaluated by measuring the concentrations in river water and suspended sediment samples collected during different time periods. Effect of floodplain sedimentation on the characteristics of topsoil, with respect to these three heavy metals, was evaluated through analyses of topsoil samples (for three heavy metals) collected before and after the flood season. This chapter presents an assessment of the concentration of three heavy metals in the selected river systems and their variation with time (before, during and after flood season). An estimation of the amounts of three heavy metals transported through the river system has also been made. This chapter also presents the characteristics of the topsoil samples in the floodplain with respect to these three heavy metals and makes an attempt to explain the role of floodplain sedimentation on the heavy metal content of topsoil samples.

## 5.2 Heavy metal Contents of River Water

Concentration of dissolved arsenic, chromium and lead of water samples collected from the Jamuna and the Padma rivers before during and after flood are presented in Table 5.1 Figure 5.1 shows the variation of concentration graphically.

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 5.1 Changes of river water quality (contaminants) with flood season**

| | 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 the addition of arsenic free rainwater during the flood season may be responsible for lowering of arsenic concentration.

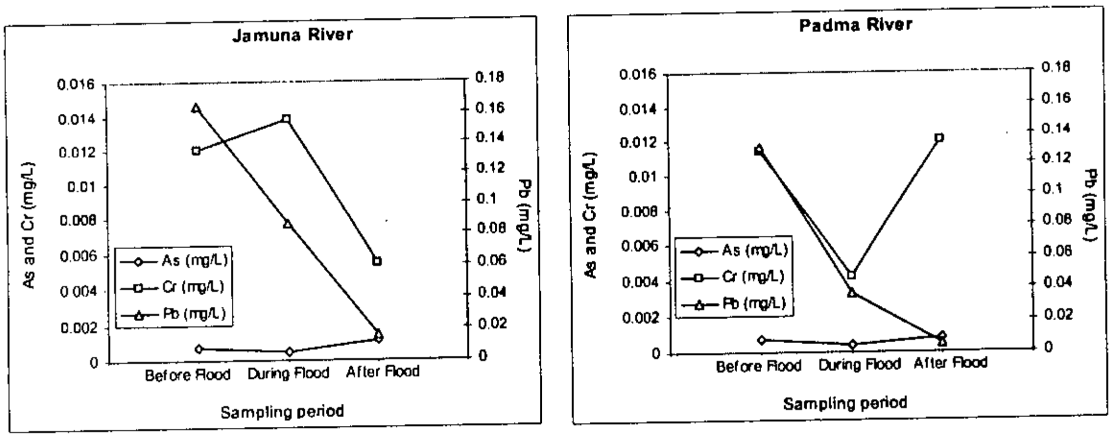



**Figure5.1 Variation of contaminant concentration in the Jamuna and the Padma during the study period**

However, Chromium concentration shows 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.

For dissolved Lead concentration both the rivers show similar trend. Dissolved lead concentration 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 (see Table 4.1, Chapter 4), which favors adsorption of metal cations on to solids.

### 5.3 Heavy metal Contents of Suspended Sediments

Table 5.2 shows concentrations of arsenic, chromium and lead in suspended sediment samples collected from the Jamuna and Padma rivers during and after flood.

**Table 5.2 Changes of suspended sediment quality (contaminants) after flood**

| | 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 |

In general, heavy metal contents of suspended sediments increased after flood. Arsenic concentration in suspended sediments moderately (6~21%) increased after flood in the Jamuna River but in the Padma the increase is quite significant (74~114%). Chromium concentration in sediments remained almost 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. The increase in the concentration of sediment-bound lead may be attributed to the increase in pH of river water after the flood (see Table 4.1, Chapter 4), which favors partitioning of metal cations to solids. Though higher pH values does not favor adsorption/partitioning of arsenic, the effect becomes apparent only after pH>8, however pH values of river water samples never reaches this level.

## 5.4 Heavy metals in Floodplain Soil and Impact of Flooding on its Characteristics

Figure 5.2 shows average profiles for arsenic, chromium and lead for the Jamuna and the Padma river floodplains before and after flood.

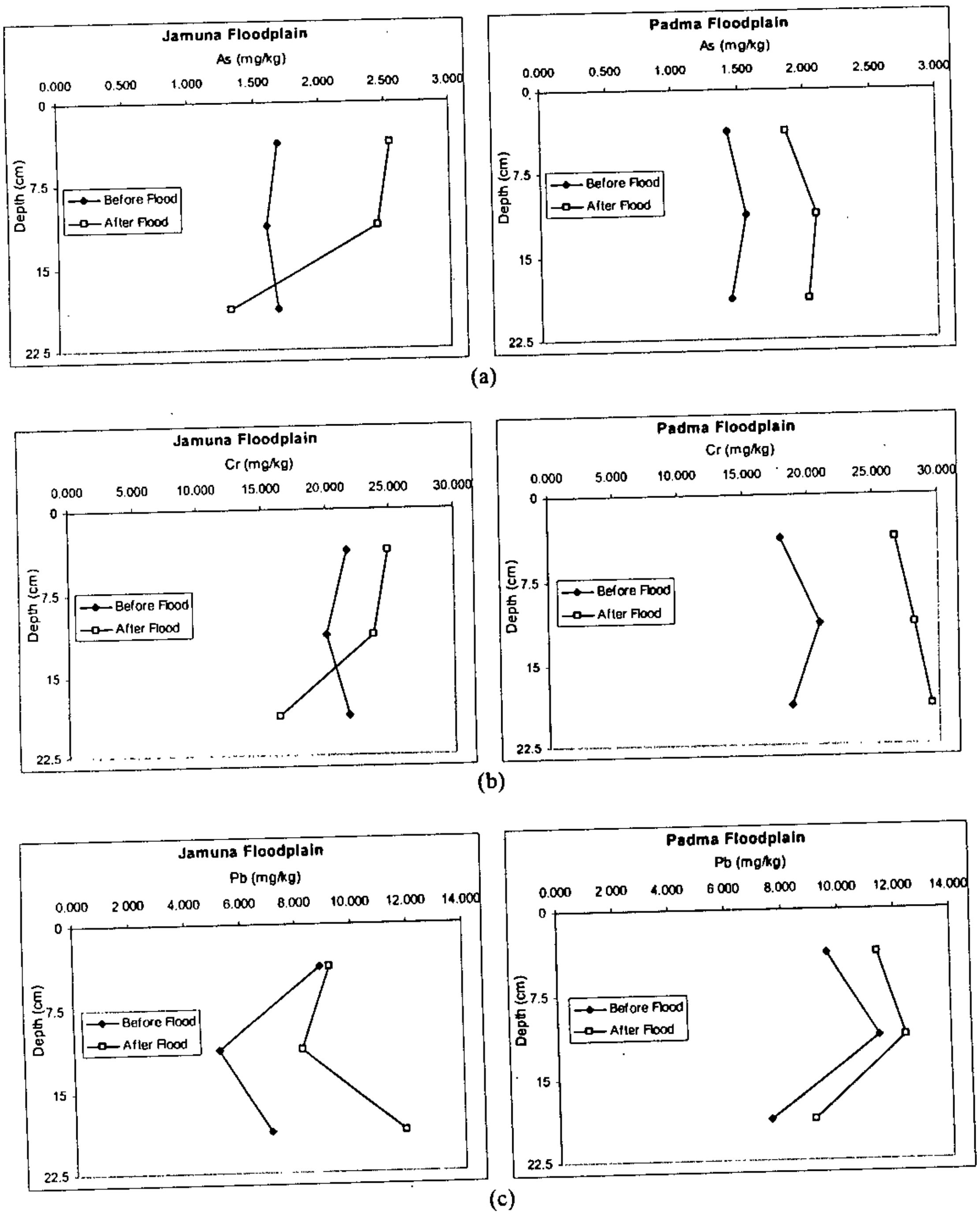



**Figure 5.2 Average profiles for (a) Arsenic, (b) Chromium and (c) Lead for the two river floodplains before and after flood**

Table 5.3 shows the heavy metal contents of topsoil samples from the floodplains before and after flood.

**Table 5.3 Changes in topsoil contaminant content before and after flood**

| Top Layer (0-7.5 cm) | Jamuna Floodplain | | Padma Floodplain | |
|---|---|---|---|---|
| | Before Flood | After Flood | Before Flood | After Flood |
| As (mg/kg) | 1.69 | 2.55 | 1.42 | 1.87 |
| Cr (mg/kg) | 21.71 | 24.85 | 17.87 | 26.70 |
| Pb (mg/kg) | 8.87 | 9.21 | 9.65 | 11.43 |

In general Figure 5.2 shows that, 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%, which 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 each of the floodplains. In both the 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 layers beginning from the top.

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 5.2 and Table 5.3 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 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.

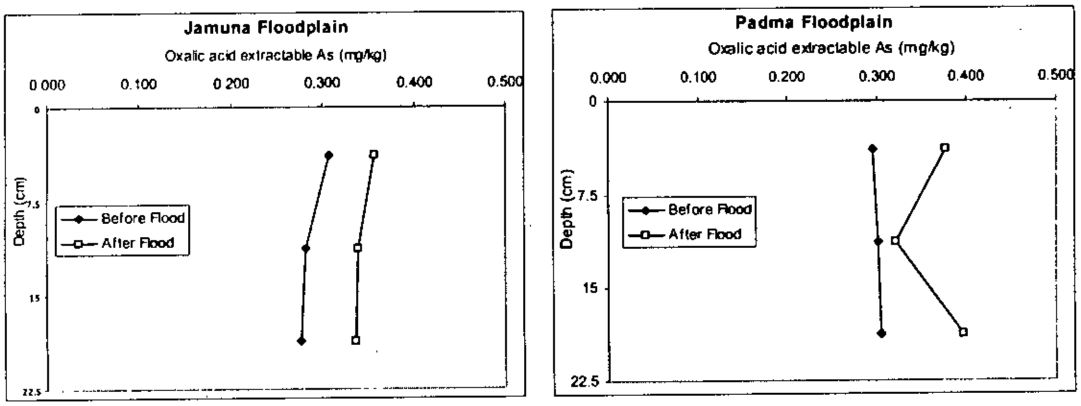
A comparison of heavy metal (As, Cr, Pb) profiles of inundated and uninundated floodplain soils (data presented in APPENDIX V) show that for Jamuna site, uninundated soils show low heavy metal content compared to the uninundated areas. whereas for Padma site the trend was reverse. It is difficult to explain these trends without historical data on heavy metal profile and inundation (if any) of these uninundated sites.

Soil profiles from Srinagar site show, lower concentrations of Arsenic and Chromium compared to the inundated floodplains of the Jamuna and the Padma, but higher concentrations of Lead.

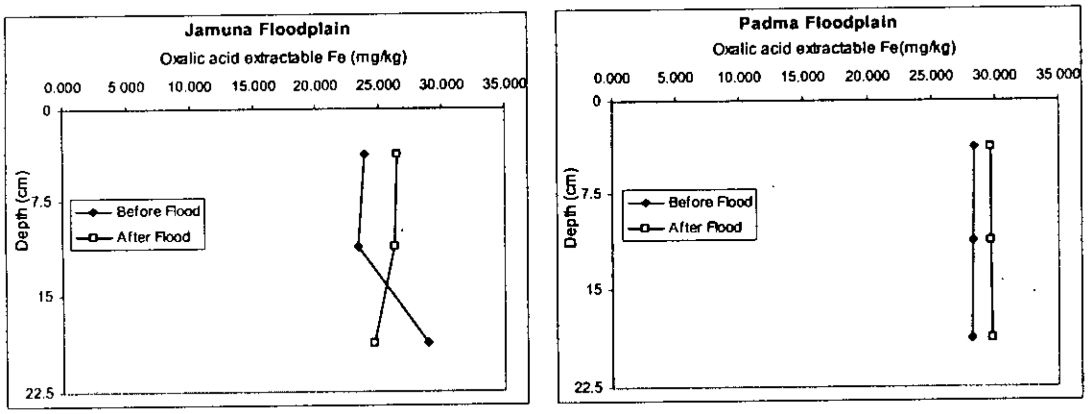
Besides total metal contents of the floodplain soil core samples, experiments were conducted to assess the concentration of easily mobilized metals in the soil core samples. As explained in Chapter Three, easily mobilized metals were determined by extraction with 0.2 M oxalic acid, which primarily provides an estimate of metal ions associated with iron-oxyhydroxides. It is interesting to note that 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. This result is significant from the point of view of arsenic mobilization, under reducing geochemical conditions (e.g. reducing environment promoting dissolution of iron oxyhydroxides). This oxalic acid extractable arsenic can be easily mobilized and would find its way into the groundwater.

Results for oxalic acid extractable contaminants are summarized in Figure 5.3.




(a)




(b)

**Figure 5.3 Oxalic acid extractable (a) Arsenic and (b) Iron from soil profiles of the Jamuna and the Padma floodplains before and after flood**

## 5.5 Mobilization of Heavy Metals from Floodplain Sediments

As explained in Chapter Three, batch experiments were conducted to assess mobilization of the 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 mixed with glucose; to simulate effect of organic matter on possible mobilization.

Results from the batch experiments, presented in Table 5.4, show increased mobilization of arsenic under inundation with water containing glucose. This increased mobilization can be explained by the fact that a significant portion of arsenic in the soil samples was present in association with iron-oxyhydroxides explained earlier in section 5.4, 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 water after the floods. However more careful monitoring is required to ascertain this phenomenon.

**Table 5.4 Results from Batch Experiments: Mobilization of Heavy metals**

| Topsoil Sample | Inundated with | As (ppm) | | Cr (ppm) | | Pb (ppm) | |
|---|---|---|---|---|---|---|---|
| | | Without OM[1] | With OM | Without OM | With OM | Without OM | With OM |
| Jamuna | DW[2] | 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 |

[1]OM=Organic Matter

[2]DW=Deionized Water

[3]RW=Rain Water

Results of batch experiments show decreased mobility of lead under inundation with glucose (organic matter). Since, it has been found that none of the lead is associated with iron-oxyhydroxides content of soil, it can be concluded that 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 mobilization due to the addition of glucose. This may be due to the fact that no chromium is associated with iron-oxyhydroxides.

## 5.6 Estimation of Heavy Metal Transport through the Jamuna and the Padma Rivers

An estimate of the amount of arsenic, chromium and lead transported through the Jamuna and the Padma Rivers was made based on river flow and suspended sediment concentration data (FAP 24, 1996a) and concentration of these metals in water and sediment samples determined in the study. Table 5.5 shows estimated amount of As, Cr and Pb transported with river water and sediments each year.

**Table 5.5 Contaminant Load Estimate from the Jamuna and the Padma Rivers (All in tons per year)**

| | Jamuna River | | | Padma River | | |
|---|---|---|---|---|---|---|
| Contami-nants | Dissol-ved | Sediment Associated | Total | Dissol-ved | Sediment Associated | Total |
| As | 481 | 297 | 778 | 561 | 508 | 1069 |
| Cr | 6691 | 4120 | 10811 | 8240 | 6455 | 14695 |
| Pb | 57032 | 1435 | 58467 | 51364 | 2644 | 54008 |

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.

# CHAPTER SIX

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusion

The Ganges-Padma and Brahmaputra-Jamuna river systems carry a billion tons 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 and organic contents to assess the effect of the geochemical processes during inundation in mobilizing 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 peak 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 was 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. In the study, 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 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 maybe responsible for the increase in organic matter content.

Among the nutrients nitrogen, phosphorus, calcium and copper shows 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 were in opposite pattern, at the Jamuna floodplain it decreased by 39% but increased at Padma floodplain by15%. Other than these, magnesium, potassium, iron, manganese and zinc show insignificant changes at topsoil.

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. Immobilization of phosphorus under reducing environment was also consistent with the river water quality data. The increase in phosphorus content at topsoil after flood may be attributed to floodplain sedimentation. The phosphorus content of suspended sediments during flood was much higher than those at the topsoil, which may have resulted the increase in phosphorus concentration at the floodplains of both the rivers. Slight mobilization of potassium, copper and zinc is also evident from the water quality data of the two rivers especially during and after flood.

Batch experiment results supported increased mobilization of calcium and manganese of the two rivers especially during and after flood. Increase in calcium content at floodplain soil after flood may be attributed partly to partitioning of dissolved calcium to topsoil during inundation.

Biogeochemical processes occurring within the floodplain during inundation by floodwater may play a significant role in regulating soil as well as river water characteristics.

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. River water characteristics, especially pH appear to play a significant role in the partitioning of heavy metals ions between aqueous to solid phases. As for example, lower dissolved concentration of lead after the flood may be related to the higher partitioning of lead from aqueous phase to the solid phase at increased pH level after flood.

Dissolved arsenic concentration in river water samples decreased during the flood season due to dilution with arsenic free rainwater. Dissolved lead concentration continues to decrease after the flood season due to the higher partitioning of lead from aqueous phase to solid phase, which was favored by the higher pH values. 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 sediments and floodplain soil is associated with iron-oxyhydroxides. Results from batch experiments suggests that arsenic can be easily mobilized under the reducing environment created in the floodplain during inundation, especially in the presence of organic matter. Thus it appears that small amount of arsenic are still being transported through the river systems and the arsenic associated with sediment/soil can be easily mobilized under the geochemical environment prevailing in the floodplains. 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.

An estimate of the nutrients and heavy metals transported annually through the Jamuna and the Padma was made, which showed among the nutrients iron and manganese, and among the heavy metals arsenic and chromium are significantly sediment bound and the rest are negligibly so.

## 6.2 Recommendations

Particle size distributions may have an influence on metal adsorption. So, grain size analysis can be included for this type of studies in future.

To assess the cumulative effects of nutrient accumulation through floodplain sedimentation, sampling both inside and outside of a flood control project is necessary. In future studies, it can be included through appropriate site selection.

Future soil studies should try and assess the contributions that blue-green algae, other algae, mycorrhiza, terrestrial and aquatic plants and other biological agents make floodplain soil nutrition.

A program of research studies is needed to establish the extent to which soil nutrition levels measured in the laboratory actually indicate plant nutrient level (more specifically extraction method). Such research is especially needed for seasonally flooded soils, the chemistry of which is quite different from the upland soils for which methods of laboratory soil-test are developed.

For large floodplains many samples required to represent a site. The more the number of samples the better the floodplain will be represented. But, considering the parameters necessary to characterize floodplain soils, too many samples would lead to a huge number of tests required, which may not be feasible. To overcome this problem, in future studies, mixed samples can be used where all the samples collected from a site (say 30mX30m) of a floodplain will be mixed to represent that site of the floodplain. This will reduce the number of tests required at the laboratory drastically but at the same time better represent larger floodplains. However, this process will increase the fieldwork in the research program.

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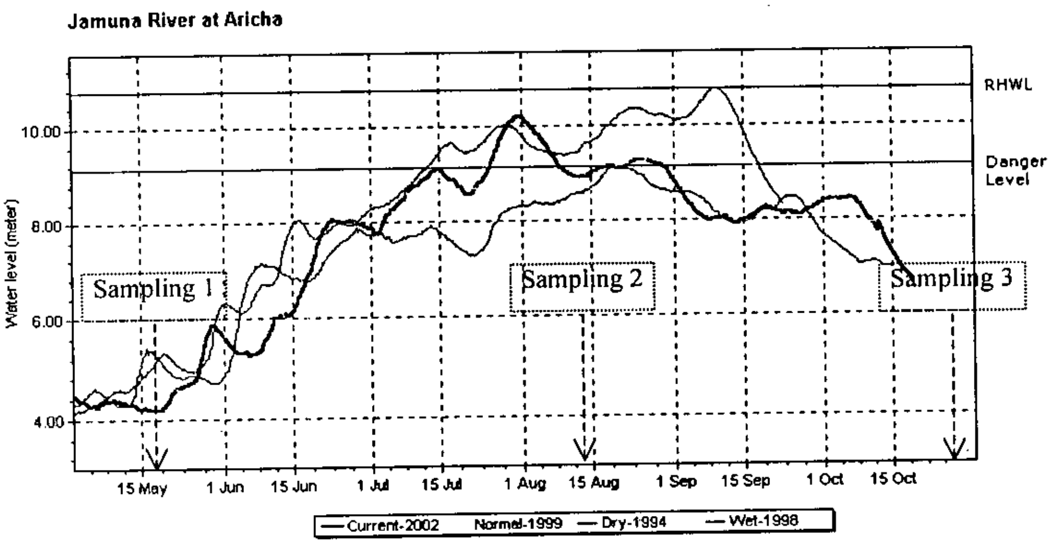
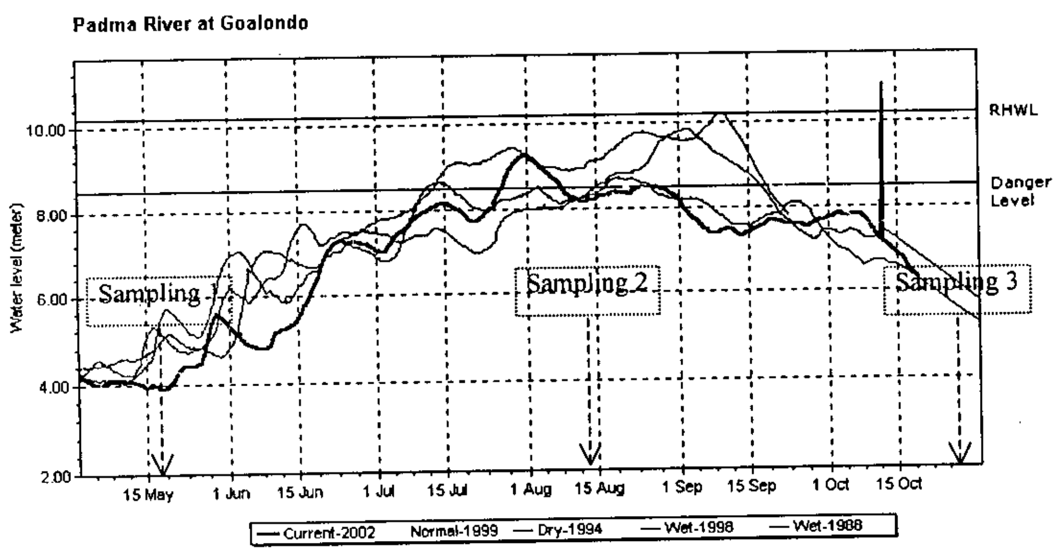
# APPENDICES

# Appendix I

## HYDROGRAPHS OF THE JAMUNA RIVER AT ARICHA AND THE PADMA RIVER AT GOALONDO

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## Appendix II

## AVAILABLE PHOSPHORUS DETERMINATION

### A. Reagents:

1. *Troug's extraction reagent*: Prepare an exact 0.002N $H_2SO_4$ solution and buffer it with the addition of 3 gram $K_2SO_4$ per liter to produce a pH of 3 in the final solution.
2. *Sulfomolybdic acid solution, 2.5%*:

   Solution A: Dissolve exactly 25.0 gram of ammonium molybdate $[(NH_4)_6Mo_7O_{24}.4H_2O]$ in 200 ml of distilled water and warm to $60^0C$ and filter if sediments are formed.

   Solution B: Dilute 275 ml of phosphorus-free and arsenic-free concentrated sulfuric acid (36N) to 750 ml with distilled water. .

   After both solutions have been cooled, slowly add solution A, with stirring, to solution B. Dilute the combined solution exactly to 1 liter and store it in an amber-colored glass bottle.
3. *Freshly prepared stannous chloride solution, 5%*: Dissolve 2.5 gram reagent grade stannous chloride ($SnCl_2.2H_2O$) in 10 ml of concentrated hydrochloric acid (HCl), with warming if necessary. Then add 45 ml of distilled water to this solution.
4. *2,4 dinitrophenol*: Add 2.5 gram of 2,4 dinitrophenyl hydragin in 1 liter of distilled water (ie. 0.25% solution)
5. *N/20 HCl*
6. *N/20 NaOH*

### B. Preparation of standard solutions and standard curve:

1. Dissolve 0.2195-gram potassium dihydrogen phosphate ($KH_2PO_4$) in 400 ml distilled water and add 25 ml of 7N $H_2SO_4$. Mix thoroughly and dilute it to 1 liter. This will give 50-ppm stock solution of P.
2. Dilute 5 ml of the 50ppm stock solution to 500 ml to obtain a 0.5-ppm solution. From this 0.5-ppm solution take 5ml, 10ml, 15ml and 20ml and dilute to 50 ml to obtain 0.05-ppm, 0.10-ppm, 0.15-ppm and 0.20-ppm standard solutions respectively.
3. Take 5/10/25 ml of solution (depending on phosphorus concentration), of which phosphorus is to be determined, in a 50ml volumetric flask and add about 25 ml of

distilled water. Add exactly 2 ml of ammonium sulfomolybdate solution and mix thoroughly.

4. Add 2 drops of 2,4 dinitrophenol indicator to the solution. If the indicator gives yellow color add N/20 HCl drop-wise until it becomes colorless. If the indicator gives colorless solution (pH<3), then add N/20 NaOH drop-wise just until a yellow color appears. Finally add N/20 HCl until yellow becomes faint.
5. Add 3 drops of freshly prepared stannous chloride solution which will develop a blue color. Make the volume up to the mark (ie. 50 ml) and shake again thoroughly. Color of stannous chloride stays for 12-15 minutes and then disappears.
6. Transfer 10 ml of the clear solution to a colorimetric tube.
7. Read color intensity at 660 nm in a spectrophotometer.
8. For standard curve of available phosphorus, plot color intensity in Y-axis and phosphorus concentration in ppm in X-axis.

Table II.a Color intensity for standard curve

| Phosphorus concentration, ppm | Color intensity |
|---|---|
| 0.05 | 0.029 |
| 0.10 | 0.077 |
| 0.15 | 0.089 |
| 0.20 | 0.106 |

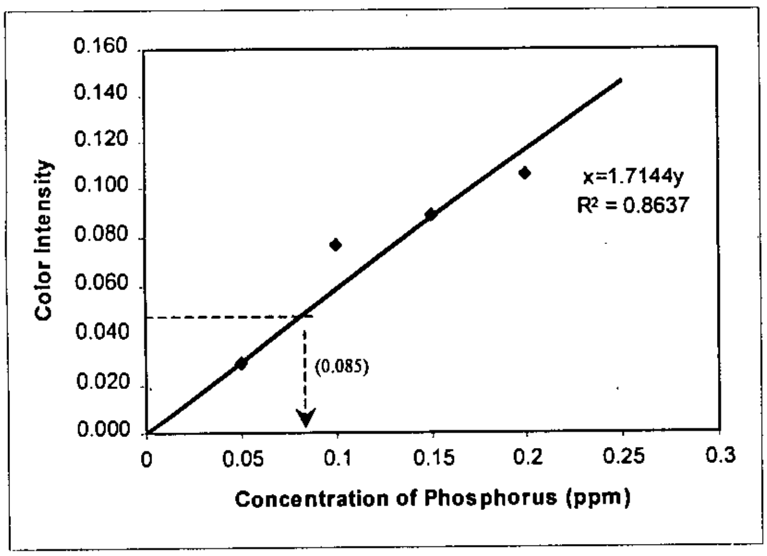


Figure II.a Standard curve for available phosphorus

**C. Available phosphorus determination:**

1. Take 5 gram of soil in a 250 ml beaker, add 50 ml of Troug's solution and then shake for 30 minutes.
2. Filter the suspension through a Whatman No. 44 filter paper.
3. Follow steps 3 to 7 to determine color intensity, and obtain phosphorus concentration from the standard curve for the soil sample.

**D. Sample calculation:**

Available phosphorus, ppm =

$$\frac{\text{ppm from standard curve X volume of Troug's solution added X volume of dilution after blue color attained}}{\text{amount of soil in gram X volume of solution/ filtrate used}}$$

$$= \frac{0.085*50*50}{5.00*10}$$

= 4.25 ppm

## Appendix III

## GENERAL CHARACTERISTICS OF WATER SAMPLES, SUSPENDED SEDIMENT SAMPLES AND FLOODPLAIN SOIL CORE SAMPLES

**Table III.A.1** General Characteristics of Water Samples Before Flood

| Site | | pH | EC (μS/cm) | TS (mg/L) | TDS (mg/L) | TSS (mg/L) | Turbidity (NTU) | Hardness |
|---|---|---|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 7.59 | 91 | 75 | 42 | 33 | 50 | 31 |
| | Aricha | 7.44 | 91 | 83 | 44 | 39 | 56 | 29 |
| Padma River | Paturia-Ghat | 7.38 | 90 | 81 | 69 | 12 | 42 | 26 |
| | Paturia-Village | 7.30 | 92 | 91 | 84 | 7 | 46 | 30 |
| Sribagar | Site 1 | 6.96 | 142 | 123 | 98 | 25 | 29 | 37 |
| | Site 2 | 7.06 | 148 | 142 | 102 | 40 | 26 | 41 |

**Table III.A.2** General Characteristics of Water Samples During Flood

| Site | | pH | EC (μS/cm) | TS (mg/L) | TDS (mg/L) | TSS (mg/L) | Turbidity (NTU) | Hardness |
|---|---|---|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 7.59 | 89 | 399 | 135 | 264 | 179 | 32 |
| | Aricha | 7.53 | 90 | 460 | 129 | 331 | 188 | 30 |
| Padma River | Paturia-Ghat | 7.50 | 88 | 448 | 129 | 319 | 175 | 28 |
| | Paturia-Village | 7.12 | 89 | 345 | 137 | 208 | 180 | 32 |

**Table III.A.3** General Characteristics of Water Samples After Flood

| Site | | pH | EC (μS/cm) | TS (mg/L) | TDS (mg/L) | TSS (mg/L) | Turbidity (NTU) | Hardness |
|---|---|---|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 7.91 | 127 | 420 | 230 | 190 | 63 | 42 |
| | Aricha | 7.88 | 124 | 348 | 227 | 121 | 44 | 42 |
| Padma River | Paturia-Ghat | 7.98 | 116 | 384 | 198 | 186 | 59 | 40 |
| | Paturia-Village | 7.94 | 117 | 348 | 184 | 164 | 60 | 36 |

**Table III.B.1** General Characteristics of Suspended Sediment Samples During Flood

| Site | | PH | EC (μS/cm) | % Organic Matter |
|---|---|---|---|---|
| Jamuna River | Near Bank | 7.3 | 65 | 0.8641 |
| | Away From Bank | 7.2 | 63 | 2.5197 |
| Padma River | Near Bank | 6.7 | 40 | 0.6171 |
| | Away From Bank | 6.8 | 32 | 0.3282 |

**Table III.B.2** General Characteristics of Suspended Sediment Samples After Flood

| Site | pH | EC (μS/cm) | % Organic Matter |
|---|---|---|---|
| Jamuna River | 7.3 | 55 | 1.2299 |
| Padma River | 6.8 | 55 | 1.1621 |

**Table III.C.1** General Characteristics of Floodplain Core Soil Samples Before Flood

| | | pH | | EC (μS/cm) | | % Organic Matter | |
|---|---|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Floodplain | 0-7.5 | 6.2 | 6.0 | 131 | 141 | 1.1624 | 1.2332 |
| | 7.5-15.0 | 6.5 | 6.2 | 105 | 92 | 1.1142 | 1.1887 |
| | 15.0-below | 6.7 | 6.5 | 97 | 80 | 1.2254 | 1.2364 |
| Padma Floodplain | 0-7.5 | 6.9 | 6.5 | 89 | 85 | 0.7126 | 1.4928 |
| | 7.5-15.0 | 6.7 | 6.4 | 115 | 102 | 1.0877 | 1.4380 |
| | 15.0-below | 6.6 | 6.0 | 119 | 114 | 1.4004 | 1.4250 |
| Srinagar Floodplain | 0-7.5 | 4.3 | 4.2 | 32 | 34 | 1.6671 | 3.0947 |
| | 7.5-15.0 | 4.5 | 4.6 | 45 | 32 | 1.4226 | 1.9885 |
| | 15.0-below | 4.8 | 4.7 | 50 | 34 | 1.4145 | 1.7047 |

**Table III.C.2** General Characteristics of Floodplain Core Soil Samples After Flood

| Site | Depth (cm) | pH Core Sample 1 | pH Core Sample 2 | EC (μS/cm) Core Sample 1 | EC (μS/cm) Core Sample 2 | % Organic Matter Core Sample 1 | % Organic Matter Core Sample 2 |
|---|---|---|---|---|---|---|---|
| Jamuna Shibalaya Floodplain | 0-2.5 | 7.7 | 7.5 | 71 | 69 | 1.1688 | 0.7278 |
| | 2.5-5.0 | 7.0 | 7.0 | 74 | 83 | 1.2767 | 0.8783 |
| | 5.0-7.5 | 7.2 | 7.2 | 77 | 85 | 2.6356 | 1.4145 |
| | 7.5-15.0 | 7.0 | 7.5 | 62 | 62 | 1.1049 | 0.2449 |
| | 15.0-below | 7.0 | 7.3 | 67 | 44 | 1.4188 | 0.2596 |
| Jamuna Aricha Floodplain | 0-2.5 | 7.2 | 7.3 | 106 | 83 | 2.2621 | 1.4159 |
| | 2.5-5.0 | 6.3 | 6.5 | 97 | 69 | 2.2934 | 0.8597 |
| | 5.0-7.5 | 6.5 | 7.0 | 79 | 80 | 1.2956 | 1.1876 |
| | 7.5-15.0 | 6.5 | 6.5 | 100 | 79 | 1.9242 | 1.3916 |
| | 15.0-below | 7.0 | 6.5 | 47 | 47 | 0.4077 | 0.2536 |
| Jamuna Uninundated Floodplain | 0-7.5 | 7.0 | | 262 | | 1.7844 | |
| | 7.5-15.0 | 7.2 | | 100 | | 1.7421 | |
| | 15.0-below | 7.0 | | 64 | | 1.8206 | |
| Padma Paturia-Ghat Floodplain | 0-2.5 | 7.8 | 7.5 | 85 | 94 | 0.5064 | 2.0683 |
| | 2.5-5.0 | 7.5 | 7.5 | 87 | 67 | 1.2225 | 1.4199 |
| | 5.0-7.5 | 7.0 | 7.0 | 101 | 81 | 1.1971 | 1.4685 |
| | 7.5-15.0 | 7.0 | 6.5 | 96 | 76 | 1.2550 | 2.1183 |
| | 15.0-below | 7.3 | 7.0 | 120 | 74 | 1.4033 | 1.6247 |
| Padma Paturia-Village Floodplain | 0-2.5 | 7.1 | 7.2 | 140 | 177 | 1.2668 | 2.0471 |
| | 2.5-5.0 | 6.5 | 6.5 | 114 | 97 | 1.1428 | 0.6128 |
| | 5.0-7.5 | 7.0 | 6.5 | 82 | 110 | 1.2480 | 1.7679 |
| | 7.5-15.0 | 6.7 | 7.0 | 113 | 107 | 1.3482 | 1.3628 |
| | 15.0-below | 6.5 | 7.0 | 125 | 101 | 1.6275 | 1.9430 |
| Padma Uninundated Floodplain | 0-7.5 | 7.0 | | 454 | | 1.9847 | |
| | 7.5-15.0 | 7.0 | | 477 | | 2.0576 | |
| | 15.0-below | 6.5 | | 491 | | 1.7752 | |

## Appendix IV

## NUTRIENT DATA FROM WATER SAMPLES, SUSPENDED SEDIMENT SAMPLES AND FLOODPLAIN SOIL CORE SAMPLES

**Table IV.A.1.a** Nutrient Data from River Water Samples Before Flood

| Site | | $NH_3$-$NH_4$ (mg/L) | $NO_3$ (mg/L) | $PO_4$ (mg/L) | $SO_4$ (mg/L) | $S_2$ (mg/L) |
|---|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.1400 | 0.7000 | 0.1000 | 14.7000 | 0.0040 |
| | Aricha | 0.1390 | 0.1000 | 0.1150 | 14.4000 | 0.0080 |
| Padma River | Paturia-Ghat | 0.1690 | 0.1000 | 0.1420 | 14.2000 | 0.0050 |
| | Paturia-Village | 0.1280 | 0.7000 | 0.1330 | 15.2000 | 0.0070 |
| Sribagar | Site 1 | 0.2770 | 0.7000 | 0.4050 | 15.9000 | 0.0020 |
| | Site 2 | 0.3260 | 0.8000 | 0.4030 | 13.1000 | 0.0220 |

**Table IV.A.1.b** Nutrient Data from River Water Samples During Flood

| Site | | $NH_3$-$NH_4$ (mg/L) | $NO_3$ (mg/L) | $PO_4$ (mg/L) | $SO_4$ (mg/L) | $S_2$ (mg/L) |
|---|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 1.9720 | 0.9000 | 0.1260 | 12.4000 | 0.0160 |
| | Aricha | 2.1500 | 0.9000 | 0.1100 | 13.2000 | 0.0150 |
| Padma River | Paturia-Ghat | 1.6900 | 0.4000 | 0.1030 | 12.5000 | 0.0090 |
| | Paturia-Village | 2.0420 | 0.3000 | 0.0920 | 14.2000 | 0.0050 |

**Table IV.A.1.c** Nutrient Data from River Water Samples After Flood

| Site | | $NH_3$-$NH_4$ (mg/L) | $NO_3$ (mg/L) | $PO_4$ (mg/L) | $SO_4$ (mg/L) | $S_2$ (mg/L) |
|---|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.4760 | 1.0000 | 0.0780 | 52.5000 | 0.0140 |
| | Aricha | 0.5370 | 1.6000 | 0.0430 | 24.9000 | 0.0060 |
| Padma River | Paturia-Ghat | 0.5600 | 1.1000 | 0.0900 | 22.1000 | 0.0160 |
| | Paturia-Village | 0.4700 | 1.9000 | 0.1110 | 23.4000 | 0.0210 |

**Table IV.A.2.a** Nutrient Data from River Water Samples Before Flood (Ca, Mg, K, B)

| Site | | Ca (mg/L) | Mg (mg/L) | K (mg/L) | B (mg/L) |
|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 2.8966 | 1.8918 | 3.0921 | 0.2000 |
| | Aricha | 2.8911 | 1.8802 | 2.9845 | 0.0000 |
| Padma River | Paturia-Ghat | 2.8972 | 1.8856 | 2.9527 | 0.0000 |
| | Paturia-Village | 2.9763 | 1.8852 | 2.9752 | 0.0000 |
| Sribagar | Site 1 | 3.0357 | 2.0408 | 8.2487 | 0.0000 |
| | Site 2 | 3.0766 | 2.0556 | 6.7293 | 0.0000 |

**Table IV.A.2.b** Nutrient Data from River Water Samples During Flood (Ca, Mg, K, B)

| Site | | Ca (mg/L) | Mg (mg/L) | K (mg/L) | B (mg/L) |
|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 3.0740 | 1.8964 | 3.3201 | 0.7000 |
| | Aricha | 3.0939 | 1.8940 | 3.2773 | 0.0000 |
| Padma River | Paturia-Ghat | 3.0817 | 1.9051 | 3.2848 | 0.0000 |
| | Paturia-Village | 3.0968 | 1.9062 | 3.1621 | 0.1000 |

**Table IV.A.2.c** Nutrient Data from River Water Samples After Flood (Ca, Mg, K, B)

| Site | | Ca (mg/L) | Mg (mg/L) | K (mg/L) | B (mg/L) |
|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 3.9370 | 2.0043 | 4.2031 | 0.0000 |
| | Aricha | 3.8717 | 1.9937 | 4.4808 | 0.0000 |
| Padma River | Paturia-Ghat | 3.5677 | 1.9874 | 3.1372 | 1.0000 |
| | Paturia-Village | 3.6300 | 2.0114 | 3.1795 | 0.8000 |

**Table IV.A.3.a** Nutrient Data from River Water Samples Before Flood (Cu, Fe, Mn, Zn)

| Site | | Cu (mg/L) | Fe (mg/L) | Mn (mg/L) | Zn (mg/L) |
|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.2329 | 0.2515 | 0.0030 | 0.2489 |
| | Aricha | 0.2211 | 0.2515 | 0.0014 | 0.2489 |
| Padma River | Paturia-Ghat | 0.2494 | 0.2383 | 0.0018 | 0.2409 |
| | Paturia-Village | 0.2376 | 0.2396 | 0.0027 | 0.2425 |
| Sribagar | Site 1 | 0.2247 | 0.2145 | 0.0034 | 0.2441 |
| | Site 2 | 0.2200 | 0.1959 | 0.0040 | 0.2457 |

**Table IV.A.3.b** Nutrient Data from River Water Samples During Flood (Cu, Fe, Mn, Zn)

| Site | | Cu (mg/L) | Fe (mg/L) | Mn (mg/L) | Zn (mg/L) |
|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.2117 | 0.2529 | 0.0043 | 0.2553 |
| | Aricha | 0.2058 | 0.2436 | 0.0049 | 0.2561 |
| Padma River | Paturia-Ghat | 0.2000 | 0.3018 | 0.0049 | 0.2569 |
| | Paturia-Village | 0.1870 | 0.2330 | 0.0043 | 0.2608 |

**Table IV.A.3.c** Nutrient Data from River Water Samples After Flood (Cu, Fe, Mn, Zn)

| Site | | Cu (mg/L) | Fe (mg/L) | Mn (mg/L) | Zn (mg/L) |
|---|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.1906 | 0.2568 | 0.0047 | 0.2537 |
| | Aricha | 0.1882 | 0.2012 | 0.0046 | 0.2585 |
| Padma River | Paturia-Ghat | 0.1764 | 0.2648 | 0.0045 | 0.2537 |
| | Paturia-Village | 0.1670 | 0.2436 | 0.0038 | 0.2537 |

**Table IV.B.1.a** Nutrient Data from Suspended Sediment Samples During Flood (N, P, K)

| Site | | N as $NO_3$ (mg/kg) | Available P (mg/kg) | K (mg/kg) |
|---|---|---|---|---|
| Jamuna River | Near Bank | 0.7 | 9.6882 | 1243.1000 |
| | Away From Bank | 0.6 | 18.2869 | 1559.1900 |
| Padma River | Near Bank | 3.1 | 7.0204 | 1255.8800 |
| | Away From Bank | 1.7 | 18.1127 | 1353.0300 |

**Table IV.B.1.b** Nutrient Data from Suspended Sediment Samples After Flood (N, P, K)

| Site | N as $NO_3$ (mg/kg) | Available P (mg/kg) | K (mg/kg) |
|---|---|---|---|
| Jamuna River | 6.0 | 15.1641 | 1421.7700 |
| Padma River | 6.1 | 6.7396 | 1392.6100 |

**Table IV.B.2.a** Nutrient Data from Suspended Sediment Samples During Flood (Ca, Mg, Cu)

| Site | | Ca (mg/kg) | Mg (mg/kg) | Cu (mg/kg) |
|---|---|---|---|---|
| Jamuna River | Near Bank | 109.1200 | 174.7377 | 42.3400 |
| | Away From Bank | 116.7400 | 174.5714 | 80.4500 |
| Padma River | Near Bank | 67.8800 | 168.3873 | 23.7600 |
| | Away From Bank | 102.2100 | 167.5262 | 33.6400 |

**Table IV.B.2.b** Nutrient Data from Suspended Sediment Samples After Flood (Ca, Mg, Cu)

| Site | Ca (mg/kg) | Mg (mg/kg) | Cu (mg/kg) |
|---|---|---|---|
| Jamuna River | 96.6200 | 172.2132 | 56.5800 |
| Padma River | 132.6100 | 175.4129 | 56.8100 |

**Table IV.B.3.a** Nutrient Data from Suspended Sediment Samples During Flood (Fe, Mn, Zn)

| Site | | Fe (mg/kg) | Mn (mg/kg) | Zn (mg/kg) |
|---|---|---|---|---|
| Jamuna River | Near Bank | 1632.2200 | 28.0300 | 63.9000 |
| | Away From Bank | 1856.0900 | 61.3100 | 283.1800 |
| Padma River | Near Bank | 1463.1600 | 13.8900 | 39.4100 |
| | Away From Bank | 1646.9200 | 23.9300 | 62.0600 |

**Table IV.B.3.b** Nutrient Data from Suspended Sediment Samples After Flood (Fe, Mn, Zn)

| Site | Fe (mg/kg) | Mn (mg/kg) | Zn (mg/kg) |
|---|---|---|---|
| Jamuna River | 1754.6800 | 40.5600 | 92.9300 |
| Padma River | 1754.0200 | 42.7600 | 92.9300 |

**Table IV.C.1.a** Nutrient Data from Floodplain Core Soil Samples Before Flood (N, P, K)

| | | N as $NO_3$ (mg/kg) | | Available P (mg/kg) | | K (mg/kg) | |
|---|---|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Floodplain | 0-7.5 | 4.4 | 6.1 | 8.5649 | 8.1905 | 1400.9400 | 1495.3100 |
| | 7.5-15.0 | 3.5 | 7.0 | 9.8286 | 8.9861 | 1396.8900 | 1452.3200 |
| | 15.0-below | 3.5 | 12.2 | 8.2373 | 9.5010 | 1459.2700 | 1355.0600 |
| Padma Floodplain | 0-7.5 | 7.0 | 4.8 | 6.9268 | 6.9400 | 1280.8800 | 1329.2500 |
| | 7.5-15.0 | 17.4 | 5.7 | 5.4759 | 5.2600 | 1356.8500 | 1341.5800 |
| | 15.0-below | 4.4 | 3.9 | 8.9393 | 8.2000 | 1434.9600 | 1360.5000 |
| Srinagar Floodplain | 0-7.5 | 9.1 | 7.8 | 62.8327 | 14.4621 | 1318.6000 | 1374.0900 |
| | 7.5-15.0 | 7.7 | 5.2 | 53.2850 | 22.0441 | 1423.2800 | 1364.6600 |
| | 15.0-below | 1.3 | 3.5 | 102.5683 | 73.9952 | 1389.4800 | 1367.9000 |

**Table IV.C.1.b** Nutrient Data from Floodplain Core Soil Samples After Flood (N, P, K)

| Site | Depth (cm) | N as $NO_3$ (mg/kg) Core Sample 1 | N as $NO_3$ (mg/kg) Core Sample 2 | Available P (mg/kg) Core Sample 1 | Available P (mg/kg) Core Sample 2 | K (mg/kg) Core Sample 1 | K (mg/kg) Core Sample 2 |
|---|---|---|---|---|---|---|---|
| Jamuna Shibalaya Floodplain | 0-2.5 | 1.7 | 1.3 | 26.9584 | 12.2155 | 1305.7000 | 1300.2600 |
| | 2.5-5.0 | 1.1 | 1.9 | 24.7119 | 11.3029 | 1359.1100 | 1341.2300 |
| | 5.0-7.5 | 1.3 | 1.0 | 16.0066 | 12.1453 | 1384.4500 | 1344.7600 |
| | 7.5-15.0 | 0.2 | 0.9 | 13.1984 | 12.2857 | 1371.4300 | 1116.4900 |
| | 15.0-below | 1.6 | 1.0 | 15.7257 | 13.1984 | 1317.6800 | 1153.6400 |
| Jamuna Aricha Floodplain | 0-2.5 | 4.8 | 5.2 | 14.3217 | 9.9690 | 1422.4700 | 1386.7700 |
| | 2.5-5.0 | 4.1 | 1.3 | 9.2670 | 11.4667 | 1352.7400 | 1361.2500 |
| | 5.0-7.5 | 3.7 | 2.6 | 5.9674 | 13.4792 | 1312.8800 | 1368.4800 |
| | 7.5-15.0 | 4.0 | 4.4 | 8.7053 | 12.5431 | 1445.0300 | 1373.0500 |
| | 15.0-below | 1.0 | 5.7 | 16.9192 | 9.5010 | 1178.4600 | 1164.0600 |
| Jamuna Uninundated Floodplain | 0-7.5 | 7.3 | | 64.9389 | | 1363.3300 | |
| | 7.5-15.0 | 6.5 | | 158.0296 | | 1311.7200 | |
| | 15.0-below | 5.0 | | 91.0548 | | 1386.1900 | |
| Padma Paturia-Ghat Floodplain | 0-2.5 | 1.5 | 3.0 | 9.7584 | 11.1625 | 1192.9300 | 1307.0300 |
| | 2.5-5.0 | 1.7 | 1.8 | 8.7755 | 9.0563 | 1373.9800 | 1318.0800 |
| | 5.0-7.5 | 2.0 | 2.4 | 8.3543 | 11.8645 | 1410.5500 | 1328.7300 |
| | 7.5-15.0 | 1.7 | 1.3 | 8.0735 | 9.8286 | 1372.5900 | 1293.0900 |
| | 15.0-below | 0.6 | 1.8 | 7.3012 | 12.1453 | 1359.0500 | 1400.0700 |
| Padma Paturia-Village Floodplain | 0-2.5 | 4.3 | 3.9 | 9.6180 | 8.7053 | 1380.4600 | 1350.4300 |
| | 2.5-5.0 | 3.3 | 5.2 | 5.4057 | 11.0455 | 1348.4000 | 1244.7700 |
| | 5.0-7.5 | 2.4 | 3.9 | 15.1641 | 9.1733 | 1384.3300 | 1417.2000 |
| | 7.5-15.0 | 2.5 | 2.2 | 4.9845 | 9.8286 | 1443.1200 | 1334.9800 |
| | 15.0-below | 1.8 | 3.9 | 6.5992 | 10.2966 | 1414.4800 | 1379.9400 |
| Padma Uninundated Floodplain | 0-7.5 | 8.1 | | 49.9854 | | 1439.5900 | |
| | 7.5-15.0 | 8.7 | | 56.2335 | | 1372.0100 | |
| | 15.0-below | 13.5 | | 48.2303 | | 1335.7300 | |

Table IV.C.2.a Nutrient Data from Floodplain Core Soil Samples Before Flood (Ca, Mg, Cu)

| | | Ca (mg/kg) | | Mg (mg/kg) | | Cu (mg/kg) | |
|---|---|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Floodplain | 0-7.5 | 83.9500 | 104.3300 | 226.1384 | 225.8252 | 71.7500 | 57.4000 |
| | 7.5-15.0 | 86.7200 | 92.9500 | 230.8156 | 226.5298 | 50.3400 | 51.8700 |
| | 15.0-below | 83.8900 | 73.0200 | 226.3145 | 233.9076 | 55.2800 | 55.2800 |
| Padma Floodplain | 0-7.5 | 145.7600 | 40.2400 | 227.0679 | 226.1971 | 31.5200 | 39.5200 |
| | 7.5-15.0 | 112.4000 | 40.3700 | 226.6570 | 225.2675 | 41.2900 | 36.9300 |
| | 15.0-below | 73.9200 | 39.7000 | 226.6863 | 225.0207 | 43.2900 | 41.1000 |
| Srinagar Floodplain | 0-7.5 | 65.1800 | 31.8200 | 226.1677 | 226.5493 | 29.6400 | 27.0500 |
| | 7.5-15.0 | 64.0900 | 44.6100 | 225.8546 | 228.5063 | 32.2300 | 24.7000 |
| | 15.0-below | 48.2800 | 63.1900 | 226.2264 | 227.4887 | 32.4600 | 25.1700 |

**Table IV.C.2.b** Nutrient Data from Floodplain Core Soil Samples After Flood (Ca, Mg, Cu)

| | | Ca (mg/kg) | | Mg (mg/kg) | | Cu (mg/kg) | |
|---|---|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Shibalaya Floodplain | 0-2.5 | 138.7900 | 159.8100 | 231.3244 | 227.2734 | 28.9400 | 25.2900 |
| | 2.5-5.0 | 136.7900 | 131.0700 | 227.9584 | 227.3321 | 40.7000 | 27.7600 |
| | 5.0-7.5 | 156.5900 | 167.5800 | 229.7392 | 227.7724 | 59.5200 | 40.7000 |
| | 7.5-15.0 | 205.5100 | 51.7500 | 229.8077 | 221.8721 | 29.2900 | 5.4100 |
| | 15.0-below | 135.7600 | 70.8700 | 228.5063 | 221.5198 | 34.1100 | 7.2900 |
| Jamuna Aricha Floodplain | 0-2.5 | 229.2600 | 189.3800 | 225.3556 | 226.1188 | 50.8100 | 43.6400 |
| | 2.5-5.0 | 265.2300 | 135.7600 | 226.6961 | 224.7880 | 49.6400 | 30.8200 |
| | 5.0-7.5 | 188.1200 | 159.2000 | 229.2500 | 228.2519 | 35.9900 | 36.9300 |
| | 7.5-15.0 | 254.7500 | 190.0800 | 227.2832 | 227.8899 | 50.9300 | 43.2900 |
| | 15.0-below | 89.0300 | 75.7200 | 221.3535 | 220.4924 | 6.8200 | 6.3500 |
| Jamuna Uninundated Floodplain | 0-7.5 | 106.6100 | | 225.3653 | | 38.8200 | |
| | 7.5-15.0 | 71.6700 | | 226.4025 | | 39.5200 | |
| | 15.0-below | 77.8800 | | 228.1932 | | 43.0500 | |
| Padma Paturia-Ghat Floodplain | 0-2.5 | 173.8200 | 122.4600 | 224.9837 | 224.9642 | 23.2900 | 43.8700 |
| | 2.5-5.0 | 152.2500 | 120.7200 | 224.9544 | 222.8115 | 43.7600 | 36.2300 |
| | 5.0-7.5 | 236.0500 | 109.5400 | 227.9486 | 225.4045 | 43.1700 | 42.1100 |
| | 7.5-15.0 | 307.6600 | 97.3900 | 224.0541 | 227.4104 | 44.2300 | 49.0500 |
| | 15.0-below | 225.1200 | 107.0900 | 225.8252 | 226.6178 | 47.9900 | 48.1100 |
| Padma Paturia-Village Floodplain | 0-2.5 | 106.1900 | 145.2100 | 225.8839 | 161.4595 | 46.5800 | 46.4600 |
| | 2.5-5.0 | 131.7100 | 110.0200 | 227.4300 | 161.0877 | 44.7000 | 26.2300 |
| | 5.0-7.5 | 112.6200 | 115.6100 | 227.1364 | 163.4752 | 47.7600 | 45.0500 |
| | 7.5-15.0 | 115.6400 | 104.2700 | 223.1050 | 162.8000 | 48.7000 | 43.8700 |
| | 15.0-below | 135.5100 | 107.0300 | 227.2049 | 163.7296 | 52.4600 | 50.1100 |
| Padma Uninundated Floodplain | 0-7.5 | 184.4600 | | 165.3441 | | 47.7600 | |
| | 7.5-15.0 | 278.2100 | | 158.8763 | | 41.8700 | |
| | 15.0-below | 156.7200 | | 161.4791 | | 41.8700 | |

**Table IV.C.3.a** Nutrient Data from Floodplain Core Soil Samples Before Flood (Fe, Mn, Zn)

| | | Fe (mg/kg) | | Mn (mg/kg) | | Zn (mg/kg) | |
|---|---|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Floodplain | 0-7.5 | 1748.5900 | 1775.6000 | 40.9200 | 42.3900 | 88.3100 | 95.6400 |
| | 7.5-15.0 | 1747.0000 | 1755.7400 | 38.0400 | 40.0700 | 87.1900 | 89.3400 |
| | 15.0-below | 1760.5100 | 1767.5200 | 40.8200 | 40.7700 | 93.9700 | 95.3300 |
| Padma Floodplain | 0-7.5 | 1697.4900 | 1757.3300 | 34.0000 | 33.5100 | 73.5500 | 93.8100 |
| | 7.5-15.0 | 1750.8400 | 1747.8000 | 41.0200 | 32.4900 | 104.1800 | 92.6900 |
| | 15.0-below | 1763.4200 | 1760.3000 | 38.5800 | 34.2000 | 98.2800 | 94.7000 |
| Srinagar Floodplain | 0-7.5 | 1713.1100 | 1709.0100 | 29.1900 | 28.5100 | 104.6600 | 101.4700 |
| | 7.5-15.0 | 1753.7500 | 1718.4100 | 40.2900 | 41.4100 | 102.7400 | 103.5400 |
| | 15.0-below | 1753.8900 | 1743.4300 | 48.6000 | 48.5800 | 106.4100 | 109.6800 |

**Table IV.C.3.b** Nutrient Data from Floodplain Core Soil Samples After Flood (Fe, Mn, Zn)

| | | Fe (mg/kg) | | Mn (mg/kg) | | Zn (mg/kg) | |
|---|---|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Shibalaya Floodplain | 0-2.5 | 1703.9800 | 1688.4900 | 32.4100 | 31.8400 | 81.2100 | 77.7000 |
| | 2.5-5.0 | 1727.9400 | 1706.7600 | 34.0800 | 33.0900 | 86.5500 | 81.6800 |
| | 5.0-7.5 | 1778.9100 | 1766.4600 | 47.2100 | 44.5400 | 109.2900 | 109.6000 |
| | 7.5-15.0 | 1741.7100 | 1475.3400 | 35.2300 | 14.9400 | 83.7600 | 40.6800 |
| | 15.0-below | 1680.5400 | 1510.5600 | 30.2500 | 16.2600 | 73.0700 | 45.3100 |
| Jamuna Aricha Floodplain | 0-2.5 | 1832.7900 | 1786.3200 | 51.2000 | 45.2100 | 109.3700 | 105.6200 |
| | 2.5-5.0 | 1813.7300 | 1746.4700 | 49.3000 | 34.3200 | 110.0800 | 93.4900 |
| | 5.0-7.5 | 1772.2900 | 1767.5200 | 38.9000 | 41.1700 | 89.5800 | 100.6700 |
| | 7.5-15.0 | 1822.3300 | 1786.3200 | 52.2500 | 44.2100 | 120.7700 | 111.6800 |
| | 15.0-below | 1544.5800 | 1508.5700 | 15.1200 | 15.1500 | 42.5200 | 47.3000 |
| Jamuna Uninundated Floodplain | 0-7.5 | 1689.9400 | | 32.9300 | | 168.1600 | |
| | 7.5-15.0 | 1668.8900 | | 31.6300 | | 189.6100 | |
| | 15.0-below | 1669.4200 | | 31.5200 | | 194.7200 | |
| Padma Paturia-Ghat Floodplain | 0-2.5 | 1582.4400 | 1734.9600 | 19.6900 | 39.1700 | 51.8500 | 90.7000 |
| | 2.5-5.0 | 1747.5300 | 1697.2200 | 37.2200 | 31.7200 | 87.1900 | 76.4200 |
| | 5.0-7.5 | 1746.4700 | 1730.3200 | 39.5500 | 37.4100 | 88.5400 | 87.2700 |
| | 7.5-15.0 | 1744.3500 | 1756.2700 | 37.8800 | 42.7500 | 87.8300 | 96.5200 |
| | 15.0-below | 1747.8000 | 1759.3100 | 36.3500 | 41.2700 | 91.9000 | 93.2500 |
| Padma Paturia-Village Floodplain | 0-2.5 | 1761.5700 | 1760.5100 | 42.2600 | 41.1200 | 93.6500 | 100.8300 |
| | 2.5-5.0 | 1754.9500 | 1636.0600 | 39.9200 | 24.1100 | 92.2100 | 60.4700 |
| | 5.0-7.5 | 1758.9200 | 1765.8000 | 41.9300 | 40.7000 | 93.9700 | 97.4800 |
| | 7.5-15.0 | 1769.5100 | 1742.7700 | 41.6700 | 39.0500 | 97.0000 | 91.7400 |
| | 15.0-below | 1770.7000 | 1759.1800 | 42.4900 | 44.0000 | 99.0700 | 97.6400 |
| Padma Uninundated Floodplain | 0-7.5 | 1757.3300 | | 42.5800 | | 122.0500 | |
| | 7.5-15.0 | 1728.3400 | | 38.4300 | | 101.1500 | |
| | 15.0-below | 1726.6100 | | 35.1300 | | 102.9000 | |

## Appendix V

## CONTAMINANT DATA FROM WATER SAMPLES, SUSPENDED SEDIMENT SAMPLES AND FLOODPLAIN SOIL CORE SAMPLES

**Table V.A.1** Contaminant Data from River Water Samples Before Flood

| Site | | As (mg/L) | Cr (mg/L) | Pb (mg/L) |
|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.0007 | 0.0120 | 0.1721 |
| | Aricha | 0.0007 | 0.0120 | 0.1565 |
| Padma River | Paturia-Ghat | 0.0008 | 0.0144 | 0.1460 |
| | Paturia-Village | 0.0006 | 0.0084 | 0.1147 |
| Sribagar | Site 1 | 0.0080 | 0.0192 | 0.1304 |
| | Site 2 | 0.0086 | 0.0144 | 0.1356 |

**Table V.A.2** Contaminant Data from River Water Samples During Flood

| Site | | As (mg/L) | Cr (mg/L) | Pb (mg/L) |
|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.0006 | 0.0144 | 0.0834 |
| | Aricha | 0.0005 | 0.0132 | 0.0887 |
| Padma River | Paturia-Ghat | 0.0004 | 0.0012 | 0.0417 |
| | Paturia-Village | 0.0003 | 0.0072 | 0.0313 |

**Table V.A.3** Contaminant Data from River Water Samples After Flood

| Site | | As (mg/L) | Cr (mg/L) | Pb (mg/L) |
|---|---|---|---|---|
| Jamuna River | Shibalaya | 0.0010 | 0.0084 | 0.0156 |
| | Aricha | 0.0011 | 0.0024 | 0.0156 |
| Padma River | Paturia-Ghat | 0.0008 | 0.0084 | 0.0052 |
| | Paturia-Village | 0.0008 | 0.0156 | 0.0052 |

**Table V.B.1** Contaminant Data from Suspended Sediment Samples During Flood

| Site | | As (mg/kg) | Cr (mg/kg) | Pb (mg/kg) |
|---|---|---|---|---|
| Jamuna River | Near Bank | 1.1510 | 14.3900 | 4.6900 |
| | Away From Bank | 1.5330 | 27.4600 | 5.2200 |
| Padma River | Near Bank | 0.6370 | 8.4000 | 3.1300 |
| | Away From Bank | 1.0220 | 13.1900 | 3.1300 |

**Table V.B.2** Contaminant Data from Suspended Sediment Samples After Flood

| Site | As (mg/kg) | Cr (mg/kg) | Pb (mg/kg) |
|---|---|---|---|
| Jamuna River | 1.6240 | 20.2700 | 9.3900 |
| Padma River | 1.7740 | 22.3100 | 10.4300 |

**Table V.C.1** Contaminant Data from Floodplain Core Soil Samples Before Flood

| | | As (mg/kg) | | Cr (mg/kg) | | Pb (mg/kg) | |
|---|---|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Floodplain | 0-7.5 | 1.4390 | 1.9360 | 21.3500 | 22.0700 | 6.2600 | 11.4700 |
| | 7.5-15.0 | 1.5480 | 1.6470 | 19.1900 | 20.8700 | 4.1700 | 6.2600 |
| | 15.0-below | 1.7370 | 1.6120 | 22.0700 | 21.4700 | 5.2200 | 8.8700 |
| Padma Floodplain | 0-7.5 | 1.3840 | 1.4630 | 16.5500 | 19.1900 | 6.7800 | 12.5200 |
| | 7.5-15.0 | 1.6770 | 1.4380 | 21.1100 | 20.6300 | 12.5200 | 10.4300 |
| | 15.0-below | 1.4280 | 1.4580 | 20.1500 | 17.3200 | 6.7800 | 8.2900 |
| Srinagar Floodplain | 0-7.5 | 1.7510 | 1.6960 | 20.1500 | 20.6300 | 18.7800 | 17.7300 |
| | 7.5-15.0 | 2.0820 | 1.7470 | 20.9900 | 20.3900 | 16.6900 | 14.6000 |
| | 15.0-below | 2.0340 | 1.8890 | 20.8700 | 22.0700 | 17.7300 | 17.2100 |

**Table V.C.2** Contaminant Data from Floodplain Core Soil Samples After Flood

| Site | Depth (cm) | As (mg/kg) Core Sample 1 | As (mg/kg) Core Sample 2 | Cr (mg/kg) Core Sample 1 | Cr (mg/kg) Core Sample 2 | Pb (mg/kg) Core Sample 1 | Pb (mg/kg) Core Sample 2 |
|---|---|---|---|---|---|---|---|
| Jamuna Shibalaya Floodplain | 0-2.5 | 1.7940 | 2.6122 | 22.1900 | 23.0300 | 9.9100 | 8.3400 |
| | 2.5-5.0 | 1.9550 | 3.3609 | 23.0300 | 23.9900 | 7.8200 | 5.2200 |
| | 5.0-7.5 | 2.8550 | 3.9996 | 26.7500 | 29.0200 | 4.1700 | 6.2600 |
| | 7.5-15.0 | 3.2044 | 0.8743 | 24.7100 | 14.1500 | 3.1300 | 14.6000 |
| | 15.0-below | 2.3404 | 1.0883 | 21.7100 | 16.7900 | 4.1700 | 13.0400 |
| Jamuna Aricha Floodplain | 0-2.5 | 2.6080 | 2.3814 | 30.1000 | 22.3100 | 13.5600 | 10.4300 |
| | 2.5-5.0 | 1.8770 | 2.2250 | 28.9000 | 19.4300 | 12.5200 | 11.4700 |
| | 5.0-7.5 | 2.2770 | 2.5890 | 25.9100 | 23.5100 | 14.6000 | 6.2600 |
| | 7.5-15.0 | 2.7710 | 2.9340 | 30.4600 | 25.4300 | 8.3400 | 6.7800 |
| | 15.0-below | 0.8890 | 0.9360 | 15.2300 | 11.6300 | 16.6900 | 13.5600 |
| Jamuna Uninundated Floodplain | 0-7.5 | 1.8988 | | 23.8700 | | 0.5200 | |
| | 7.5-15.0 | 1.7658 | | 23.5100 | | 0.5200 | |
| | 15.0-below | 1.9535 | | 24.2300 | | 4.6900 | |
| Padma Paturia-Ghat Floodplain | 0-2.5 | 0.9191 | 2.3035 | 19.1900 | 27.3400 | 5.2200 | 13.5600 |
| | 2.5-5.0 | 1.8826 | 1.8001 | 25.7900 | 24.7100 | 4.1700 | 7.3000 |
| | 5.0-7.5 | 2.0502 | 2.0355 | 27.5800 | 26.2700 | 11.4700 | 10.4300 |
| | 7.5-15.0 | 1.9436 | 2.5494 | 27.3400 | 27.5800 | 11.4700 | 9.3900 |
| | 15.0-below | 2.3860 | 2.1625 | 28.5400 | 27.4600 | 8.3400 | 9.3900 |
| Padma Paturia-Village Floodplain | 0-2.5 | 2.3920 | 2.7229 | 29.0200 | 29.8600 | 13.5600 | 16.6900 |
| | 2.5-5.0 | 1.6736 | 1.1842 | 28.5400 | 23.1500 | 10.9500 | 12.5200 |
| | 5.0-7.5 | 1.9635 | 1.4674 | 28.5400 | 30.4600 | 14.6000 | 16.6900 |
| | 7.5-15.0 | 2.0658 | 1.7903 | 29.0200 | 28.9000 | 15.1300 | 13.5600 |
| | 15.0-below | 1.7300 | 1.8222 | 30.4600 | 31.1800 | 11.4700 | 7.3000 |
| Padma Uninundated Floodplain | 0-7.5 | 2.1880 | | 30.9400 | | 15.6500 | |
| | 7.5-15.0 | 1.2344 | | 28.7800 | | 14.6000 | |
| | 15.0-below | 0.9800 | | 28.4200 | | 12.0000 | |

## Appendix VI

## OXALIC ACID EXTRACTED ARSENIC AND IRON FROM SUSPENDED SEDIMENT SAMPLES AND FLOODPLAIN CORE SOIL SAMPLES

**Table VI.B.1** Oxalic Acid Extracted Arsenic and Iron from Suspended Sediment Samples During Flood

| Site | | As (mg/kg) | Fe (mg/kg) |
|---|---|---|---|
| Jamuna River | Near Bank | 0.3362 | 29.7494 |
| | Away From Bank | 0.2651 | 29.8011 |
| Padma River | Near Bank | 0.2971 | 28.9558 |
| | Away From Bank | 0.1391 | 22.5154 |

**Table VI.B.2** Oxalic Acid Extracted Arsenic and Iron from Suspended Sediment Samples After Flood

| Site | As (mg/kg) | Fe (mg/kg) |
|---|---|---|
| Jamuna River | 0.4143 | 18.4260 |
| Padma River | 0.4859 | 20.0908 |

**Table VI.C.1** Oxalic Acid Extracted Arsenic and Iron from Floodplain Core Soil Samples Before Flood

| | | As (mg/kg) | | Fe (mg/kg) | |
|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Floodplain | 0-7.5 | 0.3360 | 0.2794 | 19.0029 | 28.8464 |
| | 7.5-15.0 | 0.2594 | 0.3044 | 18.3365 | 28.3233 |
| | 15.0-below | 0.2773 | 0.2750 | 29.0274 | 28.7330 |
| Padma Floodplain | 0-7.5 | 0.2694 | 0.3234 | 28.4705 | 28.4446 |
| | 7.5-15.0 | 0.2761 | 0.3275 | 28.4824 | 28.1960 |
| | 15.0-below | 0.2787 | 0.3316 | 28.2437 | 28.1085 |
| Srinagar Floodplain | 0-7.5 | 0.4880 | 0.4425 | 28.3750 | 26.6625 |
| | 7.5-15.0 | 0.4761 | 0.4281 | 27.9812 | 29.7434 |
| | 15.0-below | 0.4814 | 0.4273 | 26.9429 | 28.1642 |

**Table VI.C.2** Oxalic Acid Extracted Arsenic and Iron from Floodplain Floodplain Core Soil Samples After Flood

| | | As (mg/kg) | | Fe (mg/kg) | |
|---|---|---|---|---|---|
| Site | Depth (cm) | Core Sample 1 | Core Sample 2 | Core Sample 1 | Core Sample 2 |
| Jamuna Shibalaya Floodplain | 0-2.5 | 0.3523 | 0.3918 | 31.9035 | 31.6767 |
| | 2.5-5.0 | 0.4750 | 0.4452 | 31.6568 | 31.6051 |
| | 5.0-7.5 | 0.4430 | 0.4664 | 31.7284 | 31.6529 |
| | 7.5-15.0 | 0.2451 | 0.1641 | 31.5534 | 31.2551 |
| | 15.0-below | 0.4572 | 0.1803 | 31.5454 | 31.4042 |
| Jamuna Aricha Floodplain | 0-2.5 | 0.4024 | 0.2590 | 20.5085 | 21.1788 |
| | 2.5-5.0 | 0.3216 | 0.2358 | 22.1654 | 21.2246 |
| | 5.0-7.5 | 0.3480 | 0.2578 | 22.0679 | 20.4827 |
| | 7.5-15.0 | 0.4290 | 0.3559 | 22.0003 | 20.2679 |
| | 15.0-below | 0.1613 | 0.0941 | 18.3286 | 17.3997 |
| Jamuna Uninundated Floodplain | 0-7.5 | 0.1713 | | 31.5096 | |
| | 7.5-15.0 | 0.2869 | | 31.3903 | |
| | 15.0-below | 0.2440 | | 31.4699 | |
| Padma Paturia-Ghat Floodplain | 0-2.5 | 0.2136 | 0.4694 | 31.1815 | 28.8583 |
| | 2.5-5.0 | 0.2774 | 0.4072 | 31.4699 | 29.5246 |
| | 5.0-7.5 | 0.3282 | 0.5859 | 31.2968 | 29.6778 |
| | 7.5-15.0 | 0.1791 | 0.5667 | 31.2531 | 29.5923 |
| | 15.0-below | 0.3979 | 0.6376 | 31.4261 | 29.7494 |
| Padma Paturia-Village Floodplain | 0-2.5 | 0.4747 | 0.3587 | 29.2104 | 29.0154 |
| | 2.5-5.0 | 0.4696 | 0.2075 | 28.8205 | 28.9001 |
| | 5.0-7.5 | 0.5516 | 0.2869 | 29.1149 | 29.0234 |
| | 7.5-15.0 | 0.4932 | 0.2871 | 28.9836 | 29.0234 |
| | 15.0-below | 0.3141 | 0.3589 | 28.9956 | 29.0552 |
| Padma Uninundated Floodplain | 0-7.5 | 0.3276 | | 29.2561 | |
| | 7.5-15.0 | 0.3689 | | 29.4650 | |
| | 15.0-below | 0.2321 | | 29.2044 | |